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Vulnerability And Exposure Of Assets To Climate Change Related Hazards Models On Different Levels

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To effectively anticipate, react to, and recover from the impacts of climate change related hazards on infrastructures, building, and systems or subsystems of assets, it is imperative to implement proper adaptation actions. Precision in these adaptation measures is crucial for improving systems' resilience. To achieve this, a primary step involves modelling the risk of physical damage to these assets or systems of assets due to climate change related hazards. The estimation of physical damage is feasible through the modelling of exposure and vulnerability and the associated uncertainties. For adaptation actions to be effective, they must exhibit consistency across different levels. Actors of adaptation need to have a clear vision of actions relevant to their specific level, while being able to consider broader or narrower ones. This implies that there is a need for a clear vision of risk among various levels and well-defined underlying models, including exposure models, vulnerability models, and the associated uncertainty. This paper proposes vulnerability and exposure models that can adapt to different levels.

Ongoing climate change will have an impact on infrastructures. The IPCC (2021) report shows how climate change could modify the frequency and intensity of hazards under different climate scenarios. Vulnerability and exposure, which are key concepts in evaluating infrastructure resilience, could be expressed or defined in different ways depending on the asset level, asset type, or the available hazard information. Having a consistent notation to represent vulnerability and exposure among asset levels or available hazard information is essential if we want to go from one level to another. This notation can be useful for the modelling of the vulnerability and exposure with the objective of keeping track of the asset level under study. Furthermore, mathematical formulation of the relationship between levels enables going from a micro vision to a macro vision of vulnerability and exposure of assets, and specifically to climate change related hazards.

Van Westen and Greiving (2017) explain that the exposure models of assets take information about the hazard and about the asset as inputs. In the context of climate change, the change in the frequency and intensity of hazards will have a direct impact on the outputs of the exposure models of these assets. Furthermore, in this context of climate change, these changes in the frequency and intensity of hazard considered for a vulnerability analysis could have an impact on some of the vulnerability model outputs. For an actor involved in physical asset construction, maintenance or management – such as an individual, a company, or a state – it could be important to quantify exposure and vulnerability at different levels: an ensemble of assets (residential buildings, commercial buildings, roads, bridges), a specific type of assets (e.g., residential buildings), a subtype of assets (e.g.,, one floor houses), one specific asset (e.g., one specific one floor house), a subsystem (e.g., the building cover), or even components (e.g., roof window). Estimation of exposure and vulnerability at different levels has an importance for the quality of adaptation measures. In fact, having the estimation of exposure and vulnerability only at the ensemble of assets level, will allow the application of adaptation measures at this specific level. Whereas, having the information of the estimation of exposure and vulnerability at the ensemble of asset level,

and at finer levels up to the component level allows to put into practice more precise adaptation measures. To illustrate the different levels of modelling approaches, in the vulnerability modelling literature: Papathoma-Köhle et al. (2019) has worked on the physical vulnerability of buildings to one hazard at the building level, with a training sample in the European Alps, which can be characterized as an ensemble of building types. This study is taking into account the vulnerability indicators for a given building, vulnerability indicators are often used, in literature, at building level (Kappes et al., 2012; Papathoma-Köhle et al., 2022). Scawthorn et al. (2006) has worked on the potential physical damage on buildings to one hazard at the building level, characterizing different building types. In Huizinga et al. (2017), part of the work is on the potential damage on buildings facing one hazard at the building level, without differentiating building types. In Aznar-Siguan and Bresch (2019), the vulnerability model is estimating not only one type of asset damage but the economic impact facing one hazard. In Mühlhofer et al. (2023) several types of assets are taken into account in the risk analysis, and previously in the vulnerability model. These examples of vulnerability models from the literature are targeting one or few specific levels of assets with a specific vulnerability model. A contribution could be to model the link between different levels of assets not only for vulnerability models, but also for exposure models. Vulnerability and exposure definitions, vulnerability and exposure notations adaptable to asset types, levels and hazard's level of information would be a precise tool for an effective adaptation to climate change related hazards.

Our approach is to, first, identify what are the definitions of exposure and vulnerability in the literature. Then, we establish simple and adaptable definitions of exposure and vulnerability. These definitions are the bases for the mathematical definitions in the further work. While the methodologies to model the exposure are often similar, methodologies to model the vulnerability can differ significantly. To understand the different methodologies to model vulnerability, we choose to focus the literature research on only one infrastructure type for a precise study of the physical vulnerability models. We study the physical vulnerability assessment of buildings mainly thanks to two methodologies:

- physical vulnerability indicators-based models;
- physical vulnerability curves.

This focus study along with the study of exposure reveals the importance of the proper modelling of assets and hazards as key inputs for the exposure and vulnerability models. By studying this literature, we understand that there may be a need to have models that can generalize among levels for vulnerability, exposure. We, therefore, establish a notation which is adaptable to different types of levels and hazard's information. These notations need to describe both exposure and vulnerability. Technically, the goal is to propose quantification results corresponding to the notations of vulnerability and exposure at different levels while including different exposure, vulnerability quantification methodologies. This clarification paves the way for future research.

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