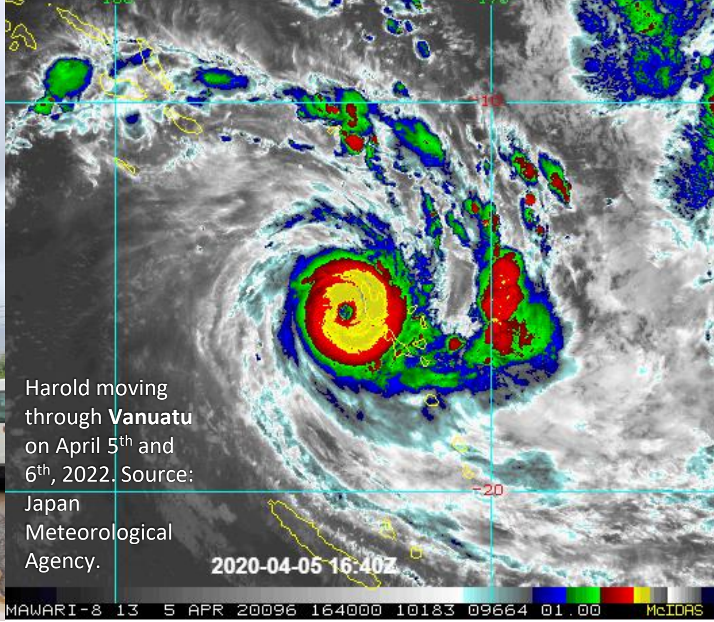

Strengthening the Resilience of Public Facilities in Tonga, Samoa, and Vanuatu

Presenter: Ettore Fagà, PhD

Contributors: Ömer O, Andrea A, Zacharias F, Ettore F, Gianbattista B, Anna M, Andrea S, Georgios R, Dimitrios V, Nikolaos K, Mohsen K, Paolo B, Michael B, Rebecca M

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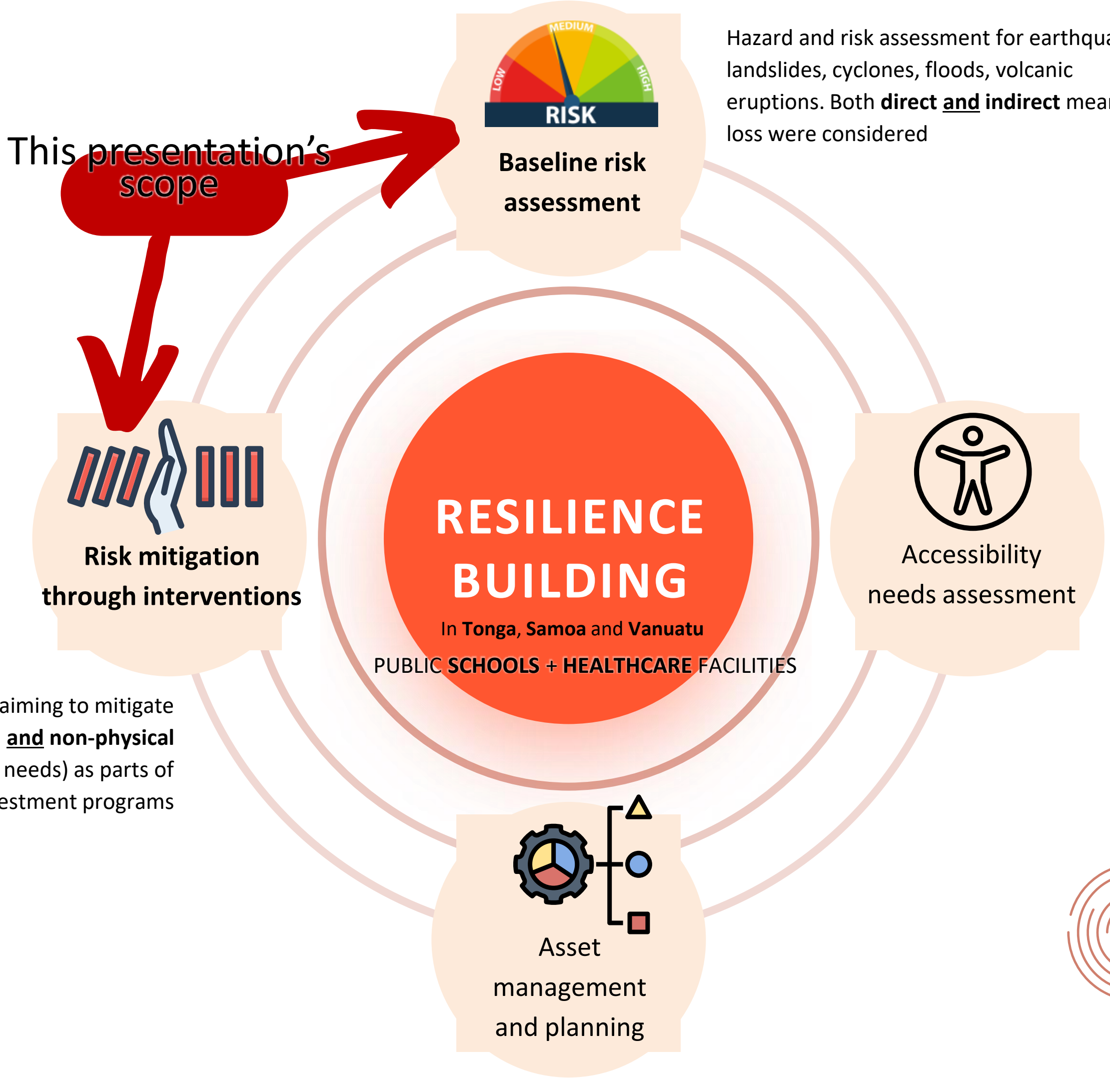
Scope

The objective of the project was to inform and support the World Bank's dialogue with the Governments Tonga, Samoa, and Vanuatu to increase the public facilities' resilience to natural hazards through strategic investment planning and risk reduction intervention options.



Hazard and risk assessment for earthquakes, landslides, cyclones, floods, volcanic eruptions. Both **direct and indirect** means of loss were considered

Recommending **physical** (such as retrofits aiming to mitigate the structures' vulnerability against disasters) **and non-physical interventions** (e.g., addressing accessibility needs) as parts of potential future investment programs

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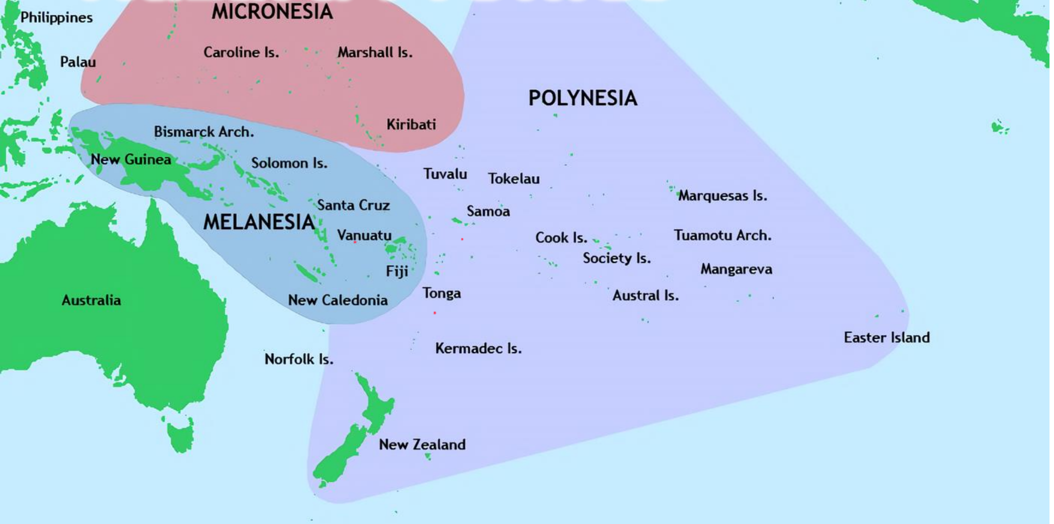
Hazard Profiles



*except tsunamis

SAMOA

WIND — VERY HIGH

Tropical Cyclones (TC) impose frequent high-wind events and storm surge (flooding). Since 1960, Samoa has been hit by 0.6 tropical cyclones per year.

FLOOD — MODERATE

Combination of frequent pluvial, riverine, and coastal flooding drive hazard and risk levels

EARTHQUAKE — LOW

VOLCANIC — LOW/MODERATE

Volcanism in Savai'i is still poorly understood, but historical events raise concern to its potential danger

TONGA

WIND — VERY HIGH

Tropical Cyclones (TC) impose frequent high-wind events and storm surge (flooding). Since 1960, Tonga has been hit by 0.6 tropical cyclones per year.

FLOOD — HIGH

Combination of frequent pluvial and coastal flooding across low-lying land of Tonga drive hazard levels

EARTHQUAKE — VERY HIGH

Tonga's proximity to the Pacific 'Ring of Fire' renders it highly exposed to earthquakes.

VOLCANIC — MODERATE

Tonga is home to multiple active and dangerous volcanoes, though most schools are outside the range of their disastrous effects*

VANUATU

WIND — VERY HIGH

Vanuatu is struck by Tropical Cyclones on a regular basis that expose the landscape to high-speed winds and coastal flooding.

FLOOD — LOW/ MODERATE

Coastal flooding borne by TC drives the flood hazard

EARTHQUAKE — VERY HIGH

Frequent destructive earthquakes cause strong ground motion especially across Sanma and Malampa in the Northwest

VOLCANIC — MODERATE

Vanuatu is home to some of the Earth's most active volcanoes. Some schools are prone to their effects

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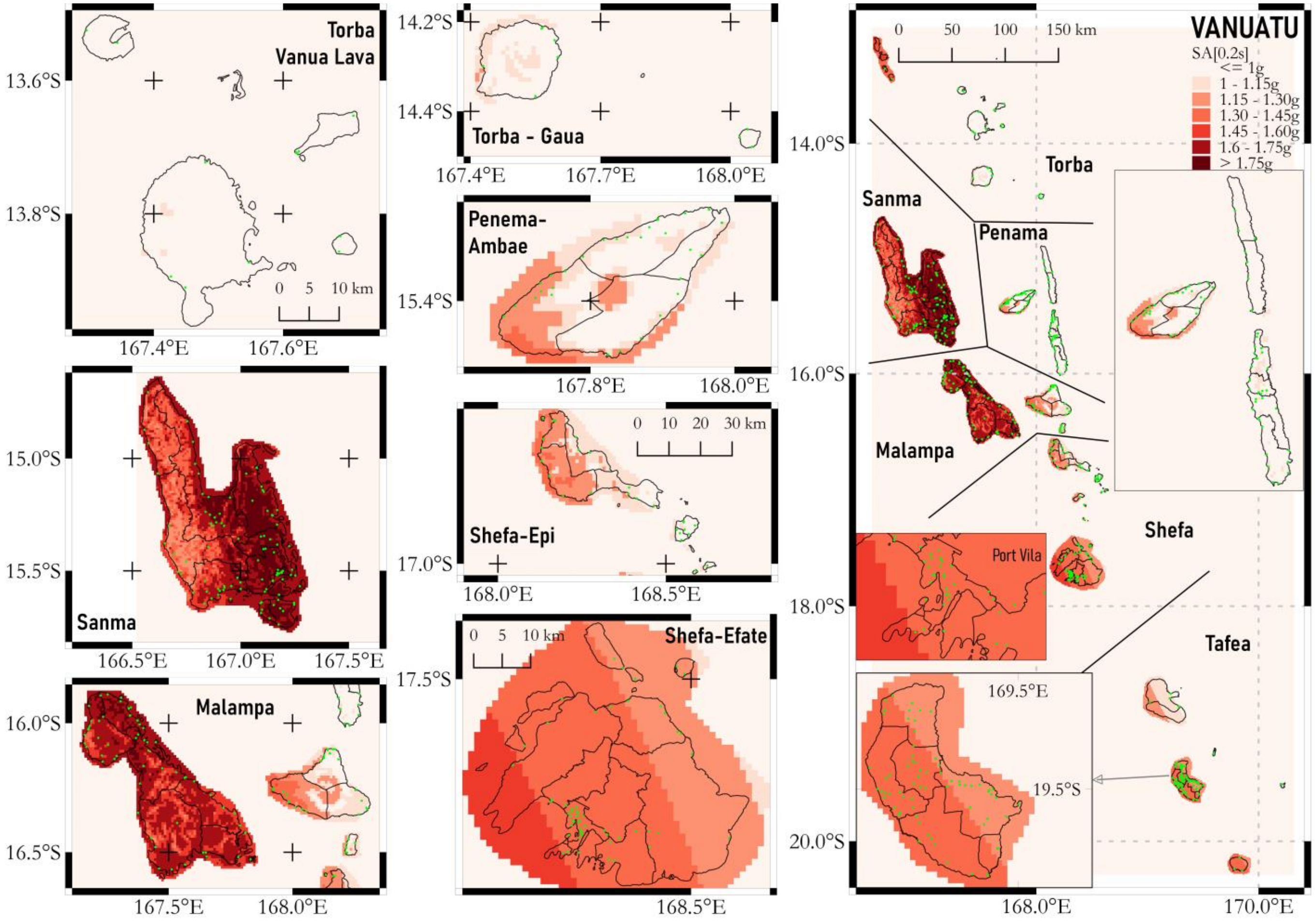
Hazard Profiles



Vanuatu – EQ Snapshot

Computed earthquake hazard map in terms of SA[0.2s] at 500-year return period

● exposure

Baseline risk: exposure & vulnerability

Education & **healthcare** exposures of all three countries were put together via remote and on-site **surveys** during the COVID19 pandemic and multiple disasters.

Building survey campaign in Samoa involved a local engineering firm and Ministry of Education and Training staff

Tonga	**Samoa**	**Vanuatu**
934 buildings in 122 schools	256 buildings in 23 schools	4,009 buildings in 482 schools

Detailed info such as the type and status of **roof systems**

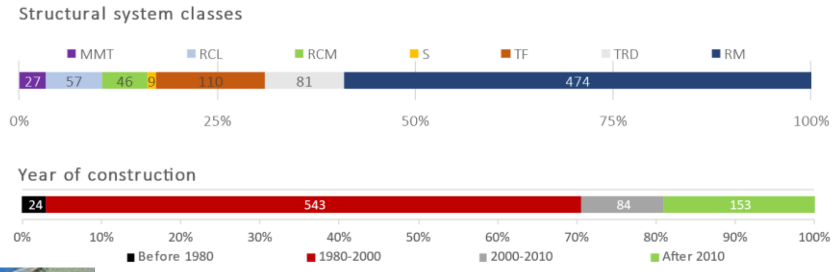
Info such as the **structural system type**

- ✓ **Detailed**, **rapid**, and **remote** forms from individual buildings
- ✓ **General** forms from instead each school of the survey campaign.

E.g., **student enrollment** numbers for economic losses due to education disruption and other needs-related parameters

Baseline risk: exposure & vulnerability

The built environment in the Pacific Island countries such as Tonga, Samoa, and Vanuatu are characterized often by ***single-story***, ***large aspect ratio***, ***timber or masonry*** buildings.

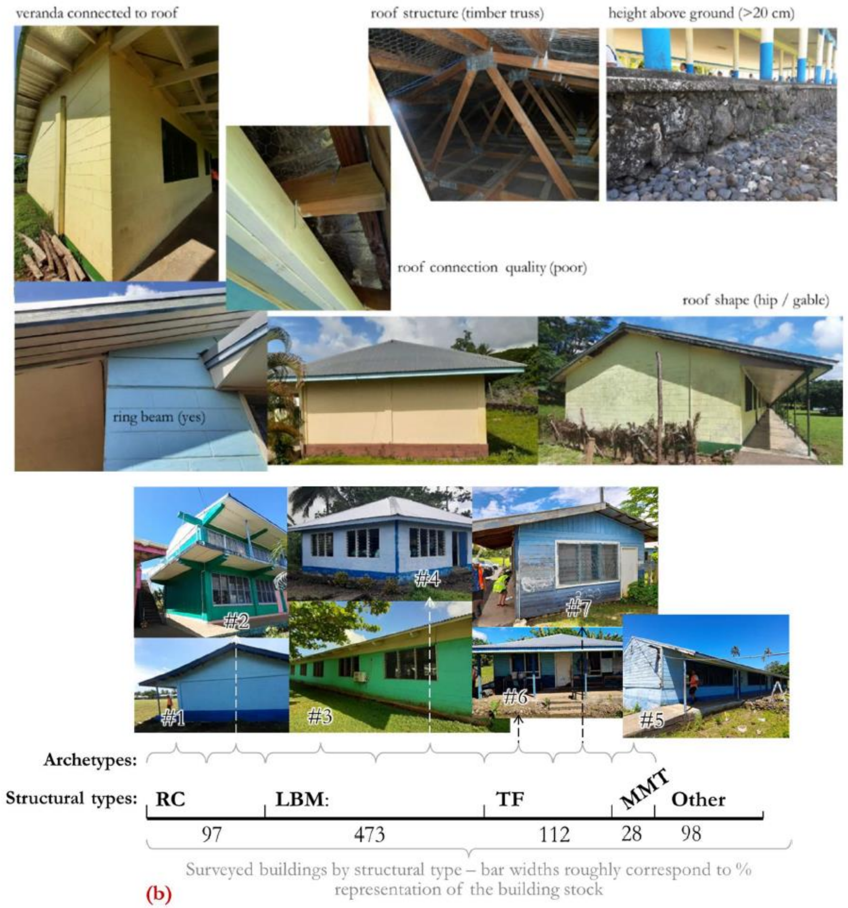


MMT: mixed masonry-timber, RCL: low-rise reinforced concrete, RCM: mid-rise reinforced concrete, S: steel, TF: timber frame, TRD: traditional, RM: reinforced masonry

Exposure is characterized as per the **GLOSI taxonomy** for the consequent vulnerability analysis stage.

Baseline risk: exposure & vulnerability

Poor structural features rendered vulnerability characterization a challenging task



Baseline risk: exposure & vulnerability

How would you characterize this foundation for analysis? Fixed foundation? Maybe base isolated?

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Baseline risk: exposure & vulnerability

A snapshot of the developed physical baseline **vulnerability functions**

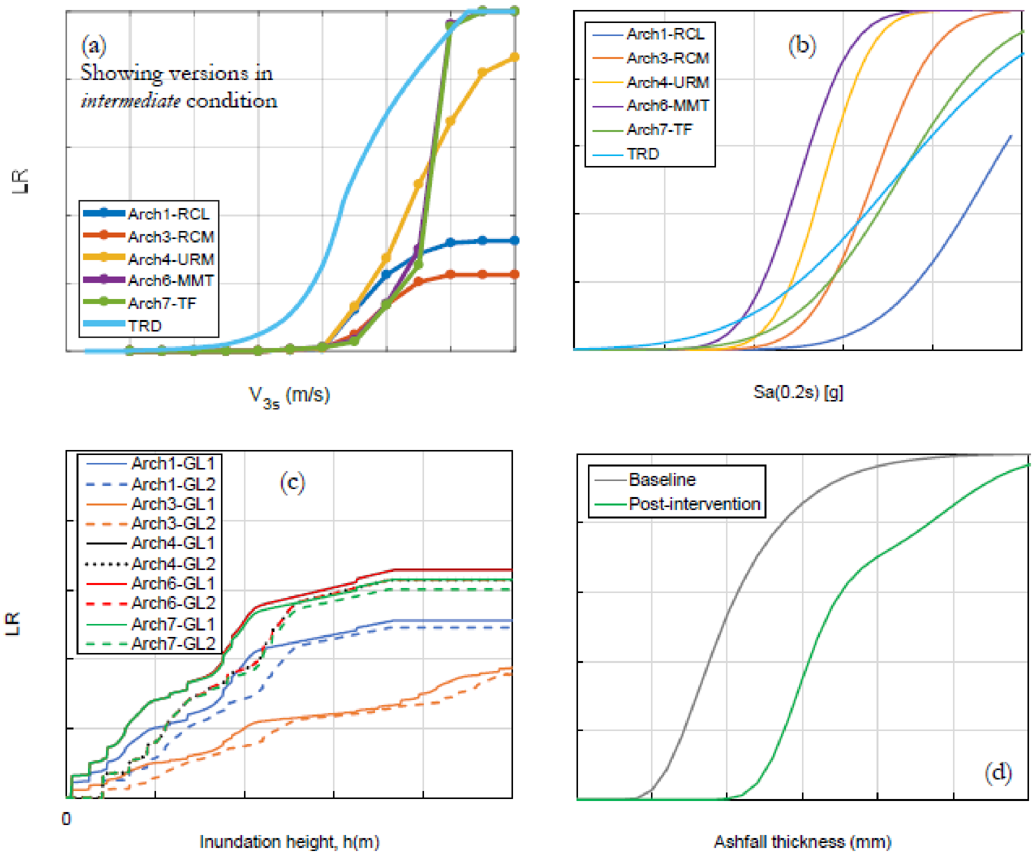


Figure 2. Main (a) wind, (b) earthquake ground motion, (c) flood and (d) ashfall (volcano) vulnerability functions. RCL: reinforced concrete low-rise, RCM: reinforced concrete mid-rise, URM: unreinforced masonry, TF: timber frame, MMT: mixed masonry timber, TRD: traditional.

Baseline multi-peril risk

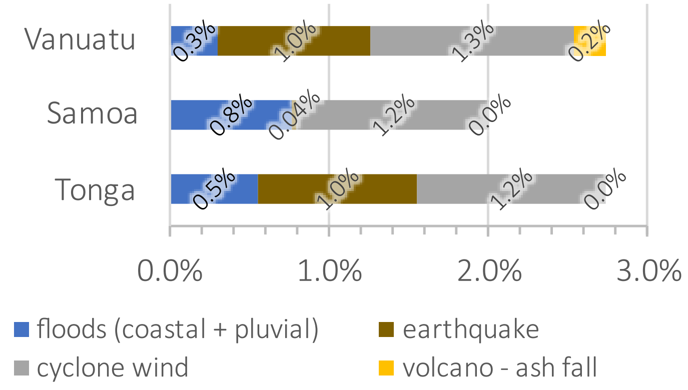
Natural disasters* are expected to cost the education sectors of Tonga, Samoa, and Vanuatu **~1.5% of their GDP** and **~500,000 interrupted student education days** every year (in total).

* Considering the direct and equivalent monetary cost of disruption of education due to:
earthquake ground motion, landslide, (pluvial, fluvial and coastal) flood, ashfall following volcanic eruptions.

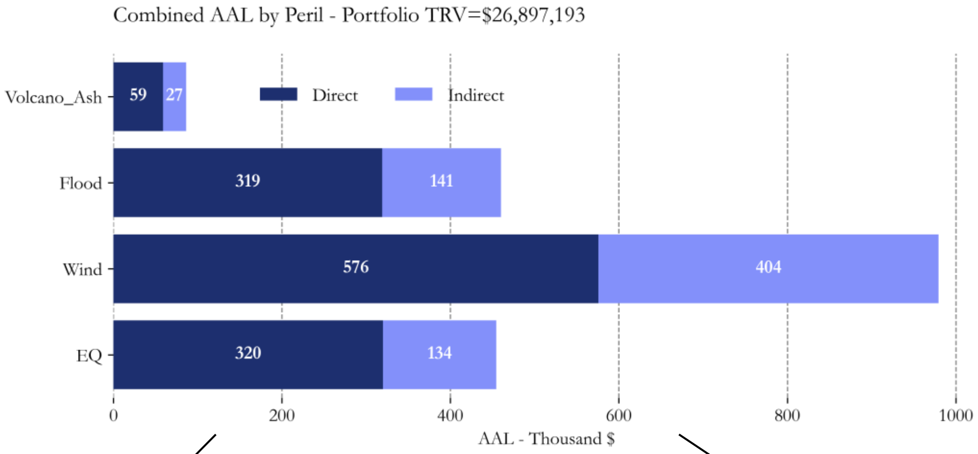
Baseline multi-peril risk

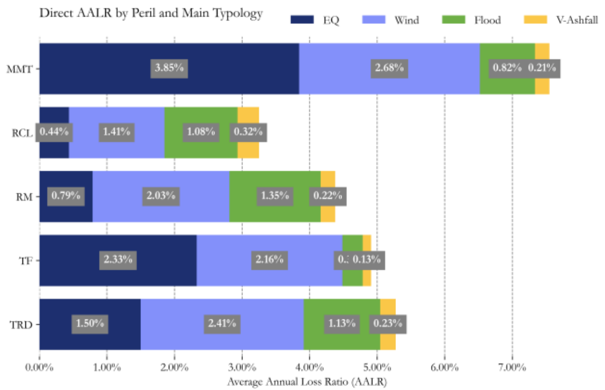
An overview of risk estimates for the education sectors

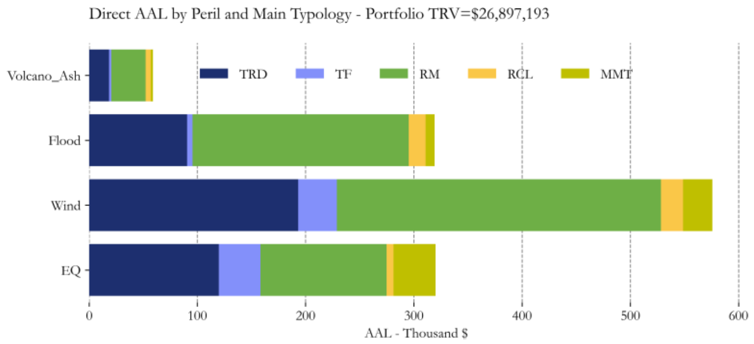
Average annual loss ratios by peril



Average annual losses – direct v. indirect







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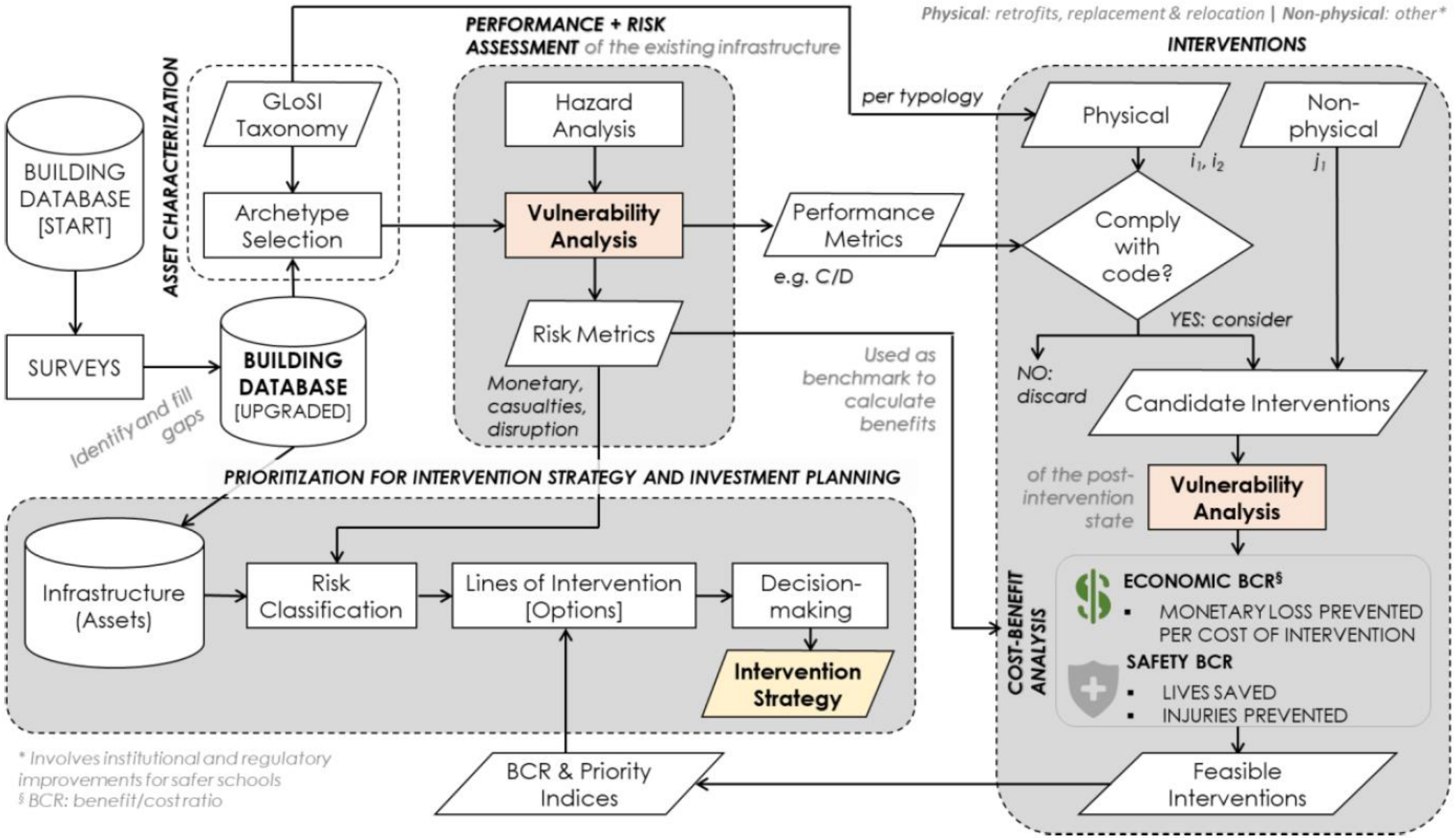
Strengthening Resilience

Initial recommendation for the prioritization framework based on **return on investment**



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Strengthening Resilience

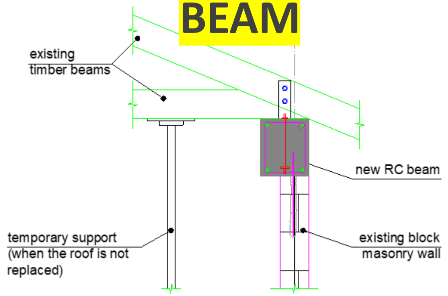
We considered more than 10 **feasible interventions** for risk mitigation

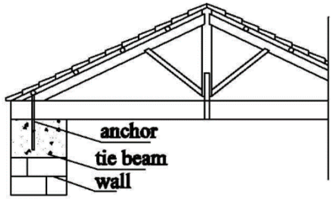
Following the definition of this list,

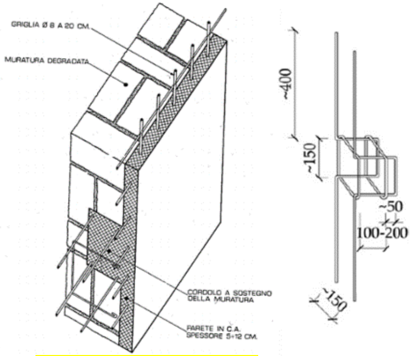
1. Intervention costs were estimated
2. Post-intervention vulnerability functions were developed
3. Interventions classified by **permit requirement**
4. Multi-peril risk mitigation has been taken into account by (NPV) **cost-benefit analysis**

NPV: net present value

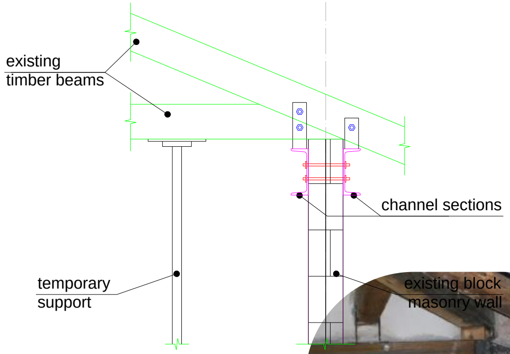
RC RING BEAM



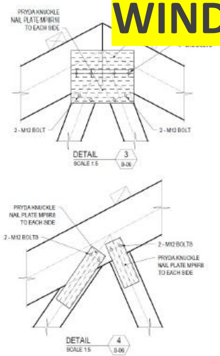


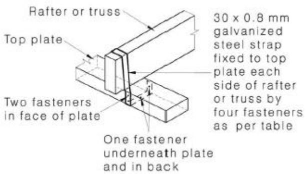


STEEL RING BEAM



ROOF FIXINGS & WIND TIE-DOWNS





TIMBER STRONGBACKS

CONCRETE MORTAR LAYER

Strengthening Resilience

Prioritization scheme (for the education sector) agreed amongst stakeholders:

Main criteria hierarcy

1. Prioritize **highest-risk <u>schools</u>**
2. Deliver **code-compliance** against cyclones and earthquakes – *results in a lot of replacements*
3. Prioritize highest economic **benefit per dollar invested** amongst intervention alternatives for a given asset

Some of the best-fitted interventions can deliver **up to 60$ in mitigated losses for every $ invested** across a 20-year investment horizon.

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Strengthening Resilience

Applying the **prioritization scheme** agreed amongst stakeholders

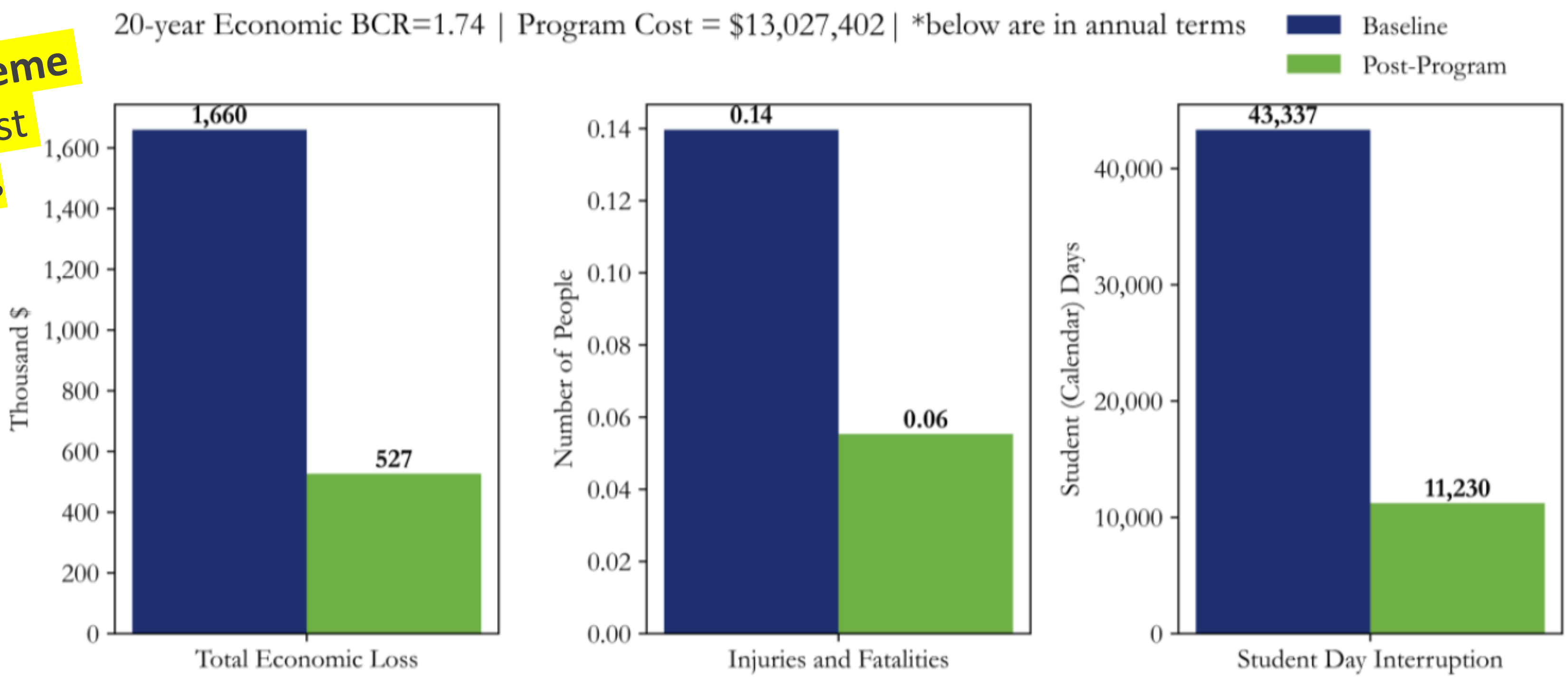

Fig. Risk mitigation statistics for a 13M US$ program for Tonga education sector. Total economic loss comprises both direct and indirect loss components. Numbers in the middle column represent the aggregated annual injury and fatality rates. The student day interruption estimates reflect calendar days by person.

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Strengthening Resilience

$13M recommended **investment program** for Tonga education sector

US$ 13 million investment program of prioritized strengthening solutions

38 schools
142 buildings
strengthened

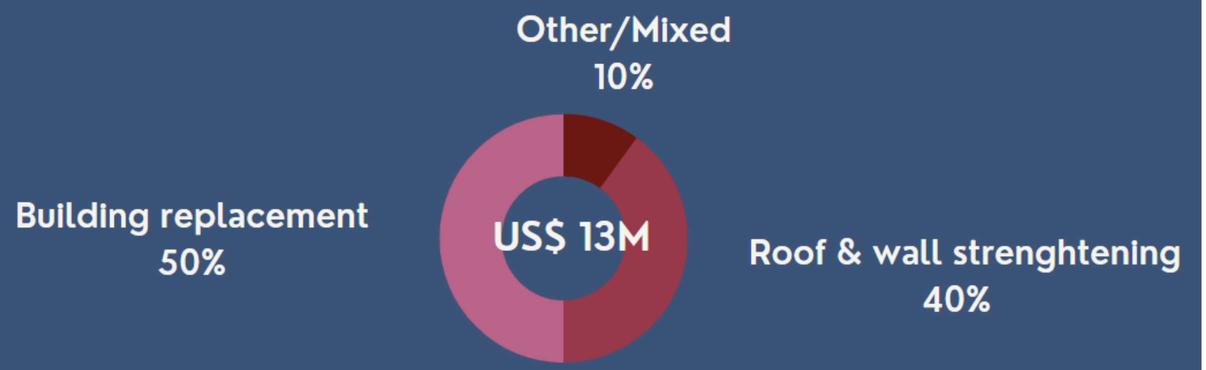
6,071 students benefit safer schools

68% Disaster loss reduction

23,000 student education days recovered/year

USD 1.1m mitigated in economic losses/year

USD 1.8 mitigated for USD 1.0 invested in 20 years



Breakdown of program by intervention type

Closing remarks

- Life in the Pacific is tough indeed
- **Non-engineered or heavily deteriorated structures** make analytical, multi-peril vulnerability modelling very challenging – forcing engineer to find workarounds.
- **Logistics** is a big factor in making risk mitigation decisions, prioritization of investments, capital allocation, etc.
- **Multi-peril risk assessment and resilience planning** requires juggling with tens of different competing priorities which are heavily subject to cultural, political biases and environmental concerns. *Triage* is the name of the game – consultant is there to inform about likely consequences of different decisions.
- Stakeholder and data-driven (e.g., highest return on investment in terms of mitigated losses) priorities do not always align. Consultant is there to inform the stakeholder, not to replace the decision-making process.

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Acknowledgements & disclaimers

The consulting services for the Strengthening the Resilience of Public Facilities in Samoa Tonga, and Vanuatu project were funded by the World Bank through the Global Facility for Disaster Reduction and Recovery (GFDRR)

The information provided here stems from the Technical Assistance (TA) provided to the World Bank by a consortium led by RED Risk Engineering and Development under the SRPF project. The outputs and conclusions provided here have been derived using input data such as in-country surveys and desktop study findings, and various well-established methodologies and models. Most reported numbers are averages, they are subject to considerable uncertainty, and they do not constitute attempts to capture reality — rather, they are model estimates intended to be useful tools for informed decision-making. None of the reported information constitute the endorsement of the consultant. The outcomes are further subject to limitations mentioned throughout the final report deliverable of the project.

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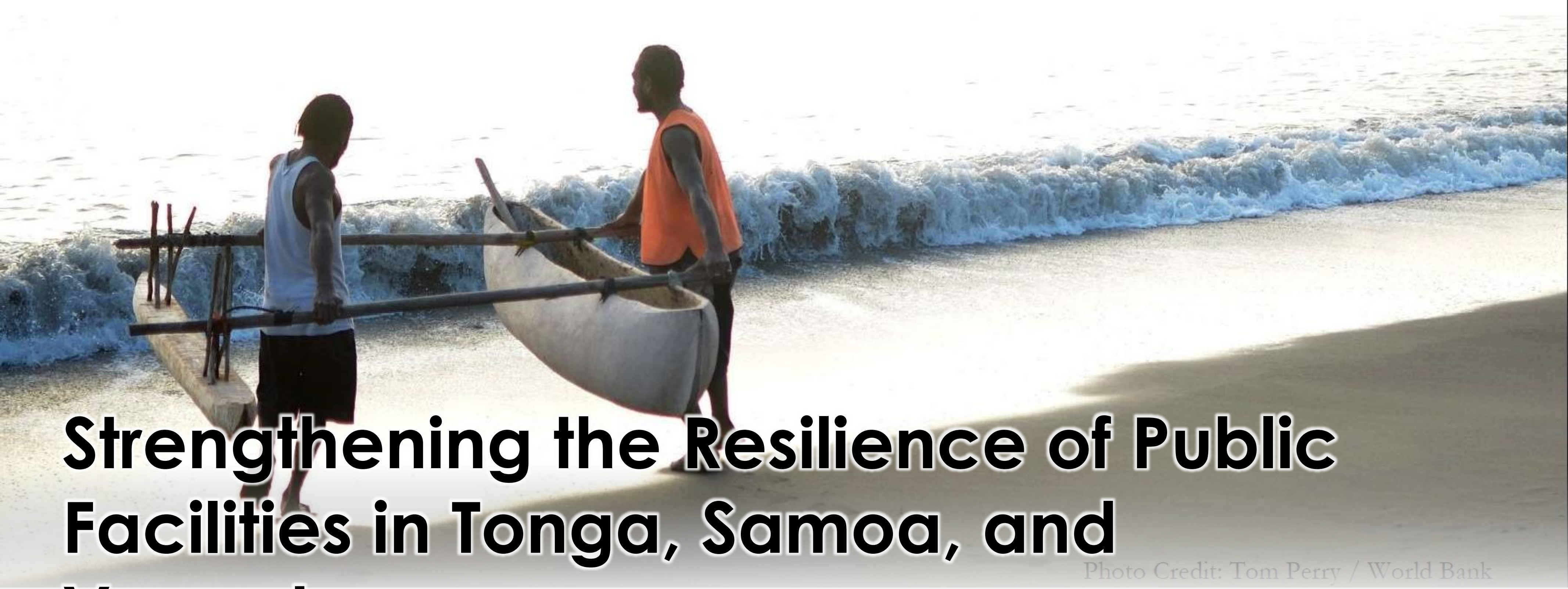

Photo Credit: Tom Perry / World Bank

Strengthening the Resilience of Public Facilities in Tonga, Samoa, and Vanuatu

Presentor:

Ettore Fagà, PhD

Contributors :

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June 15, 2023

Supplementary

Taxonomy

ID	Structural type	Photographs and Commentary
1	Single-story reinforced concrete (RCL)	  Single-story reinforced concrete frame with non-bearing concrete block masonry infills. The roof can be made of timber or steel and have any shape. The archetype has gable shape connected with a veranda, which is the prevalent configuration and the reason behind the selection. Since it does not have a meaningful impact on the overall performance, the veranda columns may be from steel, timber or concrete.
2	2-storey reinforced concrete (RCM)	  2-storey reinforced concrete frame with non-bearing masonry infills. Concrete slabs at the intermediate floor and timber roof. The columns and floor of the veranda are also made of reinforced concrete. The roof is connected to the floor (beams) underneath. Concrete beams extend outward at the upper floor and roof levels to support the balcony and the roof extension.

Supplementary

Taxonomy

3	Single-story reinforced masonry (RM) with veranda	  The walls of most load-bearing masonry systems (LBM) are made of 20cm thick concrete blocks – nearly all (98%) LBMs (except those that are MMT) in Samoa are reinforced. The walls of the surveyed LBM were found to be reinforced with steel rebars passing through holes within masonry blocks filled with mortar. As such, the walls of this archetype are also configured to be reinforced. Individual panels are, on average, 6–8 m long. While walls in the transverse direction do not have any openings, those in the longitudinal direction have large openings for windows/doors. The roofs are made of timber truss with a connected veranda as this is the most frequently seen configuration. Since most of the LBMs (70%) in Samoa incorporate RC ring beams, so does this archetype, to best represent the population.
4	Single-story reinforced masonry (RM) without veranda	  The structural configuration is similar to RM type described above (archetype #3). This archetype does not incorporate a veranda and the roof shape is hipped with eaves all around, which represents roughly 7% (34 out of 473) of the LBM population. Thus, wind actions to exert on the roof are expected to differ from those induced on its conventional counterparts. The archetype does not include ring beams, even though long openings are present. The roof is made of timber truss along both directions.
5	Mixed masonry timber (MMT)	  Buildings with unreinforced bearing masonry up to floor level (roughly up to +1.3m) and timber frame above. May be with or without ring beams, which will be delineated by evaluating sub-models or ad-hoc modification factors. These buildings are often not well-maintained. The roof can be of either timber truss or rafters, which would not cause a remarkable difference in response – this archetype will be able to represent both variations.

Supplementary

Structural analysis for baseline and post-intervention vulnerability function dev.

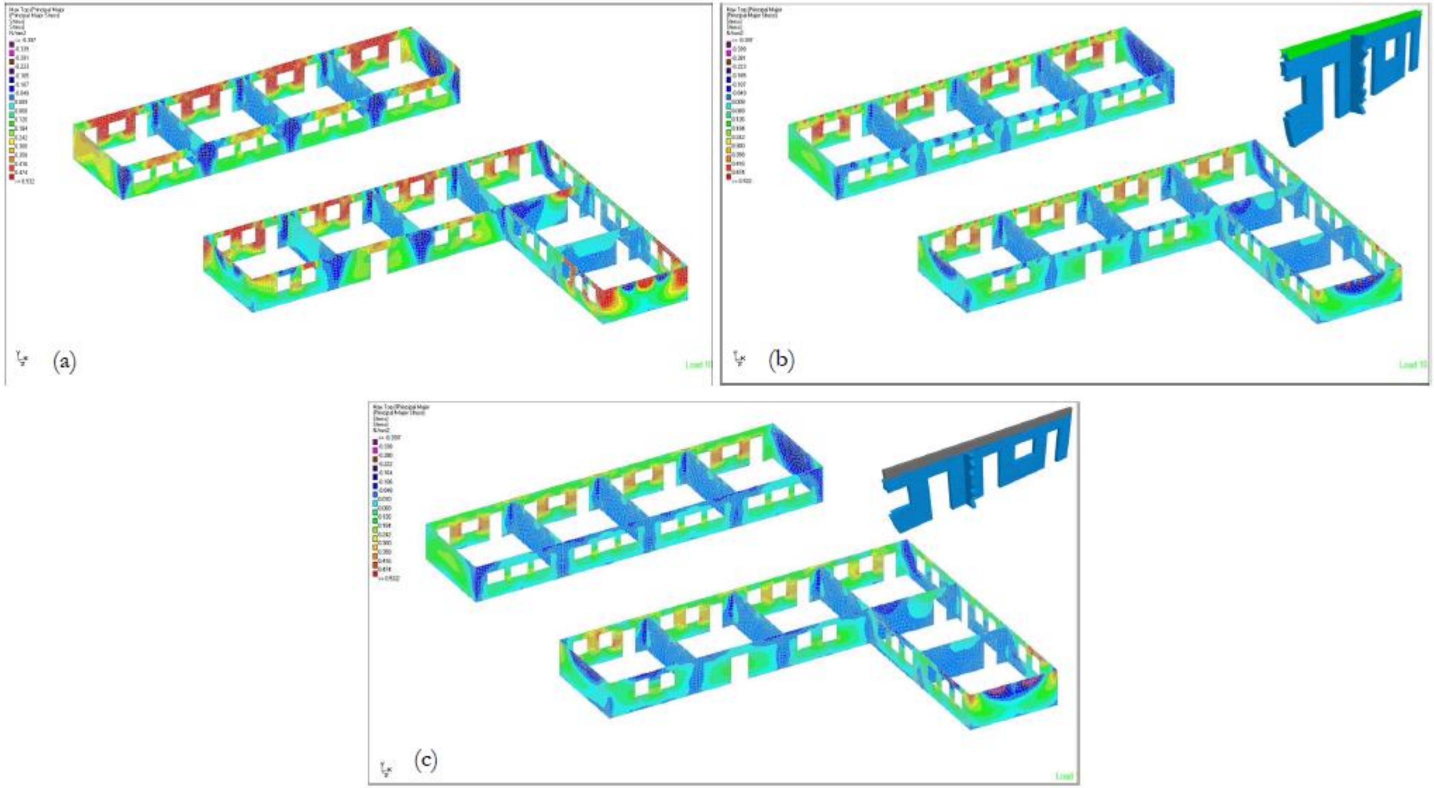

Figure 7. Representation of the effect of each structural intervention on the stress distribution of masonry walls: a) insufficient timber top plate, b) steel ring beam, c) RC ring beam. Cold-to-hot color scale corresponds to compressive-to-tensile stress. The roof is not rendered for ease of viewing.

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Supplementary

Vulnerability functions showcase

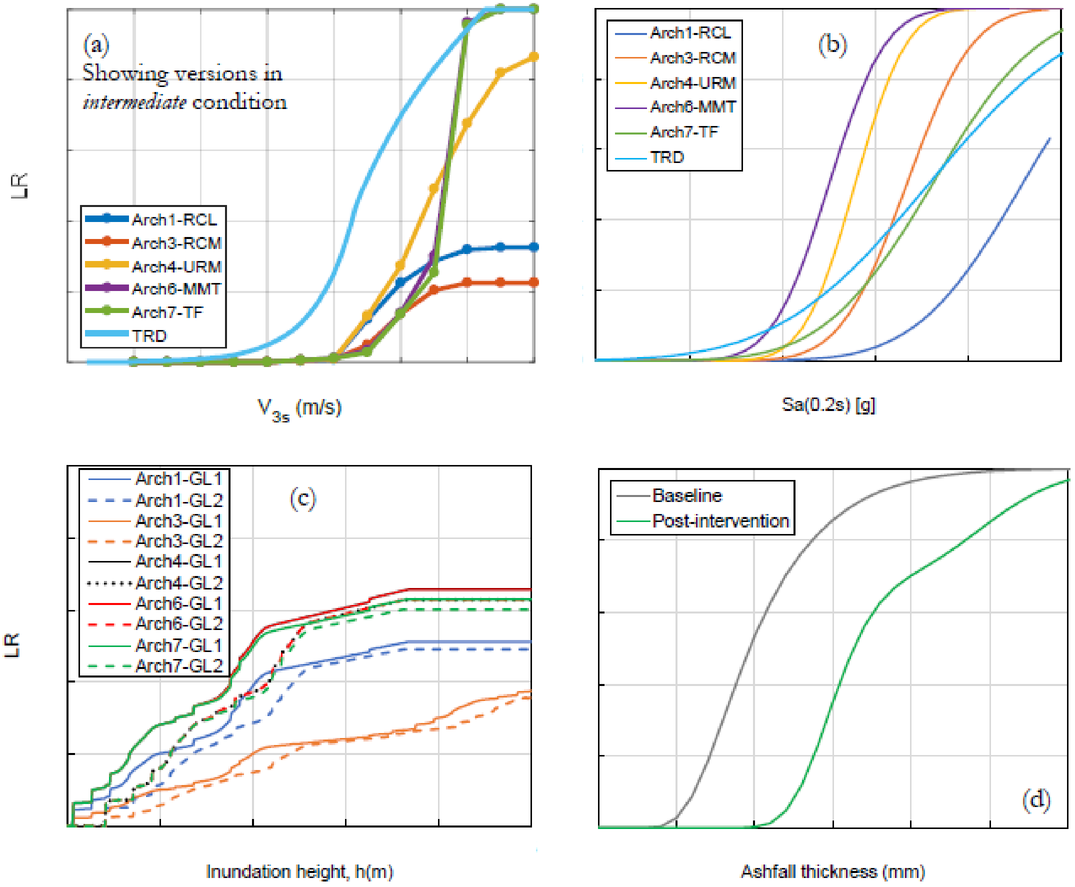

Figure 2. Main (a) wind, (b) earthquake ground motion, (c) flood and (d) ashfall (volcano) vulnerability functions. RCL: reinforced concrete low-rise, RCM: reinforced concrete mid-rise, URM: unreinforced masonry, TF: timber frame, MMT: mixed masonry timber, TRD: traditional.

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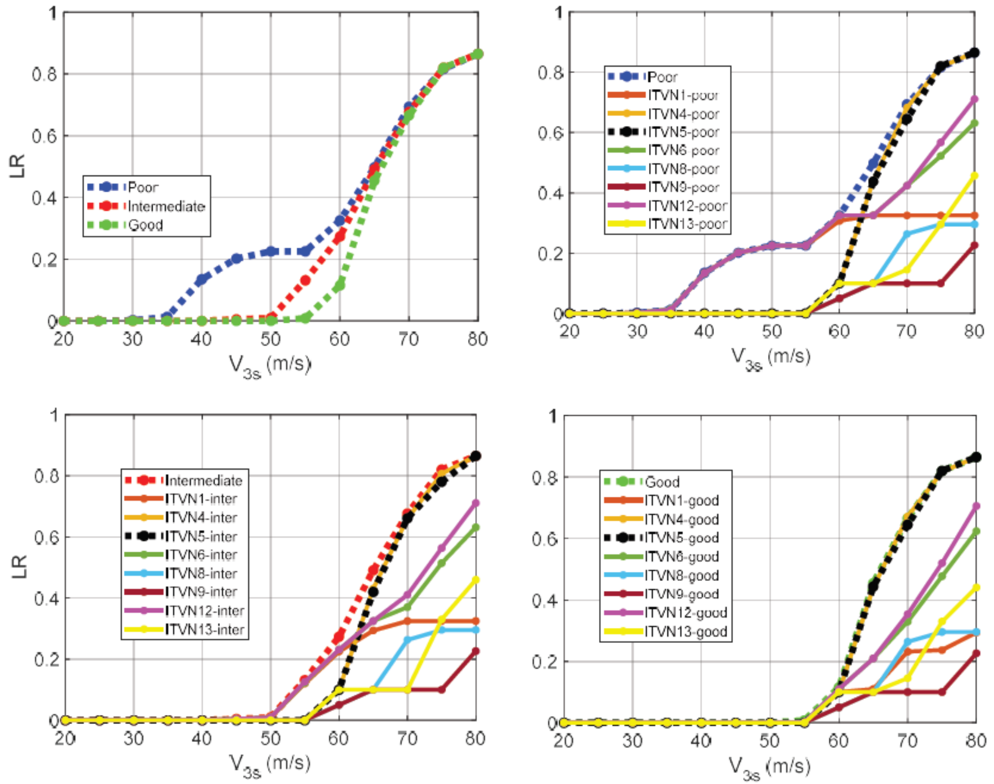
Supplementary

Analytically-derived wind vulnerability functions based on

- structural class
- roof system capacity



ITVN1: reinforced mortar layer
ITVN4: replacement of roof connections
ITVN5: roof replacement
ITVN6: steel ring beam
ITVN8: ITVNs 1&4
ITVN9: ITVNs 1&5
ITVN12: Timber strong backs
ITVN13: RC ring beam & roof replacement

Figure 8. Vulnerability functions for archetype 4/URM

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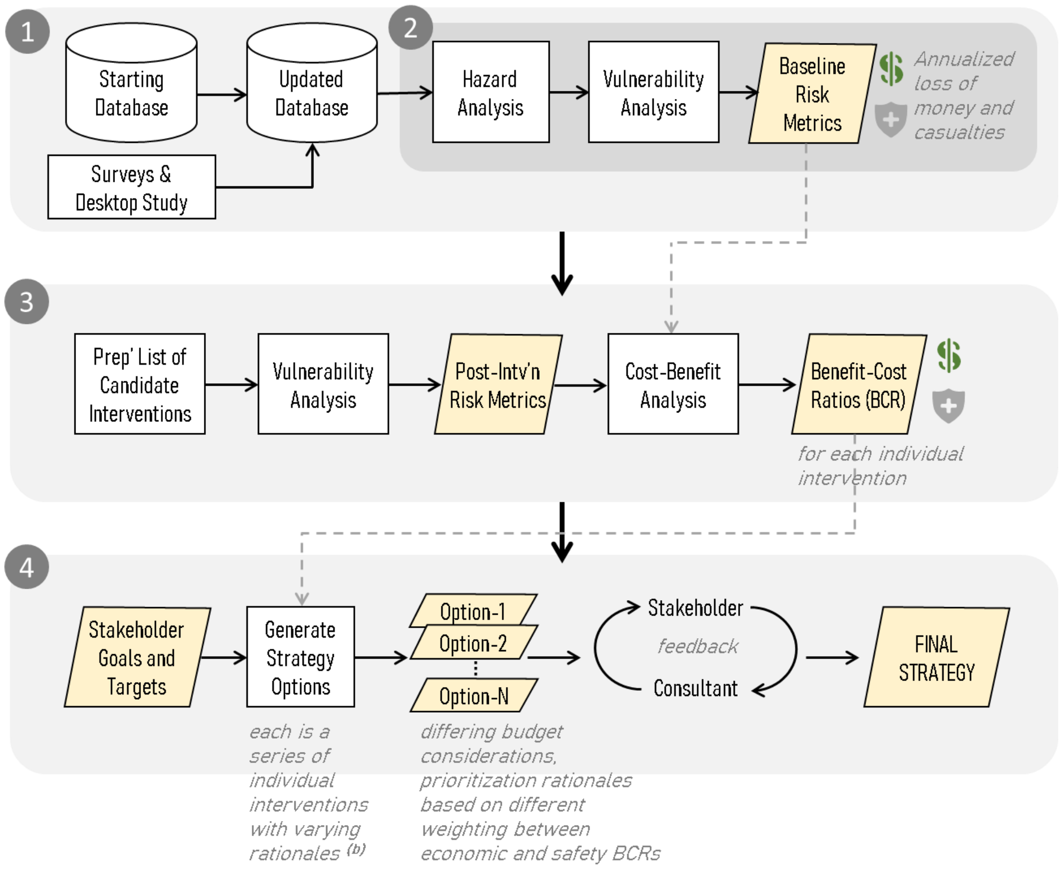
Supplementary

Prioritization framework - alternative



BASELINE DISASTER RISK ANALYSIS

INTERVENTIONS & QUANTIFICATION OF RISK MITIGATION VIA CBA

STRATEGY OPTIONS FOR INVESTMENT PROGRAMS

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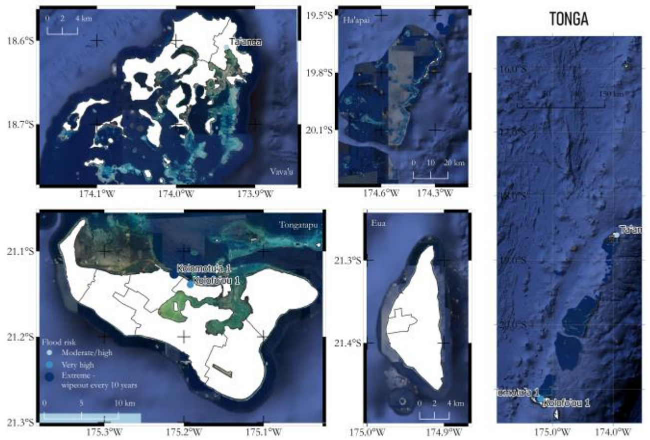
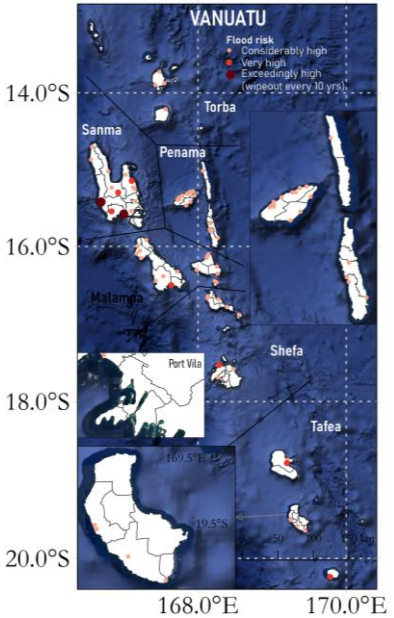
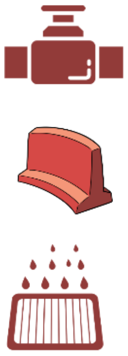
Strengthening Resilience

Specialized, data-driven, scale (site-level) **recommendations** for flood risk mitigation



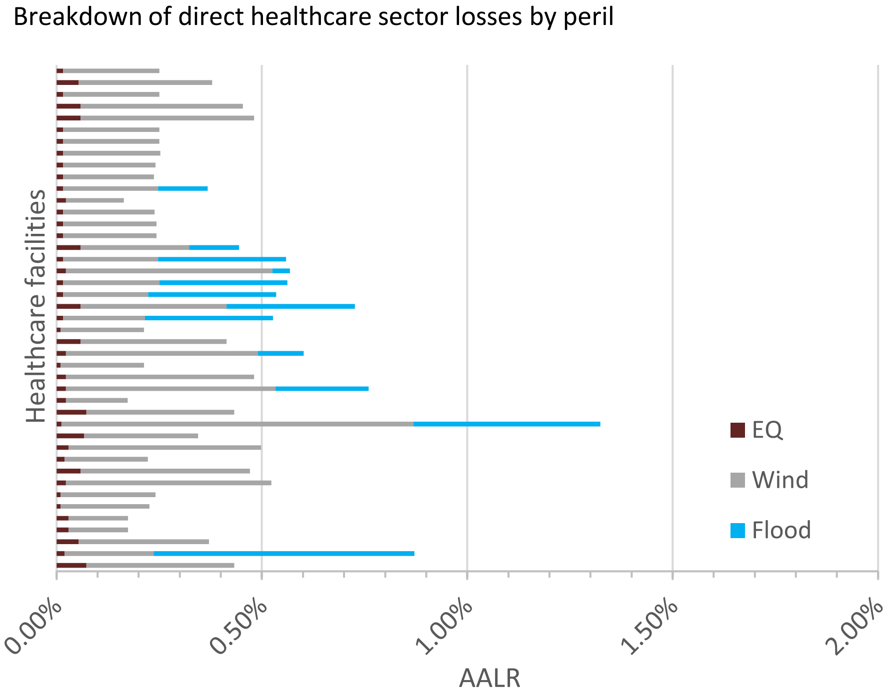


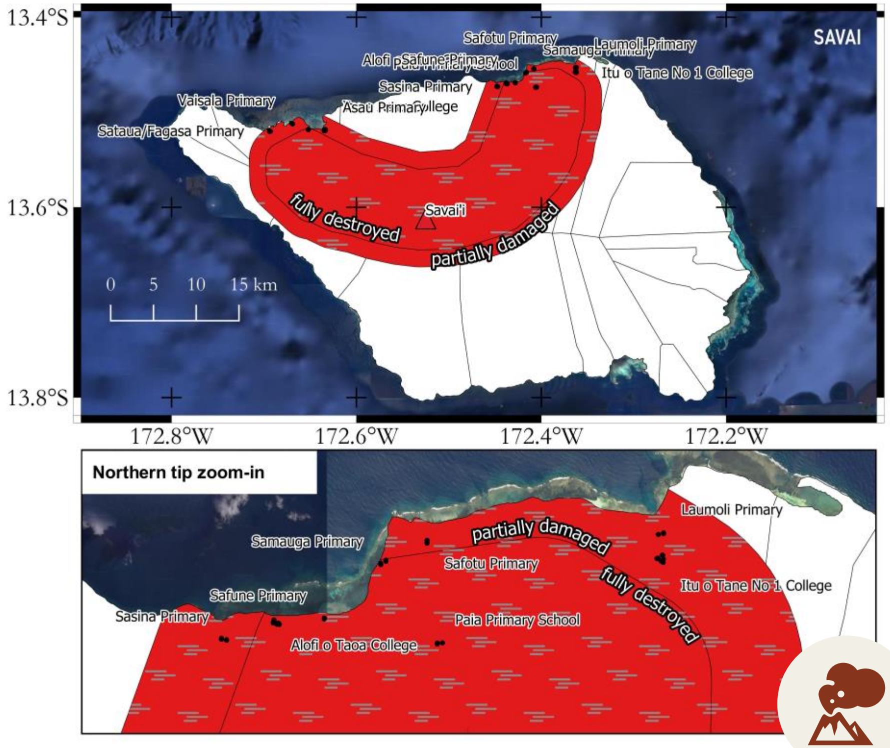
- **Flood protection levees** against coastal and fluvial (e.g., Liviela)
- **Additional drainage** mostly against pluvial (e.g., 'Apifo'ou college)
- **Flood gate / non-return valves** for water discharge mostly against pluvial (e.g., 'Apifo'ou college)
- **Relocation** if feasible (e.g., Kolomotu'a)



Baseline multi-peril risk

(Left) Quantitative risk analysis for the health exposure. **(Right)** Lava flow susceptibility map for Savai'i, Samoa.

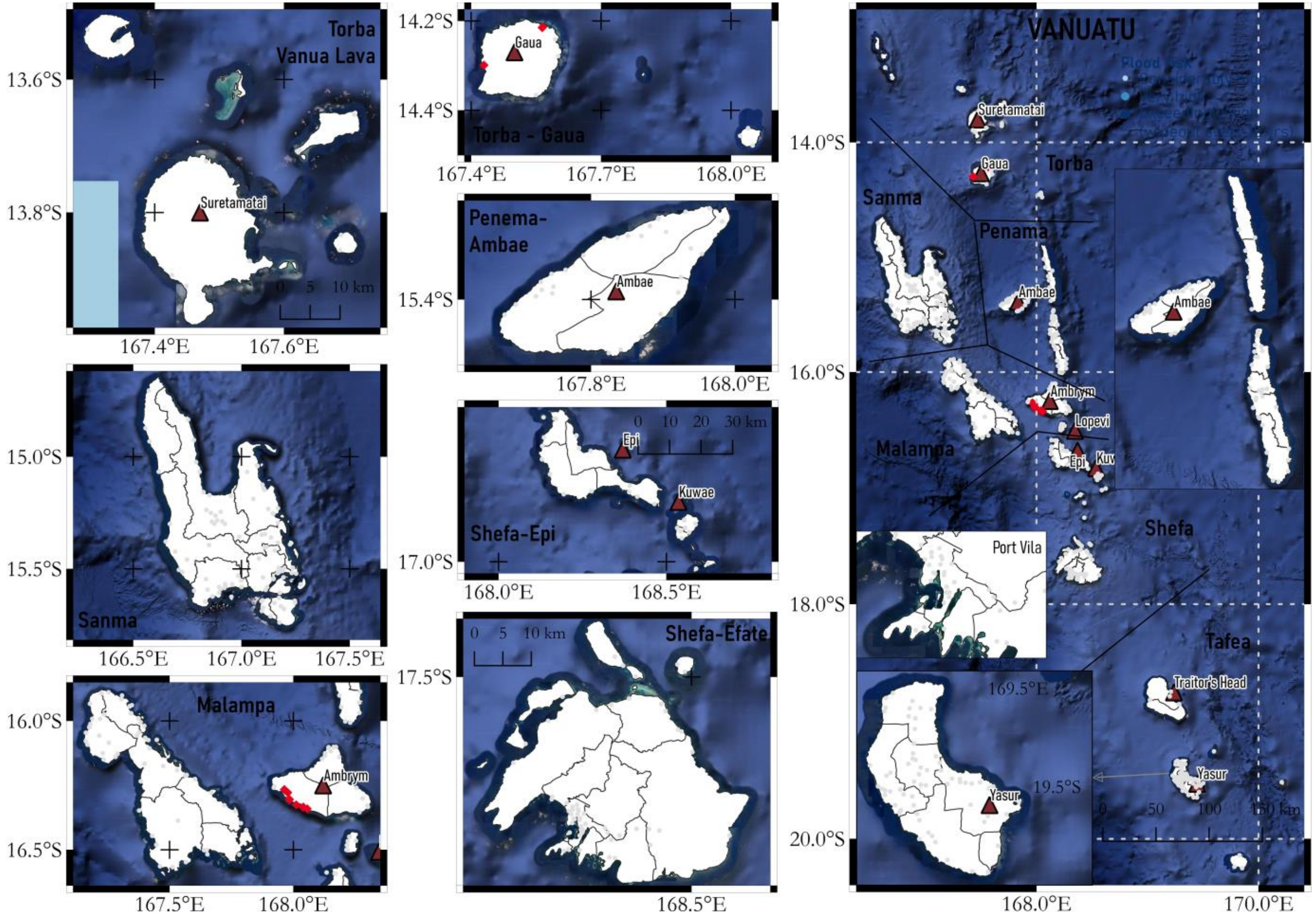




Supplementary

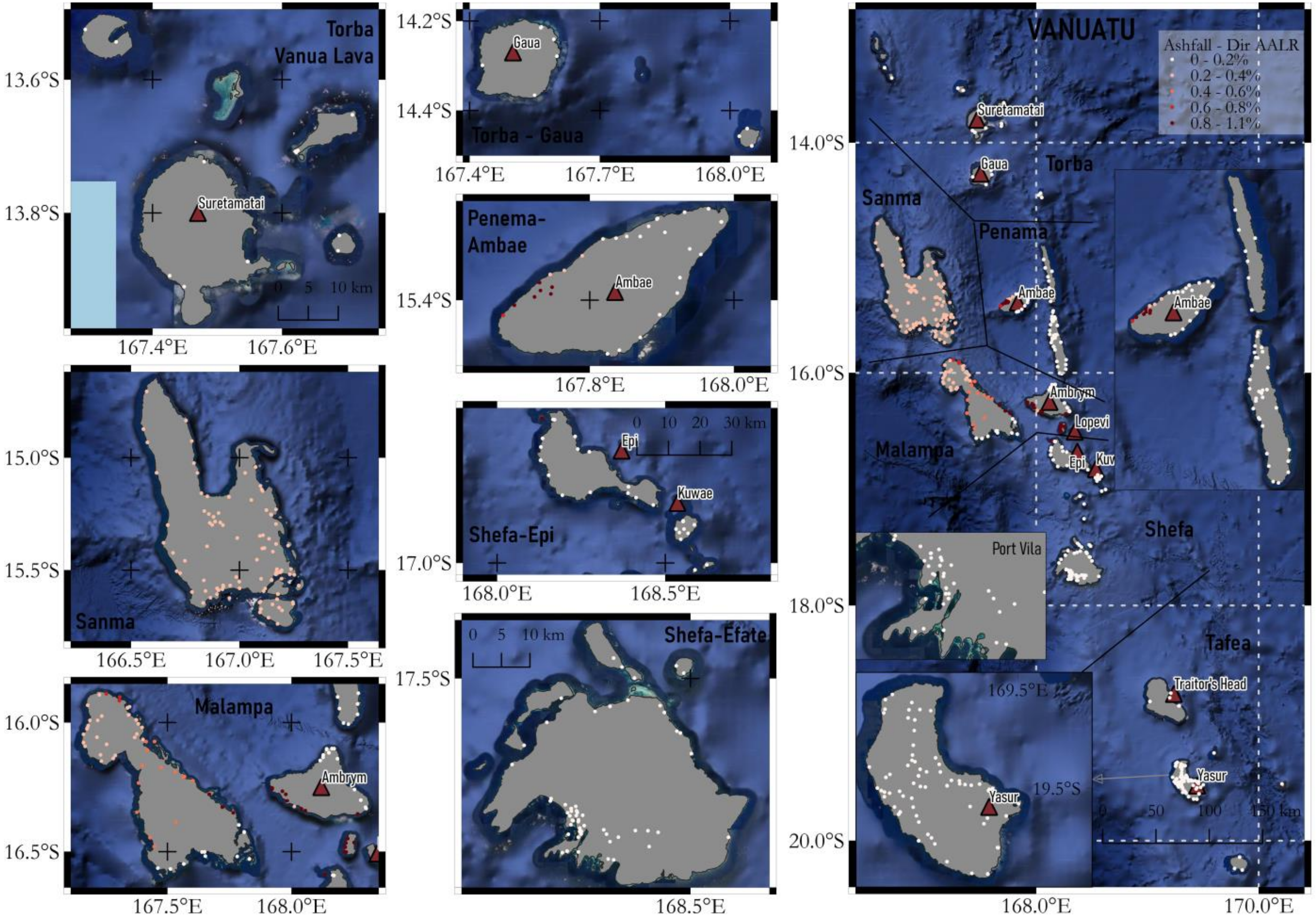
Volcano (pyro & lawaflow) susceptibility for Vanuatu

Red dots are schools/buildings expected to be completely destroyed at least once in 100 years



Supplementary

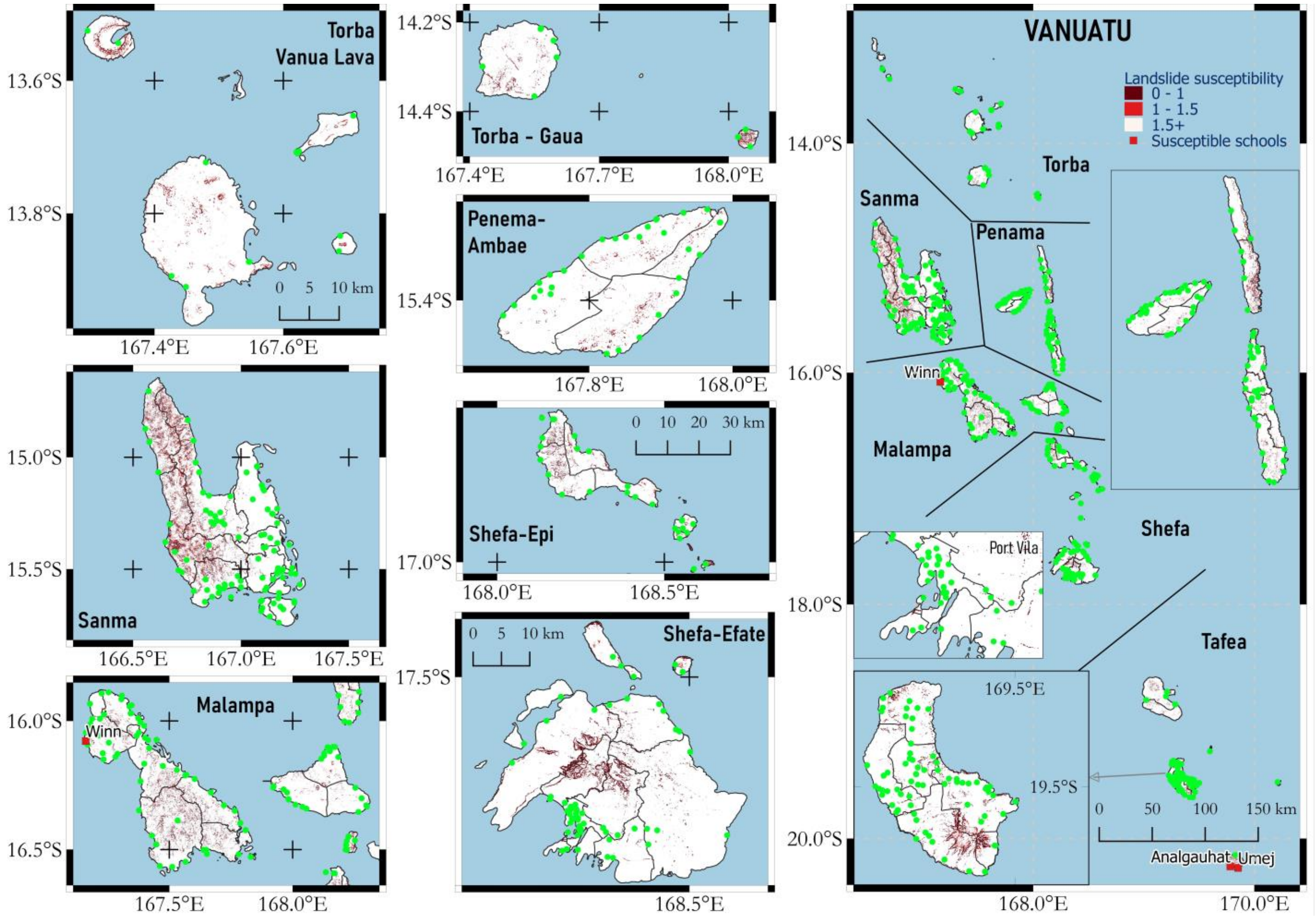
Volcano – ashfall risk (based on physical damage to buildings)



Supplementary

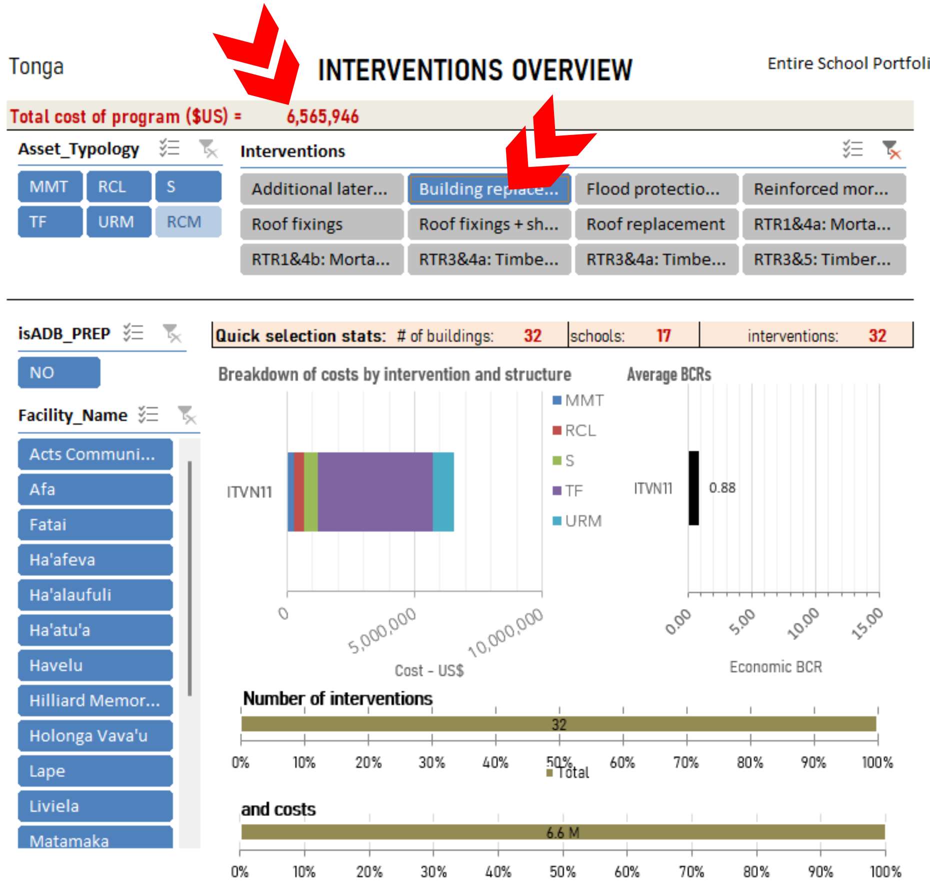
EQ-induced **landslide** susceptibility.

High-risk schools (if Ac/Acmax<1.0) labeled on map



Supplementary

Strengthening Resilience: Tools for the stakeholders



Supplementary

Indirect economic loss methodology

3 Indirect Economic Loss

Indirect economic loss is borne by the interruption of education and the consequent monetary loss of returns on education. The return on education is computed per student on a yearly basis given the *downtime* that the perils cause. Indirect loss due to student day interruption is calculated simply by combining:

- Downtime (years), d
- Number of students that a given building accommodates, n_s
- Net yearly return to education per student, NR

For a given school building, incurred average annual indirect loss is calculated as

$$Indirect\ Loss = d \cdot n \cdot NR$$

where, NR is computed using the relationship adopted as part of the SSP[5] project (ARUP and The World Bank 2020):

$$NR = \sum_t W_t \cdot (1 + GR) - C - OC$$

Here, we kept the parameter values for the function same (i.e., those adopted in the SSP):

- W_t, average wage (\$/year) = 7,945
- GR, gross return to schooling (per cent) = 10
- C, Cost of a year of education (\$/year) = 434
- OC, Opportunity cost (\$/year) = 2,384

The equation above results in a net loss of educational return, NR, of \$5,953, per student, per one year of downtime. As such, for instance, a classroom of 20 students with an estimated 5 calendar days (because downtime will also be estimated on this basis) out of 365 days (no need to normalize for weekdays provided both the nominator and the denominator to be used in calculation are in calendar days) of average annual downtime would result in an expected indirect loss of:

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