Bacteria are simple single-celled organisms that fulfill several beneficial functions in the environment. They participate in the decomposition of organic matter into simpler chemical compounds, contributing to the efficient functioning of ecosystems. However, it is essential to note that some bacteria are pathogenic and can even cause life-threatening infections and diseases.

In recent years decreasing effectiveness of commonly available antibacterial agents has been observed. This is due to their improper use and the rise of bacterial resistance. In response to this pressing problem, scientists are increasingly considering nanotechnology products to fight effectively with pathogens. However, extensive testing and research are necessary before nanotechnology-based solutions can be introduced to the market. These aim to confirm the designed solutions' effectiveness and assess their potential for safe utilization, long-term stability, and proper disposal after use. Unfortunately, the lack of a unified research methodology for studying the properties and characteristics of nanomaterials poses challenges in this regard.

Scientists have demonstrated that the antibacterial properties of nanomaterials arise from various mechanisms, which often occur simultaneously. However, using multiple methodologies in studying these properties leads to obtaining selective and incomplete information regarding the biocidal capabilities of nanomaterials. As a result, scientists may draw different and sometimes contradictory conclusions. Moreover, bacterial strains of different origins often exhibit various sensitivities to nanomaterials. Additionally, the transformation of nanomaterials, which can alter their biocidal abilities, is often overlooked. Also, the impact of nanomaterials on human cells and the environment as a whole is frequently omitted in studies. All of these factors contribute to an incomplete understanding of the bioactive properties of nanomaterials and hinder inter-laboratory comparisons. Therefore, the goal of the project is to identify and standardize methods and techniques that will enable a unified investigation of the antibacterial properties of nanomaterials and provide comprehensive information regarding the nature of phenomena occurring at the material-cell interface. When developing a universal research methodology, validation is crucial to ensure the generation of reproducible and reliable results. To achieve this, it is necessary to utilize model nanomaterials that have been designed and prepared in a manner that enables the study of their properties in a scientific context.

Within the project, I plan to utilize two-dimensional nanomaterials based on boron. I will start my research with borophene, a simple two-dimensional material composed exclusively of just boron atoms. Subsequently, this structure will be expanded by alternating layers of boron with transition metals (such as molybdenum or chromium) in two-dimensional nanostructures known as MBenes phases. These phases are obtained using a "top-down" approach from their parental MAB phases, where M represents early transition metals, A refers to an element from group IIIA or IVA of the periodic table (*e.g.*, aluminum), and B is boron. Both the chemical composition and structure of these materials indicate their high potential for application in various areas, including materials engineering, biotechnology, and environmental engineering. Furthermore, due to the partially unexplored structure, it represents a fascinating and promising research field.

The proposed novel research approach integrates achievements in the field of microbiology with innovative methods of measurements of photons scattering. Standard microbiological techniques will be employed for the initial assessment of biocidal effectiveness, such as bacterial culture on solid or liquid media. Additionally, the tendency of bacteria to colonize material surfaces and form biofilms for defensive purposes will be investigated. For this purpose, I will apply microscopic observations and surface charge measurements. The analysis of reactive oxygen species levels will expose the impact of material on bacteria cells. I will also expand such analysis by assessing the disruption of the balance between these species and the antioxidants produced by bacteria and evaluating bacteria response to these disruptions. Significant work will be placed on analyzing the optical properties related to light transformation and the potential for regulating bacterial activity, ultimately exploring the possibility of MBenes phases in photothermal therapies. The obtained results will be correlated with measurements conducted using Raman spectroscopy and validated, leading to the development of an innovative methodology and a better understanding of the interactions occurring at the material-cell interface.

The project will also focus on a detailed characterization of the material, making it suitable to be regarded as a model system. The materials intended for studies of biological properties will be characterized at first with microscopic observations. Their phase and elemental composition studies will also be carried out. An important aspect of the research is the investigation of the surface chemistry of MBenes phases, as it can influence the biological properties of the developed structures.