

Kirigami mechanisms and mechanical metamaterials

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Keywords: Kirigami, thin sheets, mechanical metamaterials, actuators.

In recent times, designing functional materials faces new challenging questions when it comes to determining both their kinematics and mechanical attributes. Because material responses (to external forcing, external field, failure, etc.) are intrinsically geometric effects, which are transmitted across length-scales from the microstructure to the bulk, building materials with high degrees of predictability, adaptability, and desirable mechanical performances, strongly depends on the choices of building-blocks. Furthermore, the control of soft modes of deformation in functional materials still lacks some insight about the role of geometric nonlinearities, which is part of the central contribution of our work.

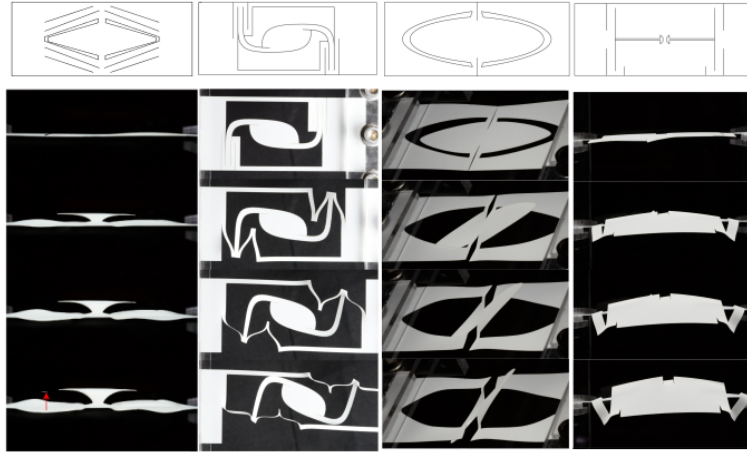


Figure 1: Examples of linear actuators from kirigami cut patterns. Extension, or applied displacement, along the x -direction causes (a.) out-of-plane deflection in the z -direction rotation about , (b.) rotation about z -axis or yaw, (c.) y -axis or pitch, and (d.) rotation about x -axis or roll.

We propose a novel way in which the geometric control of thin elastic sheets leads to highly deformable and complex behavior of materials and structures, for which engineering applications span a broad range of length-scales. We take inspiration from the Japanese art of kirigami in order to introduce new forms of crafting dynamical assembling of complex shapes for mechanical actuation. By exploiting the fundamental principles of this art, through careful tuning of geometry and topology of cuts on thin sheets, the rules of design suggest that control of complex kinematics scale down to atomically-thin 2D materials. We show that by understanding the mechanics of a single, non-propagating crack in a sheet, we can take advantage of the non-linear and anisotropic responses to external forces to generate four fundamental modes of linear actuation, namely roll, pitch, yaw, and lift. Our mathematical model demonstrates that the sheet deflection does not depend on the sheet thickness to leading order, therefore, enabling us to establish a robust link between simulation and experiment on length scales ranging over six orders of magnitude. A direct consequence of this result is an explanation for the observed invariance in kirigami actuator behavior from the macro to the nanoscale.

We will further explore the types of mechanisms shown in figure 1, whereby the identification of building blocks and better understanding of the multiple crack interaction allows for the extension of the kirigami concept towards the development of mechanical metamaterials. We will provide a better understanding of the inverse problem, *i.e.* how building blocks can be combined to generate targeted behaviors.

These findings are relevant and timely to the broad range of engineering applications, such as micro-fabrication and deployment of large structures. Kirigami structures have the potential to impact the growing field of mechanical metamaterials and provides an ideal interdisciplinary platform to study a very diverse set of problems, such as soft and flexible electronics, control and design of structures that undergo large strains, the localization of electronic states, etc. Furthermore, because the kirigami actuators are scale-invariant, our findings have the potential to bring about new applications to tailor the microstructure and functionality of materials design across a broad technological spectrum, ranging from the nanoscale (NEMS), the microscale (MEMS), and the deployability of soft mechanisms at the macroscale.

References

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