Debris flows pose a risk to mountain communities, particularly in mountainous areas subject to rainfall and where the topography favours the channelling of flows. State of the art risk mitigation is based on creating risk maps based on historical analyses and, more recently, numerical analyses. Typically, numerical modelling uses depth-averaged (DA) models based on shallow water equations. DA models allow for the integration of the velocity profile along the flow depth, thus neglecting the vertical velocity component and assuming constant horizontal velocity along the vertical. These assumptions are verified as long as the topography is smooth, and the flow depth is much smaller than the propagation length of the flow. However, hazard mitigation works can be seen as a sudden change in topography, and consequently, one of the assumptions of the models based on the shallow water equations is not met. DA models may have difficulty simulating the flow-structure interaction (FSI) due to integration along the flow depth. Recently, three-dimensional (3D) models have seen significant development, overcoming the difficulties of DA models for studying FSI. However, 3D models require more computational resources than DA models. As a result, the flow propagation phase is often approximated to a few metres with a dam break setup that might be too approximate.

In this thesis, a new method for studying debris flows is proposed. The method uses a DA model to study the propagation phase of the flow. As the flow approaches hazard mitigation structures, the results of the DA model are used as input for a 3D model. The latter conducts analyses of the interaction between flow and structure. This way of proceeding is a separation of the domain into two parts and thus allows the strengths of each numerical model to be exploited. In particular, the DA model is very efficient and reliable in studying runout but not FSI. On the contrary, the 3D model studies FSI very well but approximate the propagation phase to a small distance. In this thesis, DA and 3D models are coupled (DA-3D coupling), thus studying the FSI as a function of how the flow has previously propagated upstream, overcoming the difficulties of both DA and 3D models. The DA model is based on a finite volume solver, while the 3D model is based on the Lattice Boltzmann Method (LBM).

The 3D LBM model is validated first on a series of analytical solutions, as LBM is not widely used for frictional rheologies. Subsequently, two experiments at the laboratory scale were replicated to study the capabilities of the DA-3D model and to understand the influence on the final results by changing the position of the coupling. The results were encouraging, and once the influence of how the position of the coupling (where the DA and 3D model are coupled) on the final results was clarified, it was possible to study a debris flow that occurred in 2008 in the Italian Alps (Autonomous Region of Aosta Valley, municipality of Saint Vincent). The application of the DA-3D model at site scale offers the first application at site scale, where the advantages of the DA-3D method emerge. In particular, the FSI has been studied as a function of how the flow has previously diffused upstream, and the computational resources required were drastically reduced thanks to the coupling.