Lung-related illnesses have led mortality rates around the world for decades. Between asthma, chronic obstructive pulmonary disease, lung cancer, cystic fibrosis, idiopathic pulmonary fibrosis, pneumonia, tuberculosis, COVID-19, and many others, almost everyone knows someone who has been afflicted by a lung condition, if not themselves. The difficulty in their treatment arises from a complex landscape of physiological, technological, and regulatory challenges. Naturally, inhalable aerosol therapeutics emerge as leading candidates for treating these health conditions and others as well, as a result of the potential to use the lungs as a site of local or systemic administration. But like the debris that the lung is designed to filter out, inhalable therapeutics must reach the targeted region in the lung \textit{and} deposit on the airway surface in sufficient quantity to be effective.

For decades, aerosol formulations have been designed on the basis of relating particle size to lung deposition. However, as history has shown, one size does not fit all, and because of the sheer complexity of the lungs, existing preclinical models – whether \textit{in silico}, \textit{in vitro}, or \textit{in vivo} – often neglect even central functions such as breathing. Recent advances in medical imaging have been enabling for computational modeling and 3D printing to take a larger role in predictive modeling and personalized medicine, by replicating patient-specific anatomical features. However, there are still no tools that can incorporate the full extent of the lung airspace and account for both inhalation and exhalation maneuvers.

Here we present a paradigm-shifting platform that builds upon existing developments in the space to create a modular and extensible \textit{in vitro} system for approximating the lungs, leveraging a highly interdisciplinary approach. This platform treats the lung as a series of filters, combining 3D printed patient-derived upper airways with an approximation of the deeper airways in the form of additively manufactured lattice structures. Linking lattice structure to the airways by the average hydraulic diameter and linear airflow velocity, this theoretical approach achieves geometric properties comparable to the airways and total lung. Furthermore, with controlled actuation, we have demonstrated the ability of this system to create breathing profiles representative of adult human subjects. In a reduced-scale approximation, we have observed aerosol deposition profiles within a reasonable range of the common central-to-peripheral deposition ratio, compared to a benchmark series of studies using a nebulizer for aerosol administration under normal breathing conditions.

Through this pursuit, we also developed a set of tools for designing and fabricating mesoscale lattice structures with feature length scales ranging from 0.1-5 mm and greater, which can be made only by additive means. We share a number of theoretical and practical insights that facilitate the use of these structures in chemical engineering applications, beyond their previously relegated roles as lightweight supports in structural designs. We present generalized methods for generating conformal, self-supporting open lattices, which enable new applications by allowing material to pass through the lattice structure. In consideration of standard lattice structures, including cubic, Kelvin, rhombic dodecahedron, BCCxy, and Weaire-Phelan, we further discuss trends in printability, strategies for defect compensation, scaling behavior, and performance in fluid applications, confirming that lattices with different unit cell designs can be treated as a common class of materials. We overcome digital and physical processing barriers to produce lattice structures at overall scales up to 120 mm in diameter and 100 mm in height, which are unprecedented for fine lattices.

In sum, we present two platform technologies for pulmonary drug delivery and chemical engineering that may enable a range of novel collaborative developments, resulting in advanced engineering solutions and better treatments for patients worldwide.