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## 3D point cloud-based assessment of detailed building damage through a combination of machine learning, crowdsourcing and earthquake engineering

Vivien Zahs<sup>1</sup>, Benjamin Herfort<sup>2,3</sup>, Julia Kohns<sup>4</sup>, Tahira Ullah<sup>3</sup>, Katharina Anders<sup>1,5</sup>, Lothar Stempniewski<sup>4</sup>, Alexander Zipf<sup>2,3,5</sup>, and Bernhard Höfle<sup>1,5</sup>

<sup>1</sup>3DGeo Research Group, Heidelberg, Heidelberg University, Heidelberg, Germany (zahs@uni-heidelberg.de)

<sup>2</sup>GIScience Research Group, Heidelberg University, Heidelberg, Germany

<sup>3</sup>Heidelberg Institute for Geoinformation Technology gGmbH, Heidelberg University, Heidelberg, Germany

<sup>4</sup>Institute of Reinforced Concrete Structures and Building Materials, Karlsruhe Institute of Technology, Karlsruhe, Germany

<sup>5</sup>Interdisciplinary Center for Scientific Computing, Heidelberg University, Heidelberg, Germany

Timely and reliable information on earthquake-induced building damage plays a critical role for the effective planning of rescue and remediation actions. Automatic damage assessment based on the analysis of 3D point cloud (e.g. from photogrammetry or LiDAR) or georeferenced image data can provide fast and objective information on the damage situation within few hours. So far, studies are often limited to the distinction of only two damage classes (e.g. damaged or not damaged) and to information provided by 2D image data. Beyond-binary assessment of multiple grades of damage is challenging, e.g. due to the variety of damage characteristics and the limited transferability of trained algorithms to unseen data and other geographic regions. The detailed damage assessment based on full 3D information is, however, required to enable efficient use and distribution of resources and for evaluation of structural stability of buildings. Further, the identification of slightly damaged buildings is essential to estimate the vulnerability for severe damage in potential aftershock events.

In our work, we propose an interdisciplinary approach for timely and reliable assessment of multiple building-specific damage grades (0-5) from post- (and pre-) event UAV point clouds and images with high resolution (centimeter point spacing or pixel size). We combine expert knowledge of earthquake engineers with fully automatic damage classification and human visual interpretation from web-based crowdsourcing. While automatic approaches enable an objective and fast analysis of large 3D data, the ability of humans to visually interpret details in the data can be used as (1) validation of the automatic classification and (2) alternative method where the automatic approach showed high levels of uncertainty.

We develop a damage catalogue that categorizes typical geometric and radiometric damage patterns for each damage grade. Therein, we consider influences of building material and region-specific building design on damage characteristics. Moreover, damage patterns include

observations of previous earthquakes to ensure practical applicability. The catalogue serves as decision basis for the automatic classification of building-specific damage using machine learning, on the one hand. On the other hand, the catalogue is used to design quick and easy single damage mapping tasks that can be solved by volunteers within seconds (Micro-Mapping, Herfort et al. 2018). A further novelty of our approach consists in the combination of strengths of machine learning approaches for point cloud-based damage classification and visual interpretation by human contributors through Micro-Mapping tasks. The optimal combination of operation and weighted fusion of both methods is thereby dependent on event-specific conditions (e.g. data availability and quality, temporal constraints, spatial scale, extent of damage).

By considering observations from previous earthquakes and influences of building design and structure on potential damage characteristics, our approach shall be applicable to events in different geographic regions. By the combination of automated and crowdsourcing methods, reliable and detailed damage information at the scale of large cities shall be provided within a few days.

## References

Herfort, B., Höfle, B. & Klonner, C. (2018): 3D micro-mapping: Towards assessing the quality of crowdsourcing to support 3D point cloud analysis. *ISPRS Journal of Photogrammetry and Remote Sensing*. Vol. 137, pp. 73-83.