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Machu Picchu from an Engineer's Perspective

Machu Picchu is a masterpiece of Incan civil engineering and architecture. It took much skill to build it up high in the mountains and make it stay together for this many years. It is very pleasing to the eye; as Ruth Wright puts it, "Even the buildings of Machu Picchu were in harmony with the mountain backdrop." (caption before 15) Some of the many other elements that make it stand out are the simple construction tools used, the excellent stonework, the ingenious water supply, and the splendid Temples of the Sun, the Condor, and the Three Windows.

The Inca used the following tools to build Machu Picchu: silver plumb bobs, stone hammers, and bronze axes, chisels, and crowbars. Bingham thinks they used the axes to cut out internal corners into stones, such as those of square holes. (46) He also claims that hammerstones and sand were experimentally proven to be good enough to shape the stones here and that bronze crowbars were good enough to move them. (46-47)

Kenneth Wright suggests that they used ropes or a system of horizontal wooden ladders, levers, and sleds to move the larger building stones. (71-72) Additionally, there is a large rock in the Sacred Plaza with smaller rocks underneath which appear to work as ball bearings to make it easier to push.

In many places, the stones fit together as well as puzzle pieces. In some places there was not even any mortar in the walls. Other places, however, have clay mortar.

The roof thatching was tied to stone pegs projecting from the gables, and it rested on a wooden framework attached to stone eyes on the gables' edges. Kenneth Wright thinks the thatching was made of tree ferns and reed grass. (72)

The doors, niches, and windows here are trapezoidal, and the Main Gate and Royal Residence's door both have sizeable lintels. Other doors have double jambs to signify importance. Occasionally there were barholds beside the doors, internally connected holes ropes could go into, make a *U*-turn inside the wall, and come back out on the same side. The barholds were probably used for barring doors, hence the name. The Main Gate had a stone ring above it as well as the barholds, and one theory, proposed by Hiram Bingham, says that they held a horizontal pole, while the ring above the lintel helped a vertical post stay upright -- both holding a door made of lashed-together logs shut. Additionally, there is a view of Huayna Picchu through the Main Gate.

Machu Picchu was up in a steep mountain range. The Inca could take advantage of this position by rolling stones down cliffs at invaders, a strategy they used much in other places. (Bingham, 194) They also had military emplacements on the adjacent Huayna Picchu and Machu Picchu Mountains to detect any approaching attackers, as well as on the main trail leading here. There was even a removable drawbridge on one of the trails. Additionally, the wall next to the front door turns a corner and runs next to the path, a feature Bingham says would have allowed the Inca to hit the defenders with rocks, stopping battering ram attacks. (195) He also says they could easily defend all the paths into here, even the trail from Huayna Picchu. (194)

The water supply has an ingenious collection system. In this system, the groundwater runs from the spring in the hillside through a permeable collection wall into a ditch, then into the canal itself. The canal could take a maximum of eighty gallons or three hundred liters per minute. It was 749 meters long, approximately 5 inches (13 centimeters) deep, and about 4 inches (12 centimeters) wide. It was built of stone with the gaps possibly sealed with clay. (Wright, K. 73)

The canal runs on its own terrace across the agricultural area, bridges over the Dry Moat on an aqueduct made of a single stone slab (Wright, K. 32), and crosses the main wall. After that, it flows through the first fountain's spout, into its bowl, and out to the next of 16 fountains. The fountains work even today. They did have to be cleaned out before starting again, after being left alone for such a long time, however. For a while the tourists used this system until there were so many there was not enough water for them all. (Wright, K., 21-24)

There is also a secondary unfinished canal, designed to take water from the main one. It was to be constructed of stones with channels cut into them, as opposed to having the sides and floor constructed of separate stones.

The builders put leftover stone chips from the building process beneath places like the Main Plaza because heavy rainwater can go right through layers of them. The ones under the Royal Residence and Temple of the Condor's plazas help with stability as well as drainage. Other features that help with drainage are the holes in some of the walls and the Dry Moat, which takes rainwater out of the residential area and away from the terraces. It runs beside a staircase which, in turn, runs beside the main wall. An upright stone on one of the Dry Moat's walls could be a survey marker.

Hiram Bingham says about the Temple of the Sun, "After we had scrubbed the wall clean we discovered that the the most experienced master mason of his time had here constructed the most beautiful wall in America, built in the form of a try-square, and connecting the temple with what may have been a priest's house." (217) Other sources agree that it is the best wall in at least Machu Picchu. Burger says another of its walls, the semicircular one, looks, from the top, like a rainbow, something the Inca worshipped. (37) Additionally, this temple blends in with and matches part of its foundation and floor--a large sacred rock, which has a ledge a sunbeam hits on

June 21, the Southern Hemisphere's winter solstice. The stones in this temple are damaged, perhaps by fire. The Enigmatic Window on the north wall has a stepped sill and holes next to it, perhaps for mounting purposes.

Ruth Wright says, in *The Machu Picchu Guidebook: a Self-Guided Tour*, "You are entering a most fascinating and intricate place. With its fantastic rock formations, grottos, and subterranean passageways, the Temple of the Condor is almost theatrical. Here the Inca architects really outdid themselves in using and embellishing the natural formations." (89) It has two rock formations that look like condor wings, as well as, ahead of them, a group of carved stones that resemble a condor's head, complete with ruff, and, according to Ruth Wright, its tail. (90-91) Each of the wing formations have caves beneath them. Additionally, a staircase next to here has four niches in its wall which may have been handholds. (Wright, R. 88-89)

This estate has a higher area and a lower area. The higher has the Temple of the Sun and the Royal Residence, while the lower has most of the houses. Ruth Wright says the higher was called the *hanan* and the lower was called the *hurin*. (57) There are distinct clan groups in the lower area, walled sectors of town where single families lived. One of these has what seem to be mortars or grinding stones, with a stone found nearby seeming to be a compatible pestle. Alternatively, they could have been filled with water and used as mirrors to view the sky. (Wright, R., 73) Another of these building groups is symmetrical, including the niches in the walls. It has three double-jamb doorways and probably belonged to an important family. East of it are some storehouses, also called *quolqas*. South of it is the Artisans' Wall, made with stones of assorted shapes and sizes. The Artisans' Wall is another example of good Inca masonry.

The Sacred Rock, a silhouette of Mount Yanatin, the mountain behind it, has its own plaza. It sits on one side of the plaza, and two *wayronas* sit on two other sides, opposite each

other. A *wayrona* is a rectangular building with one of its long sides open to the outside. (Wright, R. 8-9.) The open sides of these ones face the center of this plaza. There is a stone with a drainage channel behind the south *wayrona* acting as a gutter.

Dr. Alfredo Valencia Zegarra, co-author of two of my sources and author of an essay featured in a third, has excavated the Sacred Rock area and found that Macchu Picchu has subterranean walls and granite boulders as part of multilayer foundations painstakingly constructed for centuries of use.

There is a scenic overlook in the unfinished Sacred Plaza. From the Temple of the Three Windows here, one can see the mountain range, lower residential area, and main plaza. This temple used to have five windows, but two were turned into niches. Another building here is called the Principal Temple. Its east wall has shifted because its foundation was not good enough, causing its neighbor to come apart. Ruth Wright says that the affected walls had niches too high for convenient use and suggests that they were used for permanent storage and display. (46)

The Intiwatana Stone, north of the Sacred Plaza, sits atop a terraced hill, along with some buildings (one of which has a door turned into a window), some carved rocks that resemble Mount Yanatin and Putucusi Mountain's silhouettes, an excellent staircase, and a V-shaped stone pointing south to the Inca's most sacred mountain, Salcantay. The Inca used this area, especially the Intiwatana, for religious ceremonies. There is also a stone ring here which may be a torch holder or a staff holder. (Wright, R., 51) The staff it may have held may have been a flagpole. (Bingham, 211)

Machu Picchu, seemingly the Incan emperor's estate, is sacred because the emperor himself was sacred. Another reason is that it was built as an example of the emperor's divine will

and power in that he was changing the sacred landscape to build it. Additionally, Kenneth Wright says that it had *huacas*, objects the Inca considered spiritual beings, in and around it, such as the Urubamba River, the water supply, and the mountains. (80, 91-93) "Ultimately, Machu Picchu was a place where the divine emperor could commune with his fellow deities and participate in the great cycle of life, land, and water. Balance and harmony between the real world and supernatural world were expressed and maintained." (91)

To close, here are some interesting facts about Machu Picchu:

Subterranean foundation walls have helped Machu Picchu stay around all this time; in fact, 60% of it is underground.

The stairway accessing the fountains is the longest one here.

No one knows what the Slide, a stone inclined plane next to the Temple of the Condor, was for.

Machu Picchu has more religious structures than the other Incan royal estates.

The Inca had plastered interior walls, platforms for seats and beds, niches and pegs for storage, and possibly even wall tapestries.

The Inca called niches *hornacinas*. (Burger, 29)

Machu Picchu was neither truly lost nor a full city. (Burger, 24)

There are approximately 130 drainage holes here.

A few staircases here are carved from only one large piece of stone.

The Intimachay, a solar observatory cave, has a window in its stone wall the sun comes through only near the summer solstice in December.

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