Autonomous Assembly

Designing for a New Era of Collective Construction
Granular Jamming of Loadbearing and Reversible Structures

Rock Print and Rock Wall

Granular Kohler Research (ETH Zurich) and the Self-Assembly Lab (Massachusetts Institute of Technology - MIT), Rock Print, Chicago Architecture Biennial, Chicago, 2015

The 4-metre (13-foot) tall installation, with a 2-ton load-bearing capacity, was produced without adhesives or connections. With only loose rock and gravel, the structure demonstrated the possibility of granular jamming in architectural scales.
In its more common manifestations, granular jamming relies on vacuums and membranes to bring about liquid-to-solid phase change in materials. Petrus Aejmelaeus-Lindström, Ammar Mirjan, Fabio Gramazio and Matthias Kohler of ETH Zurich, and Schendy Kernizan, Björn Sparrman, Jared Laucks and Skylar Tibbitts of the Massachusetts Institute of Technology (MIT), describe two projects as members of the two research groups at ETH and MIT that have been collaborating to examine the possibilities of jamming in architecture and construction.

Traditional methods of construction, including bricklaying and cast-in-place concrete, often require long lead times and manual labour, and lack reversibility or recyclability. Recent investigations in materials science, however, have focused on granular jamming, a phenomenon that has the ability to instantly and reversibly change phase from solid to liquid and back. Though unusual, it can be found in a number of everyday scenarios. These include a sandwiched coffee bean, which behaves like a solid when its amorphously arranged particles, when subjected to vacuum pressure, come into contact with each other and get stuck – or jam – but pour like a liquid when opened.

Unfortunately, the fragility of the membrane and need for constant vacuum mean that traditional applications of granular jamming have significant limitations for architectural structures. However, the collaborative work of Gramazio Kohler Research at ETH Zurich and the Self-Assembly Lab at the Massachusetts Institute of Technology (MIT) has recently explored a new type of architectural-scale granular jamming utilising loose rocks and fibres, without a vacuum or membrane, that enables nearly instantaneous and reversible load-bearing construction through a solid-to-liquid phase-change.

Rock Print

Rock Print, an architectural-scale prototype realised for the inaugural Chicago Architecture Biennial in 2015, combined granular jamming with robotic fabrication to realise complex architectural structures that could be fully reversed. By interlacing the granular material with string, it was possible to solidify the composite where desired. The string created a confinement around the loose aggregates and forced them to jam. Using a robotic fabrication system to deploy the string, the process defined where the material solidified and where it remained as a liquid in a controlled manner.

As such, the making of complex architectural structures composed of crushed rock and string can be directly linked to a digital design. The material principle works with a large variety of aggregates, allowing jammed architectural structures with local building material. Pulling the string separates the aggregates from it, allowing reconfiguration of the material into different architectural structures.

Rock Print was 4 metres (13 feet) tall and stood on four slender legs. The legs grew upwards together into a large solid design, accommodating the mass required to create the compressive force and needed to stabilise the assembly. The foundation of the tower, a pile of leftover aggregates inherited from the fabrication, created a barrier between the exhibition piece and the visitors. The structure was fabricated with a lightweight robotic arm, coupled with a string-laying end effector, mounted on a gantry system. The robot deployed the string into a container, followed by the manual pouring and packing of a thin layer of aggregates. Packaging was conducted with a concrete compactor to activate the string. To ensure the structural integrity of the material system, the string had to be in tension. Therefore, the pattern of the deployed string was based on circles, because of their relation between area and circumference. It was also layer-based, forming horizontal layers of string and rock. To be able to compensate for articulated geometries, such as sharp edges or overhangs, it was necessary to maintain a continuity of circles between the layers. The structure was built from the ground up and the container was extended incrementally following the vertical aggregation. The final structure was comprised of 200 fabrication layers with a thickness of 20 millimetres (approximately three-quarters of an inch) each. Once fully assembled, the container was removed, revealing the final structure. At the end of the exhibition, Rock Print was dismantled by pulling the string in one continuous process, restoring the building material into a pile of rocks and a spool of string.
The L-shaped forms featured rare earth magnets on their vertical edges, allowing them to easily snap together into a zigzag shape. Interlocking grooves on their top and bottom edges allowed them to be stacked vertically to create tall walls. C-shaped metal brackets held the forms at a set distance from each other. While the forms could be arranged in many configurations, adequate structure is provided by the “L” shape of the forms themselves.

Eight forms were required for the resulting wall prototype. This was enough to construct a wall with a maximum height of 1.2 metres (4 feet) — two forms tall — but with theoretically infinite length. As sections of the wall reached their maximum height, those forms were removed and repositioned on the unfinished end of the wall where construction continued. This dramatically increases the speed of the process and, through the use of the modular mould, allows for custom wall configurations.

A slip-casting process was developed using modular L-shaped walls that could be linked together, filled with the mud and extruded to promote jamming, then moved to the end of the line to continue pouring the wall.

The depth of the continuous geometry resulted in a fine wall that was strong in compression and stable under lateral forces. It also supported the continuous aspect of the slip-casting method, allowing future sections to be added to the wall.

Surface details of the Rock Wall reveal the densities and patterns of the coconut husks. Given the short-term nature of this installation, and the need for extreme speed of production, the system was consequently composed of varying densities and mold-to-string ratios, while still maintaining a precise and stable structure.

Notes:
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Continuing Explorations of Granular Jamming

The projects here demonstrate two unique methods for granular jammmable principles applied to architectural-scale applications, which avoid the traditional constraints of construction relying on either precisely placed building blocks or long cure-times and non-reversible concrete.

Granular jamming was also explored with unconventional materials, at significantly large scales and without a reliance on pneumatics or vacuum-sealed membranes. The first process included robotically placed fibre for precise control over form and function, while the second slip-casting process included reconfigurable moulds and the redundancy of fibres to increase speed for fast-low-cost scenarios. Both of these methods go far beyond today’s labour- and energy-intensive construction processes. Future work by Gramazio Kohler Research and the Self-Assembly Lab will aim to continually improve speed, repeatability, scalability and design freedom through granular jamming, aiming for truly instant and reversible loadbearing structures.

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Using local rock and coconut husks, the continuous wall was built in under eight hours, the speed and precision of which indicate a future scenario of instant and reversible granular jammmable construction methods.