Call: HORIZON-MSCA-2021-PF-01
(MSCA Postdoctoral Fellowships 2021)

Topic: HORIZON-MSCA-2021-PF-01-01

Type of Action: HORIZON-TMA-MSCA-PF-EF
(HORIZON TMA MSCA Postdoctoral Fellowships - European Fellowships)

Proposal number: 101064805

Proposal acronym: LEMMA

Type of Model Grant Agreement: HORIZON Unit Grant

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Proposal ID **101064805**

Acronym **LEMMA**

1 - General information

Fields marked * are mandatory to fill.

Topic	HORIZON-MSCA-2021-PF-01-01	Type of Action	HORIZON-TMA-MSCA-PF-EF
Call	HORIZON-MSCA-2021-PF-01	Type of Model Grant Agreement	HORIZON-AG-UN

Acronym LEMMA

Proposal title: Landslide and avalanchE Mechanics with Multiphysical datA

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Scientific Area: ENG - Information Science and Engineering (ENG)

Please select up to 5 descriptors (and at least 3) that best characterise the subject of your proposal, in descending order of relevance.

Descriptor 1: Environmental engineering and geotechnics

Descriptor 2: Civil engineering

Descriptor 3: ENV Environmental Hazard Analysis

Descriptor 4: Cryosphere, dynamics of snow and ice cover, sea ice, permafrost and ice sheets

Descriptor 5: Geology, tectonics, volcanology

Free keywords: *Modelling, simulation, fracture mechanics, shear bands, thermo-hydro-mechanics, data-driven, multiscale, material point method*

Please choose the scientific area and descriptors carefully, and in order of importance, since this will guide the REA in the selection of experts for proposal evaluation and the allocation of proposals to experts.

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Abstract *

Landslides and avalanches jointly cause approximately 150 deaths and €4.9 billion economic losses each year, with the impacts predicted to become more severe due to climate change. Mitigation and prevention of disasters requires accurate predictions of these phenomena, which due to their scale is only achievable via modelling and simulation. Accurate models of landslides in permafrost or avalanches must account for micro-scale (<1mm) processes such as cracks and shear bands that also involve thermal and hydrological effects that will be exacerbated by climate change. Such models do not currently exist. Further, this level of refinement is not computationally viable when modelling an entire mountainside, and so a new approach must be adopted.
This project will: 1) Develop new models for permafrost and snow subject to climate-change-induced loadings; 2) Use the new data-driven mechanics framework to transfer information from these models to the scale of the mountainside; and 3) Simulate the effects of climate change on the Mont-Blanc massif at Chamonix. This will combine the researcher's experience with shear band models with the supervisor's expertise in crack models and optimisation techniques. A secondment at a group specialising in simulating landslides and avalanches will provide the expertise to implement the simulation on a real mountainside.
This interdisciplinary project will ideally set the researcher for a career in academia in Europe, while benefiting the community at Chamonix, in particular the guide's association, as they will be able to plan adaptations and mitigations for the effects of climate change, ensuring their tourism industry remains viable. Specialised multiphysical models that are adapted to permafrost and snow will advance the state-of-the-art significantly, and the implementation of optimisation techniques in data-driven mechanics has wide applicability throughout civil and mechanical engineering, geology and environmental science.

Remaining characters 7

Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under any EU programme, including the current call? * ○ Yes ◉ No

Please give the proposal reference or contract number.

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Declarations

Field(s) marked * are mandatory to fill.

1) We declare to have the explicit consent of all applicants on their participation and on the content of this proposal. *	☒
2) We confirm that the information contained in this proposal is correct and complete and that none of the project activities have started before the proposal was submitted (unless explicitly authorised in the call conditions).	☒
3) We declare: - to be fully compliant with the eligibility criteria set out in the call - not to be subject to any exclusion grounds under the EU Financial Regulation 2018/1046 - to have the financial and operational capacity to carry out the proposed project.	☒
4) We acknowledge that all communication will be made through the Funding & Tenders Portal electronic exchange system and that access and use of this system is subject to the Funding & Tenders Portal Terms and Conditions.	☒
5) We have read, understood and accepted the Funding & Tenders Portal Terms & Conditions and Privacy Statement that set out the conditions of use of the Portal and the scope, purposes, retention periods, etc. for the processing of personal data of all data subjects whose data we communicate for the purpose of the application, evaluation, award and subsequent management of our grant, prizes and contracts (including financial transactions and audits).	☒
6) We declare that the proposal complies with ethical principles (including the highest standards of research integrity as set out in the ALLEA European Code of Conduct for Research Integrity, as well as applicable international and national law, including the Charter of Fundamental Rights of the European Union and the European Convention on Human Rights and its Supplementary Protocols. Appropriate procedures, policies and structures are in place to foster responsible research practices, to prevent questionable research practices and research misconduct, and to handle allegations of breaches of the principles and standards in the Code of Conduct.	☒
7) We declare that the proposal has an exclusive focus on civil applications (activities intended to be used in military application or aiming to serve military purposes cannot be funded). If the project involves dual-use items in the sense of Regulation 428/2009, or other items for which authorisation is required, we confirm that we will comply with the applicable regulatory framework (e.g. obtain export/import licences before these items are used).	☒
8) We confirm that the activities proposed do not - aim at human cloning for reproductive purposes; - intend to modify the genetic heritage of human beings which could make such changes heritable (with the exception of research relating to cancer treatment of the gonads, which may be financed), or - intend to create human embryos solely for the purpose of research or for the purpose of stem cell procurement, including by means of somatic cell nuclear transfer. - lead to the destruction of human embryos (for example, for obtaining stem cells) These activities are excluded from funding.	☒
9) We confirm that for activities carried out outside the Union, the same activities would have been allowed in at least one EU Member State.	☒

The coordinator is only responsible for the information relating to their own organisation. Each applicant remains responsible for the information declared for their organisation. If the proposal is retained for EU funding, they will all be required to sign a declaration of honour.

False statements or incorrect information may lead to administrative sanctions under the EU Financial Regulation.

2 - Participants

List of participating organisations

#	Participating Organisation Legal Name	Country	Action
1	INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE	France	

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Short name

Organisation data

PIC	Legal name
999547074	*INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE*

Short name: INRIA

Address

Street	DOMAINE DE VOLUCEAU ROCQUENCOURT
Town	LE CHESNAY CEDEX
Postcode	78153
Country	France
Webpage	www.inria.fr

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	no
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is no (small- and medium-sized enterprise) for the call.

SME self-declared status	unknown
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name: Inria Grenoble Rhone-Alpes - TRIPOP Team ☐ not applicable

☐ Same as proposing organisation's address

Street: 655 avenue de l'Europe

Town: SAINT ISMIER

Postcode: 38334

Country: France

Links with other participants

Type of link	Participant

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Short name

Supervisor

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Dr. Gender ○ Woman ◉ Man ○ Non Binary

First name* **Vincent** Last name* **ACARY**

E-Mail* **vincent.acary@inria.fr**

Position in org. Researcher

Department Inria Grenoble Rhone-Alpes - TRIPOP Team ☐ Same as organisation name

☐ Same as proposing organisation's address

Street 655 avenue de l'Europe

Town SAINT ISMIER Post code 38334

Country France

Website http://tripop.inrialpes.fr/people/acary/

Phone +334 7661 5229 *Phone 2* *+xxx xxxxxxxxx*

Other contact persons

First Name	Last Name	E-mail	Phone
Fanny	ROSSETTI	recettes-grenoble@inria.fr	+334 7661 5568
Matthieu	PY	matthieu.py@inria.fr	+xxx xxxxxxxxx

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Short name

Researcher

The name and e-mail of the Researcher and Supervisor are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please go back to Participant's page of the submission wizard and save the changes.

Last Name*	Collins-Craft	Last Name at Birth	Collins-Craft
First Name(s)*	Nicholas	Gender*	○ Woman ◉ Man ○ Non binary
Title	Dr.	Country of residence*	France
Nationality*	Australia	Nationality 2	
Date of Birth (DD/MM/YYYY)	05/10/1992	Country of Birth*	Australia
		Place of Birth	NORTH SYDNEY

Contact address

Current organisation name	Inria Grenoble Rhone-Alpes		
Current Department/Faculty/Institute/ Laboratory name	TRIPOP Team		
☐ Same as organisation address			
Street	655 avenue de l'Europe		
Postcode/Cedex	38334	Town	SAINT ISMIER
Phone	+334 7661 5259	Country	France
Phone2 / Mobile	+xxx xxxxxxxxx		
E-Mail*	nicholas.collins-craft@inria.fr		
ORCID	0000-0003-2510-137X		
Researcher ID			*The maximum length of the identifier is 11 characters (ZZZ-9999-2010) and the minimum length is 9 characters (A-1001-2010).*
Other ID	*Please enter the type of ID here*		*Please enter the identifier number here*

Qualifications

Doctorate Date of (expected) award		Select the exact date (DD/MM/YYYY)	22/11/2019

Place of activity/place of residence (previous 5 years - most recent one first)

Indicate the period(s) and the country/countries in which you have legally resided and/or had your main activity (work, studies, etc) during the last 5 years up until the deadline for the submission of the proposal.

Please fill in this section without gaps. Short stays (as defined in the Guide for Applicants) shall not be listed in this box.

Period from	Period to	Duration (days)	Country
01/11/2020	12/10/2021	346	France
28/05/2018	31/10/2020	888	Australia
13/09/2016	27/05/2018	622	France
	Total	1856	

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☐
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☐
IPR management incl. technology transfer	☒
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Software	*Siconos software, used for optimisation problems that arise in non-smooth mechanics, developed by the host TRIPOP team. This software will be extensively exploited in the project for both the cohesive zone model and the data-driven upscaling.*
Publication	*A Cosserat Breakage Mechanics model for brittle granular media, a journal article describing shear band analysis with advanced constitutive models, the researcher is first author. This shear band model will be extended with thermal and hydraulic effects as part of the project.*
Publication	*On the formulation and implementation of extrinsic cohesive zone models with contact, a pre-print describing a model of crack propagation with the cohesive zone technique in the framework of non-smooth mechanics, the researcher is first author. This model will be extended with thermal and hydraulic effects as part of the project.*
Publication	*Coulomb friction with rolling resistance as a cone complementarity problem, a journal article describing the formulation of an optimisation problem that arises from non-smooth contact mechanics with friction. These techniques will be included in the extension of the cohesive zone model, so that the extended model is framed in a numerically efficient way.*
Software	*Julia constitutive model integration software, a software suite to numerically integrate advanced constitutive models and predict their shear band properties, developed by the researcher. This software will be exploited in the project for the numerical integration and analysis of the shear band model.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
SMART-PROTECT	*2019-21, €565K, project financed by the region Auvergne-Rhône-Alpes, to design rock-fall protection structures. The project in which the cohesive zone model (that will be extended during the fellowship) was developed.*
SICONOS	*2001-05, €2.8M, project financed by the European Union to develop the Siconos software for numerical solution of optimisation problems arising from non-smooth mechanics. The software will be extensively exploited during the fellowship.*
SALADYN	*2009-12, €950K, project financed by the French national research agency ANR. The software package joins several preexisting software systems together to more accurately simulate non-smooth contact problems.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
GRICAD	*GRICAD is the scientific computing centre of the Université Grenoble Alpes, with which the beneficiary is affiliated. It offers high performance computing resources, educational courses, and help with writing efficient code.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (•) Yes ( ) No

Minimum requirements (building blocks) for a GEP

Public GEP: formal document published on the institution's website and signed by the top management, addressing the following issues:

- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel and students and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Minimum areas** to be **covered** and addressed via concrete measures and targets:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

3 - Budget

Is the Researcher eligible for family allowance?* ○ Yes ◉ No

Duration of fellowship	Country in which fellowship will take place
24	France

	Country Coefficient	Number of Months	Contributions for recruited researchers			Institutional contributions		Total
			Living Allowance	Mobility Allowance	Family Allowance	Research, training and networking costs	Management and indirect costs	
Fellowship	1.164	24	141914.88	14400.00	0.00	24000.00	15600.00	195914.88
Total			141914.88	14400.00	0.00	24000.00	15600.00	195914.88

4 - Ethics & security

Ethics Issues Table

1. Human Embryonic Stem Cells and Human Embryos			Page
Does this activity involve Human Embryonic Stem Cells (hESCs)?	○ Yes	◉ No	
Does this activity involve the use of human embryos?	○ Yes	◉ No	
2. Humans			**Page**
Does this activity involve human participants?	○ Yes	◉ No	
Does this activity involve interventions (physical also including imaging technology, behavioural treatments, etc.) on the study participants?	○ Yes	◉ No	
Does this activity involve conducting a clinical study as defined by the Clinical Trial Regulation (EU 536/2014)? (using pharmaceuticals, biologicals, radiopharmaceuticals, or advanced therapy medicinal products)	○ Yes	◉ No	
3. Human Cells / Tissues (not covered by section 1)			**Page**
Does this activity involve the use of human cells or tissues?	○ Yes	◉ No	
4. Personal Data			**Page**
Does this activity involve processing of personal data?	○ Yes	◉ No	
Does this activity involve further processing of previously collected personal data (including use of preexisting data sets or sources, merging existing data sets)?	○ Yes	◉ No	
Is it planned to export personal data from the EU to non-EU countries? Specify the type of personal data and countries involved	○ Yes	◉ No	
Is it planned to import personal data from non-EU countries into the EU or from a non-EU country to another non-EU country? Specify the type of personal data and countries involved	○ Yes	◉ No	
Does this activity involve the processing of personal data related to criminal convictions or offences?	○ Yes	◉ No	
5. Animals			**Page**
Does this activity involve animals?	○ Yes	◉ No	
6. Non-EU Countries			**Page**
Will some of the activities be carried out in non-EU countries?	◉ Yes	○ No	3

A research secondment will occur in Switzerland (M16 to M24). Development of the MPM solution, involving no personal data (purely mathematical models).

In case non-UE countries are involved, do the activities undertaken in these countries raise potential ethics issues?	○ Yes	◉ No	
It is planned to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	○ Yes	◉ No	
Is it planned to import any material (other than data) from non-EU countries into the EU or from a non-EU country to another non-EU country? For data imports, see section 4.	○ Yes	◉ No	

Is it planned to export any material (other than data) from the EU to non-EU countries? For data exports, see section 4.	◯ Yes	◉ No	
Does this activity involve low and/or lower middle income countries, (if yes, detail the benefit-sharing actions planned in the self-assessment)	◯ Yes	◉ No	
Could the situation in the country put the individuals taking part in the activity at risk?	◯ Yes	◉ No	

7. Environment, Health and Safety			Page
Does this activity involve the use of substances or processes that may cause harm to the environment, to animals or plants.(during the implementation of the activity or further to the use of the results, as a possible impact) ?	◯ Yes	◉ No	
Does this activity deal with endangered fauna and/or flora / protected areas?	◯ Yes	◉ No	
Does this activity involve the use of substances or processes that may cause harm to humans, including those performing the activity.(during the implementation of the activity or further to the use of the results, as a possible impact) ?	◯ Yes	◉ No	

8. Artificial Intelligence			Page
Does this activity involve the development, deployment and/or use of Artificial Intelligence? (if yes, detail in the self-assessment whether that could raise ethical concerns related to human rights and values and detail how this will be addressed).	◯ Yes	◉ No	

9. Other Ethics Issues			Page
Are there any other ethics issues that should be taken into consideration?	◯ Yes	◉ No	

I confirm that I have taken into account all ethics issues above and that, if any ethics issues apply, I will complete the ethics self-assessment as described in the guidelines How to Complete your Ethics Self-Assessment ☒

Ethics Self-Assessment

Ethical dimension of the objectives, methodology and likely impact

The project involves a research secondment period at the École polytechnique fédérale de Lausanne (EPFL), in Switzerland. This activity carries no or negligible risk, as Switzerland is as safe or safer than the host country of France. The benefit derived from this activity is access to expertise in the Material Point Method (MPM) from the secondment host, as well as access to the necessary computing resources. This level of expertise, necessary to deliver the project, is not available in France, meaning that the ratio of benefit to risk is justified.
The activities to be undertaken do not raise any ethical issues, as this part of the project involves processing data generated by mathematical models, and comparison with existing physical data in the scientific literature.
Local resources to be used amount only to the standard academic resources provided by EPFL for its staff and students.
Neither import nor export of any non-data material is planned.
The country involved is neither low nor middle income, and the situation in the country will not put anyone at risk.
Thus, the ethical dimensions of the project related to conducting a research secondment in Switzerland do not raise any concerns that require action on the part of the researcher, the beneficiary, the secondment host, or the European Union, and as such the likely impact is nil and no methodology to address them is required.

Remaining characters 3594

Compliance with ethical principles and relevant legislations

As no ethical issues are raised by conducting a secondment in Switzerland, compliance with European, French and Swiss ethical standards is guaranteed. However, in the event any unforeseen ethical issues do arise, Inria has appropriate structures to address these. The Operational Committee for the Evaluation of Legal and Ethical Risks (OCELER) was set up in 2011 to respond to legal and ethical issues raised in the research and experiments carried out by Inria project teams. The OCELER is also responsible for questions of scientific integrity within Inria, and will be consulted prior to the starting of the project to ensure legal and RRI aspects.
Link: https://www.inria.fr/en/operational-committee-assesment-legal-and-ethical-risks
Although no significantly large amount of data will be produced during this project, in the event it is deemed necessary, Inria through its local data protection expert (Grenoble) and DPO (national level) will provide adequate support.

Remaining characters 4026

Security issues table

1. EU Classified Information (EUCI)[2]		Page
Does this activity involve information and/or materials requiring protection against unauthorised disclosure (EUCI)?	○ Yes ◉ No	
Does this activity involve non-EU countries?	○ Yes ◉ No	
2. Misuse		**Page**
Does this activity have the potential for misuse of results?	○ Yes ◉ No	
3. Other Security Issues		**Page**
Does this activity involve information and/or materials subject to national security restrictions? If yes, please specify: (Maximum number of characters allowed: 1000)	○ Yes ◉ No	
Are there any other security issues that should be taken into consideration? If yes, please specify: (Maximum number of characters allowed: 1000)	○ Yes ◉ No	

[2]According to the Commission Decision (EU, Euratom) 2015/444 of 13 March 2015 on the security rules for protecting EU classified information, "European Union classified information (EUCI) means any information or material designated by an EU security classification, the unauthorised disclosure of which could cause varying degrees of prejudice to the interests of the European Union or of one or more of the Member States".

[3]Classified background information is information that is already classified by a country and/or international organisation and/or the EU and is going to be used by the project. In this case, the project must have in advance the authorisation from the originator of the classified information, which is the entity (EU institution, EU Member State, third state or international organisation) under whose authority the classified information has been generated.

[4]EU classified foreground information is information (documents/deliverables/materials) planned to be generated by the project and that needs to be protected from unauthorised disclosure. The originator of the EUCI generated by the project is the European Commission.

5 - Other questions

Information on the Researcher (future fellow)

1. Were you in the last 3 years in compulsory national service? ○ Yes ◉ No

2. Did you spend time, in the last 3 years, on procedures for obtaining refugee status (according to the 1951 Geneva Refugee Convention and the 1967 Protocol) in a Member State or Associated Country to Horizon Europe? ○ Yes ◉ No

3. Are you a national of a Member State or Associated Country? ○ Yes ◉ No

Are you a long term resident of a Member State or Associated Country? ○ Yes ◉ No

Other Questions

4. Is there a secondment envisaged in Part B of this proposal? ◉ Yes ○ No

The following are not considered as secondments:
- outgoing phase of a Global Fellowship
- optional six-months placement in the non-academic sector
- short visits or field work

Total duration of the secondments (in months): 8

5. Is the proposal eligible for funding under the Euratom Research and Training Programme (ERTP)? Please see the Guide for Applicants for this call and https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/euratom-research-and-training-programme_en for more information. ○ Yes ◉ No

Answer "Yes" only if all three conditions below are fulfilled:

- The proposal's research area is covered by the ERTP

- The host organisation (and, if applicable, the Associated Partner for the additional Placement period) is/ are established in a Member State or Associated Country to the ERTP

- The researcher is a national or a long-term resident of a Member State or Associated Country to the ERTP

6. For communication purposes only, the European Commission REA asks for permission to publish the name of the researcher (future fellow) should the proposal be retained for funding.
Does the researcher (future fellow) give this permission? ◉ Yes ○ No

7. Some national and regional public research funding authorities run schemes to fund MSCA applicants that score highly in the MSCA evaluation but which cannot be funded by the MSCA due to their limited budget. In case this proposal could not be selected for funding by the MSCA, do the researcher and supervisor consent to the European Commission disclosing to such authorities the results of its evaluation (score and ranking range) together with their names and contact details, non-confidential proposal title and abstract, proposal acronym, and host organisation? ◉ Yes ○ No

SECTION 1: EXCELLENCE

1.1 Quality and pertinence of the project's research and innovation objectives

Quality and pertinence

The European Union features significant mountainous regions that extend through several countries, the most prominent of which is the Alpine Arc, passing through France, Switzerland, Monaco, Italy, Liechtenstein, Austria, Germany, and Slovenia. This region is particularly vulnerable to the effects of climate change[1], in particular an increased risk of dangerous events such as landslides and avalanches triggered by the effects of melting permafrost, increased rainfall, and rapid temperature changes[2].

Over the period 1995-2014, 1370 deaths and 784 injuries occurred in Europe due to landslides, while the average economic damage amounted to approximately €4.9 billion (2021 values)[3]. Avalanches are similarly lethal, with 128 fatalities in the 2020-21 season[4], and can impede the safe and economic operation of infrastructure in mountainous regions[5]. Significant tourist attractions such as hiking trails are increasingly being affected by climate change, to the extent where some are no longer safe to use[6]. Thus, there is a significant interest in being able to quantitatively predict areas of increased risk as the climate changes, so that informed decisions about the appropriate responses may be made. Due to the scale of the phenomena involved, the only way to make these predictions is via modelling and simulation.

In order to make these quantitative predictions, sophisticated techniques in mechanics such as cohesive zone models or higher order continuum models must be developed and applied to the problem in a way that spans scales from the initiation mechanisms, crack formation (on the order of micrometres) and shear bands (on the order of millimetres), to entire mountainsides (on the order of kilometres). In particular, the development of a constitutive modelling framework that can unify these scales, and be applied to a digital twin of a physical site while including the effects of thermal fluctuations and increasing presence of liquid water, is critical in being able to accurately capture all of the expected effects. Further, very large deformations are characteristic of landslides and avalanches, meaning that any numerical method must be sufficiently robust in these circumstances. While models for cracks and shear bands incorporating some thermal or phase-change effects exist, they are not sufficiently applicable to the task of modelling the physics of permafrost or snow, nor have they been implemented in an appropriately robust large-deformation numerical method, which is what the researcher proposes to perform in project LEMMA. The TRIPOP team at Inria Grenoble-Rhône-Alpes (GRA) has expertise in the development of mechanical models and their application to hazard reduction in the Alps, and will be the beneficiary, while the SLAB team at EPFL has expertise in the application of material models in large-deformation numerical frameworks, and will host the secondment. The researcher is specialised in developing models for crack propagation and shear band formation. Thus, together they are well-placed to bring together a range of scientific disciplines to address the scientific challenge of developing and implementing appropriate mechanical models for avalanches and landslides due to a changing climate.

State of the art

The modelling of crack formation is a long-standing and active area of research. Among several different modelling approaches, cohesive zone models (CZM) are a particularly high-fidelity approach, with a correspondingly large computational cost when used at scale[7]. CZM model the progression of cracks by incorporating a cohesion variable within the fracture process zone that exists ahead of a crack, with the crack advancing when the cohesion reaches zero. Within this particular approach, *extrinsic* CZM, which immediately weaken as the crack opens, are recognised as the most suitable in the case of fast dynamic cracking, as well as the most physically realistic, as they do not suppose any spurious (physically non-existent) strengthening across the crack face[8] (in contrast to *intrinsic* CZM, which have this spurious strengthening). The most advanced CZM include a coupling with friction, a strong enforcement of the non-interpenetration condition when cracks close, and an efficient numerical implementation exploiting convex optimisation[9]. While some extrinsic models exist that include temperature[10], none exist that include a complete multi-physical coupling between the crack, friction, temperature and solid-fluid phase change, particularly in the context of snow and permafrost modelling.

1 Keiler, Knight, and Harrison, "Climate Change and Geomorphological Hazards in the Eastern European Alps."
2 Rist, "Hydrothermal Processes within the Active Layer above Alpine Permafrost in Steep Scree Slopes and Their Influence on Slope Stability."
3 Haque et al., "Fatal Landslides in Europe."
4 European Avalanche Warning Services, "Fatalities."
5 POCTEFA, "SAPYRA – Sécurité Des Accès Pyrénéens Face Au Risque Avalache."
6 "Massif Du Mont-Blanc : Le Réchauffement Compromet de Nombreuses Ascensions | Les Echos."
7 Carter et al., "Parallel FEM Simulation of Crack Propagation-Challenges, Status, and Perspectives."
8 Acary and Monerie, "Nonsmooth Fracture Dynamics Using a Cohesive Zone Approach."
9 Collins-Craft, Bourrier, and Acary, "On the Formulation and Implementation of Extrinsic Cohesive Zone Models with Contact."
10 Camacho and Ortiz, "Computational Modelling of Impact Damage in Brittle Materials."

Similarly, the modelling of shear bands has been of interest, particularly within the geomechanics community, for several decades. Their formation is understood to be of particular importance in the triggering of landslides[11], as well as being the underlying mechanism observed in seismogenic faults[12]. The development of thermo-hydro-mechanical (THM) models[13] is relatively much further advanced within the field of shear band modelling when compared to CZM, but remains under-developed when applied to the specific problems of snow and permafrost, as research attention has been focused on the comparatively much easier to study problem of band formation in rocks and soils at room temperature. Similarly, these models have been implemented in favourable geometry that does not require specialised numerical techniques.

There are several different methods available to conduct an upscaling, where information is passed from the micro-scale to the macro-scale. One recently developed method is data-driven mechanics[14] (DDM), that uses techniques from data science[15] to find the appropriate state of the system to match the requirements of momentum balance. The viable states of the system are selected from a database that contain data points from experiments or numerical simulations. The key benefits of this method are that it removes many of the modeller-dependent constitutive assumptions that would otherwise be necessary to fully capture complex mechanical behaviours, and as the computationally costly simulations of the material model have already been performed at the data-generation stage, speed at the implementation stage is improved. The method has already demonstrated success when employed as a method of upscaling for geomechanics[16]. While there has been some attempt at capturing the fracture process itself in the DDM framework[17], there has thus far been no use of DDM to upscale data generated using CZM or THM techniques.

In order to implement an upscaled model at the macro-scale which can be at the scale of kilometres, a numerical method must be numerically efficient and robust to very large deformations. A suitable method is the material point method (MPM), a well-developed mesh-free method. MPM techniques are frequently used in the numerical prediction of landslide and avalanche displacements[18][19], typically with large-strain elasto-plastic models[20]. DDM has not yet been implemented in the MPM framework, and offers substantial potential benefits in reducing computational cost for a method that is otherwise demanding. Hence, the objectives of the project are:

- Objective 1 (O.1): Develop THM models for cracks and shear bands that are specialised for snow and permafrost (work packages WP2 and WP3);
- Objective 2 (O.2): Develop a DDM solver using data from these models (WP4); and
- Objective 3 (O.3): implement the DDM solver in MPM and apply to a reference problem (WP5).

The details of the work packages are listed in Section 3.1. It is clear that each of these objectives represents an achievable step beyond the state-of-the-art, as they involve refinements and new applications of existing techniques. The cumulative effect of each of these increments is a very significant advancement in the ability to accurately predict the likely effects of climate change on the risks of landslides and avalanches in the alpine environment. These scientific objectives will be met by delivering a software suite implementing the models and the DDM solver, and by studying a test-case site (Chamonix), part of the Mont Blanc massif, which crosses the borders between France, Italy and Switzerland.

1.2 Soundness of the proposed methodology

Overall methodology

Each scientific objective has a corresponding methodology appropriate to the nature of the challenge.

Objective O.1 will be met by using the techniques of continuum thermo-mechanics to develop appropriate models. These techniques enable the development of material models that adhere to the laws of thermodynamics, and apply to both CZM and shear band models. Using this methodology, two models will be developed. The first of these is the multi-physical CZM (WP2). The purely mechanical part of the CZM is derived from the non-smooth modelling technique, which permits the model to rigorously enforce important behaviours such as non-interpenetration of the crack lips[21]. While an extrinsic CZM that includes temperature exists[22] in the context of

[11] Veveakis, Vardoulakis, and Di Toro, "Thermoporomechanics of Creeping Landslides: The 1963 Vaiont Slide, Northern Italy."
[12] Sulem, "Stress Orientation Evaluated from Strain Localisation Analysis in Aigion Fault."
[13] Rattez, Stefanou, and Sulem, "The Importance of Thermo-Hydro-Mechanical Couplings and Microstructure to Strain Localization in 3D Continua with Application to Seismic Faults. Part I: Theory and Linear Stability Analysis."
[14] Kirchdoerfer and Ortiz, "Data-Driven Computational Mechanics."
[15] Kirchdoerfer and Ortiz, "Data Driven Computing with Noisy Material Data Sets."
[16] Karapiperis et al., "Data-Driven Multiscale Modeling in Mechanics."
[17] Carrara et al., "Data-Driven Fracture Mechanics."
[18] Li et al., "The Mechanical Origin of Snow Avalanche Dynamics and Flow Regime Transitions."
[19] Mast et al., "Avalanche and Landslide Simulation Using the Material Point Method: Flow Dynamics and Force Interaction with Structures."
[20] Gaume et al., "Dynamic Anticrack Propagation in Snow."
[21] Acary and Monerie, "Nonsmooth Fracture Dynamics Using a Cohesive Zone Approach."
[22] Camacho and Ortiz, "Computational Modelling of Impact Damage in Brittle Materials."

rapid heating due to impact damage, and intrinsic CZM have been made use of in the context of hydraulic fracturing[23], no model exists that properly integrates thermo-hydro effects in the context of phase change between solid and liquid of the surrounding matrix, or that allows temperature or level of hydration to be treated as a loading, rather than a byproduct of mechanical loading or not modelled, respectively. All of these aspects are critical to accurately capture the effects due to climate change, as loading can occur simply as a significant increase in temperature or a large rainfall event. The multi-physical nature of the proposed model presents a challenge, as the complexity of the model increases approximately with the square of the number of physical phenomena modelled (i.e a THM model is roughly nine times as complex as a purely mechanical model), making it potentially difficult to use and understand, and increasing the simulation time required to run it (which becomes very pertinent when the model must be run thousands of times to be implemented in a DDM framework). The key approach to minimise this challenge is to choose for each step the simplest possible model that is *adequate* to capture the relevant physical principles, rather than attempting the most refined possible model. This aids both the comprehensibility of the model and its simulation time. The simulation time will also be reduced by exploiting the Siconos software package[24], developed by the TRIPOP team, which has a range of algorithms for the optimal solution of problems derived from non-smooth models. The second model is a multi-physical shear band model (WP3). Previous approaches to multi-physical modelling with respect to shear band formation have largely been focused on faults[25] and landslides[26], hence the existing work in the field is closer to the intended project application. Some modifications must be made to adapt these models for snow and permafrost, in particular noting the role of water phase-change. The numerical implementation of the model will be carried out using the robust and fast DifferentialEquations.jl[27] package for the Julia programming language, and the linear stability analysis required to predict shear band width will be implemented in a Julia software suite the researcher developed during his PhD[28]. The challenges for this part of the project are much the same as for the multi-physical CZM, and have the same solutions, other than using DifferentialEquations.jl rather than Siconos. Thus, research objective O.1 will be met using continuum thermo-mechanics, exploiting the knowledge and previously developed software of both the host team and the researcher, and will be addressed in WP2 and WP3.

Objective O.2 is the development of a DDM solver, which will be met using the techniques of mathematical optimisation. In DDM, physical laws such as momentum balance are strictly enforced, while the typical constitutive laws that describe material behaviour are replaced by a database search process that finds the material state that best adheres to the enforced physical law. In the event no satisfactory point is found, on-the-fly simulations can be conducted to generate one. The challenge for this aspect of the project is to extend DDM to non-continuous media (e.g. two bodies in contact) while ensuring that additional physical laws such as non-interpenetration are respected. This challenge will be addressed by specifying an appropriate non-smooth metric for the phase space, and using the Siconos software package that is equipped with a range of algorithms for mathematical optimisation that are robust and efficient, and that are tailored to the solution of the optimisation problems arising from non-smooth behaviour. Thus, Objective O.2 will be addressed by using this pre-existing and well-tested software developed by the host team, and will be addressed in WP4.

Objective O.3 is using an implementation of the DDM solver in the MPM, and applying it to the Mont Blanc massif at Chamonix. An existing MPM code base that has demonstrated successful resolution of advanced constitutive models[29][30], and which is used extensively by the secondment team at SLAB, in close cooperation with the code base developers, will be used. Inserting the DDM as a modular component of an existing MPM code base minimises the required development effort while ensuring that the overall system remains robust and efficient. The challenges for this task are ensuring that the implementation delivers physically realistic results at the field scale when the constitutive model is replaced with the DDM solver. This challenge will be resolved by validating the simulation on standard problems with known qualitatively correct solutions, such as ideal slopes[31]. Once reliable performance has been demonstrated, the MPM system will be applied to the problem of simulating landslides and avalanches due to climate change in Chamonix. This area has been extensively studied and measured by the EDYTEM laboratory of Université Savoie-Mont-Blanc, meaning that high-fidelity information is available to use for

[23] Sarris and Papanastasiou, “The Influence of the Cohesive Process Zone in Hydraulic Fracturing Modelling.”
[24] Acary et al., “An Introduction to Siconos.”
[25] Veveakis, Sulem, and Stefanou, “Modeling of Fault Gouges with Cosserat Continuum Mechanics: Influence of Thermal Pressurization and Chemical Decomposition as Coseismic Weakening Mechanisms.”
[26] Seguí et al., “The Interplay between Phyllosilicates Fabric and Mechanical Response of Deep-Seated Landslides. The Case of El Forn de Canillo Landslide (Andorra).”
[27] Rackauckas and Nie, “DifferentialEquations.Jl – A Performant and Feature-Rich Ecosystem for Solving Differential Equations in Julia.”
[28] Collins-Craft, “Julia Constitutive Model Integration.”
[29] Jiang et al., “The Material Point Method for Simulating Continuum Materials.”
[30] Wolper et al., “CD-MPM: Continuum Damage Material Point Methods for Dynamic Fracture Animation.”
[31] Li et al., “The Mechanical Origin of Snow Avalanche Dynamics and Flow Regime Transitions.”

specific prediction purposes[32]. A collaboration with EDYTEM researchers is foreseen for the final stage of this objective, so that the existing data and extensive local knowledge can be exploited to best target specific area to simulate. Hence, objective O.3 will be completed using the expertise and software base of the secondment team, as well as with high-fidelity data at Chamonix, and will be addressed in WP5.

Integration of methods and disciplines

The project and methodological approach is inherently cross-disciplinary. While the core discipline of the project is mechanics, which would typically fall within civil and mechanical engineering, it features significant interactions with other neighbouring disciplines. Of particular note is that DDM inherently demands the cross-disciplinary adoption of techniques from data science, in order to achieve solutions that are satisfactory within the realm of mechanics. In order to implement both mechanics and data science methods in an effective and efficient manner, techniques developed within applied mathematics for the solution of differential equations (MPM) and convex optimisation problems (cone complementarity problems) will be applied. Finally, the physical context in which the macro-scale method will be applied is the domain of geology, while the physical inputs to observe the mechanical changes effected are to be drawn from climate science. Thus, five separate disciplines are employed in the project, with particularly important contributions from mechanics and applied mathematics. The different disciplines implicated in each work package are listed in the table below:

	Disciplines				
Work Package	Mechanics	Applied mathematics	Data science	Geology	Climate science
WP2: CZM	***	**			
WP3: Shear band	***	**			
WP4: DDM		*	***		
WP5: MPM	***	**		**	**

The number of * indicate the extent to which different disciplines are employed in different WPs, with three * indicating the highest level of importance.

It should be noted that WP4 relies on WP2 and WP3, and WP5 relies on WP2, WP3 and WP4, meaning that certain disciplines are still required to deliver WP4 and WP5, even if they are not implicated in the WP itself.

Gender dimension

No gender dimension is foreseen, as the project deals purely with physical data and its mathematical treatment.

Open science practices and research data management

Open science practices will be implemented as a core part of the project. A key part of the project is the generation of data by means of repeated simulations of micro-scale models. These models will be made available in open code repositories as soon as it is available, for scrutiny, implementation and adaptation by other scientists and engineers, for their own use in both scientific and engineering work. This code will be accompanied by extensive documentation and references to the model that it simulates, and pending sufficient interest, an open code workshop will be held to support wider uptake. Further, the generated data itself will be made available through the open-access repository Zenodo, which is supported by the EU and operated by CERN. Zenodo stores data with a unique and searchable identifier, as well as the appropriate metadata, and is accessible over the internet. Thus data on Zenodo is inherently both *Findable* and *Accessible.* For this project data and metadata will be stored using the widely-used xdmf standard, and metadata will contain references to where its vocabulary is explained, and links to other relevant data sets. These protocols ensure that the data is *Interoperable*. The metadata will be made as rich as possible, by including durable links to descriptions of the models and codes that generated given data sets, ensuring that the data provenance is clear and the metadata meets the standards of the mechanics community. The data will be released under the permissive Apache licence. These protocols ensure that the data is *Reusable*. This ensures that all of the data generated in the project is managed under FAIR principles. Including these open science practices as part of the project ensures that the code base and the data of the project have the earliest and widest diffusion possible. This, in concert with the data management plan and the dissemination plans detailed in Section 2.2, will enable the researcher to gather feedback from the scientific community, and ameliorate any key weaknesses or shortcomings identified, thus meaning that the predictions made in WP5 to address O.3 are more likely to be robust and reliable.

1.3 Quality of the supervision, training and of the two-way transfer of knowledge between the researcher and the host.

Qualifications and experience of the supervisors

The supervisor at Inria will be Dr Vincent Acary. He is currently the team leader of the TRIPOP team at Inria GRA. This team is composed of four permanent full-time researchers and one researcher shared with another research

[32] Ravanel, Magnin, and Deline, “Impacts of the 2003 and 2015 Summer Heatwaves on Permafrost-Affected Rock-Walls in the Mont Blanc Massif.”

institute (INRAE Grenoble), as well as two associated university faculty members and two research engineers, three postdocs and four PhD students. Two of the current postdocs, and four of the PhD students are supervised by Dr Acary. In addition, he has previously supervised six postdocs, seven research engineers, four PhD students and supervised a further four students during PhD internships. Of his previously supervised postdocs, four continued in academia while the remainder are in private industry. His research interests relevant to this project lie in several areas of computational mechanics, in particular cohesive zone modelling, rigid-body mechanics and convex optimisation, in all of which he has over twenty years of experience, dating back to his PhD work. His main international collaborations are with Olivier Brüls (University of Liège) and Matthias Legrand (McGill University). He has led the the French national research agency ANR project SALADYN (2009-12, €950K), participated in the EU project SICONOS (2001-05, €2.8M) and the ANR projects VAL-AMS (2007-09, €261K), ChaSlim (2011-15, €370K) and DIGITSLID (2019-21, €338K), and the Auvergne-Rhône-Alpes region project SMART-PROTECT (2019-2022, €565K). In addition, the project will feature key input from Dr Franck Bourrier (Inria and INRAE), who has extensive expertise on the application of rigid-body mechanics to mountainous hazards such as rockfalls and landslides. TRIPOP also has extensive support for the software development and implementation required to deliver the project, through two research engineers, who are key contributors to the development of Siconos.
The project will feature an academic secondment phase, where the researcher will be supervised by Dr Johan Gaume. He is an assistant professor at the École Polytechnique Fédérale de Lausanne (EPFL), and leads the Snow and Avalanche Simulation Laboratory (SLAB). This team is composed of four postdocs and four PhD students, all supervised by Dr Gaume. He is the co-supervisor of two additional PhD students. His research interests relevant to this project are the study of large-deformation problems such as avalanches via numerical methods, in particular using the MPM. He has worked in this problem area for over a decade, including during his PhD. His main international collaborations are with Chenfanfu Jiang and Joseph Teran (both at the University of California, Los Angeles). He has received over CHF 2M of financing from the Swiss National Science Foundation.

Planned training activities for the researcher

The researcher will be trained at three levels, by the supervisors, the host institutions, and by the Grenoble research community, primarily via Université Grenoble-Alpes (UGA). The primary research training method will be training-through-research, with more intensive training delivered by the project supervisors Dr Vincent Acary and Dr Johan Gaume as required. In the case of model development, where the researcher already has extensive experience, training will be as-needed, and thus dispersed throughout WP2 and WP3. For the areas where the researcher is less experienced, optimisation and MPM implementation, the training will be delivered intensively at the start of the work packages WP4 and WP5. Further, the researcher will attend courses made available by the UGA doctoral school to add breadth and depth to his knowledge of data science before starting WP4, and will attend courses made available by UGA GRICAD to strengthen his competences in high performance computing (HPC) and data management before starting WP5. GRICAD also offers support and training on improving code, which can be accessed as required. The researcher will also undertake extensive transversal training. The researcher will be trained in science communication to journalists and the wider public via a two day intensive workshop offered by the Inria Communications Office. The researcher will attend a two day course offered by the UGA doctoral school for teaching at the tertiary level. Dependent on student availability and interest, the researcher will take a role in the supervision of masters students during their research internships, where he will be trained in research supervision by his own supervisors. The researcher will participate in the monthly “Parlons Europe” sessions offered by Inria GRA, that trains researchers in scientific management and grant writing, particularly with respect to ERC projects. Finally, the researcher will undertake a workshop and intensive coaching offered by Inria, directed towards succeeding in the competitive process to obtain a permanent research position. The training and time allocated for each activity are listed in the table below:

Training activity	Training level	Type of skill trained: scientific (S), transversal (T)	Time
Model development	Supervisors	S: Research	~20 days in total, throughout WP2 and WP3
Algorithm implementation	Supervisors	S: Research	~5 days in total, at start of WP4
MPM implementation	Supervisors	S: Research, software development	~10 days in total, at start of WP5
Data science tools	Grenoble environment	S: Fundamental background, research, software utilisation	7 days, as available (to be completed before WP4 starts)
High performance computing, data stewardship	Grenoble environment	S: Research, software development, data maintenance	9 days, as available (to be completed before WP5 starts)
Project and grant management and applications	Host institutions	T: Project management and grant writing, particularly for the ERC	1 hour/month, throughout project duration (WP1)
Scientific communication	Host institutions	T: Scientific communication to a wider public	2 days, when available (WP6)

Teaching at the tertiary level	Grenoble environment	T: Lecturing and supervision of university students	2 days, as available
Gaining a permanent research position	Host institutions	T: Professional development	Up to 5 days, in the second year of the project

Two-way transfer of knowledge

Inria will transfer knowledge to the researcher, particularly in the form of CZM and convex optimisation techniques, via training-through-research. This transfer will come via the main supervisor, as well as interactions with other members of the TRIPOP team, and will be supported by Inria's provision of resources. Software development principles will also be transferred to the researcher via interactions with the TRIPOP research engineers. EPFL will transfer knowledge to the researcher via training-through-research applied to the MPM. This transfer will be via the secondment supervisor, and will be supported by EPFL's provision of the appropriate resources for project implementation. Exposure to a wider network of researchers, such as the applied mathematicians working in optimisation or MPM, will serve to broaden the researcher's knowledge.

The researcher will also transfer knowledge to Inria. The researcher has extensive expertise in the modelling of shear band formation, particularly in the context of complex physical systems. His PhD thesis was centred on modelling shear bands in crushable granular media, and he will transfer his knowledge of the appropriate continuum modelling techniques, as well as the appropriate numerical approaches for successful analysis of shear band behaviour, a key part of the project. The researcher will also contribute to strengthening Inria's reputation in the mechanics community by integrating it within the ALERT Geomechanics community, that includes 33 universities or research institutes across Europe. The researcher also brings extensive contacts within the mechanics community in his home country of Australia, offering further opportunity to integrate Inria and strengthen its reputation in this field. This integration will take place via the dissemination of the scientific project in this community, the production of documentation for the code base, the delivery of scientific seminars to research groups in this community, and the teaching of courses, in particular at the doctoral school attached to the annual ALERT workshop.

1. 4 Quality and appropriateness of the researcher's professional experience, competences and skills

The researcher is appropriately qualified to undertake this project. The researcher completed a PhD in geomechanics, with previously mentioned focus on shear band modelling of crushable granular media. As a consequence the researcher has expertise in the development of complex constitutive models that take into account the changing micro-structure of the material being modelled. In addition, the model the researcher developed during his PhD is embedded in the Cosserat continuum, a type of higher-order continuum. The use of higher-order continuum models is essential in order to be able to correctly model shear band formation, as in the absence of higher-order terms, shear bands are falsely predicted to have zero thickness. This in turn leads to gross inaccuracies when trying to model the behaviour of the overall system. This work resulted in a publication in the Journal of the Mechanics and Physics of Solids (JMPS), one of the most highly regarded journals in solid mechanics. Further, the researcher has presented his work at several selective international conferences, as well as several smaller seminars. Thus, parts of the researcher's expertise that are necessary for successful completion of the project lie outside those of both the host team (CZM and optimisation), and the secondment team (MPM). Each participant in the project has complementary skills necessary for the project's success.

The researcher has (since November 2020) been engaged as a postdoctoral scholar, working on the development of extrinsic cohesive zone models. These models are used to model crack propagation, and are particularly suitable in situations of rapid crack propagation. Further, the model is developed in an efficient numerical framework exploiting the structure of linear complementarity problems so that it can be resolved more rapidly than is typical for models of this type. The model also implements concepts from rigid-body mechanics, that ensure accurate physical behaviour when cracks are closed, or when fully cracked bodies impact each other[33]. This background means that the researcher is already well-integrated in the host team, and is well-placed to efficiently deliver WP2 and WP3.

SECTION 2: IMPACT

2.1 Credibility of the measures to enhance the career perspectives and employability of the researcher and contribution to his/her skills development.

Expected skill development of the researcher

The researcher will further develop his existing scientific skills in continuum mechanics, with a particular emphasis on CZM, shear bands and multi-physical couplings, to be delivered via training-through-research and continued

[33] Collins-Craft, Bourrier, and Acary, "On the Formulation and Implementation of Extrinsic Cohesive Zone Models with Contact."

dissemination activities. The researcher will gain new expertise in mathematical optimisation and techniques from data science, delivered by training courses as well as training through research. The researcher will widen his knowledge of numerical simulation techniques, through the implementation of the MPM, and undertaking training courses in HPC techniques. The researcher's transversal skills will be developed via training courses in scientific communication and teaching at a university level, coaching for grant writing and management, and obtaining a permanent academic position. Thus, the researcher will develop all of the skills necessary to starting a career as a permanent academic researcher, through the training program listed in section 1.3.

Expected impact on the researcher's career perspectives

The project is expected to substantially strengthen the researcher's employment prospects within academia. In the first instance, the relevance of studying the effects of climate change on a range of systems is likely to only increase in the future, and thus the knowledge and skills gained in the project will continue to be applicable all over the world. Secondly, the modelling and simulation techniques that will be developed and refined for the project are relevant for a very wide range of problem areas in mechanics, ranging from the natural landscapes, such as rocks, to artificial materials such as concrete and laminates. In particular, DDM is an area that is expected to receive increasing focus and attention in the near future.

The additional transversal skills and professional network developed in the project, as well as the coaching in obtaining a permanent academic position, strongly increase the researcher's prospects in finding a permanent academic post in Europe, both in his core disciplines of civil and mechanical engineering, but also in applied mathematics or geology. The host institution, Inria, offers specific positions to early career researchers that provide extensive support towards obtaining ERC grants, making such a position a logical next step after this fellowship.

2.2 Suitability and quality of the measures to maximise expected outcomes and impacts, as set out in the dissemination and exploitation plan, including communication activities.

Dissemination, communication and exploitation activities

The *dissemination* of the results will be targeted to mechanicians and members of adjacent communities such as geologists, in particular those focused on geomechanics. Key journals serving the relevant communities will be targeted, particularly those with Open Access (OA) policies . Corresponding wide-audience conferences will also highlight the project to a broad range of researchers. The researcher will also focus dissemination on specific scientific communities that he already has existing links with, such as the ALERT Geomaterials community (that is based in Grenoble). The yearly meeting in October is a particularly strong candidate for dissemination activities. Contacts in the researcher's native country of Australia, built during his PhD, will be exploited at highly selective conferences, as well the wider French mechanics community represented by the Mécamat organisation and its annual colloquium. Specific dissemination targets are listed in the table below:

Dissemination mode	Typical dissemination targets	Intended audience
Journals.	Mechanics journals such as JMPS (gold OA), geomechanics journals such as the Journal of Geophysical Research: Solid Earth (hybrid OA) and Open Geomechanics (diamond OA), and journals focusing on cold environments such as The Cryosphere (gold OA).	Mechanicians, geologists, environmental scientists, respectively.
Wide-audience conferences	International Congress of Theoretical and Applied Mechanics, EUROConference on Rock Mechanics and Rock Physics, GeoProc, and the American and European Geophysical Unions' congresses.	Mechanicians and geologists, particularly those interested in multi-physical processes. There is considerable overlap between these communities.
Narrow-focus conferences	ALERT Geomaterials workshop, Patterns in Geomechanics, Mécamat colloquium	European geomechanics researchers, global geomechanics researchers, and the French mechanics community respectively. The researcher already has extensive links with the first two scientific communities, while Dr Vincent Acary has long-standing ties to the third.

The preprints and postprints of journal articles and conference contributions will be made available on the durable open-access repository HAL that is supported by the French state scientific organisation CNRS, to allow free access to all the key research outputs of the project. In his dissemination activities, the researcher will highlight to the scientific community the power and flexibility of the DDM method, the high physical fidelity of the CZM and shear band models, and the pressing societal relevance of the scientific questions.

Communication will be targeted to the general public, with a special emphasis on residents of the Alpine Arc. General interest media that reaches the widest possible audience will be addressed via websites such as The Conversation, which has a large readership and publishes in several different languages. Inria also possesses a Communications Office, that will assist in targeting appropriate regional media outlets, such as newspapers and radio and television stations, so that residents of the Alpine Arc in particular are reached. Scientifically curious

members of the public will be addressed by participation in special scientific outreach events, and through regular media segments focusing on science. Specific communication targets are listed in the table below:

Communication mode	Typical communication targets	Intended audience
Websites	The Conversation, in both English and French language editions. This website has 42M readers each month across all editions, and articles can be freely re-used by other publications.	The general public
Alpine regional media	Regional newspapers such as Dauphiné Libéré (175K readers), Neue Zürcher Zeitung (240K readers). Radio and television stations such as France 3 Auvergne-Rhône-Alpes, Radio France Bleu Isère.	Residents of the Alpine Arc
Scientific outreach events and segments	Local scientific media segments such as the weekly discussion of Inria research projects on Radio France Bleu Isère, organised scientific outreach events such as The Pint of Science Festival, MSCA events such as the European Researchers' Night.	Scientifically curious members of the general public.

The communication strategy will emphasise the increased risks that are expected to be demonstrated due to the effects of climate change on the likelihood of avalanches and landslides. This will be accompanied with a call-to-action, that readers press their governments to address climate change at the global scale, while also putting in place mitigations and safety measures at the local scale, particularly within the alpine environment.
The *exploitation* of the work will be focused on two key audiences, engineers and the Chamonix guides association. The first of these will be targeted via attendance and presentation at the joint academic-industrial International Symposium on Rock Slope Stability, that occurs biannually in Chambéry, the neighbouring city to Grenoble. The researcher will highlight for the industrial audience the flexibility and computational efficiency of the method, as well as its open-access nature, allowing them to exploit it for industrial purposes. Secondly, the results of the project will be communicated via seminar to the association of mountain guides for Chamonix. The code for the project will be delivered to the association with a simplified user-friendly interface, allowing guides to run their own simulations on areas of concern on their personal computers. This will allow them to better asses the level of increased risk to their guided hiking trails, and plan safer routes over the Mont-Blanc massif that will be less affected by climate change, as well as communicate these results themselves in the regular seminars they hold for the public.

Management of intellectual property

No intellectual property that is commercially exploitable is expected to be generated by this project. The underlying data and codes produced will be made publicly available, with the permissive Apache licence, so that other members of the scientific community or the wider public can further develop and use the project's results in their work.

2.3. The magnitude and importance of the project's contribution to the expected scientific, societal and economic impacts

Scientific

Scientifically, the project's aims of developing micro-scale constitutive models that are comprehensive in terms of the included physics (including thermal and hydro effects within the context of crack and shear band modelling for permafrost, snow pack etc) represents a significant increase over the state-of-the-art within the field. In addition, the framing of the models in terms of convex optimisation problems allows the creation of extremely numerically efficient models, relative to standard solution techniques. This is essential when running models at a large-scale, such as a mountainside, often requires tens or hundreds of CPUs running for hundreds of hours. Further, the data-driven paradigm adopted for the project represents a significant advance over the typical modelling approach adopted in geomechanics. The large numbers of parameters and assumptions that are used in the standard approach to constitutive modelling result in models where results are highly dependent on modeller choices, and models can become extremely inaccurate outside of their calibrated range. By using only micro-scale models, the project will constrain the constitutive assumptions to levels where they can be more accurately measured in laboratory or field tests. Thus, when using the data-driven mechanics paradigm to upscale to the field scale, fewer model assumptions are carried, and a significant reduction in the effect of subjective modeller choices occurs. This allows the macro-scale model to continue making accurate predictions under almost any conditions, as the micro-scale models that generate the data remain well-constrained and within their calibrated range. This is particularly important when considering that the implementation framework for the macro-scale model is the MPM, which is typically used in cases where very large deformations occur, placing models well outside their calibrated ranges.
The impact on the targeted scientific community is expected to be significant. Taking the ALERT Geomaterials community as an example, the 2021 workshop dedicated its first day to the study of landslides, while the second day was dedicated to machine learning and data-driven mechanics. The attached doctoral school was on the topic of constitutive modelling. This indicates a significant appetite within the community for exactly the advances that are offered by the project, which integrate constitutive modelling, data science and large-deformation implementations

in MPM. As a rough estimate, two-thirds of the ALERT community work in constitutive modelling, numerical methods, or their intersection, and it is expected that the advances made by the project will be of significant interest to anyone within that subset. This ratio, and the concurrent interest, is likely to hold for the wider (i.e. outside Europe) geomechanical community as well. Further interest from the wider mechanics community is expected, as the data-driven framework as applied to crack modelling in particular is of wide applicability across areas as broad as soft materials, laminates and advanced manufacturing such as 3D printing.

Societal and economic

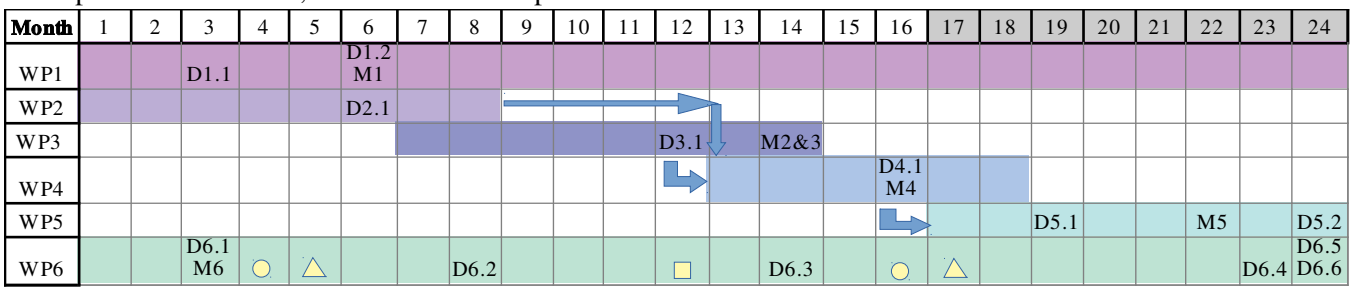
The societal and economic impacts of the project are closely intertwined. By applying the model to Chamonix, specific predictions of landslides and avalanches can be made. Thus, risk maps can be updated, showing where building may be allowed, where protection structures must be added and where infrastructure must be removed or adapted. This is expected to reduce mortality and economic damage from landslides and avalanches. As the tourist income of the village depends significantly on the Mont Blanc massif, accurate knowledge of the local consequences of climate change is particularly important to plan adaptation and mitigation strategies. While the exact numbers cannot be accurately calibrated in advance of the results of the project, between 1995-2014, 1370 deaths occurred from landslides and €4.9 billion (in 2021 values) of economic loss were incurred on average each year[34]. As landslides and avalanches will be more frequent under climate change, the risk will dramatically increase. Thus, being able to predict the required mitigation efforts is likely have a significant benefit both economically, and in terms of lives saved.

SECTION 3: QUALITY AND EFFICIENCY OF THE IMPLEMENTATION

3.1 Quality and effectiveness of the work plan, assessment of risks and appropriateness of the effort assigned to work packages.

Overall structure of the work plan

The work plan is divided into 6 work packages, with WP1 devoted to project management, and WP6 to communication and dissemination. WP2 and WP3 relate to the development of the models, WP4 to the development of the solver, and WP5 to the implementation in MPM.



Gantt chart showing the allocated time in months from the start of the project. The months highlighted in grey indicate the period on secondment at EPFL. The arrows indicate the relations between the work packages. The triangles, circles and squares indicate ALERT conference, European researcher's night, and a Pint of Science respectively, assuming a project starting in June.

Work Package and effort	**Aims, tasks (T), milestones (M), deliverables (D)**
Work Package 1: Project management Researcher: 2 person-months Supervisors: 0.25 person-months	Aims: Monitoring and planning of project T1.1 Fortnightly meetings with supervisors, T1.2 Organisation of secondment period, T1.3 Training activities (other than training through research). D1.1 Career development plan, D1.2 Data management plan M1 Career development and data management plans complete
Work Package 2: Crack model Researcher: 5.5 person-months Supervisors: 0.5 person-months	Aims: Development of a multi-physics crack model and generation of micro-scale data from model T2.1 Model development, T2.2 Data generation, T2.3 Training through research D2.1 Model code and data-set
Work Package 3: Shear band model Researcher: 5.5 person-months Supervisors: 0.5 person-months	Aims: Development of a multi-physics shear band model and generation of micro-scale data from model T3.1 Model development, T3.2 Data generation, T3.3 Training through research D3.1 Model code and data-set M2&3 Both models complete
Work Package 4: Data-driven solver Researcher: 2 person-months Supervisors: 0.25 person-months	Aims: Implementation of data-driven solver T4.1 Solver development, T4.2 Training through research D4.1 Solver code M4 Solver complete
Work Package 5: MPM implementation Researcher: 7 person-months Supervisors: 0.5 person-months	Aims: Implementation of micro-scale models into macro-scale model via data-driven solver T5.1 Integration of data-driven solver into existing MPM code base, T5.2 Test macro-scale model on standard problems, T5.3 Apply macro-scale model to field-scale problems, T5.4 Training through research D5.1 MPM code with integrated solver, D5.2 Simplified interface to code M5 Field application at Chamonix complete

[34] Haque et al., "Fatal Landslides in Europe."

Work Package 6: Communication, dissemination and exploitation Researcher: 2 person-months Supervisors: 0.25 person-months	Aims: Communication, dissemination and outreach T6.1 Present conference communications T6.2 Write scientific papers T6.3 Write communication articles T6.4 Prepare communication and exploitation seminar D6.1 Dissemination and Exploitation plan D6.2 Paper for crack model, D6.3 Paper for shear band model, D6.4 Paper for MPM implementation, D6.5 Have communication articles published, D6.6 Deliver seminar for Chamonix guides M6 Dissemination and Exploitation plan complete

Mechanisms to assess and mitigate risk

As each milestone is achieved, the time taken to complete the task will be assessed to ensure that the project remains on track. Any unforeseen risks that reveal themselves will be considered, and mitigation measures will be put in place for the remaining work packages. The main risks to the successful completion of the project are listed below:

Risk description, probability of occurrence (P) and impact (I)	**Risk management strategies**
Risk 1: Multi-physical crack model takes longer than foreseen to develop and implement, simulation speed is slower than foreseen (WP2). *P=moderate, I=low.*	WP2 is scheduled to be completed 8 months before it is required, to be implemented in WP5, giving a very large buffer time to resolve issues. The model is to be an extension of one that the researcher has already developed, significantly aiding familiarity. In the worst case, one of either the temperature or hydraulic effects can be removed, while still capturing important climate-change-related processes.
Risk 2: Multi-physical shear band model takes longer than foreseen to develop and implement, simulation speed is slower than foreseen (WP3). *P=moderate, I=low.*	WP3 features less buffer time than WP2, but still has 2 months during which WP4 is to be completed as a buffer time to resolve issues. The multi-physical aspects of the shear band model are generally shared with those in WP2, meaning that the development time allocated to WP3 is over-estimated, giving further buffer time. and in the worst case, the same mitigation as WP2 can be applied.
Risk 3: Data-driven solver is difficult to integrate with other software (WP4). *P=low, I=moderate.*	WP4 features significant buffer time to allow iteration and debugging of its integration with other software (Siconos and MPM primarily). The expertise of TRIPOP research engineers will be exploited to ensure good code development practices, minimising the risk of failed integration. In the worst case, one of the models can be removed from the solver, to reduce the size of the task.
Risk 4: MPM implementation is slow or unreliable (WP5). *P=low, I=moderate.*	The MPM will be implemented using a well-established code base that is known to run quickly and reliably, minimising the risk of the implementation being poor. Further, standard tests are included as measures of both software reliability and simulation fidelity. In the worst case, the DDM component can be removed, and the developed material models simulated directly, however this will require smaller and less realistic simulations in order to remain computationally viable.
Risk 5: MPM implementation cannot be applied and disseminated (WP5 and WP6), *P=low, I=moderate.*	Even in the event where application to the Chamonix site proves impossible, the general principles of the implementation and their potential use there will still be disseminated.

3.2 Quality and capacity of the host institutions and participating organisations, including hosting arrangements.

Quality and capacity of the host institutions

The researcher will be hosted in the TRIPOP team of Inria, at the Centre Inria Grenoble-Rhône-Alpes, in the Grenoble metropolitan area. Inria will provide all of the standard research support required, including access to an office and workstation, Human Resources and Information Technology and library services. Inria is a signatory to the European Charter & Code for Researchers, and has been given the HR Excellence in Research Award, showing sustained support for researchers and the research environment. Inria also offers substantial support to its researchers in making applications to external funding agencies, with support at both the level of the national institute, as well as the local centre. TRIPOP has access to research engineers to aid in the development of numerical tools, as well as local computing resources.

As part of its integration in the Grenoble research environment, Inria GRA is associated with Université Grenoble-Alpes (UGA). UGA is a large research university, with 59,000 students (of which 2900 are PhDs), 3,100 researchers, and 3,700 support staff. Researchers at the university have been awarded 124 ERC grants since 2007. Through Inria, the researcher will have access to UGA high-performance computing (HPC) resources through the GRICAD service of the university. This service also provides technical support in the implementation of HPC by assisting researchers in deploying their codes in an efficient way to maximally exploit the available computational resources. Similarly, the researcher is able to access relevant courses offered by UGA, either through GRICAD, or the doctoral school.

The researcher will also perform a secondment at the École Polytechnique Fédérale de Lausanne (EPFL), where he will similarly have access to the standard research support required, such as office space and workstation, IT and HR support. The workstations are optimised for scientific computing, with substantial CPU, RAM and GPU resources, and access is available to EPFL's HPC cluster SCITAS. EPFL is a signatory to the European Charter & Code for Researchers. He will be integrated into the Snow and Avalanche Simulation Laboratory (SLAB), a team lead by Dr Johan Gaume, who currently supervises four postdoctoral researchers and four doctoral students. This integration will occur by the researcher participating in lab meetings, presenting his research work to date in an introductory seminar, as well as general participation in the life of the lab, such as taking a role in the partial supervision of masters students (where student availability and interest allows).

Curriculum Vitae – Nicholas Anton Collins-Craft

Experience

Postdoc in the TRIPOP team at Inria Grenoble-Rhône-Alpes, supervised by Dr Vincent Acary and Dr Franck Bourrier. Commenced 01/11/2020 (start delayed from 01/04/2020 due to the pandemic).

- Theoretical development of cohesive zone model for the propagation of cracks in quasi-brittle materials, using techniques from non-smooth analysis.
- Numerical implementation of the model in the Siconos software package, using convex optimisation algorithms.
- Industrial linkage with partner company Géolithe via Project SMART-PROTECT.

PhD student jointly between the SciGEM laboratory at the University of Sydney, and the CERMES team at École nationale des ponts et chaussées (ENPC). Jointly supervised under a cotutelle agreement by Professor Itai Einav (Sydney), Professeur Jean Sulem and Dr Ioannis Stefanou (ENPC). From 22/06/2015 to 01/05/2020.

- Experimental investigation of the effect of grain size polydispersity in controlling the width of shear band formation, using the experimental apparatus ACSA.
- Development and adaptation of image analysis techniques suitable to the non-rectilinear nature of the experimental apparatus.
- Theoretical development of a constitutive model integrating Breakage Mechanics with the Cosserat continuum, enabling length scale evolution to be included in geomechanical models.
- Theoretical and numerical study of shear band model predictions by means of linear stability analysis, and development of software suite in Julia to enable model integration and bifurcation analysis.
- Numerical study of shear band formation by means of the finite element method to enable accurate determination of post-localisation behaviour.

Education

Doctor of Philosophy/Doctorat from the University of Sydney and Université Paris-Est (undertaken at the École nationale des ponts et chaussées).
Thesis title: *The effect of evolving micro-structural length scale on the macroscopic constitutive behaviour of granular media*. Commenced 22/06/2015, defended 22/11/2019, completed requirements 01/05/2020.
The University of Sydney is Australia's oldest university and forms part of the Group of Eight of elite Australian research universities. In the 2021 QS World University Rankings, the School of Civil Engineering was ranked 14th in the world. École nationale des ponts et chaussées is the world's oldest school of civil engineering, and one of France's most selective *grandes écoles*, being ranked 4th best by the Le Figaro rankings in 2021.

Bachelor of Engineering in Civil Engineering with First Class Honours and the University Medal from the University of Sydney.
Honours Thesis advisor: Professor Itai Einav.
Thesis title: *The Contribution of Granular Rotation to Improving the Efficiency of Heat Transfer.* Commenced 28/02/2011, completed 23/11/2014.

- Civil engineering degree completed with specialisations in wind engineering, foundation analysis, advanced analysis of steel structures, and advanced analysis of concrete structures.
- Graduated first in cohort with highest honours obtainable.

Certificate of Advanced Engineering from the University of Sydney.
Undertaken as an extension program in parallel with the Bachelor's degree. Commenced 28/02/2011, completed 23/11/2014.

- Humanitarian engineering: developing a project for Engineers Without Borders to supply clean drinking water for the village of Devikulam in Kerala, India.
- Educational outreach: developing and delivering a teaching program for the Abbotsleigh School for Girls in Sydney, Australia, in order to encourage more girls to study engineering at the tertiary level.
- Product commercialisation: developing and pitching a business plan in order to attract financing from commercial investors.

Journal Articles

A Cosserat Breakage Mechanics model for brittle granular media,
N. A. Collins-Craft, I. Stefanou, J. Sulem & I. Einav, in the *Journal of the Mechanics and Physics of Solids,* Volume 141, August 2020, https://doi.org/10.1016/j.jmps.2020.103975. Cited 11 times. JMPS is regarded as the premier journal in the field of mechanics of solids, and covers all areas and approaches to the field, from experimental to theoretical, and from the fundamentals of mechanics to newly discovered applications. It has an acceptance rate of 24%, and is typically read by researchers in all sub-specialisations of solid mechanics.

Pre-prints

On the formulation and implementation of extrinsic cohesive zone models with contact,
N. A. Collins-Craft, F. Bourrier & V. Acary, preprint avilable on HAL at https://hal.archives-ouvertes.fr/hal-03371667v1/. Article for submission to JMPS.

Software

Julia constitutive model integration code,
N. A. Collins-Craft, software suite for the numerical integration of constitutive models, available on github at https://github.com/nickcollins-craft/julia_constitutive_model_integration.

Conference Presentations

International Congress of Theoretical and Applied Mechanics 2020+1, Milan, Italy, 22/08/2021 – 27/08/2021.
Unifying Breakage Mechanics with the Cosserat continuum to predict shear band localisation. N. A. Collins-Craft, I. Stefanou, J. Sulem & I. Einav.

Micro2Macro 2018, Reggio Calabria, Italy, 29/05/2018 – 01/06/2018/
A theory to predict shear band formation in granular media with evolving grain size distributions. N. A. Collins-Craft, I. Stefanou, J. Sulem & I. Einav.

12th EURO-conference on Rock Physics & Geomechanics, Ma'ale HaHamisha, Israel, 05/11/2017 – 10/11/2017.
A formulation of Breakage mechanics in the Cosserat continuum to predict shear band formation in granular media. N. A. Collins-Craft, I. Stefanou, J. Sulem & I. Einav.

Conference Posters

Patterns in Geomechanics, Sydney, Australia, 29/01/2019 – 01/02/2019.
The effect of grain size reduction on shear band formation. N. A. Collins-Craft, I. Stefanou, J. Sulem & I. Einav.

AGU Fall meeting, Washington D.C., USA, 10/12/2018 – 14/12/2018.
The effect of grain size reduction during shearing of granulated fault gouge. *N. A. Collins-Craft*, I. Stefanou, J. Sulem & I. Einav.

Navier Seminar, Paris, France, 05/03/2018.
Modelling crushable granular media in the Cosserat continuum. *N. A. Collins-Craft*, I. Stefanou, J. Sulem & I. Einav.

ERC REALISM Kick-off Meeting, Paris, France, 15/03/2017
Progress towards a constitutive model for crushable granular media using Cosserat continuum modelling. *N. A. Collins-Craft*, I. Stefanou, J. Sulem & I. Einav.

Invited Seminars

TRIPOP seminar, Inria Grenoble-Rhône-Alpes, 07/12/2020.
Predicting strain localisation in crushable granular media using the Cosserat continuum.

CoQuake seminar, École centrale de Nantes, 02/06/2020.
A Cosserat Breakage Mechanics model for brittle granular media, and An Introduction to Julia.

Granular Forum, the University of Sydney, 20/06/2018.
The effect of evolving micro-structural length scale on the macroscopic constitutive behaviour of granular media.

CERMES seminar, École nationale des ponts et chaussées, 19/02/2018.
The effect of evolving micro-structural length scale on the macroscopic constitutive behaviour of granular media.

ENS seminar, École normale supérieure, 03/03/2017.
The effect of evolving micro-structural length scale on the macroscopic constitutive behaviour of granular media.

Seminars to masters students

MSROE seminar, École nationale des ponts et chaussées, 11/01/2018
L'effet de l'evolution de l'échelle de longeur micro-structurel sur le comportement macroscopique constitutif des milieux granulaires (in French). Approximately 30 students.

MSROE seminar, École nationale des ponts et chaussées, 05/01/2017.
The effect of evolving micro-structural length scale on the macroscopic constitutive behaviour of granular media. Approximately 30 students.

Prizes, Scholarships and other academic achievements

2017 Early Career Researcher grant to attend the 12th EURO-confererence on Rock Physics & Geomechanics. Conference attendance fee waived.

2016 Postgraduate Research Support Scheme from the University of Sydney. School, accommodation and flight fees covered to attend a doctoral school in Perth, Western Australia.

2015 Australian Postgraduate Award, University of Sydney Merit Award, both from the University of Sydney, for three and a half years each, and totalling A$30.5K per year.

2014 D. G. Walkom Prize for First Class Honours in Civil Engineering, Dean's List of Excellence in Academic Performance.

2013 D. Campbell-Allen Prize in Civil Engineering, invitation to the Summer Research Scholarship program.

2012 University of Sydney Academic Merit Prize, Dean's List of Excellence in Academic Performance, invitation to the Summer Research Scholarship program.

2011 University of Sydney Academic Merit Prize, Dean's List of Excellence in Academic Performance, invitation to the Summer Research Scholarship program.

2010 Roads and Maritime Services (a New South Wales state government entity) Scholarship in Civil Engineering, for length of the Bachelor's degree. A$12,500 per year.

Academic Service

Reviewer for *Computational Mechanics*, *Powder Technology*, and *Computer Methods in Applied Mechanics and Engineering*.
Computational Mechanics and *Computer Methods in Applied Mechanics and Engineering* (CMAME) are both journals that focus on the application of numerical techniques to the resolution of complex problems in all fields of mechanics, from biomechanics to structrural mechanics. They both have an emphasis on sophisticated mathematical models and advanced technical implementations., and are the leading journals for researchers working in computational mechanics. The journal impact factors are 4.014 for Computational Mechanics and 6.756 for CMAME.
Powder Technology focuses on the mechanics and characterisation of systems of particulate solids, ranging in scale from aerosols to mined materials. Experimental, numerical and theoretical approaches are included, and it is an important journal for researchers working in both granular physics and industrial processes. It has a journal impact factor of 5.134.

Organisational assistant for 6th International Conference on Coupled THMC Processes in Geosystems, Paris, France, 05/07/2017 – 07/07/2017.

Previous academic employment

The University of Sydney, 2015 - 2019.
Tutor for CIVL3411 Geotechnical Engineering (2015) and ENGG1801 Engineering Computing (2016), assignment marking and substitute tutor for CIVL2410 Soil Mechanics (2019).

École nationale des ponts et chaussées, 2017 - 2018.
Scientific English editing for a wide variety of scientific papers written by other researchers.

Participation in financed projects

European Research Council Starting Grant "Controlling earthQuakes (CoQuake)"
Participation in the CoQuake project, with principal investigator Ioannis Stefanou. All journal articles, conference presentations and poster presentations from 2018 onwards were performed in association with this project.

Australian Research Council Discovery Projects "Experimentally validated theory for the mixing of granular materials" and "Long-term chemically induced crumbling of unsaturated brittle geomaterials"
Participation in two simultaneous projects, with principal investigator Itai Einav. The

journal article was written in association with these projects.

Technical skills

Theoretical constitutive modelling.

Specialisation in modelling the localisation of deformation.

- Higher order continuum mechanics, in particular the Cosserat continuum.
- *Linear stability analysis of mechanical systems.*
- Cohesive zone modelling of crack propagation.

Programming.

- Proficient in Python, Julia, MATLAB and Mathematica.
- Competent in C++.
- Some notions in Haskell, Fortran, Basic.

Software.

- Proficient in FeniCS, Siconos, LATEX and Microsoft Office suite.
- Competent in GIMP.
- Some notions in MOOSE.

Operating systems.

- Proficient in Microsoft Windows, Ubuntu Linux.

Citizenship

Australian.

Languages

English (mother tongue), French (proficient).

Contact Information

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nicholas.collins-craft@inria.fr

SECTION 5: CAPACITY

5.1 Overview of the Participating Organisations

Organisation role	PIC	Legal Entity Short Name	Academic organisation	Country	Name of Supervisor
Beneficiary	999547074	Inria	Y	France	Vincent Acary
Associated partner linked to a beneficiary	897379108	UGA	Y	France	Vincent Acary
Associated partner for secondment	999973971	EPFL	Y	Switzerland	Johan Gaume

5.2 Capacity of the Participating Organisations

Beneficiary	
Institut de recherche en informatique et automatique, Inria, France	
Inria is the French national institute dedicated to research in computer science, applied mathematics, and control theory (http://www.inria.fr). Founded in 1967, Inria's mission is twofold: to carry out frontier research and to ensure technology transfer, thus stimulating the economic and societal impact of its scientific achievements. Inria covers a wide spectrum of topics in the above-mentioned fields, as well as interdisciplinary topics, in particular in conjunction with the life, medical and environmental sciences. Inria's identity and strength are forged by its capacity to stimulate creativity in the digital sciences and to generate innovative technologies that, among other things, lie at the basis of more than 160 start-up companies. The institute has almost 200 research groups, spread throughout the country and gathered in eight research centres. 80% of these groups are joint with universities and other institutes in France and abroad. Inria has a workforce of 3,500 scientists with an annual budget of €236 million, 25% of which comes from direct contracts with industry and from projects granted by national, European and international funding agencies. Over the last decade, Inria has been very active in the FP7 and H2020 programs (ERC, FET and ICT). In particular, more than 50 ERC Starting, Consolidator, and Advanced grants, ten Proof-of-Concept grants, and one Synergy grant were awarded to Inria scientists by the European Research Council. Inria is involved in more than 160 H2020 funded projects for a total EU contribution of more than 95MEUR; including 4 FET-OPEN projects. Inria has a Technology Transfer, Innovation and Partnerships Department (TIPD) which organises research partnerships through bilateral collaboration with businesses and implements the transfer of the project teams' technology results to industry. In Grenoble, where the TRIPOP group is located, the TIPD team is composed of 6 permanent Partnership and Innovation Project Leaders. Inria is a signatory of the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers since 2006, and has been awarded the HRS4R label in 2019.	
Role and profile of supervisor	Dr Vincent Acary is a Director of Research and team leader of the TRIPOP project-team at Inria Centre Grenoble-Rhône-Alpes, dedicated to non-smooth mechanics, control and optimisation of dynamical systems. This team is composed of four permanent full-time researchers and one researcher shared with another research institute (INRAE Grenoble), as well as two associated university faculty members and two research engineers, three postdocs and four PhD students. His role in the project is to supervise the researcher during the development of the constitutive models and data-driven mechanics solver, where his expertise in contact and fracture mechanics, convex optimisation and associated algorithms will be pertinent. He currently
Key research facilities, Infrastructure and Equipment	Inria provides standard research facilities such as an office and workstation to its researchers, as well as access to support mechanisms such as Human Resources, Information Technology, and experts in grant proposal preparation. Within the TRIPOP team, there is access to a server for calculation, and if necessary access to significant high performance computing resources through the GRICAD facility. TRIPOP has two research engineers available to assist in the development and implementation of research software during the project. The team is also linked to another research institute, Inrae, via Dr Franck Bourrier, who is attached to both. The team leader, Dr Vincent Acary, is also associated with UGA, as he is attached to the laboratory of applied mathematics.
Previous and current involvement in EU-funded research and training programmes/actions /projects	TRIPOP and its predecessor team BIPOP have participated in the EU project SICONOS (2001-05, €2.8M) and the (French national research agency) ANR projects VAL-AMS (2007-09, €261K), ChaSlim (2011-15, €370K) and DIGITSLID (2019-21, €338K), as well as the Auvergne-Rhône-Alpes region project SMART-PROTECT (2019-2022, €565K). Each of these projects has contributed to the development of relevant software and mathematical techniques that will be used in the project.

Associated Partner linked to a beneficiary	
Université Grenoble Alpes, UGA, France	
Large French research university that carries out a full suite of research and teaching activities across numerous sites in the French Alps, concentrated within Grenoble and its neighbouring communes of Saint-Martin-d'Hères and Gières. The main project supervisor is academically affiliated with the university, and some university resources will be exploited for the project.	
Role and profile of supervisor	Dr Vincent Acary is academically affiliated with Laboratoire Jean Kuntzmann, the laboratory of applied mathematics of the university. This affiliation exists for the purposes of teaching at the bachelors and masters level, and for registration of PhD students.
Key research facilities, Infrastructure and Equipment	UGA will provide computational resources for the project under the aegis of GRICAD, the computational centre of UGA, which Inria has access to. The doctoral school will also be used for the delivery of training activities, relating to improving the researcher's knowledge of data science, high performance computing, and transversal skills such as teaching at the tertiary level..
Previous and current involvement in EU-funded research and training programmes/actions /projects	Due to the academic affiliation of TRIPOP with both Inria and UGA, the list of projects is duplicated here: EU project SICONOS (2001-05, €2.8M) and the (French national research agency) ANR projects VAL-AMS (2007-09, €261K), ChaSlim (2011-15, €370K) and DIGITSLID (2019-21, €338K), as well as the Auvergne-Rhône-Alpes region project SMART-PROTECT (2019-2022, €565K).

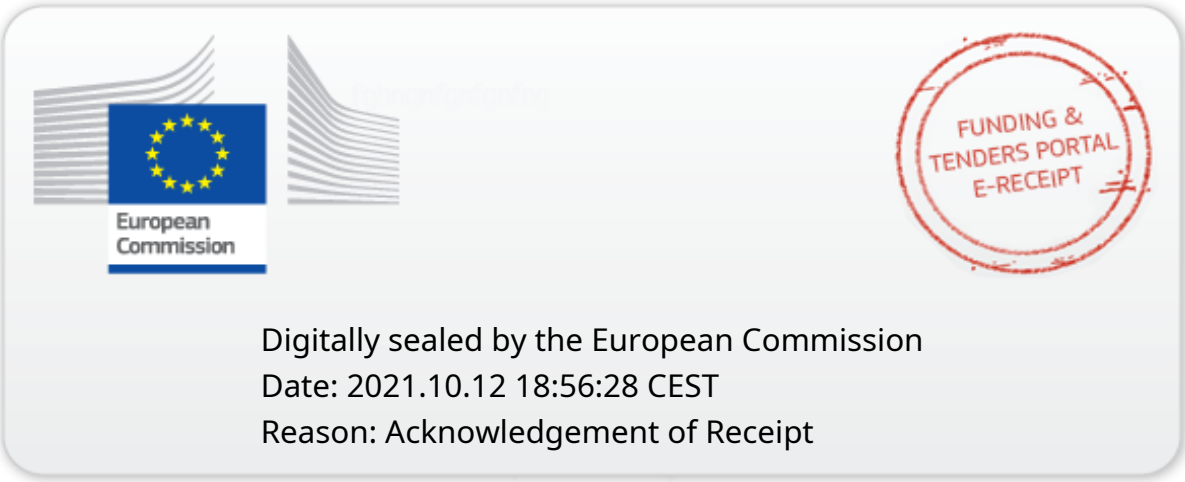
Associated Partner for secondment	
École polytechnique fédérale de Lausanne, EPFL, Switzerland	
Moderate sized technical university, specialising in engineering and science, as the leading federal technical university for the French-speaking part of Switzerland. The secondment organisation for the project. EPFL has over 6300 staff, and over 370 laboratories across a full range of scientific disciplines with an annual budget of CHF 1.06 billion. At the end of 2020, 161 ERC grants had been awarded to EPFL researchers. EPFL is a signatory of the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers since 2009.	
Role and profile of supervisor	Dr Johan Gaume is a professor and leader of the Snow and Avalanche Simulation Laboratory (SLAB), that sits within the institute for environmental engineering at EPFL. His role in the project is to supervise the researcher during the secondment, where his expertise in the material point method will be of crucial importance.
Key research facilities, Infrastructure and Equipment	EPFL provides standard research facilities such as an office and workstation to its researchers, as well as access to support mechanisms such as Human Resources and Information Technology. In particular, SLAB has access to the high-performance computing resources necessary to run the large simulations required to implement the model, via appropriately equipped workstations, and via the high performance computing cluster SCITAS.
Previous and current involvement in EU-funded research and training programmes/actions /projects	SLAB has participated in several Swiss National Science Foundation projects. The most important of these are “Multiscale analysis and modeling of slab avalanche release processes” (Ambizione scheme, 2016-2018, CHF 337K), “Unified modeling of snow and avalanche mechanics using the material point method” (Eccellenza scheme, 2019-2023, CHF 1.7M), and “A Material Point Method for Alpine Mass Movements in a Climate Change Context” (Spark scheme, 2020-2021, CHF 96K). Each of these projects has contributed to the development and application of MPM techniques that will be exploited during this project.

SECTION 6: ETHICS

All information pertaining to ethics in this proposal is included in Part A.

SECTION 7: SECURITY SCREENING

This project does not raise any issues pertaining to security.



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