The picture of the modern world is rapidly changing due to the accelerating technological progress, as can be seen in the increasing presence of electrical devices in everyone's lives. As the energy and electronics market grows, so does the need to deeply explore the world of engineering associated with modern methods of manufacturing advanced materials. One type of material playing a key role in the energy and telecommunications-related sectors are magnetic materials, of which ferro- and ferrimagnetic materials are the most influential groups. These materials can be further subdivided according to a parameter called coercivity (which refers to how difficult it is to remove magnetisation from a material once it has been magnetised before) into soft, semi-hard and hard magnets. Hard magnets, which are characterised by high coercivity values, are used in applications where it is important to provide a stable magnetic field of a certain strength. Soft magnets, on the other hand due to their ease of magnetisation and demagnetisation are used, among other things, to enhance and channel the magnetic flux.

Ferrites, magnetic materials that have garnered significant interest among researchers, are ceramic materials composed of iron oxides and other metals such as nickel, cobalt, or zinc. Due to their chemical composition and crystalline structure, ferrites can exhibit properties characteristic of both hard and soft magnets. They are poor conductors of electricity with high resistance to corrosion, yet possess intriguing magnetic properties. Because of their unique properties, they find applications, among others, as transformer cores, electric motor components, telecommunication antennas, magnetic cooling systems, electromagnetic wave absorbers, and magnetic sensors.

Due to a wide range of applications for these materials, this project aims to focus on obtaining nickel-cobalt ferrites with a spinel structure doped with other metals (copper, zinc) using the Direct Ink Writing (DIW) 3D printing method. This would continue the author's previously conducted research within academic projects and international scientific internships.

The scientific objective is to investigate the influence of the material (paste) used for 3D printing with this method and the parameters of the applied thermal treatment on the microstructure, structure, and magnetic properties of the obtained elements. From a practical point of view, this project aims to develop a cheap and efficient method for producing nickel-cobalt ferrite elements with predetermined shapes using the DIW method. This 3D printing technique combines all the advantages of additive manufacturing, such as the ability to achieve complex geometries, capability to print on demand, reduction of waste generated during production with low cost of necessary equipment and great versatility of the materials that can be used.

In the first step, using rheological analysis, the composition of the starting material will be optimized to ensure its highest possible printability. Pastes characterized by high printability should be sufficiently fluid to allow easy extrusion from the nozzle, yet sufficiently solid to ensure that the printed elements do not spread over time. For this purpose, pastes consisting of various liquid-phases (e.g., glycerine, solutions of polyvinyl alcohol, polyethylene glycol) and different liquid-phase to metal powder ratios will be tested. Subsequently, using the selected pastes, the optimization of 3D printing parameters (including applied pressure, printing speed, and layer height) will be conducted to ensure the highest quality of the obtained elements. Next, the obtained green-bodies will undergo a firing process under various thermal conditions. The resulting elements will be subjected to microstructural analysis using SEM/EDS techniques and structural analysis using methods such as XRD, Mössbauer spectroscopy, and Raman spectroscopy. In the final step, the electrical properties (using impedance spectroscopy) and magnetic properties (using vibrational magnetometry) of the printed samples will be analysed.

In summary, due to the wide applications of magnetic ferrite materials in both industrial machinery and everyday devices, as well as the unique features of additive technologies, the presented topic appears to be highly promising for the future. From a scientific standpoint, this project will fill a gap in scientific knowledge regarding the relationship between structural properties and magnetic properties in specific systems fabricated using the DIW method. In terms of the applications, this project aims to help solve the problem of manufacturing and delivering functional ceramic materials in situations where access to traditional supply chains is difficult.