Damage detection techniques and algorithms are constantly present amongst most significant research subjects focused on analyzing elastic waves in solid structures. There is still a great demand for improvement of damage prediction and recognition processes effectiveness, therefore significant amount of research works is directed on developing passive and/or active methods in Structural Health Monitoring and Non Destructive Testing. However, effective management and control of mechanical energy flow in these structures is critical for their operational characteristics and the resulting performance. If we are able to directly control dynamical phenomena occurring in the structure, vibrations and noise reduction/cancellation may be effectively applied in relatively simple and low-cost methods of designing smart structures.

The proposed project addresses the idea of mechanical energy flow management through the design of acoustical logical devices (ALDs) with tunable (controllable) spectral characteristics. It is expected that application of such devices may significantly reduce vibrations and noise by performing logical operations on wavefields propagating in the structure. These would include logical N/AND, X/OR operations, frequency filtering, multiplexing, directing energy flow, switching, phase-shifting and amplifying. The purpose of developing the devices able to perform these operations and therefore manage mechanical energy may relate to amplitude-dependent mitigation of vibrations and noise by filtering, partial conversion and internal redirection of wave components to different substructures that possess pre-designed damping characteristics, isolation of selected critical structural parts from noise and vibration in the case of changing excitations and incident fields or dynamic creation of desired noise transmission paths between structural components. These all are vital problems in modern science and engineering. It is also believed that the development in new phonon-computing areas would significantly contribute not only to structural design but also computer science.

As mentioned above, the main goal of the project is to design and develop acoustical (supporting longitudinal and shear wave modes) devices performing logical operations on wavefields. What is important, these devices are expected to provide possibility of tuning (controlling) their spectral characteristics, able to be reconfigured due to their pre-designed nonlinear properties. If so, nonlinear effects can be used to develop novel acoustical devices operating on nonlinear logical principles. The second general goal of the project aims at developing new metamaterials for elastic waves in solid media, under transformation acoustics (TA) design principles, with further applications in ALDs. Achieving this goal for acoustical devices is proposed through the metamaterial design based on combining the previous works of authors with the TA methodology and structural optimization techniques. The third general goal of the project is to develop new type smoothly reconfigurable ALDs that employ nonlinear responses for manipulating and controlling wavefields, enhancing the state of the art solutions known up to date.

In order to achieve these main objectives of the project and combine them into logic-enhanced smart structures, the following research works will be carried out. Firstly, it is necessary to design theoretical operational characteristics of selected type ALDs. In other words, specific assumptions on manipulation of acoustical wavefields will be defined for the acoustical AND, OR and NOT gates, which combined will form a complete set of logical systems. For these objects, spectral characteristics, design limitations and boundary conditions will be considered in the first place. Consequently, it is necessary to investigate the possibility of developing and designing physical devices featured with designed operational characteristics. Therefore, acoustical metamaterials for ALDs will be developed along with their structural design (shape, boundaries, gratings etc.). As a natural consequence, these designed metamaterials will be then combined into ALDs, manufactured with milling and 3-D metal printing. Fourth stage of research works will be focused on employment of non-linear wave-wave interactions for modifications of spectral properties of developed ALDs. The effect of tunable ALD properties will be achieved by material and structural design employing nonlinear stress-strain characteristics and will allow to perform addition, subtraction and multiplication of elastic wavefields. Significant attention will be paid to complete verification and validation (linear and non-linear) of logical function realization by the designed and manufactured ALDs. Spectral properties of the devices, measured within the range of interest (5-20 kHz and 20-60 kHz) with the use of advanced tools (laser Doppler vibrometers) will be compared with theoretical ones, developed at earlier stages.

Successful performance of above-mentioned steps will result in combination of ALDs with structural elements into a controllable smart structure, capable of mechanical energy management. The system will be structurally and functionally embedded into an example mechanical structure and compared to structures: with active control system and without an energy management system; with the aim of demonstrating that the simple ALDs can be integrated to implement a more complex control system that serves a specific, desirable purpose.