Artificial photonic architectures provide a versatile arena for exploring fundamental physics within simple optical settings. These structures are intentionally crafted arrays of photonic components such as waveguides, microcavities, or nanoparticles arranged in layouts inspired by the geometrical patterns of 2D materials. There, individual photonic components play the role of artificial “atoms” forming the lattice. For example, nanoscaled disks made of dielectrics can be arranged in a hexagonal pattern in analogy to carbon atoms forming a graphene sheet. When the size of these disks and the distances between them are comparable to the electromagnetic wavelength, light can tunnel from one disk to another similarly to how an electron moves from site to site on a material lattice. In consequence, in photonic arrays light can realize physics analogous to the inherently quantum phenomena characteristic of electrons in low-dimensional materials. Examples are the photonic analogues of the famous quantum Hall effect where light flow is induced in predefined directions or light localization on defects, e.g., disks of slightly different geometry.

However, photonic platforms offer far more flexibility than conventional materials due to their tunability at the level of individual components. Among the variety of applications that stem from this tunability is the realization of new types of so-called topological lasers from sources spatially extended along a domain wall - an edge between slightly different architecture layouts. These phenomena are just examples of the rich physics arising due to the new capabilities sustained by photonic architectures that may reach far beyond what is possible with the materials that inspired them. **The goal of this project is to harness the potential of photonic architectures to host physics in new regimes for fundamental insights and novel applications.**

The unique capabilities of photonic architectures which lie at the heart of this theory project include

- Access to modulation of the lattice geometry for new approaches to the design of materials targeted at specific wavelengths or novel beam steering techniques.
- Breaking symmetry by introducing disorder or structuring domain walls in the lattice. Such walls may support light flow at engineered velocity, direction and high robustness against imperfections.
- Introducing symmetries hardly accessible with materials, e.g. in multilayered architectures with individually customized layers.
- Exploiting the optical tunability of the refractive index of the material forming the photonic components, meaning that the index may depend, e.g. on the intensity of light illuminating the material. This effect is an example of optical nonlinearity. On the fundamental level, nonlinearities may be used to emulate new types of interaction inaccessible for electrons in material platforms. On the application side, the nonlinear action can be enhanced in volumes where light localization is engineered by geometry design. High nonlinearity is essential, e.g., for laser applications.

These effects and their interplay will be thoroughly investigated throughout the project implementation.

The key to efficiently tackling these problems is the analogy between the equations governing the electron dynamics in materials and the evolution of light in photonic architectures. This project extends the methodological framework and the associated numerical toolbox previously developed by the PI and her partners in the 2D material context. During the project implementation, the framework and the toolbox will be adapted to capture the specific character of photonic array architectures and the new capabilities they bring. The applied methodology allows for efficient numerical simulations at a much reduced computational cost compared to the traditional exhaustive solving of Maxwell's equations. The delivered toolbox will be released in an open form so that it can be used by anyone interested in calculations concerning fundamental and application-oriented questions on photonic architectures.

The project's potential to push forward the boundaries of photonics is accompanied by its ambition to inspire new pathways for fundamental research on low-dimensional materials, which is where lies its transformative impact.