Introduction – the site and the scope of work

Despite the strong Incan characteristics of Samaipata, the site served as a sacred place for many pre-Hispanic local cultures, and its origins date back to around 300 AD. Its present form is mainly the result of activities from the time of Inca dominance over this area, which also coincides with the last century of the Inca Empire before it collapsed during the Spanish conquest in the 2nd half of the 16th century.

For more than two centuries, the site has attracted scholarly attention [1]–[4], mainly due to the unique scale and density of decorations covering the natural rock. These decorations include not only multiple terraces, platforms, and water reservoirs, but also many figural and geometrical petroglyphs, all of them arranged in a very complicated layout (Fig. 1).

Between those various carvings covering nearly the whole surface of the rock, several circular openings with diameters ranging from 8 cm to approximately 60 cm are extant. Apart from those that are of natural origin or caused by rock erosion, these openings are usually interpreted as offering holes for ceremonial libations. They typically neighbour figural petroglyphs either as singular holes or are grouped in irregular patterns. Up until now, much less attention was placed on another group of openings that are arranged in a long line alongside the northern slope of the rock (Fig. 2).

Two much shorter lines of such holes (Fig. 3) can also be found on the southern hillside on the border between sector W04 and W07, as well as on the border between sector W11 and S12. During our survey in 2016, we detected yet another group of similar holes in sector S28 – barely visible traces of such holes are arranged there in a rectangular shape, measuring roughly 2.5 × 4.5 m.

The diameter of all the holes on the northern slope of the hill ranges from 12 to 20 cm, and they were drilled more than 20 cm into the surface of the rock (Fig. 4). There is a consensus among researchers that these holes were used to fix vertical wooden posts. The discussion, however, concerns the dating and the function that these posts served.

One local hypothesis assumes that the posts were used to attach torches that illuminated rituals performed on the rock. However, the most common interpretation is that the posts were part of the construction of traditional quincha walls. According to the authors of this article, three fragments of a quincha wall located on the southern slope are the relics of buildings that were once there. However, three separate sections of post-holes located on the northern slope we interpret as free-standing walls, not associated with any building.

Two arguments are usually raised against this latter interpretation. First of all, it is noted that at the base of a quincha wall, there is usually a shallow ditch. In our case, there is no such feature. The second argument considers the local weather conditions, namely the strong winds...
Fig. 1. El Fuerte de Samaipata, as seen from the west
(photo by J. Kościuk)

Fig. 2. The northern slope of Samaipata rock.
The green arrows mark rows of round holes for quincha posts.
The hill-shaded 3D cloud from terrestrial laser scanning (TLS) is used as the background:
A – the western part;
B – the eastern part
(elaborated by J. Kościuk)
Interpretation of traces of hypothetical quincha walls in Samaipata

Therefore, the main objective of this study will be to prove that a quincha wall could withstand the windy conditions of the northern slopes of Samaipata.

Albert Meyers, the director of the German Samaipata Archaeological Research Project (Proyecto Arqueológico en Samaipata, PIAS) in the years 1992–1996, drew the authors’ attention to another possible interpretation. The holes drilled in the rock may theoretically come from the colonial period and be a part of the Spanish fortifications strengthening the top of the hill as the last defence point. Such dating cannot be a priori excluded in the absence of any relevant evidence that could offer absolute dating of the drilled holes.

An exchange of e-mails resulted in the following conclusions. The Spaniards who arranged the military post there would have wanted to protect the margins of their settlement located south of the rock. Fortifying the top of the rock from the northern side, where the natural slope is so steep that one can hardly imagine any attacks from this side, makes no military sense. Therefore, providing shielding from the wind or undesirable observation remains the only plausible explanation for the function of the postulated quincha wall. Were Spaniards interested in this? During discussions, we did not find any arguments in favour of such an interpretation, so in our opinion, the most likely provenience is from Inca times.

Basic information on pre-colonial quincha walls and interpretation of the function of vertical wooden posts

The term quincha is borrowed from the Quechua verb (Quinchani – cercar de septo) [5] denoting separating by a septum. Unlike modern constructions also referred to as quincha, the pre-Hispanic quincha walls were not timber frame-based. The traditional form of this type of construction is still popular not only in the Andean region, but also in the whole of Central America (Fig. 5). Internet resources are full of webpages devoted to local initiatives promoting the use of this simple and economical construction technology [6].

In contrast, post-Hispanic and modern timber frame-based quincha constructions are of interest to many scientists, mainly due to their tolerance to seismic phenomena [7], [8] and problems related to the maintenance and conservation of architectural heritage [9]. Simple pre-Hispanic constructions of quincha walls are practically not analysed in terms of strength, and their models are not subjected to experimental strength tests. Due to this, it is difficult to solve our main problem solely using current literature on the subject.

In terms of construction methods, traditional pre-Hispanic quincha walls can be divided into four distinct groups. The simplest structure, the single-interlaced type, consists of vertical posts between which horizontal, thinner branches or rods of local bamboo are intertwined (Fig. 6A).

Such a construction can be additionally strengthened with successive vertical rods interlaced between horizontal crossbars – the cross-interlaced quincha wall (Fig. 6B). In both cases, clay mixed with chaff tightly covers the wooden construction. Variants are also possible when, instead of interlacing, individual elements are bonded together using...
plant fibres. The next two types differ slightly in their construction. Horizontal elements connecting vertical posts are still present, but the clay filling the wooden construction is much more compacted. Depending on whether the horizontal crossbars are attached on one or both sides of the post, the two further types of wall are distinguished as one-sided (Fig. 6C) or double-sided (Fig. 6D). In the last type, we often notice an infill of small stones or more frequently of adobe.

One of the essential advantages of such constructions is the use of local, easily accessible materials: clay with the addition of organic chaff, small tree branches, bamboo sticks, and trunks of trees of appropriate diameter for vertical posts. Detailed identification of plant species that may have been used in the 14th and 15th centuries by Inca builders is difficult. For natural reasons, such organic materials are rarely preserved in a state that allows for the identification of originally used species on archaeological sites. An additional complication is the 15 climate zones specific to Peru and Bolivia [10], each with typical vegetation. Thus, it is difficult to determine which particular plant species were used by builders on the eastern slopes of the Bolivian Andes. Contemporary tutorials that promote the reintroduction of traditional quincha construction recommend the use of hardwood species for vertical posts – preferably madera tornillo (Cedrelinga catenaeformis) [11], and for horizontal elements and wattle work, local bamboo, caña brava (Gynerium sagittatum) or caña guayaquil (Guadua angustifolia) [11], [12].

**Discussion of hypothesis**

The only common point of discussions about the purpose of the round holes drilled in the northern slope of Samaipata is that they were for fixing vertical, wooden posts. According to the authors of this paper, the hypothesis of using them as support for torches is too fanciful. Additionally, in many places, the holes are located not on the edge of the hill, but on its steep slope, making some posts practically inaccessible (Fig. 7).

Therefore, the only plausible alternative interpretation seems to be that of quincha walls. Their function could have been to shield people from the wind, to cover the ceremonial zones to avoid undesirable observation from outside, or, as we will later try to prove, to enlarge the ceremonial platforms behind the walls.

It is worth noting that the line of post-holes on the northern slope of Samaipata rock is interrupted in two places. These coincide with specially shaped channels enabling rainwater to flow down the slope (Fig. 8). This observation alone indicates that once, along the line of holes, there was an artificial barrier that allowed for rainwater runoff. This is one of the crucial arguments supporting the hypothesis postulated by the authors about the existence of a quincha wall in this place. Based on the preserved traces, this interpretation seems to be most likely.

As already mentioned, in some places, the line of post-holes does not run directly on the edge of the artificially carved platforms, but it traverses the slope obliquely to the contour lines (Figs. 7, 9A). A hypothetical wall placed along such a line would not protect the platform behind it from the wind or unwished-for observation from outside. It seems likely that, between the line of wooden posts and the steep slope behind it, there was originally a backfill that enlarged the platform above (Fig. 9B). Today, similar constructions still occur in Bolivia – even in the immediate vicinity, at the ticket offices at the entrance to Samaipata (Fig. 10).

What would a backfill enlarging the terrace behind the quincha wall look like? Except for the round holes for the posts, there are no traces that could provide guidance. However, the question can be formulated otherwise – how would this kind of platform be properly built and do we know of any examples from the pre-Hispanic era?

Looking at the issue from an engineering point of view, we have two fundamental problems to solve here: how to
Interpretation of traces of hypothetical quincha walls in Samaipata

We have ample evidence that Inca builders coped with such problems perfectly. The most known are probably the constructions of the terraces on the slopes of Machu Picchu, where both problems had to be solved simultaneously. Admittedly, stone-retaining walls were used there, not quincha walls as in the case of Samaipata, but the essence of the solution ensuring adequate drainage and stability of the hopper remains analogous – the bottom layer consisted of [...] larger stones overlain with a layer of gravel and above that a layer of somewhat sandy material [13, p. 39, Fig. 5–6]. The use of the lowest layer of broken stone with sharp edges, especially if the terrace was founded directly on a steep slope of solid rock, had another advantage – it increased the friction between the layers of the backfill and the face of the rock. Such a solution was observed in the case of the retaining terrace (Fig. 11) of the Inca astronomical observatory El Mirador de Inka-raqay [14].

In the case of Samaipata, the application of this engineering knowledge could have resulted in a similar solution (Fig. 12). It takes into account both the methods of construction of traditional quincha walls that we know of, and the principles used by Inca engineers in the construction of terraces. This hypothetical reconstruction introduces one more element – plant-fibre mats laid between layers of the backfill (Fig. 12, item 2). Their function is analogous to the geotextiles used today. The use of plant-fibre mats is already known from the architecture of the pre-Inca Wari culture [15]. We can, therefore, assume that it was also known to the Inca builders.
Nevertheless, the problem of the lack of shallow ditch at the base of the wall remains unsolved. However, from a structural point of view, such a ditch, usually filled with stones, is mandatory for *quincha* walls placed directly upon uncompacted soils. It acts as a foundation, securing the proper anchoring of piles and evenness of wall settlement, and ensures adequate tightness at the foot of the wall. In the case of *quincha* walls erected directly on solid rock, such a foundation, and therefore the ditch, is not necessary from a structural point of view. This may explain the lack of it in our case. The proposed reconstruction is one of the many ways in which, at the-then level of building skills, this problem could have been solved. In summary, it can be said with a high degree of certainty that the round holes in the rock (and the posts that were likely once embedded in them) indicate the existence of a *quincha* wall in this location.

Nevertheless, the question of the resistance against wind pressure remains unanswered. An affirmative answer may render our hypothesis even more credible.

There are no accurate meteorological data for El Fuerte de Samaipata itself, but the data obtained for the town of Samaipata indicate the same tendency we observed on the top of the hill. The predominant winds are those from a NNW direction; thus, nearly perpendicular to the line of circular, drilled holes alongside the northern slope of the rock. The main problem, however, is wind speed. While in the town located in the valley 300 m below, the wind usually does not exceed 40 km/h (Fig. 13), it is much stronger on the top of Samaipata rock. When working on the top of the hill, we experienced considerable difficulties in...
Fig. 12. Hypothetical reconstruction of the principle of enlarging the terrace behind the quincha wall: 1 – split stones; 2 – plant-fibre mats; 3 – crushed stone; 4 – compacted earth; 5 – compacted clay; 6 – rainwater drainage channel; 7 – compacted clay with chaff; 8 – drainage at the foot of the wall (elaborated by J. Kościuk)

Fig. 13. The wind rose for Samaipata town (source: https://www.meteoblue.com/en/weather/forecast/modelclimate/samaipata_bolivia_11494517 [accessed: 27.11.2017])

Table 1. Mechanical parameters of materials used in the numerical simulation (elaborated by J. Kogut)

<table>
<thead>
<tr>
<th>Name</th>
<th>Young modulus E [MPa]</th>
<th>Poisson ratio [-]</th>
<th>Density [kN/m³]</th>
<th>Internal friction angle [deg]</th>
<th>Cohesion [kPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>10000.0</td>
<td>0.3</td>
<td>21.7</td>
<td>40</td>
<td>5000</td>
</tr>
<tr>
<td>Clay wall</td>
<td>20.0</td>
<td>0.3</td>
<td>20.0</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Timber</td>
<td>7000.0</td>
<td>0.3</td>
<td>6.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Infill (clGr)</td>
<td>20.0</td>
<td>0.3</td>
<td>20.0</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>


**Discussion of results**

The maximum value of the total displacements (Fig. 15) of the analysed wall scarcely exceeded 3 mm in the worst-case scenario. The displacements are presented as deformed models, separately for the wall, wooden posts, and the rock. The rock deformation did not exceed 0.09 mm. The simulated *quinchas* wall construction proved to be so flexible that it could feasibly survive harsh winds. The maximum values of the total strains (Fig. 16) can be seen at the bottom of the *quinchas* wall. The differences in the behaviour of the wall are due to the fact that the wall is...
a continuous structure, a part of which has backfill that enlarges the platform behind it. As expected, analyses of vertical $\varepsilon_{zz}$ strains in the wooden posts (Fig. 17) showed that wooden fibre on the windward side experienced tension, while fibre on the leeward side was compressed. In the overall conditions, they were balanced. It is evident (Figs. 18, 19) that the entire wall, as well as the rock, was subjected to small stresses, even in such harsh conditions. As for the rock itself, the maximum stress value can be seen in the post-holes, but it does not exceed the strength of the sandstone. The value of 0.5 MPa is well below the threshold value that may destroy the material around the holes.

A closer look at the internal behaviour of the quincha wall shows that the maximum shear stress is carried by the posts, and it is a stress level of 0.2 MPa in tension and 1.5 MPa when compressed. This is even more visible when the $\sigma_{zz}$ stresses are analysed (Fig. 18). It should be noted that the compression strength of the wood was assumed to be equal to $R = 21$ MPa. Additionally, the horizontal elements of the wall reinforcement did not exceed a stress level of 0.3 MPa, and torque and bending moments were negligibly small.

**General conclusions**

The results obtained on the basis of the FEM simulations allow us to state that the hypothetical quincha walls should have been able to withstand the assumed wind loads. The load capacity is so significant that, even after any changes in the strength parameters, taking into account the humidity status of wood and clay, the wall would still have been stable. It should also be noted that, in the simulation, a more advanced model was used in which horizontal elements reinforcing the wall were included. It can even be assumed that a lighter type of wall (for example, one-sided, Fig. 6C), would have also met the conditions.

The above text is an extended and rewritten version of our paper presented at the Structural Analysis of Historical Constructions 2018 Conference in Cusco [23].
References/Bibliografia


[14] Astete Victoria F., Ziolkowski M., Kościuk J., On Inca astro-


[21] Quinn N., D’Ayala D., Moore D., Experimental testing and nu-


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Abstract

El Fuerte de Samaipata, commonly known as Samaipata, is an archaeological site in Bolivia. It was inscribed on the UNESCO World Heritage List in 1998. The most characteristic feature of the site is a natural rock that served as a wak’a (sacred place) for several local, pre-Hispanic cultures, so its current condition is the result of at least 1200 years of development. The rock was comprehensively studied and documented by German scholars. Due to the threat of progressive erosion, a new documentation project was executed by a Polish team. The main objective of the project was to document the nesting site using 3D laser scanning. The research was conducted in close cooperation with the Centre for Pre-Columbian Studies of the University of Warsaw in Curso. Specialists from many other universities and research centres also joined the project.

Key words: Fuerte de Samaipata, Bolivia, rock art, quincha walls, numerical modeling
Streszczenie
El Fuerte de Samaipata jest stanowiskiem archeologicznym w Boliwii wpisanym na Listę Światowego Dziedzictwa UNESCO w 1998 r. Najbardziej charakterystyczną cechą tego miejsca jest naturalna skała, która służyła jako waq’á (święte miejsce) dla kilku lokalnych kultur prehiszpańskich, więc jej obecna forma jest wynikiem co najmniej 1200 lat rozwoju.

Pod koniec XX w. i na początku XXI Samaipata była wszechstronnie badana i dokumentowana przez niemieckich uczonych. Ze względu na postępującą erozję polski zespół wykonał nowe pomiary, których głównym celem była precyzyjna rejestracja zagrożonych reliktów za pomocą laserowego skanowania 3D.

Większość dotychczas opublikowanych wyników badań na temat Samaipata koncentruje się na złożonym zespole nisz i tarasów, figuralnych i geometrycznych petroglifów, a także kanałów i zbiorników wodnych rzeźbionych w skale. Długie rzędy małych okrągłych wywierconych otworów przyciągają mniej uwagi naukowców. Są one powszechnie kojarzone z pionowymi słupkami stosowanymi do tradycyjnych ścianek quincha. Wątpliwości co do wytrzymałości ścianki quincha na ekstremalnie silne wiatry na szczycie skały skłoniły autorów tego artykułu do przeprowadzenia komputerowych symulacji w celu wyjaśnienia tych zastrzeżeń. Model 3D został oparty na wynikach skanowania laserowego 3D, a samą analizę przeprowadzono z wykorzystaniem metody elementów skończonych (MES).

Słowa kluczowe: Fuerte de Samaipata, Boliwia, sztuka naskalna, ścianki quincha, modelowanie numeryczne