Mechanical metamaterials are a class of systems that are capable of exhibiting counter-intuitive mechanical properties such as negative Poisson's ratio, negative thermal expansion or negative stiffness based on the way how they are designed. In fact, over the years, highly unusual mechanical properties have been reported to be useful in the case of a variety of applications ranging from biomedical to protective devices. Because of this, in the last two decades, the research community has shown a continuously growing interest in studies related to mechanical metamaterials and new types of their applications that could be utilised in the industry. Particularly interesting in this regards are structures capable of having their motion, as well as the exhibited mechanical metamaterials, controlled in a programmable manner. This stems from the fact that such control would make it possible for a material to adjust its behaviour to a specific type of the application. This, in turn, would result in an increase in the efficiency of the particular mechanical metamaterial. However, this direction of studies is still at its infancy and the fully programmable control over the behaviour of mechanical metamaterial which is not predominantly dependent on the initial design is yet to be discovered. Nevertheless, one of the most promising approaches allowing to achieve such control over the behaviour of the structure seems to be the use of magnetic inclusions combined with the implementation of the external magnetic field.

In order to achieve the main goal of this project, i.e. the design of specific programmable magneto-mechanical metamaterials suitable to be used in the case of different applications, this project is divided into three mutually complementary parts.

In the first part of the project, a novel hierarchical mechanical metamaterial with magnetic inclusions is proposed. The considered system is expected to be able to exhibit different deformation patterns as well as different mechanical properties based on the variation in the external magnetic field. Particularly interesting in this regard will be the possibility of a transition from one unusual mechanical property to another without the need of reconstructing the system. This concept will be investigated both by means of computer simulations as well as experimental prototypes. It is worth to note that in the case of the experiment, an attempt will be made to construct the considered system both at the macroscale (with the size of the system reaching several centimeters) and at the microscale through the use of the micro 3D printer available at the host institution, i.e FEMTO-ST research facility. The latter part is particularly impressive and important from the point of potential applications as dimensions of the the unit-cell of the system at the microscale are expected to be in the vicinity of 10-50 micrometers, where 10 micrometers stands for one hundredth of a millimeter.

In the second part of the project, I am planning to propose a novel magneto-mechanical metamaterial acting as an actuator with shape memory. To do this, a specific foldable 3D lattice will be taken into account which can significantly change its shape and dimensions based on the variation in the external magnetic field. In this case, in addition to computer simulations, similarly to the first part of the project, the behaviour of the structure will be analysed both by means of the macroscopic and microscopic prototype. Particularly interesting from the point of view of potential applications will be the second approach as, in addition to numerous other possibilities, it may lead to the design of a material suitable to be used as an efficient biomedical device allowing for example to actuate different parts of a tissue.

Finally, in the last part of my project, I intend to focus on the design of a novel 3D magneto-mechanical metamaterial capable of exhibiting several different unusual mechanical properties at the same time. This, in turn, can prove to be very important from the point of view of future applications such as superior vibration damping devices utilised for example in the case of foundations of a building. This stems from the fact that the considered system, in addition to other properties, is expected to be able to concurrently exhibit auxetic behaviour and negative stiffness with these properties being known to be efficient in the case of protective and vibration damping devices respectively. To assess the potential of the considered system to exhibit such characteristic, properties and the behaviour of the magneto-mechanical metamaterial will be analysed by means of computer simulations and the experiment incorporating tensile loading testing and the use of the external magnetic field.