Shape-Shifting Materials for Programmable Structures

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Abstract
In this paper we discuss how the jamming phenomenon of granular materials might be exploited to achieve programmable matter – a robotic material that permits user specified shape changes. Opportunities for applying this research to the field of architecture are discussed. Experimental results are presented, which reveal the performance of a wide variety of materials under jamming conditions.

Keywords
programmable matter, jamming phenomenon, granular materials, robotics, architecture

ACM Classification Keywords
I.2.9 Robotics. J.5 Arts and Humanities---Architecture. J.2 Physical Sciences and Engineering---Physics.

Introduction
Programmable matter [2] describes a form of controlled, shape-shifting matter. Such a material would have the ability to transition from its current shape into any desired shape; and, this transition would occur on command, under the matter's own power, and with complete reversibility. If fully realized, programmable matter could lead to a paradigm shift in

the way architects, engineers, and everyday citizens view materials.

We differentiate our approach form other attempts at programmable matter by proposing that large areas of the goal structure might be assembled from ordinary granular materials, without decreasing the functionality of the final shape. Thus, by exploiting the jamming phenomenon of granular materials, we can develop a cellular system composed of controllable, membrane bound cells, which each encase some granular material.

The jamming phenomenon [1] is a unique property of granular materials which allows them to undergo a fluid-like to solid-like phase transition without a change in temperature. When grains are loosely combined, they yield under shear stress (like a fluid); if they are packed together, they jam in position and resist applied stresses (like a solid). Thus the fluid state is called the un-jammed state and the solid state is called the jammed state, with the jamming transition occurring between them.

Opportunities in Architecture

The mechanical and electrical nature of our programmable matter system lends itself to reconfigurable structure design, structural health monitoring, and material reuse. Buildings that incorporate programmable matter could have reconfigurable floor plans, interact with inhabitants, determine controllable failure modes, and rebuild themselves after disasters.

The cellular unit we are currently experimenting with is a cylindrical beam. The beam model has several advantages including separate and parallel actuation of the beams, as well as increased robustness through redundancy. The beam model also lends itself to futuristic building design and construction. Robotic programmable matter beams could become one of the basic construction units of the future. Just as steel and wood beams are used today, programmable matter beams could be used as frame or truss elements in buildings, bridges, and other structures.

Performance of Jammed Materials

We evaluated the hardness of 15 jammed, granular materials using a custom-built desktop testing device in conjunction with custom-made testing tubes. In performing these tests, we are searching both for a material with easily exploitable jamming characteristics, and also for some intuition about how a material will perform when jammed. We find that acrylic peanut grains not only exhibit the highest hardness in compression, but also the steepest jamming transition, which is desirable for programmable matter because it can be controlled to flow well or be very hard when desired.

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References

[1] Liu, A.J. and Nagel, S.R. Jamming is not just cool any more. *Nature* **396**, (1998), 21.

[2] Toffoli, T. and Margolus, N. Programmable matter: concepts and realization. *Physica D* **47,** (1991), 263-272.