A peculiar architecture: The open staircase of Naples

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This is a summary of a much wider research that, starting from a specific aspect of the architecture of Naples of the 17th and 18th centuries, aims to find common roots between Neapolitan technicians and scientists and other scientists in Italy and Europe; it seeks to understand if and to what extent new sciences influenced consolidated techniques and how the social, economic and political context speeded up or slowed down new developments. In this paper, we study in particular the Neapolitan open staircase in minor architecture, which borrowed from famous examples what have become common features of the buildings of the city.

THE NEAPOLITAN OPEN STAIRCASE

The enduring Greco-Roman urban layout in the old town center of Naples and therefore of the building lot generally closed on three sides has brought about the development of a particular type of construction that inherited the airing and lighting of the internal courtyard from the Roman domus.

In the second half of the 15th century, there was the Aragonese city wall and laws prohibited all extra moenia development. Population growth caused buildings to grow upward and the use of excellent volcanic tufa quarried in situ enabled buildings of the same lot, with constructions of maximum 2 storeys, to be raised to 4 or even 5 floors. The resulting high buildings are out of proportion with the streets, which totally coincide with the preexistent cardines and decumens, virtually preventing the development of a continuous street front.

Though Renaissance influence at times led architects to use some sort of rules, street fronts are generally fragmentary and hardly ever viewed as a whole: only the vaulted entrance and the portal display the pomp of aristocratic buildings.

This gives rise to a new element of architecture, another façade: the internal courtyard front facing the entrance at such a distance from the street axis as to allow the view of good part of it through the entrance hall; a new element to fit in the overall architecture. The internal yard, at times completed by loggias of medieval or Renaissance origin, acquires new elements: vertical connections.

This distribution typology, which becomes a feature of the city, isn’t shown in a modern zenith map since the separation of the public spaces (streets) from the private (dwellings) can’t fully represent the connections nor the real aspect; in ancient maps, for instance the one by the Duke of Noja (1750–1775), cross-sectioned at an height of 6 (palmi) spans (about 1.60 meters), where the city is drawn according to path contours, the interconnections between public and private spaces are reported and the latter are integrated in the general layout of the city thanks to the continuity of a wider visual space of the entrance hall opening out onto the courts (Fig. 1).

The typical Neapolitan staircase opening out onto the courtyard thus completes the façade with a series
of screens from street to dwelling, from public to private spaces, a continuous filter created by the entrance hall-court-staircase system.

The first examples of Neapolitan open staircase from the Renaissance derive from the loggia plan and sometimes they are in fact set in loggias; the resulting flights of stairs, positioned at right angle to the yard, are borne by two staggered rampant barrel vaults jointed on the same bearing wall and cross-vaulted (or cap vaulted) at the level of the intermediate landing, paired up by a separating arch corresponding to the thickness of the wall. Level with the aspect on the court and with the landing leading to the two flats, we again find the same pair of vaults, whose arch is normally held by a monolithic pillar in piperno also used for facing the arches: a loggia with the same cadence at times on all levels is thus formed.

**The staircase on central bearing wall**

In this type of staircase developing on two flights on barrel vault, achieved through successive round arches built on a slanted plane resting unbroken on the external wall of the staircase and on the central bearing wall linked by paired cross or cap vaults with the necessary bearing points, a further transformation takes place: the elimination of the façade pillar generates a single segmental arch but with rise equal to the others and the consequent cap union between two half cross vaults or the deformation of two cap vaults jointed by a haunch. The central bearing wall staircase is usually found on the side front of the court, creating asymmetry between the two flats, only one with internal outlook and the other facing the street and with outlook onto the yard.

Though more convenient for the type of vaults used, this solution has the drawback of the length of the flights which, as in this case, are two. To solve this problem, some steps were often added at the central bearing wall level and it's this development that, maintaining the barrel vault, has led to the next type of staircase with three flights.

**The closed stairwell**

Unlike the staircase on central bearing wall which is always rectangular, this type has a planimetry divided in nine uneven squares with the central one, the stairwell, closed on four sides (the interior is generally inaccessible) to allow unbroken support for the three barrel flights whilst for the two vaults at intermediate landing level a bearing point is necessary, as in the previous type of staircase, with cross or cap vaults. The vault of the main landing overlooking the court is quite interesting since it rests on three squares: a single segmental arch overlooking the yard, two side distorted cross or cap vault sections
and a half barrel vault at the level of the well wall. Though cheap, this solution has an unsolvable drawback: the inner flight of stairs is badly lit.

The stairwell on pillars

The next step was knocking down the well and replacing the continuous wall with four pillars leaving the same layout of nine squares and three flights of stairs. The vaults had to rest on bearing points and the look of the flight support changes while the intermediate landings remain the same: rampant cross vaults (created by the intersection of a flying barrel and a bevelled barrel vaults) or rampant cap vaults (distorted cap vaults to create bearing points at various heights). Obviously, the facing arches of these vaults are bevelled (goose neck) to joint the pillars; unlike the previous models based on continuous support, an almost medieval structure system of arches bearing the vaults is created. Like the closed stairwell, the main landing too in this case develops on three squares, the side squares with distorted cross or cap vaults, whilst in the central one corresponding to the well, instead of the half barrel, there is a fanlight forming almost half a real cross vault and the other half is mock.

The segmental arch overlooking the court is thus charged athwart but its mass is still considerable enough, compared to the relatively small vaults, to ensure neutralization of the thrusts.
This staircase often consists of only two almost adjacent flights of stairs with the well reduced to the minimum but it can also have three flights though, in this case, the rear arch becomes a beveled barrel vault with two landings resting on the extrados at different levels jointed by a flight of steps. This vault too is charged abeam and bears the weight and the thrust of the rampant plattbands at the level of the landings. The need to joint the oblique plattbands to the bearing arches has led to an improper vault, the so-called rampant half barrel vault, which is a half vault in appearance but it’s a flat arch along the directrix and as such it’s built, though it follows a quarter of the arch in the opposite direction for jointing purposes.

Later developments

These four types of stairwell in masonry with infinite practical applications remain a typical architectural feature of Naples even when the city walls had become of no use and it was legal to build extra moenia. The 17th-18th century lot enclosed by streets includes an open space but the built-up area around it has developed according to a consolidated type of housing with the only difference that it has a previously absent rear façade for air and light and the staircase at the back of the courtyard has a view of the garden only if it is either borne by pillars or is open. If instead it’s a staircase on bearing walls or, less often, it’s a closed stairwell with side layout, other stratagems such as archways and loggias on the rear side create the possibility of viewing the garden (Fig. 6).

The strained search for symmetry even in what is not naturally symmetrical led architects to contrive solutions such as: space permitting, splitting the stairwell on pillars in two interpenetrated flights of stairs with a third flight in common, the typical pincer-shaped layout; in insufficient space, the structure often seems split only at ground level with an added opposite flight of stairs going no further but which is symmetrical to the first flight (Fig. 7).

Other stratagems were contrived to make up for the height difference of the intermediate landings. Unable to vary the corresponding planimetry of the wall structure and, even less, the ratio tread/riser, some steps have been placed, where necessary, at the level of the bearing wall thickness or curtail steps added.
outside the closed well or well on pillars where interpolation is not at all possible.

Since vaults need provisional structures in any case, these staircases are assembled so that part, if not all, of the centering was re-employed.

In staircases on bearing wall, the centering of the rampant barrel vaults is normally the same and was used twice for each level and the same for the centering of the intermediate landing vaults, whether cap or cross vaults. In the Renaissance solution with the two front arches and two equal landings, it could in fact be used four times. In the single segmental arch, however, it was possible to use half of the mould of the cap or cross vault, given the characteristics of the main landing vault, preparing the division along the diagonal and re-assemblying the centering on the other floors. It only involved adding to the prepared half centering the suitable barrel and cap joints. The same logic can be seen in all other types: the centering was reusable at the same level and in any case the added parts could be used again for each floor.

At this point, it behoves us to say a few words about the Neapolitan metric system and the laws of the time concerning cutting the tufa in specific sizes. The *Palmo Napoletano di costumanza* (The Neapolitan palm in use) corresponds to 0.26333 m (from 1480 to 1840) and the *Palmo Napoletano decimale* corresponds to 0.26455 m (from April 6 1840). There is reference to the *Palmo Napoletano di costumanza* in the Pragmatica of August 27, 1564 of the Viceroy Don Perafán de Ribera Duke of Alcalà where, amongst other important norms to eliminate frauds in the building industry, it’s made compulsory for the *tagliamonti* (tufa quarrymen) to furnish tufa blocks in three standard sizes: the *pezzo* (1½×1½×1½ palms or spans), the *spaccata* (2×1½×1½ spans) and the *spaccatella* (1×1½×1½ spans) with two constant dimensions (a thickness of 1 span, equal to 13.16 cm and a height of spans, equal to 35.11 cm) and only the length varying (39.50, 52.66 and 26.33 cm respectively) to ensure total modularity. Since these stones were fitted with minimum adjustment, the stressed surface remains constant according to the chosen size and, considering the load on these arches, it was more than enough for the purpose. Easy to saw, a property of the yellow variety of Campania, the tufa could be quickly transformed in tapered ashlars. The cutting operation created a lot of scrap material often employed as filling but also mixed with lime and pozzolana to make real concrete similar to the Roman *opus cementicium* to build directly the landing and flight vaults. Therefore, in the stairwell structure, the arches and the vertical elements are the load-bearers of the main structure and the vaults, supported by the former, load-bearers of the secondary structure, given the relatively small dimensions. The vaults, however, often have a rough centering over which was poured the concrete to level the extrados. A rather light concrete was used made of lime, lapilli and sometime even lava foam (normally used especially as prop) and the already mentioned *mazzacani* (quarry rubble).

In the open stairwell, however, the vault structure centering of the landings, due to the absence of main structures, is quite precise and similar to the slanted flat arch centering that bears the flights of stairs, the so called half-barrel flights.

*Pragmatica* also contains norms concerning the piperno quarrymen, obliging them to furnish blocks according to precise standards for structural purposes and banning the use of this stone for sole decorative purposes. This stone is used for archways (moulded in position), often for pillars, for reinforcing openings such as doors and windows as well as for steps, because of a certain abrasion resistance. The steps are often made of single blocks which load on the arches, on the perimetrical wall and, where present, on the bearing wall, thus unburdening greatly the flight vaults. Slabs separating the tread from the riser have instead been used in open stairwells to lighten the oblique platbands.

**SCIENCES IN NAPLES**

It’s impossible to understand innovations and weaknesses in the scientific field of the city without a glance at the political situation and institutions of the time; if it’s true that the 17th and 18th centuries represent the «golden age» of Naples for art, music and architecture, it’s also true that there are many shadows as well as light, marked by contrasts between the Viceroyalty and Barons and the Church whose political, legal and economic power actually represented «states within the State». In the middle, a weak bourgeois and lower classes without social awareness and rights. Nonetheless, a ferment of innovations was running through the city: in 161
Academy of the Oziosi was founded and in 1663, following the examples of the Academy del Cimento of Florence and the Royal Society of London, the Academy of the Investiganti, which critically revised old Aristotelian models and spread a new scientific culture. Galileo’s teachings became heritage of local scientific circles and the study of natural philosophy through theory and experiments sought «hidden Truth in the Book of Nature»; absent in the European scientific field, a school of Mathematics, amongst the most advanced in Italy, was founded advocating the introduction of algebraic methods in geometry.

In the following century, with increase of population, trade and exchanges with other countries, the city became more and more cosmopolitan: destination of grand tours for Englishmen, Frenchmen and Germans drawn not only by the discovery of antiquities but also by the intellectual ferment, contacts with research centres abroad became intense. Debate in the Academies —for example the Royal Academy or of Medinaceli— and in private studios was lively and intense: Descartes, Newton, Leibnitz, the calculus treatises by De La Hire and de L’Hôpital, the famous texts by Belidor and Borra were subject of great debate. In the elaboration of Newtonian thought, two parties formed. On the one side, those who basically accepted Newton’s empirical and descriptive aspect —as is the case of Newtonianesimo per le dame (Algarotti 1737)— and on the other, the richer and complex one by Pietro de Martino who published Philosophia naturalis institutiones libri tres in 1738.

With the conquest of Naples by Charles of Bourbon in 1734, a period of great changes finally started: the reduction of the power of barons and clergy was accompanied by reforms in the school and University system strongly upheld by Antonio Genovesi who saw in the creation of expert technicians the necessary condition for the young Kingdom to compete with other States: hence the birth of schools and military Academies where technical subjects and mathematics were the basis of studies.

It was a necessary and courageous decision in that context which however penalized scientific Academies whose best scientists were called to work in government and schools; whilst in France, England and the Netherlands Academies continued to be breeding ground of scientific culture in progressive and rapid development, in Naples they were emptied. Furthermore, economic hardships due to taking part in the War of the Austrian Succession, the plague in Calabria and finally Charles Bourbon’s rise to the Spanish throne marked the start of the decline: too brief and discontinuous, the social and economic reforms were put aside and though the ideas of the Enlightenment were widely shared by scholars, they did not spread to society at large. The gap between the élite and the Crown grew, culminating in the Parthenopean Republic and its dramatic end: the ensuing Restoration led to the massacre or exile of good part of the intellectuals of the city while the old ruling class quickly took up power again.

In these difficult conditions, remarkable figures distinguished themselves: remaining in our field, mention must be made to Vincenzo Angiulli, lecturer at the Reale Accademia della Nunziatella who published in Naples the Discorso intorno agli equilibri whose «action law» is the present day «principle of virtual work»; Nicola Carletti and his Instituzioni di Architettura Civile (1772) still influenced by 16th century treatises and Vincenzo Lamberti, whom we’ll delve into in some depth, quoted by Bernoulli and Milizia. Born in 1740, Vincenzo Lamberti, engineer and member of the Royal Academy of Science and Fine Arts of Naples, published his first work, Voltimetria retta, in 1773; two years before he had had a harsh debate with Fuga and Vanvitelli about the cause of the damages of the cupola of Gesù Nuovo in Naples. Vanvitelli, an architect with vast experience, was in favour of demolition; he had just worked in Rome on the consolidation of the cupola of St. Peter, whose project was elaborated by the mathematician Poleni: on the other side, Lamberti, younger and with less field experience but aware of new theories aiming at bringing together experience and mathematical control of the problems, was in favour of restoration. Of course, the cupola was demolished but the negative experience brought him to deepen his researches on the causes of damage, which he delved into in the last part of his Statica degli Edifici (Naples 1781) which represents the first original research in this field.

From the introduction, the aim of Statica degli Edifici is clearly set out: put at the disposal of technicians a useful instrument to calculate the structural elements, hence the language deliberately accessible to all and the rejection of «rigorous
mathematical terms». He criticized Architects for giving too much weight to Vitruvius’s *venustas and concinnitas* sacrificing the *firmitas* in constructing buildings either too weak or uselessly over-dimensioned. He contested the theoretical foundations of treatises of the past; solidness and stability don’t derive naturally from the respect for eurhythmy, for the module or symmetry nor are «imperfections of the materials» the cause of fractures. Bearing in mind Galilei’s assumption that matter does not obey «abstract and ideal reasoning», Lamberti was convinced that only experimental data of the resistance of materials and an accurate use of mathematics ensured the stability of buildings: investigation of physical phenomena, governed by independent laws, started to move definitely away from consolidated rules repeated for centuries.

The brief space at our disposal can only allow treating what seem to us the most significant aspects concerning the statics of vault structures.

**Resistance of the Materials**

The first aspect to underline is Lamberti’s attention towards the resistance of the materials (Chapter 3, book II of his treatise). On the basis of known experiments (Mariotte, Parent, Musschenbroek, etc.), he assumed a priori that «there was no constant ratio between the absolute force — breaking load under traction — and the relative force — breaking load under bending stress — » and organised a series of experiments to determine the values of the «relative resistance» of the various materials used in Campania: tufa, piperno, lime and pozzolana. The tests were carried out on small prismatic samples with square base, fixed at one end and loaded at the free base, or resting on both ends and loaded at midpoint. The experiment data were then revised (using the equilibrium of the angular lever and the hypothesis of constant distribution of the resistance on the section of maximum stress, as Galileo had already done), in order to obtain values independent of sample geometry and of test methods (Fig. 8).

Lamberti thus obtained the following values of the breaking load of cube samples with the side of 1 Neapolitan palm, fixed at one end and loaded at the free end: Campania tufa (*rotoli* 1.873); piperno (*rotoli* 10.080); lime and pozzolana (*rotoli* 939).²

These elements were sufficient for him to obtain theoretically, with only the aid of geometrical similarities, the necessary formulae to dimension the beam elements under different constraint and load conditions. Particularly original and interesting are the rules concerning the determination of the ultimate load, R, of arches, semicircular and not, obtained by
analogy with that, \( P \), of a beam of the same material and thickness and with a length equal to the span of the arch itself. The formula he obtained for the semicircular arch (Fig. 9).

\[
P = \frac{3}{5} \frac{Gq + AG}{BE},
\]

arch and vault thrusts

In the analysis of these elements, Lamberti singles two types of problems:

a. The minimum thickness to give to the vault so that it resists to its own weight and of the elements loaded on it;

b. The thickness of the piers.

In the formulation of the first type of problems, he essentially applies formula (1), or its derivatives for the segmental arch, obtaining firstly the load bearing on the arch and then the thickness of the beam of equal length to the free span.

The way he delves into the type b problems seems more interesting. The theoretical instrument is again that of the angular lever and the end formulae, worked out by long chains of geometric similarities, are in fact revisions and adaptations of the ones obtained in the analysis of isolated walls. The originality of his approach, in our opinion, is to be found in his conclusions: for each significant type of vault, the author numerically solves a standard problem; from this, he obtains factors that don’t change with geometric data variations of the single problem and hence defines a new practical calculation procedure combining these constant terms with the variable data.

For example, to determine the thickness of the abutment of a round barrel vault, after calculating the dead force \( P \) exerted by the arch, Lamberti arrives at a first value \( "a" \) of the thickness by applying the formula previously obtained for the isolated wall. In the case examined, however, force \( P \) does not pass through the pier edge and hence the solution must be corrected to determine the new thickness, \( x+a \), to re-establish balance (Fig. 11). Thus, the following expression is obtained

\[
x = \frac{a \times m \times n}{a \times h + a \times m}
\]

that measures the required thickness.

Applying the above procedure to a vault made of Campania tufa with a radius of \( r_m = 8 \) palms and an impost height of \( h_m = 24 \) palms, Lamberti obtains the dead force \( P_m = 23.17 \) rotoli and the thickness of the pier \( a_m = 6.4 \) palms. These data are sufficient to
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Figure 11
The thickness of the piers
determine the thickness of the abutment of any round barrel vault made of Campania tufa with the formula —pratica I—
\[
y = \sqrt{\frac{Prxh_m \times a_m}{P_m \times r_m \times h}} = \sqrt{\frac{Pr \times 24 \times 6.4}{23.17 \times 8 \times h}}
\]
where \( r, h \) and \( P \) stand for the radius, the impost height and the dead force.

Similarly, he arrives at six other praticas, founded on six basic numerical solutions covering the different types of barrel vaults, with or without piers exceeding the impost, and flat arches.

The static behaviour of the cap and cross vaults is deduced from the wall bond and the proportionment of the system refers to the most stressed basic components. In cap vaults, isolated, on piers, Lamberti indicates as elements to be «calculated» the perimetrical arches and the piers (Fig. 12). In the former, he observed that the acting forces, conveyed by the cap vault calotte increase from the middle to the impost, but must not be considered in their entirety since the orthogonal component at arch level «is destroyed» in meeting the «obstacle of the thickness of the arch». To size the abutments it's necessary to consider the thrusts coming from the big arches and the action of the vault pertaining to the pier. Their resultant will in any case have the direction of the diagonal of the space to be covered and consequently the pier section will need to be an homothetic figure to it, of which he determines the diagonal length. In the cross vaults, created by the intersection of two semi-cylinders or by two semi-spheroids (cross vaults with or without «reguglio», i.e. higher keystone), the most stressed elements are the same as in the cap vaults and therefore the author reaches the same operative conclusions (Fig. 13). The

Figure 12
The cap vault's static

Figure 13
The cross vault's static
static differences between the two types of vaults—cap and cross—lie in the behaviour of the diagonal section: the former, characterized by closed and continuous curves in the planes parallel to the impost plane, do not transmit the plane thrust to the layers beneath, instead in the latter, the resultant of the forces transmitted by the vaulted spaces to the diagonal arches are lead along the arch «by which the former acts less than the latter in the corners».

In the analysis of the piers where more arches rest, he points out nine significant cases (Fig. 14). Particularly interesting are cases IV and V in which the pier, stressed by two «contrary» forces, is proportioned to the difference between them and, in extreme cases, is arbitrarily small if the two forces are equal. If, instead, three forces act on the pier, two «contrary» and the third «converging» (cases VI and VII) or four thrusts «converging» in pairs (cases VII and IX), the problem is similar to the one with two «converging» actions, replacing the two «contrary» forces with their difference. In particular, if one of these is nil—equal and contrary forces—the size of the pillar is determined in the direction associated to the «converging» force whilst the other is discretionary.

**CONCLUSIONS**

The stimulating ideas emerging from the treatise we’ve tried to illustrate briefly have led us to compare the rules of proportionment laid out by Lambert with the geometry of some buildings; the small number of tests has not enabled us to reach significant conclusions though the first numerical results are encouraging. The next steps will concern a more widespread survey to check if the deduced rules correspond in fact to the practice of the time, and a control of the gap between Lamberti’s values and the values that would be obtained today applying the limit analysis and correcting some blatantly mistaken hypotheses.

**NOTES**

1. **DE MAGISTRIS ARTIUM SEU ARTIFICIBUS TITULUS LXXXII PRAGMATICAE Prima in Blasius Altimarus, Pragmaticae, Edicta, Regiaque Sanctiones Regni Neapolitani** (Naples, 1682)

2. 1 Neapolitan palm or span = 26.3 cm; 1 rotolo = 0.891 kg.

**REFERENCE LIST**


Giannone, P. 1723. *Dell’Istoria civile del regno di Napoli*. Napoli


Strazzullo, F. 1969. *Architetti e Ingegneri napoletani dal 500 al 700*. Napoli

Detailed references on treatises, scientific knowledge and theories of vaulted structures can be found in Benvenuto (1991) and Di Pasquale (1996).