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The use of pointed vaults and side shaped walls for a new structural form consequent to one Renaissance original design

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A COMPOSITE ANTHROPOMORFIC RELIQUARY BASILICA

The beginning of the building of the Basilica of the Holy House at Loreto dates back to 1469 but, if archive sources do not supply the name of the designer engineer, it seems to be certain that the first project is to be assigned to Francesco di Giorgio Martini.

However it is sure that besides Francesco, many other world-famous men such as Baccio Pontelli, Giuliano da Maiano, Antonio da Sangallo and Donato Bramante worked there.

In any case, the important considerations that may be made about the building are so many that they justify the definition of an extremely original and interesting church, even though in the wide field of the Humanistic architecture.

It is to be pointed out indeed the fact it is a reliquary basilica, having been built to keep and to honour the Room of Mary, the place of the Annunciation and, before, of the Conception of the same Mother of God, after being transported here by the Crusaders from Nazareth in Palestine, to save it from certain desecration and destruction. A reliquary church that, having to protect a unique value for Christianity, destination of a great number of pilgrimages from all over Europe, wanted to show it in the best position for the aesthetic and philosophical sensibility of the time, that is in a central position. The Room was not a small building structure having

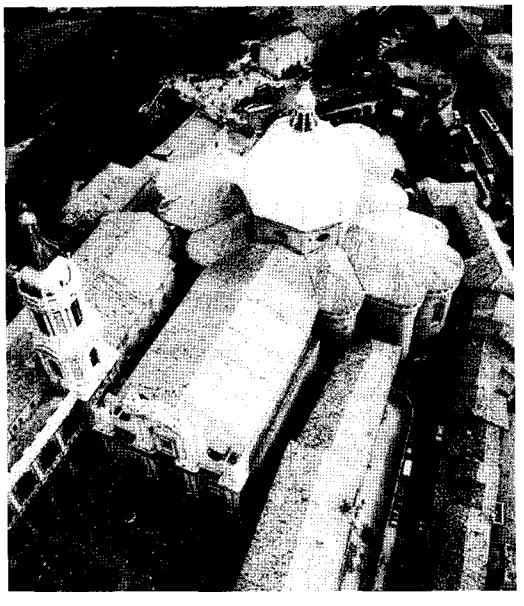

Figure 1
Bird's eye view of the Basilica

6×8 m external proportions, that became 6×11 m, when it was completed as a little church, with a height of 7 m at the ridge of the roof. These values have been rounded up to the metre to give an account of the volumes, considering that the marble covering prevents from making accurate measurements of these values.

The immediate consequence of this reality was to enclose the top of the hill, being unthinkable to dismount once more a structure that defined a holy space, also after the transport. The Holy House is still today inside the Basilica as upon a hill, a condition with some implications, being the hilly ground upon which it rises, clayey and rich in waters.

Furthermore the building was to allow the reception of large quantities of faithful men during the liturgical services having the heart in the relic.

Observing the plan of the holy building, the project is to be considered made in 1469; we may clearly see that the same plan has a composite shape, a fully Renaissance form, theorized by the best men of the period, first of all by Francesco di Giorgio, since the date of the beginning of the Treatises is to be fixed around 1479, but taken again by Leonardo da Vinci —cod.B 24r, 35v, 52r, 55r, all drawings belonging to 1490 and cod. Atlant. 235v, to 1510, even if only one example of such typology was really built just in the planning period, the Loreto Basilica.

While St. Peter's in Vaticano in Rome has become a composite plan Basilica by means of following additions, after having been erected according to a central plan, such uniqueness may be explained with the technical and constructive difficulties met in the practical realization of the spaces. We can find a confirmation of this assertion in the Cathedral of Pavia begun twenty years after the Basilica of the Holy House, architectural structure that, according to P. Fugazza's (1497–1519) scale model, was to be composite, but that was never completed and is still today under restoration, notwithstanding the series of the previous interventions. It was a church planned by highly skilled men such as Donato Bramante and Amodeo, a church that could enjoy other experiences, and, what is more, it was built in a plain land and was not to enclose the top of a hill in the middle.

The choice of the constructive composite plan at Loreto allowed to facilitate the liturgical customs such as the processions to visit the Room, holy space and last aim, and to realize a deambulatory around the hill with the Holy House.

At Loreto furthermore the Church rises according to a plan having an anthropomorphic proportionment, as it clearly appears superimposing the design by Francesco di Giorgio Martini f 42v, also enhancing from this point of view the aesthetic and philosophical aspirations of the time.

The building taken into consideration under the constructive outline appears to be an application of a modular notion of construction, that certainly derives from Gothic experiences, but that surpasses them for rationality, for organization of the parts, for the co-ordination of what was produced, a whole well expressing the technical spirit of the time.

The modular choice is motivated by the following technical requirements: it is mainly an expression of a way of planning and building based upon the use of proportions, simple and effective means to express different forms that may be taken back to the same family.

In large and very crowded yards the use of proportions made up the impossibility of the ubiquity of the works manager and contemporaneously exalted the abilities and the responsibilities of the single teams, who were proud of the work they realized. Modules and proportions therefore were useful for the management of the yard, but they were also considerable facilitations for the men who had to link different parts among them, such as the series of pillars,the scanning of the vaults, the behavioural homogeneity in the different elements that conjugate the one with the other, just as the terms of a proportion, so as to realize a functional and feasible whole with few uncertainties. Therefore there was the necessity of simplifying the building of a very complex volume as a composite church was, and this was attained with structural solutions statistically and constructively proved.

This way of acting, besides having economic consequences on the management of the yard, had the biggest effect of making work human, responsible in the personal autonomy, expressing Christian values and rules.

Renaissance plan with pointed arch vaults and pointed arches and outward vertical shaped walls

The other choices follow from these premises. Only at a first brief survey the Loreto experience seems to be out of time, since some parts recall in an unmistakable way the Gothic elements of a former and far period of time. Therefore just for the beginning date, it appears a much more unique than unusual Renaissance solution looking like an

Figure 2
View of the north-east apses outside the Renaissance walls

application of an architectural style according to a Linneo classification.

These aspects may lead to highly deceiving conclusions, if we think that near Gaiole in Chianti there is a church erected in 1540 by the Ricasoli family, called St. Peter in Avenano, having Gothic vaults as those at Loreto. Hence the Basilica of the Holy House may boast of many originalities, but certainly not that of being a structure with Gothic forms realized in the Humanistic period.

We may remember here the work of Bernardo di Matteo Gambarelli called the Rossellino at Pienza in the rebuilding of the Cathedral (1459), the experiences of the Logge del Papa by Antonio Federighi (1460) and the Church of S. Maria in Portico in Fontegiusta by Francesco di Cristoforo Fedeli (1480) both in Siena, and at Bosco ai Frati the church of S. Francesco, in the convent of S.Bonaventura, a work by Michelozzo di Bartolomeo (1434) and the interventions of the same author in the Dominican Church of S.Marco in Florence (1436–43). All these works together with Rossellino's experiences at Pienza can be considered the bases of the beginning of the Loreto construction. Rossellino was fundamental.

If from the examination of the vaults we move to that of the outward wall structures, the Renaissance thought shows itself in its fullness. It is evident indeed the influence of the new knowledges about the defensive works not only for what regards the external aspect that is to communicate the feeling of a sure place, foreshadowing those that will develop in the Room at the level of Christian faith, but first of all at the level of the structural strength of the building. In fact at Loreto we find the experiences made in the military stronghold towers, that were to rise in an advanced position on difficult grounds of uneven natural places.

The stronghold towers of the circle of walls at Casole d'Elsa and the Fortress of Sasso Corvaro that encloses inside an old tower, may be given as an example.The same experiences have been here re-elaborated and practically used to be resistant to the horizontal thrusts not due to blunt instruments but to those of arches and vaults.

From the examination of the techniques to the reasons of the choices

Wanting to build a church of a maximum length of 100,8 m, a maximum width of 73,4 m at the transept and an external width of the nave of 28 m, they had to resort to experimented techniques because this was required by the foundation ground and the orography of the place. The light structures typical of a Gothic architecture well become to a treacherous ground.

With the same building typology it was possible to contain the side thrusts and hence the thickness of the buttress structures. The thrust of an arch is in fact proportional to the load, to the square of the light, while it is inversely proportional to the rise thought as the height of the crown with respect to the springer plan.

We are of the opinion that the main reason of such a choice is to be found in the necessity of the covering

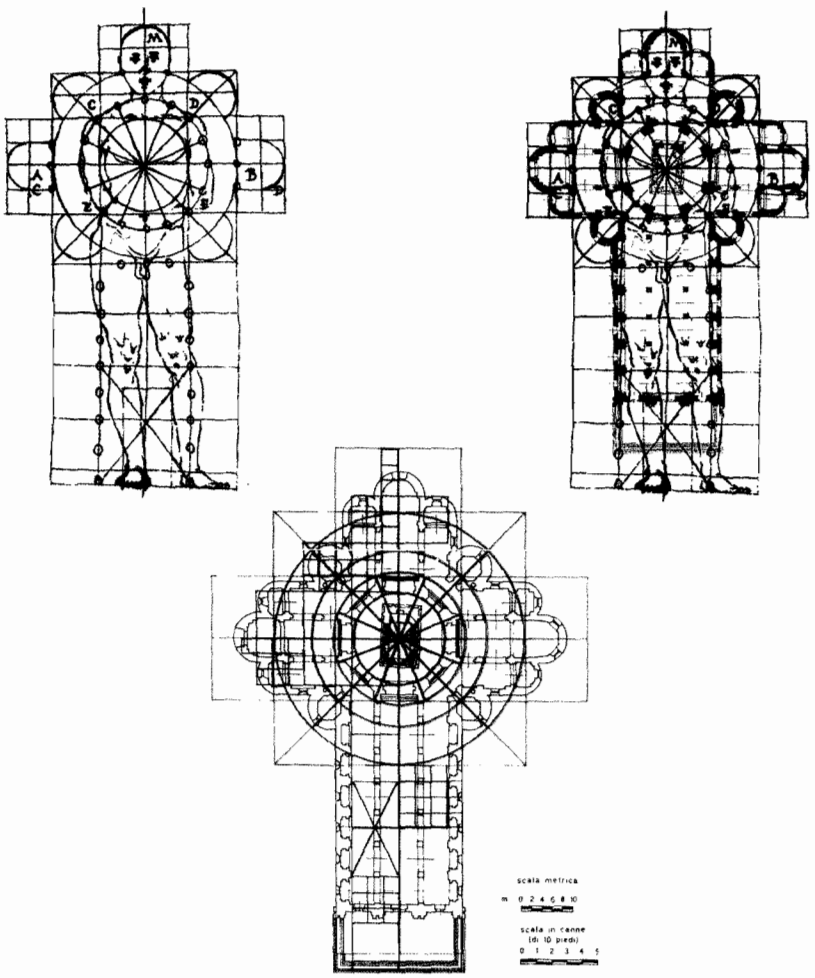

Figure 3
To the left Francesco di Giorgio's drawing f 42 v, to the right superimposition of the plan of the Basilica to the same design and below partition in modules of 10 piedi romani and multiples of 3 and 4 canne of 10 piedi

of the deambulatory with vaults that could conjugate harmoniously with the side aisles ones of the nave and with those side ones of the transept, as to create an annular way around the central body that was to intersect the cross series of the central vaults at a superior height without any problem.

Then there were purely geometrical reasons to be considered. The deambulatory is in fact as wide as the side aisles either in the central body or in the transept divided for the root of two «sorda radice», according to Francesco di Giorgio's terminology, which obliges to give up to round arches, not being able to adopt piers out of proportions and beginning and terminal arches strongly depressed.

At Pavia the problem was solved doing without a deambulatory with vaults at the same level as those of the side aisles, solution that with the lack of a simulacrum in axis with the cupola, allowed to give a better soaring to the central body. Furthermore to improve the statics of the building there was added a

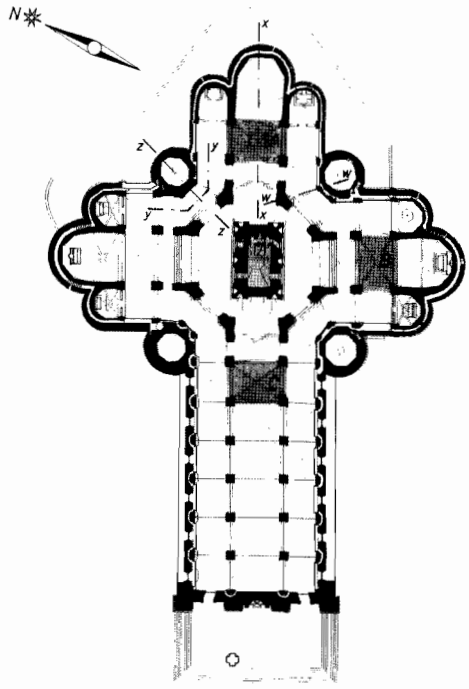

Figure 4
Plan of the Basilica referring to the following drawings

radial vertical wall at 45° as to the axes, non existent at Loreto.

However this was a seriously penalizing solution that did not damage S.Siro's, being here different the needs which were more ideological-aesthetical than functional for the liturgy.

The necessity then of having a series of vaults going from the centre to the perimetrical wall, a geometrical limit, forced to definitively reject the round arch on behalf of the pointed one, more adaptable in the shape than the first, being able to vary arches and proportionment of the springers or in the case of the terminal solutions the possibility of using more suitable arches to transmit axial loads.

There is another reason, which is very important about the use of vaults and pointed arches:it is the possibility to find in the Marche and its surroundings labor force skilled in preparing such structures.

Development and Renaissance use of Gothic structural elements

However the structure of the Loreto Basilica shows that the solutions, even if Medieval,have been submitted and adapted to the new Renaissance spirit.

The first element that immediately attracts our attention looking at the series of the vaults is the use of piers as compensation parts to realise the same succession of vaults and the mutual contrast of the thrusts from the central nave to the side aisles along the external walls. The piers are based upon pillars along the inside perimeter of the cross of the central nave at a level of 1220 cm from the floor of the deambulatory. To this end two examples may be given: the Pienza Cathedral experiences and the Logge del Papa in Siena (1462).

The cross vaults are then with such rises as to have bays with double curvature so projecting and shaped as to reject any Medieval likeness.Also the vaults «a creste e vele», if we go back to Medieval experiences, rely on the fast development of the Florentine realization: the old sacristy of S.Lorenzo as the most

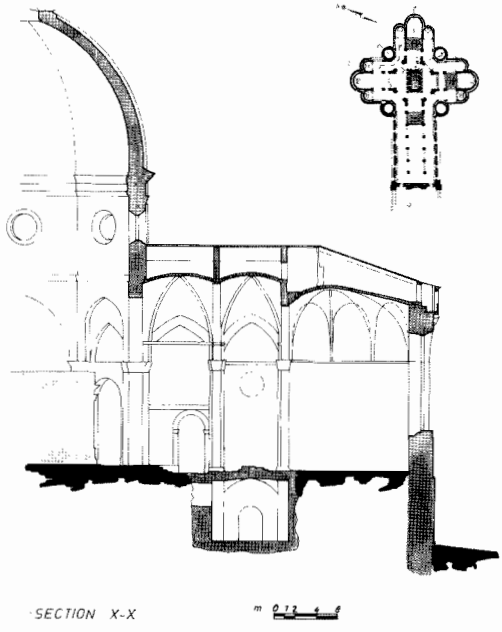

Figure 5
Longitudinal section of the apse

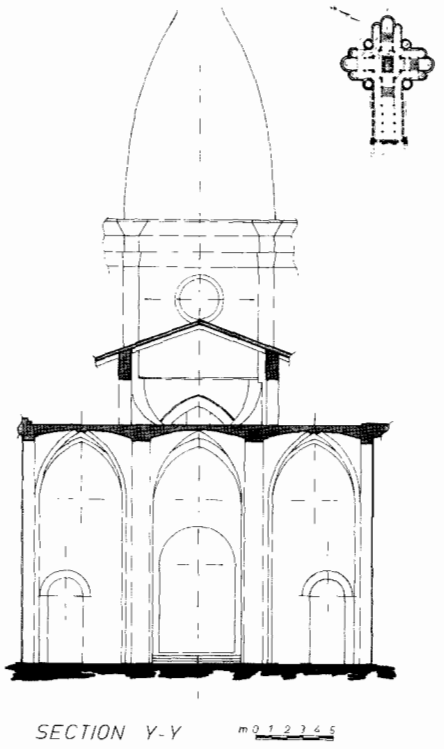

Figure 6
Section on the barrel pointed vault and on the adjacent cross vaults. You can see the spurs and the rafters in the loft

distant experience, and above all, the Pazzi Chapel by F.Brunelleschi, the apse of S.Francesco a Bosco ai Frati by Michelozzo and the less famous work of an unknown technician of the Grancia of Cuna near Monteroni d'Arbia. The same experiences improved and adapted to the specific needs were taken again by Donato Bramante in the Cathedral of Pavia. It is also very interesting the use of the big niches along the side walls of the central body made to lighten the loads, to make the construction easier, to spare building material without damaging the resistance and the endurance of side thrusts.

It is also very important to notice that these big niches have domes spanning a semicircular area instead of pointed arches, lacking any reasons for this kind of construction. In short they research a behavioural homogeneity not only limited to the structural homogeneity of the Gothic architecture.

The big niches and the floorings of the loft corresponding to the vaults of the side aisles, planes upon supports that stiffen the horizontal planes in connection with the outward walls, besides opposing the thrusts of the vaults in the central axis, are a proof of such a laying.

Rounded arches or depressed arches are constantly used in the planes placed under the trampling floor of the Basilica, where, lacking the ground for the shape of the hill, we should resort nowadays to the filling material to realize the same trampling floors.

The central cupola by Giuliano da Sangallo is such as to have octagonal plan and proceeding that, like the one by Brunelleschi at S.Maria del Fiore, recall the Gothic Architecture. In the four corner towers where the old sacristies are lodged, at an intermediate level, there are octagonal rooms in the inside plan having cloister vaults or rounded arch dome vault, that have nothing to do with a Medieval proportionment Proceeding to a comprehensive examination of the building, the main peculiar aspect is a structure in a plan closed by vertical walls that in the less far areas from the main source of the horizontal thrusts, the cupola, has an arcuated concave shape working with the four towers. This was the solution chosen to contain the depths of the masonries on the same results.

ANALYSIS OF TYPOLOGIES AND OF THE WEB COURSING OF VAULTED STRUCTURE

The Cross-Vaults

The vaults that will be described here for what regards their web are those upon the axes of the plan because those of the perimetrical side aisles, either of the central body or of the transept, are all floored in the upper part, having been filled the supports with inert materials; they cannot be surveyed because all the intradoses of the vaults in the basilica are plastered or decorated. Furthermore at Loreto there two typologies of web coursing of the vaults on the central axis: **a**) that of the vaults on the transept and in the apsidal area and **b**) the one of the seven vaults of the nave.

a) They are vaults starting with rows of bricks symmetrically placed under the edge of the extrados, creating together an angle that is of

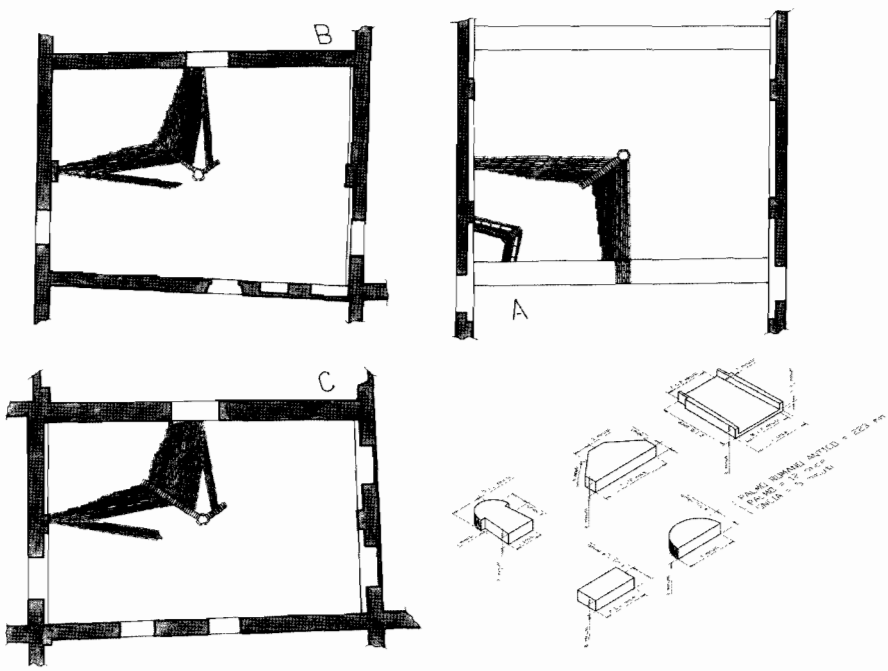

Figure 7
Radial section on the north-east tower. In the detail above it is evident the shape of the buttress contained in the structure

15° for the vaults of the transept and of 20° for the apsidal arm according to the herringbone pattern. Being the vaults 30 cm deep, the bricks are mostly placed in a pseudovertical position, that is radial. These vaults, as well as those «a creste e vele» have been built with a wooden centering for the crests in conformity with a strengthened technique, since they could have been built thanks to the herringbone pattern as partly self-bearing bays. The self-bearing of these bays comes from the fact that the rows of bricks are placed at 7,5° or 10° as to the ridge of the roof and from the position of the bricks radially placed upon inclined bed. Every row becomes an arch between the impost arch and the diagonal arch, balancing their thrusts upon the diagonal ribs, proceeding continuously in the four bays after choosing a course of construction. Remnants of shaped bricks as well as ribs of these bays let us suppose vaults built upon shaped ribs in baked bricks.

b) These cross vaults are different from the previous ones for the much higher rise and for the apparatus. All the rows of bricks are in fact placed in a parallel way to the axis of the ridge. The vaults are about 30 cm deep, being the bricks placed radially and some of them projecting from the extrados for a half of their length. They have bricks reinforcements of 13 cm in the supports cooperating with the vault. The rises measured on the intrados between the key of the vault and the key of the arch of impost of the six modules along the axis of the nave are included between 120 cm and 130 cm against 91 and 93 cm of the rises of the two cross vaults of the south side of the transept, going from the cupola towards the outside, and similar values are in the apsidal east area. The comparison is made among vaults that, while having a different position, have the same module, shape and dimension of the covering area in the plan.

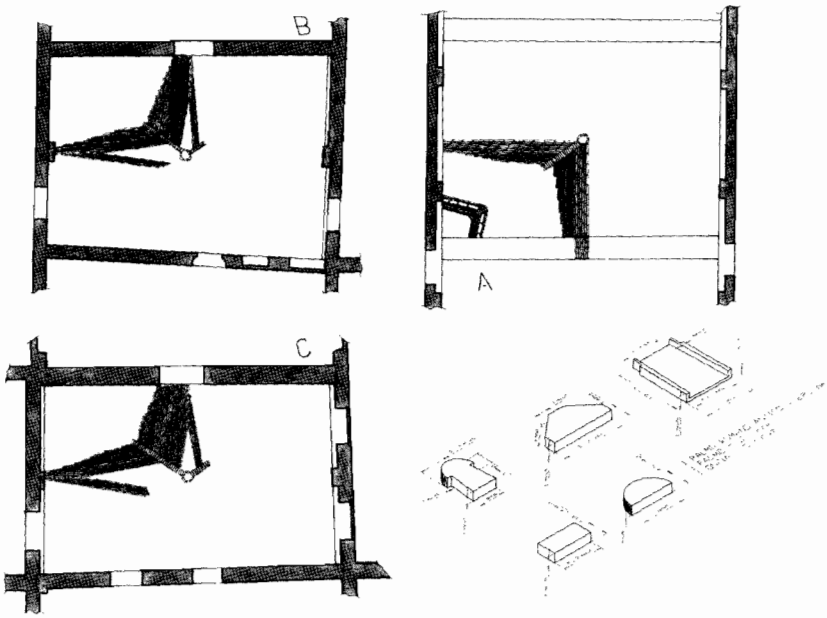

Figure 8
Apparatuses of the cross vaults A, B, C and shapes and dimensions expressed in Renaissance unities of the bricks and special parts in baked brick

The data above mentioned show that the two families of vaults accomplish different statical functions, of mutual contrast, the second ones conjugate with the front of the Basilica, the first ones with the vaults «a creste e vele» at the end. We do not examine the cross vaults of the side aisles, because the extrados is floored on the supports, so it is not possible to have enough elements of judgement. It is however to be pointed out that also all the terminal vaults of the side aisles of the transept are «a creste e vele», while in the apsidal area they are cross vaults for obscure reasons.

The vaults «a creste e vele»

The name given to this typology of covering may be the object of different opinions. Here this name is used and not the one of vaults «ad ombrello», ribbed vauls, because this name as well as the one of the vaults «a lunette e vele» well expresses the true structural form of the covering of all the terminal chapels of the transept and of the choir with the only exception of the two side chapels of the apse which on the contrary have cross vaults. These names lunette,creste e vele are Renaissance words.

These vaults are characterized by a surface of the extrados very different from the intrados. In fact if the intrados is made by a couple of radial groins creating a pointed arch with decreasing rise going from the outward walls to the key of the vault, the extrados is made by depressed arch vaults between crest and crest.

In the apparatus as well as in the typology of the extrados and of the supports the likeness with that of S. Francesco a Bosco ai Frati is noticeable. The difference between the two vaults is in fact in the lower bays that Michelozzo made as rounded arches, which made him have a rise bigger than the one existing at Loreto.

In the extrados of the vault which seems to be the last realized, that is in the north arm of the transept, there is a brick curb that for its position and form appears to stiffen the superior part of the covering with depressed vaults against the twist.

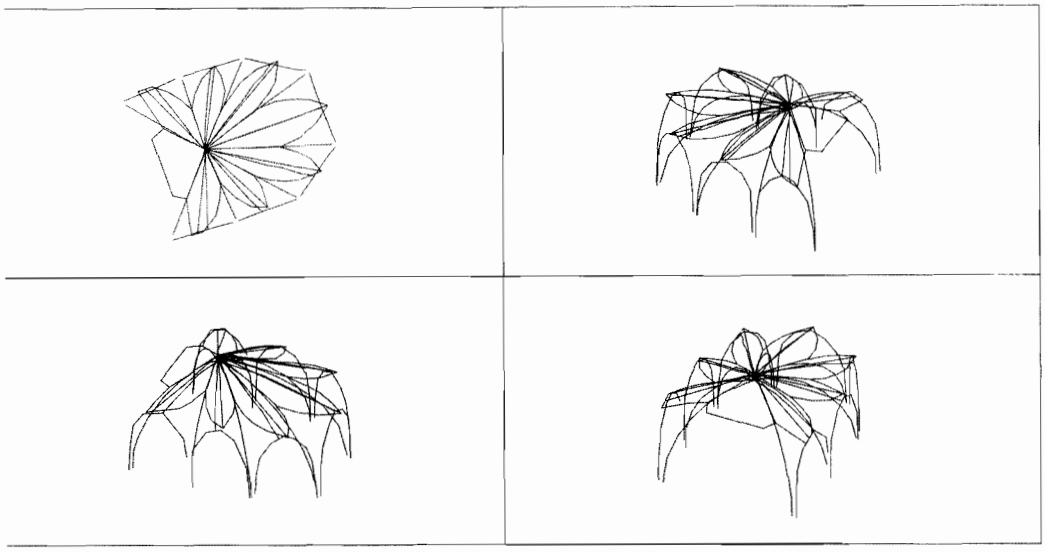

Figure 9
Survey of the apse vault «a creste e vele»

The crests are realized on a shaped brick ogive in the pattern of a mushroom with radially placed bricks so as to create a vertical face, «cresta». For the domes of the extrados the web coursing of the radially placed bricks is in rows parallel among them and to the axis of every little vault. The depth of the vault «a creste e vele» reaches about 35 cm and they are made with wooden centering under the crests and a large use of lath.

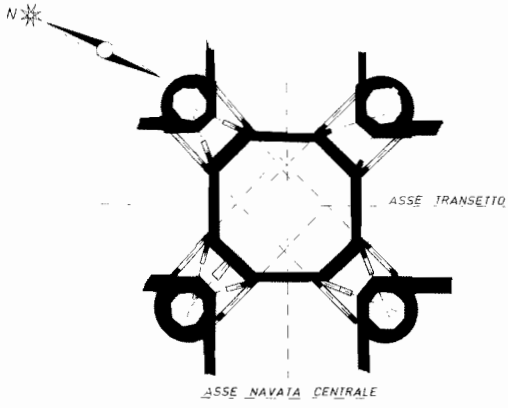

Figure 10
Schematic section of the drum with the indications of the spurs and the rafters and with the indication of their direction of action

The pointed barrel vaults with lunettes

These vaults are perhaps the most interesting ones because of some geometrical aspects and of the contribution they give to the statics of the building, even if not in a direct and evident way.

We particularly refer to the arches of impost at the end of the vault that do not appear in conformity with the right angle, being the pointed profile of the impost inclined as to the axis of symmetry of the barrel so that the directions of the two terminal arches are converging on a point of the symmetry axis perpendicular to the axis of the vault. This point is on the vertical axis of symmetry passing in the centre of the tower adjacent to the vault. The solution is not casual, since these arches have as a superior delimitation some concave spurs starting from the octagon and,as the arches, they have a radial direction with respect to the towers. The wall defined by these

arches accomplishes a double function, the second of which is more important than the first. The arch at its end fully stiffens the vault for the action of cutting, but, what is more, the whole of the lower arch and of the superior one, as a buttress of Gothic memory, contrast the thrusts of the cupola. These thrusts for the presence of a transverse barrel pointed vault could not be otherwise unloaded on the perimetrical parts fit to this purpose. The barrel vault was built with lunettes to allow large openings at the base of the octagon. This open surface was required by the aesthetic rules of the time that wanted to enhance the perspective from the various corners. Contemporaneously discharging arches inside the masonry were useful to the statics of the building. The excellence and the originality of this solution may be appreciated, comparing it with the one proposed for the project of the new S.Petronio's in Bologna,»Imbocco del Peribolo» in the XVI Century drawing, Arch. Of the Fabbriceria, Bologna, arm.V.

The Cupola

At Loreto the Cupola was surely built according to the «concinnitas» rule largely diffused by L. B. Alberti.

The previous design lets us think of a different solution, a hemispherical vault that may be found in the Treatises by Francesco di Giorgio as in the anthropomorphic drawing f 42 v of the same author,that is considered the plan of the Basilica of Loreto.

With the hemispherical cupola the profile would have recalled that one of the central plan building of «La Città ideale», Tables at Urbino and Baltimora by unknown author.

However it is certain that the actual cupola was erected by Giuliano da Sangallo (1499–1500), with a little thrusting profile, only two iron chains of 3×10 cm for hoping. The cupola seems to be designed staring from the intrados proportioned with bays along the main axes with a beam equal to 2/3 of the circle inscribed in the base octagon and a centre equal to a 1/12 of its diameter, over the cornice crowning the drum. This last one was built by Giuliano da Maiano in conformity with the proportionment of the drawing c 41 r by Francesco di Giorgio.

As little known as it is, the cupola has a spinapesce —herringbone— pattern apparatus according to Sangallo's style. For these peculiarities it is

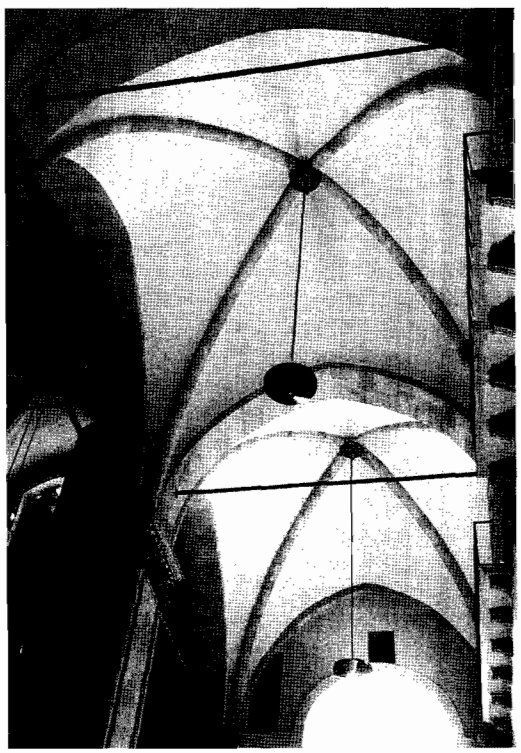

Figure 11
View of the inside with the cross vaults of the side aisle

connected to the covering of S.Maria della Pietà at Bibbona, work by V. Ghiberti and R. Tripalle, while the spirit and the values are well expressed by the frescoes situated on the left side of the nave of S. Polo in Rosso near Gaiole in Chianti.

Analysis of the structures contrasting the thrusts

It is known that a composite plan church completed by a cupola in the central part is considered a highly pushing structure as it is shown by the comparison with other project previsions of the time after the Loreto experiences. The projects demonstrating this assertion are either P. Fugazza's little model of S. Siro Cathedral of Pavia with its external buttresses and the four corner towers, or the graphic plan for the new S. Petronio's in Bologna with inside partition walls between chapel and

chapel having the evident function of windbracing and with box-type structures and pillars in the four corner areas, that at Loreto are occupied by the towers. The drawing of S. Petronio's was made by B. Peruzzi, while the little model is by A. Arriguzzi (1515).

We have already dealt with the spurs and the rising above rafters when the barrel pointed vaults have been examined. Only one aspect of their function is to be pointed out: the different terminal subjects upon which the loads are discharged. To remove the thrusts, the spurs, that are true buttresses, when considered conjugated with the concave impost arch of the barrel vault, unload upon the four corner towers. The rafters lying upon the same plane containing the diagonal major arch of the cross vault below, with the function of flying buttresses, unload the thrusts on the intersection of the external facings of the Basilica, in correspondence of the towers, masonry angle characterized by a big moment of inertia. Remembering the nature of the ground in which the building was erected, the solution seems to be particularly remarkable.

We have already dealt with the vaults «a creste e vele» as a final element lacking any polar symmetry: they unload the thrusts of the series of vaults upon the external cylindrical surfaces creating every apse.

The materials

The walls, the vaults and the roof of the Basilica are all built with plain and shaped bricks for the cornices and the ribs, tiles and plain roofing tiles and also columns.

The Marche and the coast are made of clayey hills rich in waters that supply very good material for the manufacture of tiles. At Montorso, a hill between Loreto and the coast of the Adriatic sea, therefore very near the actual Basilica, there was a very active brick factory till the first years of the XX Century. On the contrary the region is almost totally without marble material, especially in the area around Loreto. This fact explains why the Basilica of the Holy House is all built with bricks linked with lime mortar.There are very few stone applications and all of them are in a type of limestone generally known as Pietra d'Istria, coming from Istria, or from Dalmatia, the actual Croatia. The reasons of this choice are either in its quality or in the easiness of the transports, since it is

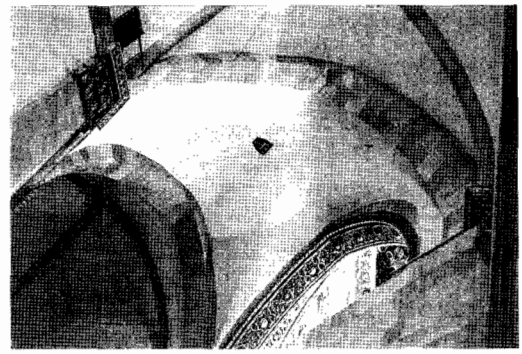

Figure 12
View of the barrel pointed vault

preferable to travel some more miles by sea than to walk for some kilometres less with carts pulled by oxen. The Istria stone puts together very good physical and mechanical characteristics and an exceptional endurance to the attack of the brackish air. Furthermore it is a remarkable experienced material, being not only the most used stone in Venice but also very common in the decorations of the Marche high-class palaces in the examined area. Therefore the material was known to the artisans who had to work it.

The Istria stone transported by sea was very cheap and easily to be supplied, being the quarries in a friendly territory under Venice, and easily to be embarked because they were very near the sea, coming from the Brazza island, the Veselje valley, or from the quarry near Pisino, called Orsera, today Kirmenjak or near Rovigno, nowadays Zlatni Rat. The coast near Loreto was rich in ports.

The wood used for the beams was imported, since in the Marche there were not forests that could supply the necessary square measure. Reading the Acts we understand that the purchase of the wood beams was a bigger problem than that of the stone.

For the presence of many rivers flowing from the Appenines there was a large availability of stone to produce lime and of lath to make mats.

The instruments used for the management of the yard

The use of instruments is not proved by archives sources, but by the practical necessity to realize what

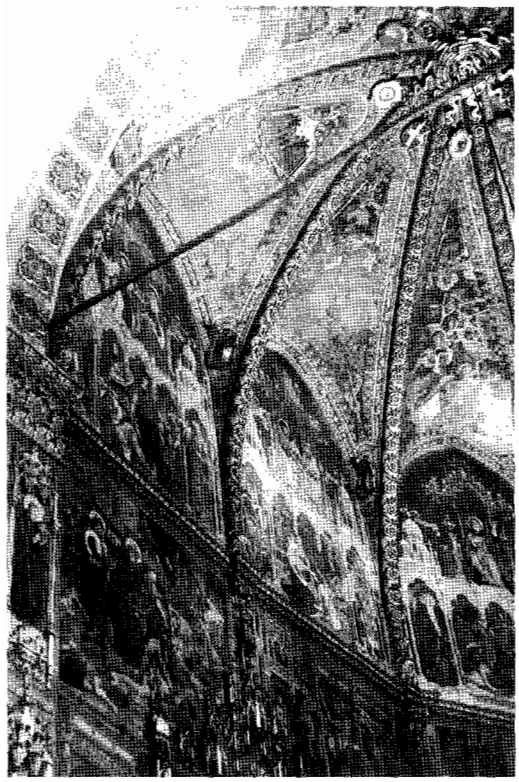

Figure 13
Detail of the intrados of a vault «a creste e vele»

was built.

The technicians erected a building containing the superior part already built of a hill, a new structure with the foundations on a three-dimensional ground. For these reasons they could not absolutely trace out the plan of the building judging the straightness of the surface by the eye and it was even less possible for them to realize a nearly approximate positioning in the centre of this plan of what existed without the instruments. The new building rose just to have the relic in the middle.

From here the necessity to resort to the geometrical quadrante and to the archipenzolo, also called square. The use of these instruments requested the presence in the yard of men with a very good knowledge of geometry. These instruments for the survey of the ground are described in the books of the time, such as the Treatises by Francesco di Giorgio, those by Mariano di Jacopo called Taccola and those by L.B.Alberti, even if their main application was for the best use of the new-born artillery. To be able to use practically these instruments,it was indispensable to have a tower in the area to be built.

From the examination of the structures the tower that may be considered pre-existent, or if not pre-existent however built, is the north-east tower. An indirect confirmation of this supposition about its use as a base for the measurements is the ascertainments of a constructive detail: the existence of a correction of the plan once arrived with the walls to a constant plane over all the perimeter that allowed to sight with a better accuracy as to the instruments. On this plane completely in view they made a correction of the dimensions proved by a step of varying width along the external perimeter. The north-east tower has zero error as to the base below confirming in this way to have been used as zero point of reference for the measurements.

Note

Tranlation into Englis by Anna Rosa Monelli

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