RESPONSE TO REVIEWER COMMENTS:

Authors' General comment: Thank you for the Reviewer's constructive comments concerning our manuscript entitled "Sensitivity analysis of a built environment exposed to debris flow impacts with 3-D numerical simulations" (ID: nhess-2022-173). Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied comments carefully and have made correction which we hope meet with approval. Revised portion are marked in red in the paper and response letter, and the manuscript is re-submitted in clean format to the Journal. Please also find below my response to Reviewer's comments.

REVIEW COMMENTS:

According Martinez-Carvajal et al (2018), a natural phenomenon (hazard) may be characterized in terms of temporal, spatial and magnitude probabilities. The effects of the interaction between the hazard and the exposed element depend on the intensity of the hazard and on the resistance, sometimes called susceptibility, of the element at risk, which describes the propensity of a building or other infrastructure to suffer damage from a specific hazard impact. Consequently, a modern concept of vulnerability must consider the intensity of the hazard as well as the structural resistance of the exposed infrastructure. This concept is referred to as physical vulnerability, and the most accepted definition is a representation of the expected degree of loss quantified on a scale of 0 (no damage) to 1 (total destruction).

Previous considerations leads me to suggest to the authors the inclusion of a broad discussion on vulnerability which certainly is the major objective of this kind of research. Comments on the effect of the buildings strength will be profitable for opening future research topics by means of numerical modelling.

AUTHORS RESPONSE: We greatly appreciate for Reviewer's good comments! As Reviewer suggested, a broader discussion on the contributions of the present paper towards debris flow hazard and vulnerability assessment was added in Line 546-568 of the revised manuscript.

Line 546-568:

It is obvious that the quantitative descriptions about the interactions between the built environment and impact forces can be useful to the built environment improvement and local adaptation measures for the impact force reduction, which are assumed as the low-cost and efficient approach for mitigating the building's structural damages. And more significantly, the present paper has extended the knowledge about the influence factors on debris flow intensity. It is demonstrated that some artificial building factors can not be ignored, except for the natural environments, in deciding the spatial pattern of the process intensity. The further research about their relative importance with the 3-D numerical simulation and sensitivity analysis can promote the relative intensity evaluation of the building, especially in terms of the indicator selection and weighting, which may open a future topic of the debris flow hazard assessment. For the building vulnerability assessment, the indicators can be mainly divided into two kinds:

the exterior process intensity and interior building resistance. The process intensity, for example the flow depth, velocity, impact force or the other proxy, was assumed absolutely necessary, either in the curve based approach or the indicator based approach (Martinez-Carvajal et al., 2018). From the current literature, however, there are some confusions in selecting the surroundings factors and process intensity indicator. To be specific, some surroundings factors or also called protection factors, including the *Surrounding buildings*, *Building row*, *Wall around building*, *Natural barriers* and so on, were still selected when the debris flow intensity had been indirectly considered (Dall'Osso et al., 2009; Dall'Osso et al., 2016; Papathoma-Köhle et al., 2019). These indicators should be independent each other theoretically. From the views of the present paper, the functions of all over the surroundings factors are the influences on the process intensity around building. Therefore, the process intensity should be exclusive with the surroundings factors. The building features factors are mainly considered to be acted on the building resistance, including the *Material*, *Structure*, *Number of stories*, *Foundation strength* and so on. However, It is not hard to find that some building indicators, for example the *Orientation*, *Shape* and *Openings*, can rebuild the process intensity. As a result, the effect of the representative building features indicators on the building vulnerability needs an in-depth discussion in future. The last but not least, a more universal, robust index may be developed using the numerical simulation approach, which can improve the locality limits resulting from the empirical data, to some extent.

[1] Martinez-Carvajal, H. E., de Moraes Guimaraes Silva, M. T., Garcia-Aristizabal, E. F., Aristizabal-Giraldo, E. V., Larios-Benavides, M. A.: A mathematical approach for assessing landslide vulnerability. Earth Sciences Research Journal, 22, 251-273. https://doi.org/10.15446/esrj.v22n4.68553, 2018.

[2] Dall'Osso, F., Gonella, M., Gabbianelli, G., Withycombe, G., Dominey-Howes, D.: A revised (PTVA) model for assessing the vulnerability of buildings to tsunami damage, Nat. Hazards Earth Syst. Sci., 9, 1557-1565, https://doi.org/10.5194/NHESS-9-1557-2009, 2009.

[3] Dall'Osso, F., Dominey-Howes, D., Tarbotton, C., Summerhayes, S., Withycombe, G.: Revision and improvement of the PTVA-3 model for assessing tsunami building vulnerability using "international expert judgment": introducing the PTVA-4 model, Nat Hazards, 83, 1229-1256, https://doi.org/10.1007/s11069-016-2387-9, 2016.

[4] Papathoma-Köhle, M., Schlögl, M., and Fuchs, S.: Vulnerability indicators for natural hazards: an innovative selection and weighting approach, Scientific Reports, 9, 15026, https://doi.org/10.1038/s41598-019-50257-2, 2019.