Masonry or Wooden Vaults?: The Technical Discussion to Rebuilt the Vaults of the Cathedral of Lima in the Seventeenth Century

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ABSTRACT: During reconstruction of the vaults of the Lima's cathedral, in the seventeenth century, master builders searched for construction systems that were more resistant to seismic activity. The original vaults, due to the earthquake of 1609, were extremely damaged. This situation motivated a discussion to analyze the causes of damages and the features that would require their reconstruction. It was thought desirable that the new construction would be Gothic-ribbed vaults, not as a return to an ancient aesthetic style, but because the masons thought this kind of vault could better resist the earthquakes than the existing barrel vaults. However the continuing damages and collapses prompted a second discussion, to determine the best way to rebuild these vaults. This time the problems of the ribbed vaults were discussed under horizontal loads, possible anti-seismic solutions were adopted and the possibility of changing the masonry vaults for the nascent curved timber plank in the colonial lands, especially after the highly structural efficient response proven by the wooden vaults in some parish churches.

INITIAL CONSIDERATIONS

The vaults erected in the city of Lima since the sixteenth century were executed in masonry, as had happened in the main chapel of the cathedral in 1551, which was made of stone. Similarly the churches of Our Lady of Mercy in 1542, Our Lady of the Rosary in 1547 and the chapels of the hospitals of Santa Ana in 1564 and of the Holy Spirit in 1573, built their vaults in brick masonry with lime mortar. On July 1586 an earthquake damaged these vaults, which were re-built in masonry.

We know that the monastery of La Encarnacion had covered the chapel of its church with a brick vault in 1587, the monastery of La Concepcion did in 1602 and the monastery of The Trinity covered its church with a barrel vault in 1614, the latter being rebuilt many times. Likewise, the mason Luis Ortiz de Vargas erected the vaults of the Dominican Church of Magdalena Ventures in 1627 in masonry. The Agustine Church of the Guide had vaults made of stone and brick in 1633, which collapsed in the earthquake of 1746 (Bernales 1972, pp.87-101).

Certainly throughout the sixteenth and seventeenth century Lima's churches continued to be erected with stone or brick domes and vaults, and then reconstructed with the same materials after having collapsed under the effects of seismic activity. This phenomenon also occurred in churches of other cities, whose masonry vaults we can still see in the ruins of San Agustin church in Zaña (Fig.1).

Possibly the techniques of vault construction that was used by the Spanish masons in South America did not have the refinement suitable for anti-seismic work. Simply observing the Byzantine domes erected in seismic areas, which not only had great masses as buttresses, but mainly they had a reinforcement solid wall plate or chains (Choisy 1997, pp.117-125). Similarly, the Italian builders of the Middle Ages strengthened their vaulted structures by the use of wooden tie beams and iron chains and tie rods (Bradford 1997, pp.219-223). These elements were not considered necessary in Spain to give stability to vaults.

In this way in the middle of the seventeenth century Lima's churches began to be built as Gothic-ribbed vaults, not as an anachronism style but because it was thought they were more stable against of earthquakes. But with the constant damage that earth tremors caused them, the constructors introduced the Spanish system of wooden vaults, encouraged also by the good structural behaviour showed by others wooden structures during earthquakes, like quincha.[1]

Figure 1: Church of San Agustin (Zaña, Peru), with vaults and arches built of brick.

Some of these early experiments were conducted in the chapel of the Inquisition and in the small church of La Veracruz in Lima by Diego Maroto in 1665 and 1666 respectively, with similar characteristics to the Spanish wooden vaults, which were sustained by another structure (Fig.2). He repeated these curved timber planks for built vaults in 1678, in the main church of the convent of Santo Domingo (Hurtado et al. 1995).
Apparently in these years master masons began to use timber vaults in parish churches in the city of Lima. In this way Pedro Alvarez de Faria, secretary of the Holy Office, after inspecting the damaged vault of the Chapel of the Inquisition and after several conferences, mentioned to the inquisitors: "it is better to build a new vault with wood and cane as have been done in other churches and chapels of equal dimensions" (NA).

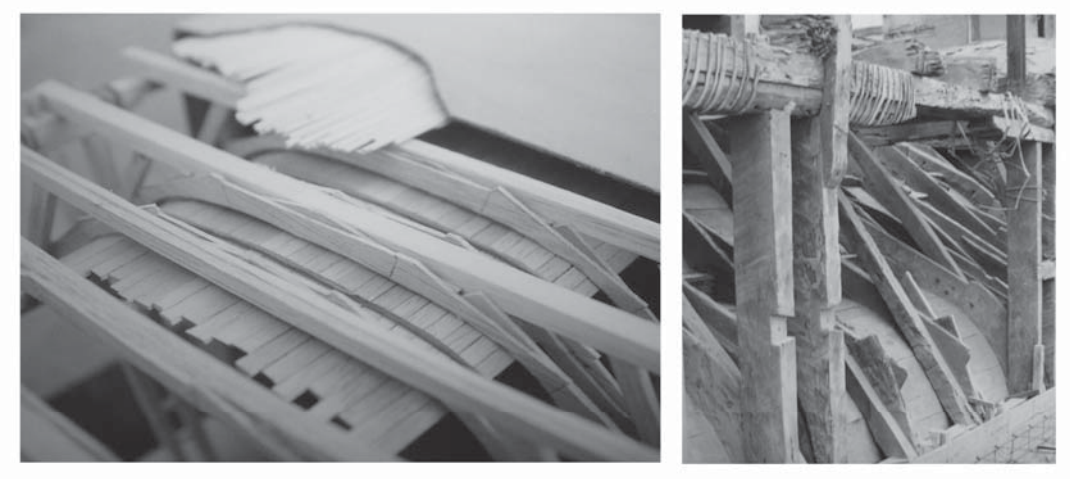

Figure 2: Wooden vault at Our Lady of Loreto chapel (Lima, Peru)

It should be remembered that the transmission of knowledge from the Iberian peninsula was permanent. Therefore it is no surprise that during the seventeenth century in the Viceroyalty of Peru were known vaults built with masonry or wood according to the constructive procedure adopted in Spain, not only through Spanish builders came to South America but in the use of books like of San Nicolas treatise (1639) or Torija manual (1661).[2] However in the case of the wooden vaults, they were not accepted immediately, despite the initial impetus of some master builders. The majority of masons believed that the wood could cause problems like fires and rot by time. In this regard Juan del Cerro mentioned during the discussions for the reconstruction of the Cathedral vaults that: "... being of wood has many risks of fire and rots and I say this from experience. I have seen in Spain, where they have been demolished by these causes in some churches and convents... " (AA, verdict of Juan del Cerro).
It is interesting to note that the early churches who changed their masonry vaults for wooden vaults were with the small dimensions, such as those mentioned in the Chapel of the Inquisition and at the church of La Veracruz. Due to the size of these churches and the fact that the great temples continued rebuilding their vaults with masonry, it appears that wooden vaults were used originally as a temporary intervention after the earthquakes, on the part of religious congregations with fewer economic resources, waiting to raise the funds necessary to begin replacing them with masonry.
We will have to wait until 1675, during the reconstruction of the San Francisco church, when Manuel de Escobar and the Portuguese architect Constantino de Vasconcellos improve the vaults of Spanish style built by

Maroto, making the new vaults self-sustaining, recalling in part to the solution proposed by Philibert De L'Orme a century ago.[3]
In this way, giving to the timber plank a curved profile, for both intrados and extrados, reinforcement elements like purlins and a wall plate on the top of walls, where will set the wooden arches. All these elements, already raised by De L'Orme in 1561, incorporate new solutions, such as the adobe fill at the bottom of the vaults to counter thrusts and flexible joints with ribbons of leather (Fig.3). The earthquake of 1687, which caused the collapse of many masonry vaults in Lima, raised again the issue of earthquake resistance of the masonry structures in the debate, especially after masons saw the good performance of the timber plank vaults in some churches years before(Hurtado 2007, pp.538-539).

Figure 3: Wooden vault, with adobe fill reinforcement (Lima, Peru)

FIRST DEBATE: GOTHIC-RIBBED VAULT OR BARREL VAULT

A turning point for the study of the vaults in the Viceroyalty of Peru was the case of the reconstruction of the vaults of the Cathedral of Lima (San Cristobal 1996, p.42). The original brick and stoned vaults during the earthquake of 1609, were extremely damaged, and originated an arduous discussion between the expert masons of the city to determine the best manner to repair or replace these vaults. The master builders had to respond to a questionnaire "... in particular concerned that remark, it seems appropriate to reinforce the vaults and if necessary lower the height of the walls and if it is convenient to continue the construction with brick or change for wooden vaults... " (MA c).
So Alonso de Arenas said that "if for security and life should be down the building and cover with wood, this will not be answered because it is not just that someone talk about something out of reason, and we can not presume that there is a person that think it "(AA, verdict of Alonso de Arenas). On the other hand Pedro Blasco alleged:

> …in terms of covering the church with wood I respond that I am not of this point of view, because there are many disadvantages. First to build the church with timber means losing everything that has been done... and covering it with wood does not guarantee security if the buttresses fail… and also has others problems, which the fire and the rot and worms, because in less than fifty or sixty years worms will eat it and get corrupted and ends... (MA c, verdict of Pedro Blasco).

These statements give us an idea that until the early seventeenth century it was believed most desirable, not only from the point of view ornamental but also structural, make the vaults of stone or brick, preferring these materials to wood. The subsequent establishment of the damage earthquakes that occurred in the existing groined and barrel vaults prompted the re-use the Gothic-ribbed vaults. The master builders used this system in the reconstruction of the cathedral's vaults, because it was thought that this kind of vault were more resistant to earthquakes. Indeed the masons believed that because the ribbed vault tends to concentrate the thrust would be enough to give to the walls buttresses with thicknesses sufficiently capable of containing as much as possible the thrusts, avoiding imbalances in the shape of the vaults that could cause collapses during earthquakes. So Juan Martinez de Arona mentioned that:

> I am of the same opinion of the greatest masters, which seems to be the best remedy will be go down the groined vaults and rebuilt with ribbed vaults... the Gothic-ribbed vault is better and we can see this kind of vault in the chapels of the Convent of Santo Domingo, where there was a big quake of the year five hundred and eighty-six and these vaults did not damage, because they have ribbed vaults, and in our Holy Church I saw injured walls, because it has a groined and barrel vaults, and the chapel of La Concepcion has resisted the earthquake because has a ribbed vaults and they do not produce the big thrust like the other vaults… (MA a/f/15r).

Excessive height of the building

One of the first actions taken to reduce the impact of earthquakes in the vaults of the cathedral was lowering the height of the walls. Besides reducing the height of the walls, builders increased their width, so as to raise a big mass against of earthquakes (Hurtado 2006). This fact is evident in the original proportions that had the cathedral, as seen in paintings and engravings of the seventeenth century, wich were different to those of later centuries. Early in 1609 master builders Cordoba and Fernando Figueroa mentioned as one of the solutions for the towers of the Cathedral was lowering its height: "That the towers do not rise as the drawings show, because we need to remove the third of its height"(CA). Similarly in 1614 the mason Juan Martinez de Arrona claimed that it was important reduce the height of the walls, on which download the thrusts of the Cathedral's vaults. He also advice that not to carry too much weight on them, thereby reducing the impact of earthquakes in the arches and vaults:

> This that in no way seeks to lift masonry on the arches more than necessary in order to sustain the vaults, and to reduce the height of chapels for more strength and safety, because the entire building must be four varas (twelve feet) lower than it has now as I said and argued...and besides will serve to save money… (MA a/f/1/5r).

Weakness of buttresses

Another problem detected in the design of the cathedral was that it did not have buttresses adequate to withstand the thrusts of the vaults during earthquakes, because their proportions were in line with the Spanish constructive traditions, and it were not made with methods that imposes a seismic area. These proportions would be adjusted by adding mass to the original buttress (6 ½ feet long by 9 feet in width), eventually becoming a buttress of 15 feet long by 15 feet wide.

> …Having seen the damage in the vaults of the temple and they have failed because missing buttresses, that received central arches and vaults, because the temple is not desirable either in accordance with good architecture. If so would not have caused the tremor all the damage that it received, and you should reinforce and repair the temple… (AA, verdict of Pedro Blasco and Antonio Mayordomo).

On the other hand the master mason Martín de Aizpitarte said:

> Although I understand that in this apparently I can not stop saying what I feel in this and to speak clearly, I say that I do not find firmness in all this work, because the building is very high and poorly mounted to resist tremors, though the walls and pillars are of double thickness and because when the tremors come they make more damage in a part than another, despite the masonry…because this land does not allow naves with widths of forty feet… (AA, verdict of Martin de Aizpitarte).

Improper use of different vaults

The masons saw that the vaults had a different cross section, so the main nave was formed by a flattened arch, while the smaller naves had high-pitched arches. This did not produce enough mutual buttressing among the vaults of the three aisles, making in some case worked nearly the limits of their stability, because flatter form producing stronger outward thrusts and required a stronger arch or heavy and powerful support. Therefore small changes in their shape during an earthquake would have caused that the line of thrust go away the perimeter of the vaults causing their collapse.

> …I think it is not appropriate to continue the work with that design because the arches are wrong, they have no right proportions to the width of the church, because some arches are flat and very loaded and others are high and unloaded ... then they are working so wrong, in particular the main nave, and the tremor is inconvenient for them… (MA a, verdict of Martin de Aizpitarte).
> I have seen that the arches of the church had no relationship between them, because some are high and others low. I say they are without force because the main arch can not download in smaller arches… (MA a, verdict of Diego Guillen).

Poor constructive processes

It also found that there was no adequate preparation in the workmanship who built the vaults, although without the advice of the master builders. Support staff was not still enough expert in the vault construction. It may be recalled that the constructive system of the vaults was unknown in South America before the arrival of the Spanish builders. But it must also be told that the disciples of the local builders acquired quickly knowledge and skills needed to build vaults.

> It was also noted that there was no thing most important to remedy that the materials and officer builders (AA, verdict of Alonso de Arenas).
> About the buttresses, I think the most important is the mortar, but due to the materials and labors in this land are poor, when the tremors come do not permit to paste the new work with the old (AA, verdict of Martin de Aizpitarte).

SECOND DEBATE: MASONRY VAULT OR WOODEN VAULT

A new turning point was the earthquake of 1687, which caused the collapse of the new Gothic-ribbed vault, so that once again there was a discussion on the best manner to rebuild the cathedral's vaults. In this moment Fray Diego Maroto gave to the Ecclesiastic Council a vision of structural safety of the wooden vaults introduced by him at La Veracruz church some years ago, proposing to rebuild in the same system the vaults of the cathedral:

> ...result that the facade and the vaults closest to it were no disturbed, when these vaults are made with cedar and plaster. The new technique has been recognized by my experience of being more secure on these repeated tremors, mostly when who made this declaration has built the vaults of the church of my convent, which discharged on walls with little masonry foundations. Vaults made over the pillars and arches had suffered the effects of earthquake and not those built of cedar and gypsum... (CA/f/70).

On the other hand Pedro Fernandez de Valdes noted that the buttresses could not contain the horizontal forces that would occurred during earthquakes, mainly on the top of buttresses. Therefore it was preferable the decrease the weight to the new vaults and make them with wood, cane and gypsum:

> …I think that the good work that can be applied with masonry is not enough, because the pillars and arcades don't resist the thrusts…particularly when the experience has shown in the work of the church of Saint Pedro Nolasco, which was implemented this genre with more materials and when arrived the earthquake it collapsed, but if the vaults were been built with plaster and wood and cane does not require further reinforcement... (CA/f/71v-72r).

Also Manuel de Escobar, mason with great renown in the Viceroyalty of Peru, which introduced the self supporting system of wooden vaults, mentioned that the wood and iron nails were granted greater security in these vaults than the big mass of masonry vaults. As a result masons came to incorporating wood and iron reinforcements to ensure the stability of the vaults:

> …the vaults that were built of brick should be made of wood, because it more convenient to remove the horror of the collapse. The wood with nails of iron is more resistant to the movements of earthquakes, and therefore is more secure for us make the vaults of timber … (CA/f/72v-73r).

Then the Metropolitan Council awarded Maroto, in his capacity as principal master builder of the cathedral, the design of the new vaults. Fray Diego Maroto explained on the Book Factory of the cathedral the constructive characteristics that would have these wooden vaults, in imitation of the Gothic-ribbed vault, describing in detail the number of wooden arches, the joints and the fixing metal system used. He mentions that these vaults are composed with arches made with timber curved plank of cedar with a cross section of 28 x 14 cm. He also gave indications of use the rubble fill in the base of the vaults (Fig.4):

> ...the first vault must make with eleven keys and be covered with the curved timber plank of cedar wood and which has few clear for the gypsum plaster that served to imitate the brick vaults... (MA b/f/38r-39v).

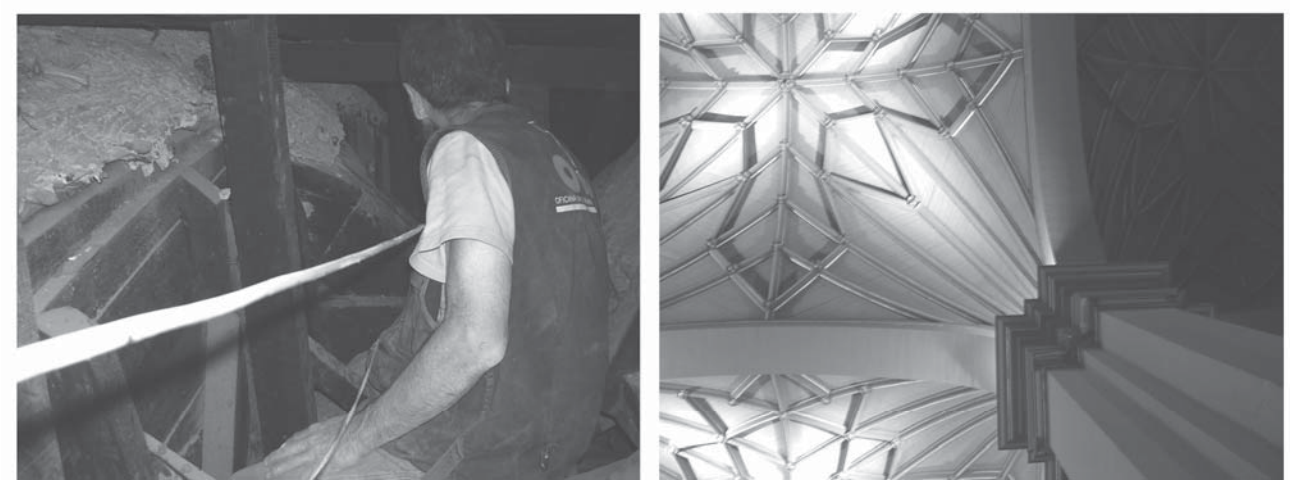

Figure 4: Intrados and extrados of the wooden vaults at the cathedral of Lima (Peru)

On 1691 had been built three wooden vaults corresponding to the back of the main facade of the cathedral and was yet to make the rest of them. Again, the Council asked the opinion of the experts about the behaviour of the new vaults after the earthquake of this year. So Pedro de Asensio stated that have been made to the vaults of wood slowed the thrusts and guaranteed their stability, compared to the stoned vaults. At the same time attributed the invention of the new system to Diego Maroto, although in reality these vaults would be an adaptation of the Spanish system to the characteristics of the telluric Viceroyalty of Peru:

> …having been made the vaults of wood, immediately it was removed the thrust that they had, and all these three vaults have been built of cedar and plaster behind the facade, and they have been recognized security for the tremor, because the tremor occurred this twentieth day on September last year six hundred ninety, that was as big as the twentieth day of October, one thousand six hundred eighty-seven and caused major ruins in other buildings and these three vaults did not receive any damage, and finally this new kind of vaults, that the main master builder of the cathedral has invented in the whole church, has shown not so corrupts the shape of the vaults… (CA/f/95v).

SPREAD OF THE WOODEN VAULT IN THE VICEROYALTY OF PERU

From the reconstruction of the vaults of the Lima's cathedral with the curved wooden plank system, this technique, with its various alternatives, began to spread throughout the Viceroyalty of Peru, emerging mainly in the coast region, which is precisely the place with the most seismic activity.
The churches of Lima belonging to the orders of the Dominicans, Franciscans and Jesuits, only changed their masonry vaults by wooden vaults after the continuous damaged caused by the many earthquakes. In the case of parish churches, they had already changed their masonry vaults long before the big churches, and in some cases when constructing new buildings they decided to build their vaults since the start under the wooden system (Fig.5). So, the builders worked empirically, depending of own previous experience from structures that they had built successful or unsuccessful. When a trouble appeared in a structure they used the knowledge gained from the past experience. Similarly the new buildings offered to master masons the opportunity to do experiments and grow their knowledge of the effects of earthquakes in the buildings.
It is relevant that Diego Maroto, as a Dominican religious, could have begun to build his wooden vaults in the main church of his religious order, however appeared in the small church of La Veracruz. Everything seems to indicate that initially the representatives of major religious orders did not accept the wooden vaults, instead they preferred to continue constructing the vaults with stone or brick. Apparently the fewer economic resources that had the parish churches made them to opt for a temporary solution, after the earthquakes, sufficiently stable to ensure the realization of the liturgy work. Therefore they used the wooden vaults, until they get the resources needed for the reconstruction of the vaults with masonry. The good performance shown by these initial wooden vaults would draw the attention of masons, which then would not hesitate to experiment with this structural formula in the new churches. The main advantages that the masons found in this system, in addition to stability, were that it was lightweight, inexpensive, easy to make and quick to assemble.

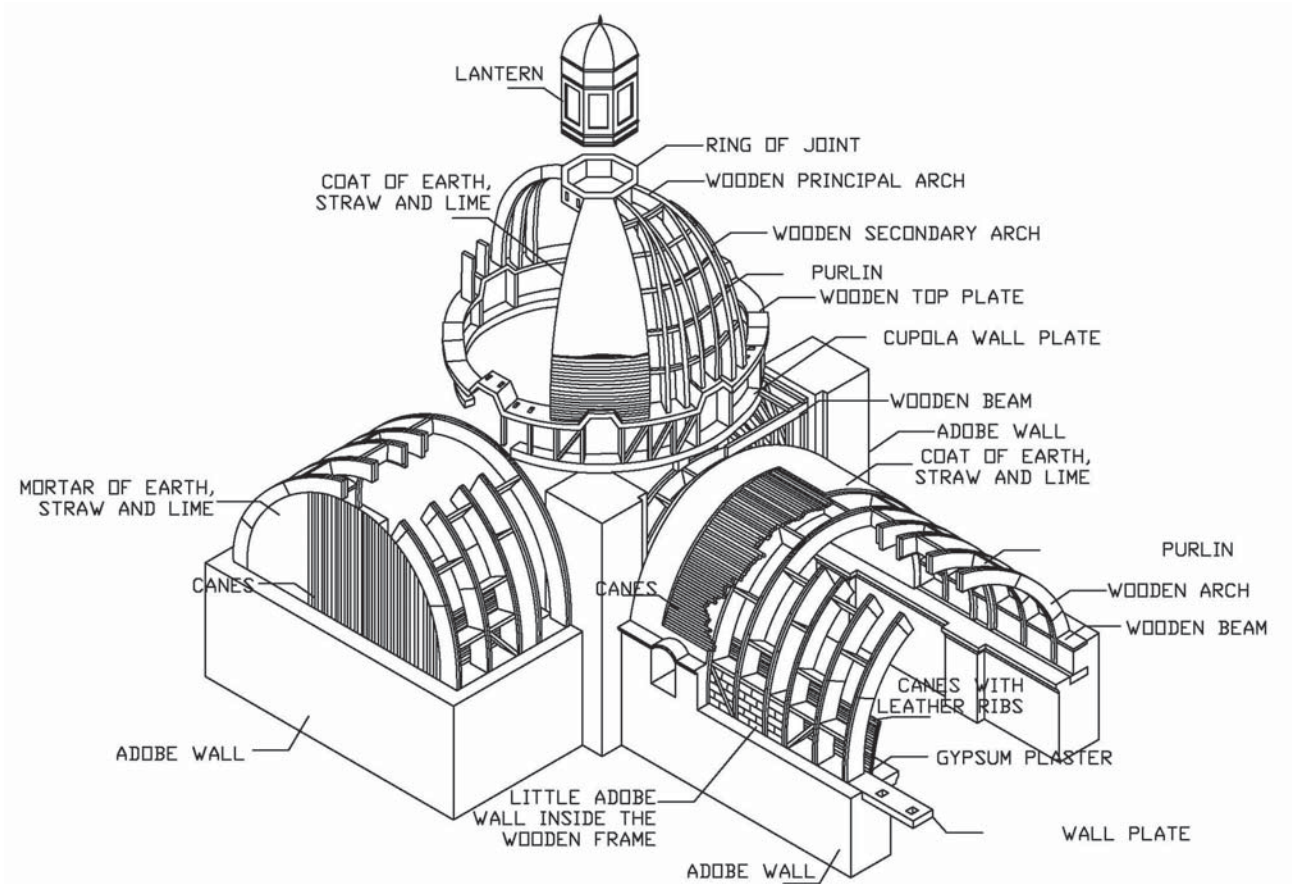

Figure 5: Wooden system vault used in the Viceroyalty of Peru in the seventeenth century

But also the Peruvians cities in the seventeenth century covered still their temples in eclectic style, because alongside the nascent wooden vaults also there were other types of wooden roof and masonry covers. We can not forget the fact that the masonry vaults did not disappear immediately with the use of wooden vaults. Because according to statements by the master builders, while they introduced the wooden vaults were researching solutions to bring stability to masonry vaults. In others words at the beginning of the seventeenth century there were vaults built with various construction systems in the Viceroyalty of Peru (Fig.6).[4]

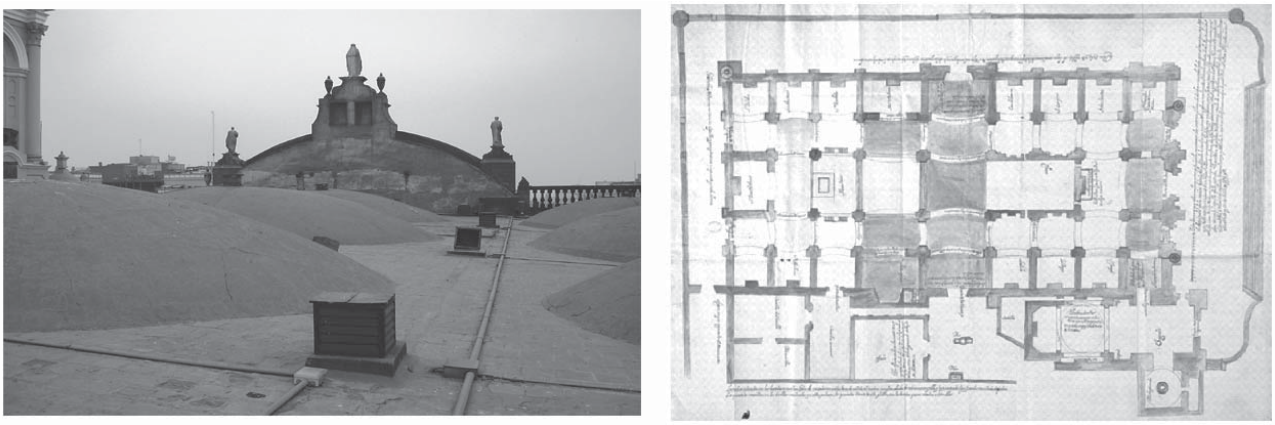

Figure 6: Cathedral's vaults and drawing with the description of the reconstruction works in 1697. Brick and stoned vaults in white and wooden vaults in gray (GAI, MP, Peru and Chile, 193)

CONCLUSIONS

Yet even today we can see a few examples of vaults made with masonry at San Agustin church in the ruins of the town of Zaña and two chapels next to the tower of the church of Our Lady of the Rosary, in the convent of Santo Domingo in Lima.[6] Others cities like Cuzco and Arequipa, located in mountainous areas and with high seismic risk, continued rebuilding their vaults with masonry, which despite continuing earthquakes have come to the present day. Certainly the presence of quarries near these towns would have motivated the use of stone, in the case of Cuzco to the granite and in the case of Arequipa to the volcanic stone. The entire experiment was done with different kinds of vaults, regardless in masonry or wood, for improve its efficiency earthquake resistant was arrested by the colonial administration, when the Viceroy Jose Manso Count of Superunda ordered the employment the wooden vaults only after the earthquake of 1746. This is main reason because almost all the existing vaults of the churches of the Peruvian coast have this construction system.[5] Not only because the masonry vaults collapsed, but because some of them were demolished arguing caution. So the authorities thought that the temples with two types of vaults would generate different thrusts, and did not guarantee an adequate balance in the building. Finally the Spanish wooden vaults absorbed the characteristics of the local school and were changed, improved and adapted to the needs of the Peruvian masons, which should work in a seismic land.

NOTES

1. The most important structure developed in the Viceroyalty of Peru was the "quincha". It refers to a wooden frame with a woven cane, filled with mud and straw and a final layer of gypsum or lime plaster.
2. That assertion is important not only to indicate the initial objection to use wood to cover the temples but to show the existence of exchange of information between masons who were working in Spain and the Spanish viceroyalty of Peru. Juan del Cerro was a master builder who worked in the first third of the seventeenth century in the Viceroyalty of Peru and had a big experience in Spain: "I said and I say, that I had seen in the town of Burgos like a master... and I say this from experience I have of a town of Valladolid called Dueñas, when the tower fell and came masters of Burgos and Valladolid... "(CA c). It also must consider that in addition arrived in South America Spanish books, such as *El Escorial on the collections of Juan de Herrera* carried by the ship La Capitana in 1589 (Ballesteros 1972, p.13).
3. Constanino de Vasconcelos died in 1668, two years after that Maroto introduced the system of wooden vaults. Initially he favored to cover the church of San Francisco with brick vaults, but finally he designed together to Escobar the wooden vault of the temple.
4. "Having made five large arches with gypsum…two next them and another to the Chapel of La Sola, three large arches with brick and lime plaster, and another eight arches and ten wooden vaults with cedar and two of the sacristy with the oak and gypsum…". (MA a).
5. Within the statement that the French Luis Goudin addressed the Viceroy, after the 1746 earthquake in Lima, he was concerned that "... clear that the country does not allow for building large or heavy construction and the walls of stone or brick, or adobes, when all of them asking in their nature a certain width ... so for the same wooden vaults that as usual will be made in quincha..." (Ballesteros 1972, p.305). State investment

in construction declined during the tenure of the Viceroy Count of Superunda. It is likely that the viceroy will opt for a constructive system that had already shown its efficiency earthquake resistant, and also the wooden vaults cost less than the vaults of brick or stone.

6. In 1547 remained seated in a contract signed by Jerome Delgado, Domenic mason, the work in the two chapels. "These chapels with Gothic-ribbed vaults are one of the oldest and most important examples of Peru, and certainly the most outdated relics of the Gothic Lima..." (Bernales 1972, p.5).

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