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## Tunable Failure in Non-periodic Architected Materials Inspired by Physarum Polycephalum Growth

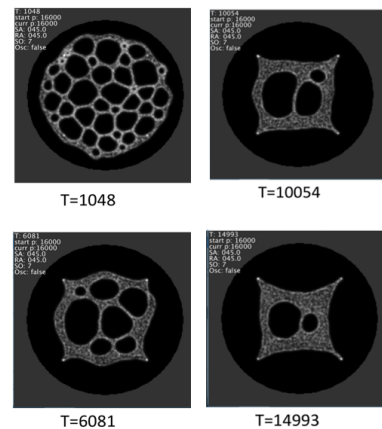
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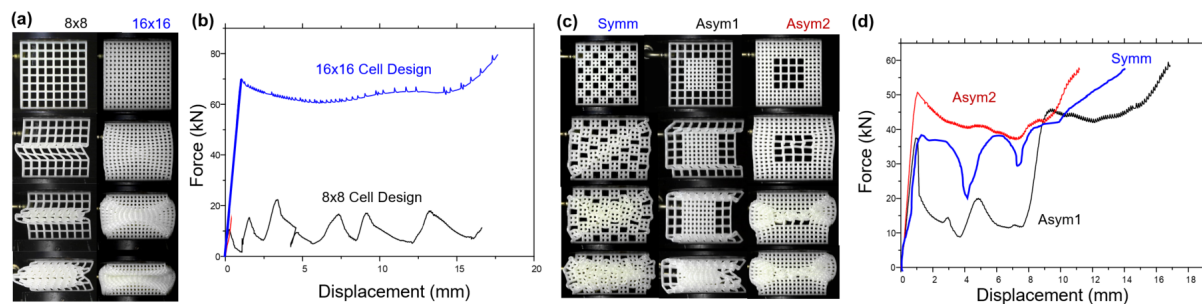
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As we have entered the era of 3D printing, it has become possible to create a new class of architected cellular materials with customized geometries and tailored properties [1-3]. The field of architected materials has been explored in many disciplines over the past decade, it has yet to be fully explored in civil engineering and architecture. From the material constitutive relation perspective, most existing efforts on metamaterials primarily use elastic buckling of soft materials, while common infrastructure materials are lacking the ability to undergo such large deformation/strain. In addition, most studies to date has maintained the symmetry of material and studied the simple periodic form. Inspired by Physarum Polycephalum growth (Fig. 1), we explored a new class of non-periodic cellular materials and conducted proof-of-concept experiments on 3D-printed specimens to compare the effect of material architecture on the failure mechanism formation.



**Fig. 1.** Representative time frame of simulating the growth Physarum Polycephalum.



**Fig. 2.** Experimentally observed response of cellular materials. Designs in series one: (a) failure sequence; (b) response curve; designs in series two (c) failure sequence (d) response curve.

Preliminary results in Fig. 2a-b showed that the size of unit cells can significantly affect the failure mode of the material. The failure mechanism in the 8x8 cell design features a layer by

layer buckling sequence, while in the 16x16 cell design the failure started along the diagonals of the material followed by the continuous crushing in the same region. Force-displacement curves in Fig. 2b show that the 16x16 cell design has a much higher absolute load-carrying capacity, which is reasonable due to a larger density of the design. Results plotted in Fig. 2c-d, which demonstrate that strategically varied cell size on the same material design domain also changed the propagation sequence of localized buckling events. In this series, we combine the cell size from both the 8x8 design and 16x16 design such that selective buckling regions can be defined. Intuitively, the regions with larger cell size will buckle first due to a lower critical buckling load. This hypothesis was proven in Fig. 2c. More importantly, the response curve given in Fig. 2d shows that although each design has different porosity, they all have similar initial stiffness prior to the first buckling event. After buckling, these designs show a wide range of features (load drops, stiffness reductions) that can be tailored later for advanced functionality. The most interesting feature observed from the designs is that a clear

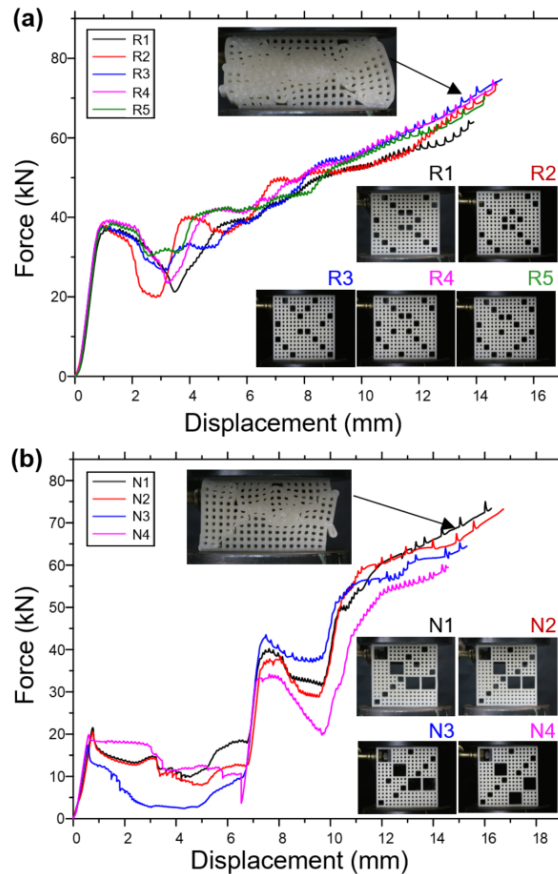
performance phase, separated by load drops, can be defined that is associated with local buckling within the sample. For example, in the Asym1 design, four phases can be observed as a function of displacement, i.e. 0-4 mm, 4-8 mm, 8-14 mm and 14-16 mm.

Based on the lessons learned from the first two series of experiments, the performance phase due to the non-periodic pattern design was the next logical step. In series three and four, failure mechanisms were further tailored with varied cell size and asymmetric distribution. Fig. 3a shows five designs with an equivalent number of larger cells but varied distribution across the X-Y axis. It is interesting to note that all five design features have a very similar response curve with less variation. Similar observations can be made in series four as shown in Fig. 3b. These four designs have even larger cell voids compared to series three, which lead to a three-phase performance that can be related to three different cell sizes across the sample.

Controlling material and structural failure is a major step toward a complex ambition of resilient infrastructure involving the ability of systems to rebound from extreme events and the corresponding repair approaches to recover capacity after those events. We will carry design principles gained from this project to further explore structural design using architected materials.

## Acknowledgments

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**Fig. 3.** Observed response and failure mechanism of non-periodic cellular materials. (a) two cell size (b) three cell size.

## References

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