Immersed granular flows are defined as a collection of solid discrete bodies called grains surrounded by a fluid. It became a widespread area of interest due to their increasing use in various industrial processes. In mechanical and civil engineering, typical immersed granular flows are, for example, concrete or cement. The chemical industry make intensively use of colloids to prepare glue or gel while the pharmaceutical and cosmetic industries study different powders to prepare drugs or beauty products. The agro-food industry uses processes like drying of grains for the treatment of moist wheat grains. The efficiency of these industrial applications is directly related to the knowledge about immersed granular flows.

An unresolved model coupling the Computational Fluid Dynamics and the Discrete Element Method for immersed granular flows is presented along with a stable scheme to couple existing models for the solid and the liquid phases. On one hand, the fluid dynamics is considered at a coarse scale by computing averaged Navier-Stokes equations with the finite element method. On the other hand, the solid phase dynamics is computed at the granular scale considering grains as Lagrangian rigid particles. The nonsmooth contacts dynamics is a time-stepping method which is used to prevent any interpenetration of the grains at each time step and allows to represent local effects due to the grains configuration. It provides a fast and efficient combination of methods to compute applications such as the density sorting of grains by water jigging.

The finite element framework enables to adapt the spatial discretization at regular time interval to capture important flow features in complex geometries with a constant number of elements. Unstructured meshes using Lagrange linear shape functions for both the pressure and the velocity ensure a fast computation of flows which requires to be stabilized.

The model developed during this thesis was first validated on settling Stokes clouds computations before being extended to consider three-phase flows (solid-liquid-gas). Through comparisons with laboratory experiments, the simulations have been used to provide information such as the mechanical stresses in granular beds or the trajectories of individual grains in multibody assemblies.