Materials exhibiting high strength and robust fracture toughness, which means that a significant energy is needed to destroy them, have been sought for centuries. Solving this problem is still a challenge. It is worth taking a closer look at what solutions the natural world has found here. The protective armor of molluscs, in particular sea snails, are characterised by unique mechanical and functional properties. It turns out that these animals, through experiments within the process of evolution lasting millions of years, obtained a material which has high strength and fracture toughness, while also being light. This result is all the more surprising because the components used to build shells are calcium carbonate (in two polymorphic varieties: calcite and aragonite) and various types of protein are materials with rather low mechanical properties. Research conducted on molluscs' protective shells revealed their hierarchically complex structure. This structure differs depending on the species' habitat, but most often, in about 90% of species, there is a cross-lamellar structure. This is constructed on four levels. Parallel fibres with a thickness of less than 1 micron form laths. These, in turn, also repeated in parallel, form a larger element - a lamella. It turns out that the neighbouring lamellae, having analogous structure, contain fibres (and laths) turned by 90 °. If the mollusc "decides" to continue the cross-shaped structure in the next layer, the lamellae arrangement that creates it again rotates by 90°. The described structure consists of mineralised calcium carbonate immersed in a protein matrix. We see, therefore, that the shell is not a chaotic arrangement, but a deeply thought-out construction carried out in accordance with the design of nature. The question then arises, how deep can the organic matrix influence the structure? Is it able to force the arrangement of atoms forming calcium carbonate crystallites? Our preliminary studies have shown that the organic matrix determines specific mutual crystallographic orientations of neighbouring grains/crystallites. As a result, it generates a structure from the nano level to the macro level, i.e. to the final architecture. This shell's construction strategy enables a multi-scale response to dynamic and static loads. Unique mechanical properties, including the ability to dissipate energy, result not only from the different properties of the organic and mineral phase, but mainly from the synergistic cooperation of structural units at individual levels of the scale. Therefore, the shell retains high strength and fracture toughness after drying. The main goal of the project is to detect the strategy of creating a structure with such exceptional mechanical properties, ranging from nano to macro level. The research will be carried out by high-class specialists from various fields including materials science, palaeobiology, geology and mechanics. At the beginning, initial analysis of the most interesting sea shells of snail species will be carried out. Of these, a group of shells with the highest compressive strength will be selected. Shells of similar structure but which exhibit the lowest strength will also be included. The next step will be the in-depth identification of the microstructure of selected snails shells, up to nano level. For this purpose, advanced electron microscopy techniques will be used, including electron backscattered diffraction (EBSD) in SEM and diffraction obtained using convergent beam (CBED) in TEM. As a result, we will identify the architecture of the shells of various species of snails, and within each of them we will determine the local characteristics of the crystallographic relations that occur at the grain boundaries of the same or different phases. Further research using high-resolution transmission electron microscopy (HRTEM) will allow reconstruction of the system of atoms occurring at the boundaries of calcite/calcite, aragonite/aragonite, calcite/aragonite. In this case, the molecular dynamics (MD) models will be developed. Due to them, we will obtain information about the nature of bonding between the crystallites of the same and different phases. Alongside structural studies, the mechanical response of the shells will be studied. The X-ray diffraction method (XRD) equipped with a robotic testing stage will reveal the residual stresses present in the structure and the evolution of stress fields generated by compression. The obtained results will be supplemented with analysis of crack initiation and development, carried out with the help of the digital image correlation (micro-DIC) system. The expected results of the project will enable the creation of a multi-scale shell model, which will reveal a number of interrelated mechanisms that provide the unique composition of mechanical and functional properties. Thus, they will provide key information about designing the synthetic materials effectively. It should be noted that the proposed studies on biocomposites and biomineralisation processes are pioneering.

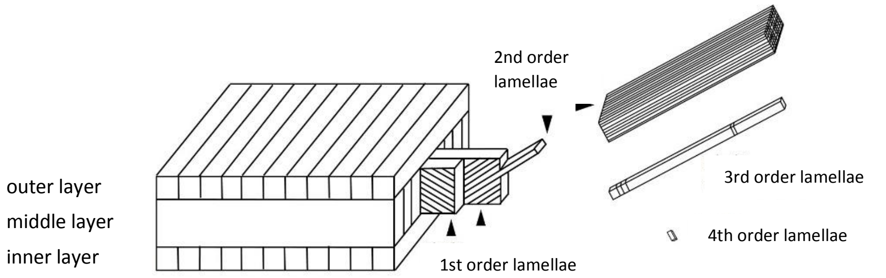

Fig. 1. Schematic representation of the shell structure.