# Archaeologists reconstruct pre-Columbian temple with 3D-printed blocks


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The unfinished temple in a southern valley of the Lake Titicaca Basin in modern-day Bolivia has been a mystery for at least 500 years. Now known as the Pumapunku—"Door of the Jaguar" in the Quechua language—the complex stone structure is part of a sprawling complex of pyramids, plazas, and platforms built by a pre-Columbian culture we now call the Tiwanaku. Construction began around 500 CE and proceeded off and on, in phases, over the next few centuries until the Tiwanaku left the site around 900 or 1000 CE.

When the Inca Empire rose around 1200 CE, they claimed the sprawling ceremonial complex as the site of the world's creation, although they didn't finish the Tiwanaku's temple.

## Old school and high tech

Spanish visitors in the 1500s and 1600s describe "a wondrous, though unfinished, building" with walls of H-shaped andesite pieces and massive gateways and windows carved from single blocks. These were set on remarkably smooth sandstone slabs, some of which weighed more than 80 tons. But after centuries of looting, the stones of the Pumapunku are so scattered that

not one lies in its original place. The Tiwanaku left behind no written documents or plans to help modern researchers understand what their buildings looked like or what purpose they served.

Unlike the pottery and bone fragments archaeologists usually put back together, many of the scattered stones of Pumapunku weigh several tons—gluing them together in a sand tray wasn't an option. So University of California, Berkeley archaeologist Alexei Vranich and his colleagues 3D-printed a scale model of nearly 150 carved andesite blocks in order to reconstruct part of the temple.

To make the high-tech solution work, Vranich had to turn to 19th-century archives for the measurements they needed to create accurate digital models of the stone blocks. Modern survey methods, like laser scanning, can produce incredibly detailed digital models of a site, right down to the subtleties of carvings or weathering on the surface of a stone block. But that actually turned out to be *too much* detail; the resulting files were much too large for site managers and local researchers in Bolivia to download and work with, since they often have limited Internet access and computer hardware.

Archaeologists didn't even need most of that detail; they just needed simple geometric measurements, though they needed them to be very precise. So they turned to the field notes of past researchers. Most of those came from an expedition in the mid-1990s led by archaeologist J.P. Protzen, but for a few of the blocks, the team had to go all the way back to an 1848 expedition to find measurements.

## Like LEGO for archaeologists

Vranich and his team added that data to a 3D modeling program called Sketchup, which they chose in part because it's available in a free version. Then they 3D-printed the blocks

with plaster powder at a four-percent scale. The whole process cost around $1,200; Vranich says using plastic filament would have been substantially cheaper, but plaster produced sharper angles and smoother edges, which were important as they tried to fit the pieces together. From there, they faced a long process of trial and error, like solving a large puzzle with blank pieces and no picture on the box.

Eventually those months of work paid off. Vranich and his colleagues say they've partially reconstructed the northern end of the Pumapunku and the general layout of the rest of the structure. The carved andesite gateways that gave the Pumapunku its modern name once stood in symmetrical lines, from 12.5 centimeter (4.9 inch) miniatures to 3 meter (9.8 feet) gateways carved from single, enormous blocks of stone. Facing one another, they probably created an optical illusion of infinite gateways stretching off into the distance.

- Archaeologists used 3D-printed blocks to reconstruct part of the Pumapunku at 4-percent scale.
  Vranich et al. 2018
- 3D printed blocks, with a cat for scale; he's helping.
  Vranich et al. 2018
- A model of the partially reconstructed Pumapunku.
  Vranich et al. 2018
- A gateway from the Pumapunku at 4-percent scale, reconstructed with 3D-printed blocks.
  Vranich et al. 2018

The key turned out to be an elaborately carved andesite block called Model Stone 1, which turned out to be a scaled-down version of larger pieces of the building's architecture. Researchers eventually fit Model Stone 1 together with several more scaled-down blocks, including a miniature gateway, and that provided a clue to the larger structure, with its symmetrical, repeating gateways.

Several of the stones are still missing, so it’s not likely that they’ll manage a complete reconstruction any time soon. But what they’ve pieced together so far actually bears a striking resemblance to buildings at earlier Tiwanaku sites in the area. That means archaeologists now have analogs to use for comparison in reconstructing other buildings at the site from the same period.

## The future of archaeology?

Technology for digitally recording and modeling archaeological sites has improved dramatically in recent years, and some have suggested that the future of archaeology could mean refitting broken pieces of everything from potsherds to buildings on a computer screen rather than by hand. This could even mean automating the process, leaving it to an algorithm to match up broken edges into an intact whole. But the technology has so far turned out to be more cumbersome and less user-friendly than expected, and Vranich says that so far, there’s no easy substitute for an archaeologist’s trained eye.

“There may be a time in the future when ceramics and bone can be tossed on a surface, scanned, and automatically fitted, but until then, the human brain, under the right conditions, continues to be much faster and more efficient than computers when it comes to manipulating and visualizing irregular 3D forms,” he wrote.

The 3D files are available free online, where anyone can download and print them. Copies have been left with the site’s managers, where Vranich hopes they’ll be a useful tool in planning future research, preservation, and restoration efforts at Tiwanaku. They’re also accessible to the public, so citizen scientists can do their own trial and error and, perhaps, help piece together a little more of the site.

The geometric, symmetrical architecture at Tiwanaku makes it possible to digitally model the blocks with a few simple sets

of measurements. Architecture from other cultures around the world might be a little harder to apply such methods to, but Vranich says it could still be useful at other sites.

It is possible that using 3D printed models of fragments could help the study of other historic sites that have fallen apart in time, such as Angkor Wat in Cambodia, or that have been the victim of recent destruction, such as Palmyra in Syria," Vranich said in a statement.

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