The Goodyear Exhibition ::

Catalogue

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UNDER THE AUSPICES OF THE CLASSICAL ASSOCIATION, THE ROYAL INSTITUTE OF ARCHITECTS, AND THE ARCHITECTURAL ASSOCIATION OF IRELAND . . . .

The Exhibits and Catalogue prepared by

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PREFACE

WITH the exception of eight introductory photographs of ancient temples, the 212 numbers of this Exhibition relate to Medieval cathedrals and churches. They are selected from a much larger number of surveys and photographs, in the Brooklyn Institute Museum, about 800 in number, relating to the same subject. These have been prepared to illustrate the subject of Medieval architectural refinements, under which general heading are included various phases of variation from formal architectural symmetry, to be presently specified. The Brooklyn collection includes variations of plan and elevation, some of which are obviously intended to produce perspective and optical illusions and, occasionally, to exaggerate effects of dimension ; while other variations of plan or alignment, or of presumably equal (but really unequal) dimensions and spacings, have the purpose of avoiding the monotony of effect which is frequently inherent in purely geometrical, or mathematically exact, architectural dimensions.

Among the cathedrals in question those of Pisa and of Notre-Dame at Paris, have been singled out as specially suited to illustrate the given subject in an exhibition of limited dimension. Thirty photographs and surveys (Nos. 23-61, inclusive) represent the Pisa Cathedral, and fifty-seven photographs and two drawings (Nos. 157-205, inclusive) have been selected to represent Notre-Dame at Paris.

Aside from other topics to be specified in the body of the Catalogue, the subject of the widening refinement (so-called by the author of these observations) has been illustrated by seventy-nine photographs (besides those among the exhibits for Notre-Dame). These are Nos. 73-145, inclusive, and

Nos. 206-210, inclusive. Among these seventy-nine photographs the Cathedral of Amiens is represented by thirty-one numbers (Nos. 115*a*-145, inclusive). Other cathedrals and churches in this class include the Cathedrals of Rheims, Laon, Rouen, and the Church of St. Ouen at Rouen (the latter is also selected as one of the examples of curvature in plan).*

* Further details will be found under the specific numbers of the Catalogue. Copies of an article in the *American Architect* on the widening refinement will be loaned to those applying for them at the Catalogue desk. The study of the exhibits for the Pisa Cathedral, for the Pisa Baptistery, and for the Leaning Tower of Pisa will be materially assisted by reference to a series of articles in the *Bulletins* of the Brooklyn Institute of Arts and Sciences, which will also be loaned to applicants at the Catalogue desk.

CATALOGUE

§ 1.—Various Architectural Refinements.

Nos. 1-6 inclusive are illustrations of Greek horizontal curvature from Pæstum and Egesta. Among these photographs those representing curves in plan, both convex and concave to the exterior, are deserving of special attention. These curves in horizontal planes (Nos. 1, 2) are to be distinguished from the curves in elevation ; i.e., curves in vertical planes (Nos. 3, 4, 5, 6) ; which have hitherto attracted more notice, and are frequently supposed to have been the only ones employed by Greek builders.

No. 7 shows that the curves in horizontal planes, convex to the spectator's eye, were also employed in Egypt. No. 8 shows that the same convex curves were employed under the Roman Empire. The concave curves in plan, similar to those of No. 2, were also known in the Roman period and are found in the temple at Cori. This is the recent discovery of Professor Gustavo Giovannoni of Rome.

The above photographs are introductory to the subject of horizontal curvature, as found in Medieval architecture (the existence of which is presumed to be a discovery of the author of the Catalogue).

Nos. 7-10 are illustrations of curves in plan in the arcaded courts of certain medieval cloisters. In the given instances it will be noticed that the curves are found in the parapets (at Verona), and that they begin at the foundations (at Bologna) ; thus eliminating the suspicion of accident as due to thrust. Such curves also occur in the larger cloister of the Certosa at Pavia, in the cloister of St. Matteo at Genoa, and in the Roman cloisters of St. Paul's Outside the Walls, and of the Lateran. Mr. Arthur Kingsley Porter, of New York, has observed these curves in the two small Renaissance cloisters of Santa Maria delle Grazie at Milan, so that they are dated here to the year 1500 A.D.—and probably to the authorship (certainly to the school) of the famous Bramante. This dating is of great interest, because the medieval refinements are rarely found in the Renaissance, and because their disappearance was due to the introduction and influence of the Renaissance architectural style.

The author's observation in the Certosa at Pavia had otherwise brought the dating for horizontal curvature down to the middle of the fifteenth century. Mr. Porter's observations, all for curvatures in parapets—thus eliminating the suspicion of thrust—also include the cloisters at Arles, Prato, Chiaravalle, Voltone, Acqui, Piona, and Aosta.

Mr. Porter's observations also corroborate those of the author of the Catalogue, for the two above-mentioned Roman cloisters. Further corroboration as to Roman cloisters has been furnished by Professor A. L. Frothingham, whose book on Rome states that all the medieval Roman cloisters have constructive curvature for æsthetic effect. He also mentions especially the early Roman cloister of the Quatro Coronati for this particular.

The special interest of these medieval cloister curves lies in their remarkable correspondence with those employed at Medinet Habou (No. 7), which were discovered by Mr. John Pennethorne, in 1833. Inside the medieval arcades these curves are concave to the eye of the spectator. In the court they are convex to the eye of the spectator. As regards optical effect they appear to the eye as rising curves in vertical planes when the concave curve is below the eye or when the convex curve is above it. They also appear to the eye as curves descending toward the centre in vertical planes, when the concave curve is above the eye or when the convex curve is below it. These variations of optical effect and the resemblance to the curves in plan which were used in antiquity, lead to the general conclusion that the purpose must have been to avoid the rigidity and formalism generally inherent in straight lines, and to give optical interest and variety to the buildings in which they were employed. The cloister curves are far from being universal. Many cloisters may be mentioned in which the parapet lines are straight. Among these are the cloister at Monreale, that of St. Maria Novella at Florence, and that of St. Francesco at Pisa. There is, however, no doubt, in view of the observations of Mr. Porter and Professor Frothingham, and also of Dr. H. Colley March (of Portesham, Dorsetshire), and of Mr. F. W. Deas, of Edinburgh, that the known number of cloisters showing curvatures will be very much increased, as soon as systematic observations in this direction are extended.

Nos. 13-18 inclusive represent a small church near Lucca, and are introductory to a remarkable feature of the Pisa Cathedral. In this church (the Pieve Nuova, at Santa Maria del Giudice), the water-tables, or base mouldings, of the side walls, follow the slope of the hill on which the church is built, instead of being levelled, as is usual both in medieval and in modern building. (See surveys and photographs, Nos. 15, 16, 17, 18.) No. 14 is a detail of the masonry which illustrates the oblique cutting of the blocks by which a true level of the window sill on the north wall was obtained, and also shows the method by which a true level was obtained in the roof cornices, although the downward slope of the base moulding on the north side is 2 ft. 4 inches in a length of about 90 feet (see No. 15).

One is inclined to consider this feature of the church as an eccentric and ugly departure from the usual practice. It proves, however, that such a practice existed, and thus is a suitable introduction to the proof that the Pisa Cathedral is built on the same method, with a much greater variation from the normal level,* and with beautiful effect as result.

§ 2.—The Pisa Cathedral.

Nos. 23, 24, 25 are introductory to this subject. The platform and base mouldings, or water-table, of the Pisa

* Nos. 19-22 will be mentioned later on.

Cathedral follow all the slopes of the earth's surface. The platform at the south-east angle of the choir is 3 feet lower than the platform at the north-west angle of the façade, but the church is so much larger than the one at Santa Maria del Giudice, and the variations of slope are distributed on so many surfaces which cannot be included in one view, that the remarkable facts have never been mentioned in any publication relating to this church, aside from those made on behalf of the Brooklyn Museum. Neither have the facts been shown by any previous survey. The levels are entered on the ground-plan, No. 26.

This method of building the church on a platform which follows all the surface slopes, with a total fall from north-west to south-east of 3 feet, defends itself as soon as we consider the alternatives. These were either to build a platform of irregular height or to build a foundation wall under the base moulding, ranging in height from 3 feet to zero, according to the various slopes which are entered in No. 26. One of the most beautiful features of this cathedral is the detail of its pilaster bases (see, for instance, Nos. 25, 28) all rising directly from the platform, while the steps of the platform all rest uniformly on the earth's surface. The means by which this effect was obtained have been universally overlooked. It is only near the apse that the slopes of surface are easily noticed. Elsewhere they escape detection in actual vision, just as they do in the photographs.

One reason for the usual oversight is that the vertical lines of the church are normal to the slopes, instead of being perpendicular. The resulting inclinations, shown by Nos. 28, 29, 30, are not easily observed, and the 14-inch inclination of the apse toward the east (No. 28) is not realised until the plumb-line test is applied. If these verticals had been built to a true perpendicular the surface slopes of the platform would be immediately observed. It will be noticed, in No. 29, that the upper storey (right of the photograph) is perpendicular, whereas the pilasters and vertical lines of the lower storey lean east very perceptibly.

Our attention is next called to the great middle string-course of the Cathedral, as shown by Nos. 31-39, inclusive. The slopes of this string-course are entered around the ground-plan, No. 26; which has already been quoted for the surface levels. From this survey it appears that the string-course is 4½ feet lower at the south-east angle of the choir than it is at the north-west angle of the façade. Thus, if settlement were in question, the upper part of the church would have settled 1½ feet more than the lower part, which is absurd.

The facts are as follows: on the north and south walls the string-course is two feet out of level, sloping downward to the east (ground-plan No. 26; surveys Nos. 36, 37, and photographs Nos. 33, 34, 35). This obliquity is obtained by oblique cutting of the masonry, which is shown by No. 35, and by Nos. 42 and 43. Observe the masonry under the cornice at the angle in No. 42 and No. 43; note the oblique cutting of the blocks above the cornice in No. 35; and, in No. 34, the method by which the masonry striping returns to the normal construction, in the second storey.

The two-feet obliquity of the string-course on the north and south walls is made good in the second storey, its roof line being normal to the platform.

We now turn to the transepts. On the west sides of the transepts the string-courses rise 5½ inches (north) and 5 inches (south) in the outward direction from the nave, and in opposition to the surface slopes which descend outward on both sides (see levels on No. 26). These slopes of the string-course on the west sides of the transepts are shown by Nos. 31 and 36. Beyond the west sides of both transepts the string-course is normal to the surface slopes (see levels on No. 26), with slight variations due to mason's error, and with approximate corrections of the same in adjacent parts of the building.

Thus, we understand why the string-course is 4½ feet lower at the south-east choir angle than it is at the north-west façade angle, while the platform is 3 feet lower. It is because the string-courses fall 2 feet on the side walls and rise, approximately, 6 inches on the west sides of the transepts, and are normal to the surface slopes beyond those west sides toward the east. If proof were needed of the purposed construction of the string-course slopes it will be found in the measures for the west sides of the transepts (on No. 26). On the west side of the north transept, where the downward surface slope outward is only 0·01 foot, the string-course rises 0·44 foot; but on the west side of the south transept, where the downward surface slope outward is 0·31 foot, the string-course only rises 0·09 foot. Thus as regards the platform and as regards the appearance of the church, the string-course has the same slope on both sides, with only 0·05 foot variation (0·45 foot, north; 0·40 foot, south).

The most probable explanation of the string-course slopes appears to lie in a general system of optical mystification which was obtained, in this instance, by the avoidance of parallel lines. The purpose is best explained by a complete and simultaneous consideration of all the other variations of this remarkable building, to be presently described. Such an optical purpose can only be realised as possible in the case of these slopes by considering what the optical results in the given case actually are, and here again it must be remembered that this great obliquity is constantly overlooked by the casual observer. It was not seen, for instance, by Mr. Ruskin, as appears from his description of the south cathedral wall in the *Seven Lamps of Architecture.* The reason for such oversight is perfectly obvious; all horizontal lines are oblique in perspective unless we stand opposite their centre. Obliquity is, therefore, a normal and usual appearance in horizontal lines and the observer is not in the habit of considering whether his standpoint is opposite the centre of the horizontal line. The obliquity of the string-courses is not represented by any previous survey; not even by the specially detailed survey which was made of the south wall by Rohault de Fleury, and published in his *Monuments de Pise* (1859).

We now turn to the façade. Whereas the earth's surface and the church platform slope downward gently to the east, and the string-courses of the side walls slope downward in the same direction, the façade leans toward the west. This is shown by Nos. 40-42 inclusive. There is a uniform westward inclination of about 9 inches in the two lower storeys of the façade (No. 41). The third storey of the façade leans outward about 1 inch (exactly 0·10 foot), and the two upper storeys are perpendicular (No. 42).

An examination of the masonry of the north and south walls proves that the façade inclination is constructive. Nos. 33, 34, 35 show a downward bend of the masonry stripes of the north and south walls, beginning in the fifth arcade from the façade. These oblique masonry stripes enter the angle pilasters of the façade at a right angle. Thus the obtuse angles of the masonry stripes at the fifth arcade must either represent a settlement extending on both sides of the church as far as the façade inclusive, or else they were intended to conceal a constructive inclination, which would be perceptible if the striped masonry courses entered the façade obliquely. That no settlement occurred is proven by the fact that the middle string-course rises over eight inches toward the façade in the given distance, and by the fact that the inclination is uniform in the two lower storeys of the façade. This last fact proves that the façade did not settle before the string-course level was reached by the builders. After this level was reached it would be impossible that the front should settle and that the string-course should rise simultaneously. The variations of measurement near the line of inclination, as shown by the surveys Nos. 36 and 37, also invalidate the theory of settlement. See especially the measurements of No. 36, near the façade. If the downward bends of the masonry stripes at the fifth arcade were due to settlement, it would also be necessary to suppose that the façade had formerly sunk 1·20 foot underground, that it had then been underpinned, and that the pilaster bases and mouldings had been taken out and re-set at the present level, after the façade had been amputated to the amount of 1·20 foot, all of which is absurd.*

The optical effect of the leaning façade is to diminish foreshortening, and to produce an illusion of greater height It also obviates a retreating or backward leaning effect, which otherwise would result from the perspective convergence of the outer vertical lines of the front. It also appears from later illustrations that a bending or curving line was generally preferred to a straight line by the builders of this cathedral.

Nos. 44-50, inclusive, illustrate the bends in elevation (i.e., the bends in vertical planes) of the gallery parapets. (Notre-Dame, at Paris, is the only other church which is known to have this peculiarity). No. 47, taken on the interior side of one of the parapets, proves that these bends are produced by oblique cutting of the parapet masonry. This is also shown by a multitude of considerations, by the exact uniformity in the position of the bends on both sides of the church, and by the correspondence of measurements on opposite sides of the church, and by the notable fact that the nave arcades decline towards the choir much more than the parapets above them (Nos. 48, 49). The optical effect of these bends is to increase dimension in both directions, and this perspective illusion was, doubtless, their purpose. The bends are invisible from the floor of the cathedral, and are only observed in the galleries when sighted from the standpoint taken by the photographs Nos. 45 and 46. They do not appear in any previous survey. It will be noted also that the galleries bend downward at the third interior bay from the west front, while the exterior string-courses continue to rise throughout their whole length on either side wall (Nos. 36, 37). Various interesting features of the surveys in elevation of the cathedral galleries (Nos. 48, 49) will be re-

* There are various other instances of leaning façades. That of Notre-Dame is included in this exhibition. Here the second storey has only one-half the rate of inclination which appears in the first, and the upper storeys are perpendicular. A constructive leaning façade of the Renaissance period is shown by Nos. 211, 212.

vealed by inspection, and are discussed at length in the *Bulletins* of the Brooklyn Institute, which are accessible to students of the exhibition.*

Nos. 51, 52 show the curves in elevation of the base mouldings of the exterior clerestory wall arcades. These arcades are a surface decoration, and no movement of the walls is conceivable which might have produced these curves. Their purpose is best understood by continuing the rehearsal of related facts.

No. 53 shows the curve in plan of the outer south wall, beginning at the foundations (22 inches deflection). No. 54 shows the curve which begins above the foundations in the outer north wall. These curves are parallel; concave to exterior on the south side, and convex to exterior on the north side. (Notre-Dame has a similar construction, beginning at the bases of the arcade columns of the nave and extending to the roof parapets of the clerestory, but the outer walls of Notre-Dame are straight.)

Nos. 55 and 59 show the curves in elevation of the gallery window sills in the same north and south walls. The lines of these sills have a rising curve toward the centre, of 7 inches deflection on the north side, and of 6½ inches deflection on the south side. The windows in No. 59 also increase in height, one foot from west to east, by gradual increase of measurement, without break in the entire series. (Compare No. 33.) This arrangement is related to the fact that the roof line of the outer wall is parallel with the platform, and does not follow the slope of the middle string-course. The increase of window height thus obscures the inequality in the distance between the roof line and the string-course at the two ends of the south wall.

The curves of the window sills were not observed until 1910, although the cathedral was diligently examined for similar arrangements in 1870, in 1895, and in 1901. These, and all other similar deflections are discounted by the eye into effects of perspective, and thus frequently elude

* See foot-note at the close of the Preface.

detection, even when the observer is endeavouring to discover them.

No. 55 also shows the interior curve in plan, already observed for the exterior in No. 54 (10 inches deflection).

Nos. 57 and 58 show the bends in plan, i.e., bends in horizontal planes, of the gallery parapets (their bends in elevation are shown by Nos. 44-50, inclusive). These curves, or bends, are parallel; convex to nave in the north gallery (No. 57) and concave to nave in the south gallery (No. 58). They begin in the alignment of the nave columns and extend up to the roof lines of the clerestory walls (whose curves in elevation are shown by Nos. 51 and 52). Similar parallel curves in Notre-Dame, also beginning at the bases of the nave columns, are shown in the roof parapets of that cathedral by Nos. 198, 199.

No. 56 shows the curve in plan, convex to north side, of the parapet and alignment of columns which separate the two aisles of the north gallery. There is a similar curve in the corresponding line of columns separating the two aisles of the south gallery. This is convex to the south exterior side. This curve has also been photographed.

Nos. 61, 62 show two of the four similar curves in plan of the transept gallery parapets. All of the mentioned curves in plan are represented on the ground-plan of the galleries, No. 27.

The optical confusion and illusions, and the effects of infinite picturesque variety and of consequent optical interest, which are inherent in the arrangements of the Pisa Cathedral, are still further accentuated by various inequalities of arcading and by systematic irregularity in the masonry striping. The systematic arcade variations of the Pisa façade were first noticed by Mr. Ruskin (*Seven Lamps*). Other arcade variations are proven to be purposed by their recurrence on both sides of the church at corresponding points. (Compare the increase in measurements for the five arcades next the façade, as related to the rest of the arcades, in Nos. 36 and 37. Compare also the larger measurement for the arcade adjacent to the transept in these two surveys.) Generally speaking, an allowance of three or four inches variation may be made for mason's error or for the free-hand masonry methods of the period; but when desired, an accuracy of spacing within the limits of $\frac{8}{100}$ of a foot ($\frac{8}{8}$ of an inch) was obtainable in the Pisa Cathedral (observe the minute variations of arcade measurements on the west side of the south transept in No. 26, which have this limit of mason's error). The variations in the bays of the nave, which are contracted toward the choir, are connected with the diminution in the height of the arches in the same direction; beginning at the fourth bay from the façade.*

Aside from various proofs which have been, or may be, advanced for the intentional construction of the bends and curves of alignment at Pisa, one proof of the greatest importance is the generally rectilinear construction of the minor and less important Pisan churches. Only three cases of curvature in alignment have been noticed at Pisa, outside of the cathedral. The most primitive and roughly built church near Pisa is S. Piero in Grado. Its walls and columnar alignment are rectilinear. These are proofs that careless construction, or indifference to straight building, are not the explanation of the bends and curves.

It holds of all the various asymmetric features of the Pisa Cathedral construction that they are most frequent and most pronounced in centres of Byzantine Greek influence, or in cathedrals which were influenced by the Pisan Romanesque. They tend to disappear in Italy during the Gothic period, especially near its close.

The following cathedrals and churches are believed to have no refinements: the Cathedral and St. Anastasia, Verona; Cathedrals of Milan, Bologna, Florence, Viterbo, and Naples, and a very large number of minor churches among hundreds which have been examined. The Church of St. Mark at Venice is the only parallel known in Italy, to the great

*Measurements to columnar centres in No. 26; measurements to columnar surfaces in Nos. 48, 49.

number and extraordinary subtlety of the refinements in the Pisa Cathedral. These two cathedrals are well known to have been the two most important ones of the given period, and when they were built Pisa and Venice were the richest, the greatest, and the most ambitious states of Italy.

We now recur to Nos. 19, 20, 21, and 22. These relate to the curves in elevation of the base mouldings or water-tables in the Churches of San Paolo Ripa d'Arno at Pisa (next in importance to the Cathedral), of Sta. Cecilia at Pisa, and of San Casciano, near Pisa. These photographs have the great importance of showing a feature which existed in the Pisa Cathedral as recently as 1870. Shortly after that date the church was repaired, and the plinth courses, base mouldings, and pilaster bases were taken out and reset to the level of the platform. The south wall water-table was specially noted by the writer, in 1870, as having this curvature in the vertical plane. This curving water-table was also observed by the German art historian, Ernst Förster (1800-1885), and is specially mentioned in his *Geschichte der Italienischen Kunst* (1869). Förster was also the first authority who otherwise commented on the curves and bends at Pisa as having been purposely constructed.

Ernst Förster also noted the inclination of the Pisa Baptistery. The levels of the water-table and platform of the Baptistery were surveyed in 1895, under direction of the writer, as found in No. 64. The inclination was estimated, in 1910, by plumb-line (inside the camera) as being 15 inches. The levels show a constructive slope of 9 inches (0·75 foot) from west to east. This corresponds to the surface slope and the Baptistery was built to this slope. The motive was, undoubtedly, as in the case of the Cathedral, to have the base mouldings and pilasters rise directly from a platform of uniform height. Thus, the surface slope was accepted as the normal base of the building.*

* For further details relating to the Baptistery see the *Bulletin* of the Brooklyn Institute, Vol. vi., No. 2.

§ 3.—Leaning Tower of Pisa.

Nos. 65-72, inclusive, relate to the intentional construction of the famous Leaning Tower. The proofs are found in measurements of the interior spiral stairway (Nos. 69-72), which are best explained by reference to the *Bulletin* of the Brooklyn Institute, Vol. vi. No. 1.*

It may be said here, briefly, that the height of the ceiling of the spiral stairway has been measured on each side of the stairway on every step in the tower. These measures are entered on the plans (Nos. 69-72) on the outer sides of each step. The measure between these, on each step, is the mean height, or height at the centre of each step. The outside measures show that the ceiling tips, or dips, at various slopes and the amount of dip of each step is entered on the outer circle of measurements.

At the point of greatest overhang, in the first storey of the tower (near H, in No. 69), the ceiling slopes downward and inward 0·75 foot, or 9 inches, in a width of 3½ feet. The weight of the ceiling is thus thrown toward the inner wall on the side of the overhang. At the 13th step from the entrance door at the point directly opposite to the greatest overhang, the ceiling is normal to the step (error of 0·03 foot). The rapid increase of the dip begins at J (0·14 foot). Beyond the point of greatest overhang the inward dip decreases (Nos. 69, 70) to the point F (No. 70). Beyond this point the ceiling is normal to the steps, with unimportant variations, all of which are shown on Nos. 70, 71, 72 (on the outer circle).

A still more interesting feature of the measurements is the increase in the height of the ceiling toward the point of greatest overhang in No. 69 at H. At the point F (13th step), on the side opposite to the overhang, the mean height of the ceiling is 7·54 foot. Near the point H of greatest overhang it ranges as high as 9·30 foot (52nd step). Thus the increase in the mean height of the stairway on the side

* A paper read before the Archæological Institute of America at the Providence meeting, December 29th, 1910.

of the overhang is 1·75 foot, or 21 inches. A decrease of the stairway height now begins, amounting to 1·94 foot, or 23 inches, near the point F in No. 70,* and ranging to 1·68 foot, or 20½ inches, at the point opposed to the overhang near G.†

From this point the stairway again rises in height toward the point of greatest overhang (near I in No. 70) to the amount of 0·52 foot, or 6 inches.‡

The systematic changes in the height of the stairway, as related to the overhang, are abandoned above this point (at the third gallery platform, and beginning of the fourth storey). Reference is made to the quoted publication for an analysis of the measures above this point, and especially to the foot-note on page 15 of the quoted *Bulletin*.

Thus, it appears that the spiral stairway of the three lower storeys of the tower alternately rises and falls in height with relation to the overhang. These changes diminished the weight of the masonry on the side of the overhang, and relatively increased this weight on the side opposed to the overhang. These changes must have had a purpose, and this purpose must have been to give additional stability to an intentionally inclined construction.

It may now be observed that the systematic variations begin at the first step. There is a gradual diminution in mean height, of 5½ inches between the 1st step and the 13th step (No. 69). Between the 3rd step and the 13th step the inward dip of the ceiling decreases from 6 inches to zero (0·49 to 0·03). Thus, if the Leaning Tower is an accident due to settlement, the builders must have known, when they began it, which way it was ultimately going to lean, which is absurd. This argument is addressed to the rather improbable suggestion which has, however, actually been published, that the builders were combating a progressive settlement by this device.

The Leaning Tower is the latest of the four great buildings

* 9·30 foot, 52nd step, No. 69; 7·36 foot, 67th step, No. 70.
† 9·30 foot, 52nd step, No. 69; 7·82 foot, 86th step, No. 70.
‡ 7·82 foot, 86th step; 8·345 foot, 118th step.

on the Piazza del Duomo, and is certainly an extreme instance of the Pisan dislike for formalism and monotonous uniformity.*

§ 4.—The Widening Refinement.

Nos. 73-145, inclusive, and Nos. 206-212, inclusive, are illustrations of this refinement. It is also shown by several intervening numbers among the photographs for Notre-Dame, but these require special description.

As regards the quoted numbers, the plumb-lines are generally apparent in the photographs, and the churches are indicated by title on the individual labels. Thus a general account of the matter will suffice here.

The widening refinement is frequently found in all territories which have been examined by these surveys; viz., Constantinople, Salonica, Italy, and Northern France. Judging from the large number of instances so far observed, it was more universally employed during the Middle Ages than any other single refinement. It appears to be mentioned by Procopius, and is certainly mentioned in Evelyn's Diary. †

* The essential facts as to the rise in height of the spiral stairway in the lower storey and as to the inward dip of the ceiling on the side of greatest overhang were observed by Ranieri Grassi, a Pisan engraver, and were published by him, but without measurements, in 1837.

† The description of the Sta. Sophia Church at Constantinople which was written by Procopius in the sixth century, includes the statement that the building "rises from the ground, not in a straight line, but setting back somewhat obliquely." See page 25 of Lethaby and Swainson's work on Sta. Sophia. This is an accurate description of the interior, as shown by a series of photographs recently taken in this church (April, 1914). These photographs may be examined by application at the Catalogue desk.

The following passage is found in Evelyn's Diary, under date of July 27th, 1665: "I went to see St. Paule's Church, where with Dr. Wren, Mr. Prat, Mr. May, Mr. Thomas Chic ly, Mr. Slingsby, the Bishop of London, the Deane of St. Paule's and several expert workmen, we went about to survey the generall decay of that ancient and venerable church, and to set down in writing the particulars of what was fit to be don, with the charge thereof, giving our opinion from article to article. Finding the maine building to recede outwards it was the opinion of Mr. Chichley and Mr. Prat that it had been so built *ab origine* for an effect in perspective, in regard of the height; but I was, with Dr. Wren, quite of another judgment, and so we entered it; we plumbed the uprights in several places."

Only two instances are so far known for the Renaissance (Nos. 208, 209). It is dated in St. Demetrius at Salonica to the beginning of the sixth century.* The latest instance, so far known, is the Schottenkirche at Vienna, which was reconstructed and restored in 1638 (No. 209).

This refinement gives an attenuated horse-shoe form to the lines of the piers and vaulting of the nave (No. 76), and is frequently accompanied by an outward widening on the exterior side of the aisles (Nos. 79, 80, 83, 84, 89, 90, 100, 132, 133, 206). It should be carefully observed of these exhibits that they represent responds facing transverse chapel walls. No instances of exterior walls are cited here. The quoted aisle cases are all instances of constructive batter in the responds (No. 79 for instance). This remark bears on the possible and natural preliminary suspicion as to thrust or settlement.

In most cases in the aisles, and in many cases in the naves, the delicate outward inclinations are in absolutely straight lines. Nos. 73, 77, 81, 82, 87, 88, 91, 92, 207, 209 are instances of rectilinear inclinations, beginning at the pavement of the nave. In other instances the arcade piers are perpendicular up to the capitals, and the vaulting-shafts diverge delicately, in straight lines, from the arcade capitals up to the springing of the vaulting (Nos. 107, 108, 115*a*, and details for Amiens Cathedral, Nos. 116-126, inclusive.)†

In some cases, the vertical lines of the nave appear to be curves (No. 210), but how far these apparent vertical curves are really produced by bends in straight lines it is difficult to say. Even the Greek horizontal curves are actually constructed with bends in straight lines, and at Rheims and at Amiens the optical effect is that of curvature, although there is really only one bend, at the capitals, with straight lines above and below. In St. Mark's at Venice

* Unnumbered exhibit, shown on application. Photographed, March 30th, 1914.

† The nave at Laon, No. 102, is shown without plumb-lines, but it belongs to this type, and its proportions and arrangements as regards the widening are well shown by No. 101 for St. Remi, Rheims.

the effect is one of graceful curvature, and is produced by three straight lines and two bends.

The æsthetic effect and optical interest of the widening refinement are well illustrated by No. 76.* In lofty cathedrals the convergence due to perspective tends to produce a contracted and spindling effect which is counteracted by this arrangement. Perhaps the cathedrals of Cologne and Tours may be cited as illustrations of the bad effects due to its absence. On the other hand, the widening refinement is also found in churches of the Byzantine and Romanesque periods which have low proportions, and it was from these churches that it passed to the more lofty ones of the Gothic period. In some cases it is confined to the apse; for instance, in the church of St. Irene at Constantinople, where this refinement has been observed by Prof. A. D. F. Hamlin, of the Columbia University School of Architecture. This is also the case in St. Demetrius at Salonica. In the Balaban Aja Mesdschid, at Constantinople, the apse is only 12 feet high.† Thus the theory that this refinement was specially intended to correct perspective convergence cannot well be accepted as a general explanation. The best explanation appears to lie in the optical interest of the attenuated horse-shoe form, in the more spacious effect obtained for the upper nave, and in the subtle and graceful transition to the arch which is effected by the outward expansion of its supporting lines.

The optical interest of the bends or apparent curvatures, where they are employed, is very obvious. This may be easily remarked at Rheims and Amiens, and is very obvious in St. Mark's at Venice and in Sta. Sophia at Constantinople. The counteraction of perspective convergence is undoubtedly a great advantage in a large number of cases. Mr. Ross Turner, Instructor in Design in the Technological Institute of Boston, has made independent observations of this refine-

* Without debating the constructive evidence for this particular instance.

† Unnumbered special exhibit, shown on application. Photographed in April, 1914.

ment at the crossing of Notre-Dame at Paris, and the writer has permission to quote his pregnant suggestion that it "removes the vanishing point to infinity."

It is an obvious reflection that vaulting thrust might cause a wholly accidental widening refinement. No doubt it may have done so in some cases and no doubt it has exaggerated the original construction in other cases. Most of the photographs of the given class are intended to serve as controversial documents on this subject. Among these the choir window at Laon is not to be neglected (Nos. 103, 104, 105). In St. Jacques at Rheims the refinement is obtained in some parts of the church by the stepping back of perpendicular sections of the shaft (No. 97) and in other parts of the same church it is obtained by the ordinary slopes (No. 98).

The topic of thrust is also debated in the article in the *American Architect*, which will be loaned on application. Since the observations, as now photographed, demonstrably include a large number of churches which widen in absolutely straight lines, either with or without the single bend at the arcade capitals, the objections due to the supposed action of vaulting thrust have been materially weakened. The photographs from Rheims and the details from Amiens show that the widening includes all the spandrils of the nave arcades. The aisle thrust toward the nave and the great weight of the aisle vaulting make it impossible for the much higher nave vaulting to thrust downward in straight lines and to operate on these surfaces in straight lines as far down as the capitals of the arcades. Thus, thrust of the nave vaulting would tend to produce bending lines rather than straight inclinations above the level of the aisle vaulting. This argument applies with still greater force when the widening rises in straight lines from the pavement, as in St. Ouen at Rouen (Nos. 91, 92), and many other cases. It may also be remembered that the outward inclination in the vaulting shafts at Rheims is only one-fourteenth part of the diameter of the shaft. At Amiens the inclination is about one-seventh part of the diameter of the shaft. Such relatively insignificant inclinations do not affect the centre of gravity of the pier, nor do they tend to weaken the stability of the church.

Certain special observations will now be offered for Amiens Cathedral and for Notre-Dame at Paris.

As a preliminary observation, leading up to the facts to be described and illustrated in these cathedrals, we may first notice the window mullions of No. 83, showing the right aisle window of St. Loup at Chalons. Although the sill is horizontal, these mullions slope outward in lines which are parallel to the sloping piers of the nave and choir. (Compare Nos. 81 and 82.) It is an obvious reflection that perpendicular mullions would, in this instance, lead the eye to notice the sloping piers and that the subtlety of the refinement would then disappear.*

Thus we are led to understand the construction of the transept vaulting-shafts of Notre-Dame (Nos. 191, 192, 193). These shafts are inclined outward in lines which are parallel to the crossing piers, one of which appears in each picture. (Compare No. 190 for the crossing piers.) These inclinations are repeated in all the arcade columns of the transept galleries (Nos. 194-196 inclusive). This system of parallel inclinations in the transepts with relation to the nave crossing is also found in the Cathedral and in the Church of St. Ouen, at Rouen, at St. Quentin, in St. Mark's at Venice, and in the Church of the Diaconissa at Constantinople.

The same arrangements are illustrated in this exhibition for Amiens Cathedral, but owing to the great height of the church and the narrow width of the transepts it is not pos-

* In 1903, when the photograph No. 83 was made, the Curé of the church, who had donated the altar under this window, told the writer that he was much annoyed by the obliquity of the window, and that he intended to have it rebuilt to the perpendicular. Two years later the pastor died, and as a tribute to his memory a sum of money was raised and the mullions were rebuilt to the perpendicular. The inclination of the left side of the window is now plastered to the perpendicular, only the inclination of the right side remains. These facts were photographed in 1907.

sible to include the entire height of the piers and vaulting-shafts in one view, as has been done at Notre-Dame, unless the camera is pointed upward. Thus No. 136 shows the slope of the south-east crossing pier at Amiens, and No. 137 shows the adjacent transept pier and vaulting-shaft (with plumb-line), taken with the camera pointing upward. No. 138 shows the outer pier and vaulting-shaft, with plumb-line, on the west side of the same transept, also taken with the camera pointing upward. All the transept piers and vaulting-shafts at Amiens have similar inclinations, parallel to those of the crossing piers, beginning at the pavement and continuing in straight lines to the vaulting.*

Thus the transept piers and vaulting-shafts at Amiens are parallel to the inclinations of the crossing piers. The nave inclinations begin, however, at the arcade capitals, the piers being perpendicular up to their capitals. (Compare Nos. 115*a*-130, inclusive.) Although the crossing piers have no arcade capitals, their constructive inclinations begin at the same height; whereas the inclinations of the transept piers begin at the pavement. (Compare Nos. 140, 142.)

The most remarkable fact at Amiens has still to be considered. The windows in the west walls of the transepts are built with mullions which are parallel to the inclinations of the transept piers. (Compare Nos. 139, 140 with Nos. 141, 142.) The philosophy of these arrangements has been explained for St. Loup, and need not be repeated here.

The series for the Amiens nave now deserves careful study. Each pier on the north side is separately and individually shown to be perpendicular up to the arcade capital.† (Nos. 116, 118, 120, 122, 126.) Each vaulting-shaft is separately photographed for the height between the arcade capital and the triforium. (Nos. 117, 119, 121,

* Enlargements, not shown in this exhibition, have been made for every pier and every vaulting-shaft in both transepts.

† A point of great importance. If the piers leaned into the nave there would be an accidental return bend above the capitals.

123, 125, 126.)* The crossing piers are shown in their entire height by Nos. 127-130, inclusive. The plumb-line photographs for the aisle widening at Amiens (Nos. 131-134, inclusive) should be compared with the similar views of Rheims Cathedral.

§ 5.—Special Features of Notre-Dame.

Aside from the widening refinement in the crossing piers of Notre-Dame, and its parallel extension to the transepts, there are many extraordinary features in this church. Some of them are found at Pisa. Others have no parallel so far known.

The façade of Notre-Dame resembles that of Pisa (Nos. 40-43) in having two separate inclinations in its lower storeys, and in being perpendicular higher up. At Pisa we find 9 inches uniform inclination in the two lower storeys, and 0·10 foot inclination in the third storey, while the two upper storeys are perpendicular. In Notre-Dame the lower storey of the façade leans forward 11 inches in about 50 feet (Nos. 158, 161), and the second storey leans forward 4½ inches in about 40 feet (Nos. 159, 160, 204). The rate of inclination diminishes by more than one-half as between the two storeys. Above the second storey the construction is perpendicular up to the summits of the towers (No. 168). On the north and south sides of the towers the buttresses and the projecting construction for the stairway follow the varying inclinations of the façade (Nos. 162-167, inclusive). Note the curve toward the perpendicular in the buttress on the right in No. 167.

In the interior there are curves in plan in the columnar alignments of the nave, extending through the gallery parapets and arcades and clerestory walls, up to the parapets of the clerestory roof (Nos. 197, 198, 199, 200). These

* Measurements of the deflections may be taken by compass and applied to the 8 by 10 inch disk, which appears in each photograph on the plane of the desired measurement. Similar enlargements are extant for the south side of the nave.

curves are parallel, like the similar ones at Pisa (Nos. 57, 58). They are convex to the nave on the south side, and concave to the nave on the north side. (The choir bends in plan toward the north, so that the entire interior plan is that of an attenuted S, or "Hogarth's line of beauty" much attenuated.)

The gallery parapets have bends in elevation similar to those at Pisa (Nos. 44, 45, 46, 47, 48, 49). These occur in Notre-Dame at the corresponding point in the nave, viz., at the junction of the third and fourth bays (Nos. 180, 186, 186*a*). They also have about the same amount of deflection, viz., about 10 inches on either side, in both churches. There is this difference between the two cathedrals: in that at Pisa, the gallery parapets rise in the first three bays and descend to the same amount in the remaining bays of the nave; while in Paris, the parapets rise about 10 inches on either side in the first three bays and then bend sharply, but without a corresponding subsequent descent. The south gallery parapet bends to an approximate horizontal, while the north gallery parapet has a fall in the remaining five bays of about 3½ inches.

So far we have correspondence in the interiors of the two cathedrals (and the parallel curves in plan have many counterparts elsewhere). We come now to the astonishing feature in which Notre-Dame appears to be unique, as far as known. To explain this we must supplement our accounts of the widening refinement by observing that various cathedrals and churches have a widening refinement in the transepts which intersects the widening system of the nave. This is found, for instance, in the Church of the Diaconissa at Constantinople, of the late sixth century.*

An intersecting transept system is also a remarkable feature of St. Mark's at Venice. The transepts at Amiens also have an independent widening system which intersects that of the nave. Photographs of this refinement at Amiens

* Unnumbered special exhibits, shown by request. Photographed in April, 1914.

have been made, but have not been enlarged. Notre-Dame has also an intersecting transept widening system as regards the crossing piers. It follows that the crossing piers of all these churches have diagonal inclinations.

As far as known Notre-Dame is the only church in which the system of parallel inclinations, so far observed for the transepts as related to the nave, is also carried into the nave as related to the transepts. The transept widenings which have been examined are also much less pronounced than those of the naves. This is the case with Notre-Dame. The delicate westward inclinations of both the western crossing piers are, however, well shown by the plumb-lines in No. 185. The parallel westward inclinations of the vaulting-shafts, as far as the tower piers, inclusive, are shown by a series of plumb-line photographs (Nos. 184, 183, 182, 181, 180, 179, 178.) These are arranged in the natural order of sequence from west to east, but for comprehension of the system it is best studied from east to west, in reversed order of numbering. The diagram, No. 186*b*, may next be consulted. This shows in exaggerated drawing the westward leans of the nave vaulting-shafts, but it adds a new feature to this remarkable combination. Whereas the vaulting-shafts all lean west, the gallery arcade columns of the same bays lean toward the apex of the gallery bends in elevation. Thus Nos. 184, 183, 182, 181 show gallery columns leaning west, like the vaulting-shafts of the same bays; but Nos, 180, 179, 178 show gallery columns leaning east in opposed direction to the vaulting-shaft inclinations in the same bays. In No. 180, which shows the apex of the south gallery bend, the arcade columns lean both ways; they lean west to the right of the vaulting-shaft, and they lean east on its left.

The diagram, No. 186*b*, may now be consulted for a final observation. Since there is a marked contrast of inclination in the first two bays of the nave as between the vaulting-shafts and the arcade columns, it seemed best to the builders of Notre-Dame to minimise this contrast by a twist in the line of the vaulting-shafts. This twist, which is exaggerated by the diagram, is shown for the pier next the tower pier on the north side by No. 173. (The inclined lower part of the same pier is shown, with plumb-line, by No. 172.) The twists occur on both sides of the church in the two vaulting-shafts next to the tower piers.

The westward inclinations of the nave vaulting-shafts begin at the pavement, and have been plumbed for each pier in the nave to the height of the capital. Their rates of inclination above the galleries may be computed from the surveyor's disks (8 by 10 inches), which are placed on the plane of the desired measure in each photograph. The total westward inclination near the crossing appears to be from 6 to 8 inches. It increases near the tower piers and these incline west 16 inches (north) and 12½ inches (south).

The use of the twist in the two vaulting-shafts adjacent to the tower piers was a compromise between two conflicting systems of vertical deflection, and was evidently intended to conceal both of them.

These systems were, on the one hand, the westward inclinations of the nave vaulting-shafts, and, on the other hand, the inclinations of the triforium columns in opposed directions toward the apex of the gallery bends.

The gallery bends in elevation were probably intended, as has been suggested for Pisa, to create the perspective illusion which they undoubtedly do actually produce. The columnar inclinations of the gallery arcades were probably intended to conceal the gallery bends in elevation.

It is certain, at least, that the bends in elevation would be much more apparent if the triforium columns were normal to the lines of the parapets, i.e., if they were set at right angles to the parapets. In that case they would diverge perceptibly at the apex of the bends, whereas they actually converge. The strong westward inclinations of the tower piers may have been intended to increase the stability of the towers, thus corresponding to the inward slope of the exterior tower buttresses. This construction of the piers resists the tendency of the arches under the towers to spread eastward.

The increase of inclination in the vaulting-shafts near the tower piers avoids an abrupt contrast of adjacent inclinations.

The marked inclination of the tower piers and adjacent vaulting-shafts (above the twists) is also disguised and concealed by the masonry construction. The lines of masonry above the triforium arcades of the three bays next the tower piers are normal to their inclination, i.e., they slope downward. This slope is worked to a level directly under the fillet below the clerestory windows. The oblique cutting of the blocks can be seen under this fillet. Nos. 176, 177 show this sloping masonry construction as related to the leaning tower piers and the oblique cutting of the blocks under the fillet.

Nos. 202-205 relate to the double bend in plan of the Notre-Dame façade, which extends from the Gallery of Kings to the upper gallery of the façade. This bend in plan has a uniform deflection at all levels, of 1·20 foot, but as seen by the spectator in front of the façade the optical effect is a bend in elevation which varies in amount according to the angle of vision, and this angle of vision naturally varies for different heights from the same standpoint. As seen from an angle of 45° the bend in plan of 1·20 foot will appear to the eye as a bend in elevation of the same amount. On closer approach, or at a higher elevation, the optical effect increases. Thus the photograph No. 205, looking up the façade, appears to show a series of bends in elevation increasing in amount with each successive storey. But this is an optical illusion reproduced by the camera and caused by a bend in plan which is uniform on every storey, as shown by Nos. 203, 204.

§ 6.—Concluding Remarks.

The optical refinements of Medieval architecture disappeared when the Gothic style was overthrown and supplanted by the Renaissance. In fact, as far as Italy is concerned, and this is the only territory which has been studied with approximate thoroughness in such particulars, the North Italian Gothic, especially of late date, already shows a remarkable diminution in the number and subtlety of its architectural refinements, thus anticipating by a pronounced decline the overthrow brought about by the Renaissance. There are, however, occasional and remarkable instances of Renaissance survival of these refinements. Mr. A. K. Porter's observation for curves in plan in the two small cloisters of St. Maria delle Grazie attributed to Bramante, and dating about 1500, has already been mentioned. No. 208 shows the widening refinement in St. Giorgio Maggiore at Venice, by Palladio. The leaning façade of St. Ambrogio at Genoa, No. 211, has been certified as constructive by the architect now in charge of the church, which dates to 1589. The oblique cutting of one of the pilaster bases is shown by No. 212.

Among the various phases of the given topic which are omitted from the present exhibition may be mentioned numerous cases of perspective illusion in plan or elevation. The subject of deflected, asymmetric, and oblique plans is also neglected. Thus we may call special attention, in the present exhibition, to the fan-shaped transepts of the Pisa Cathedral and to the remarkable S-shaped curvature in plan of St. Ouen at Rouen. The measurements for the Pisa transepts are found on No. 26, and show that they widen in plan about 1 foot on each side, in the direction away from the nave. Nos. 86 and 87 are pictures of the double curvature in plan of St. Ouen. They are taken in the two triforium galleries of the nave, looking west towards the façade, with the back of the camera close to the crossing piers and the transept parapets. Thus, not only the curve in the nave but also the beginning of the return curve toward the choir is shown by these pictures. These S-shaped curves are not only found in the pier alignments of the nave and in the triforium, but they also extend to the outer walls. The curves in plan of the nave (8½ inches, south triforium gallery; 10 inches, north triforium gallery) are strictly parallel, within the slight variation of measurement noted. They are also true curves, rather than bends, as established by measurements which show an unbroken sequence in the distance of the respective piers from the stretched cords which are seen in the photographs.

The enlarged photographs from Constantinople and Salonica, some of which have been mentioned in foot-notes, were taken during the month of April, 1914. They include important exhibits for horizontal curves in plan, in the gallery cornices of Sta. Sophia, convex to the nave on both sides; the parapets behind the cornices have no curve. These photographs are otherwise devoted to the widening refinement. There are two for St. Demetrius at Salonica and the rest are from Constantinople; four from the church of the Chora Monastery, eight from the Church of the Diaconissa, two from the Balaban Aja Mesdschid, and eighteen from Sta. Sophia.

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