ARCHITECTURAL USES OF IRON BEFORE THE EMERGENCE OF IRON ARCHITECTURE

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This colloquy is to deal with the role of iron in architecture in the first half of the 19th century. The subject is based on the assumption that iron architecture emerges in that period. However, the subject also raises the question of the role iron played in architecture before the 19th century, before the existence of iron architecture proper. More specifically, I want to raise the question of whether architecture existed before that time which could not have been what it was without the use of iron.
Raising this question as a matter of principle will first of all lead us to the problem of tools. I think it is safe to say that no building trade worker, bricklayer, carpenter or stone-mason can do without iron tools, and this finding is not only true for our more recent times but has been valid since antiquity. But if we inquire about the early days of, for instance, stone building construction, we find ashlar buildings both in Egypt and Mycenae which date from the Bronze Age and were certainly erected without the use of iron tools. Although iron has greatly simplified stone working and wood working, it has not in fact made such processes possible. Timber construction and stone construction are possible entirely without the use of iron.

In ancient Greece and Rome much iron was used in ashlar buildings for dowels and clamps. The parts of buildings were joined without any mortar being held together by dowels and clamps. In the normal steady state condition of a building these joints are unstressed. Only during building construction proper and under special stresses, e.g., under the impact of earthquakes, will they have to function. If we now wonder whether Greek and Roman buildings using iron would have looked different without the use of iron, the answer must be: no, they would be the same without iron. Iron did not influence the design of ancient buildings.

In the Middle Ages we find ring beams in a rather early building, the Palace Chapel of Aachen built in the late 8th century. At the base of the dome four anchors made of iron bars are superimposed on each other which are partly interconnected by fish plates and cotter pins, partly by forged rings slid over the bent ends of the bars. Two other anchors are located in the outer wall of the gallery; also the iron bars in the ground floor arcades known from photographs, which carried candles, are supposed to contain a ring beam. If these anchors were really put in place when the building was constructed, they would not be typical of the Carolingian period, but constitute an isolated single case.

The doubts mentioned above about the Aachen anchors being part of the original Carolingian building stem from a more general thought. We know from Carolingian sources that only very small quantities of iron were produced and available at that time. Moreover, it can be said that Romanesque building construction throughout Germany used no iron components. The Romanesque parts of Speyer Cathedral, for instance, a building whose importance to Conrad II and Henry IV is probably comparable to that of the Aachen Palace Chapel to Charlemagne, do not contain any iron components. Anchors embedded in the walls or traversing the room at the level of the base of the vault were made of timber beams. Also the windows had wooden frames, and even structural members which, in our opinion, must contain dowels, such as miniature galleries, are bricked up without any dowels.
If we compare this with Bamberg Cathedral, which is approximately 1 1/2 centuries younger, we find much agreement in principle, because

Bamberg Cathedral is an oblong bulky structure with vaults over three naves, very much like Speyer Cathedral, but here we also find iron. Although the original window trusses are not preserved, they undoubtedly were made of iron.

When the Cathedral Building Office, a couple of years ago, replaced pillars and stones of the doorcasings of the "Gnadenpforte", all these pieces were found to be clamped and doweled.
At Speyer, prior to 1100, a style of building had been adopted which obviously had not even taken into account the possibility of using iron. In Bamberg, after 1210, iron was used quite naturally. In the period between the two buildings there seems to have been a major step in development which could illustrate our question. In this period the western gate of St. Zeno of Verona was built (1135-38). The canopied porch is a piece of architecture which could not have been built in this way without the use of iron. In view of its large overhang it would not be stable without a tension rod. The semi-ciboria of a very similar shape in the crossbars of Speyer (before 1100) protrude far less and can therefore do without reinforcement.

In the eight decades between the gate of St. Zeno and the Bamberg Gnadenpforte the Gothic style developed in France in which iron played a major role.

(1) The glazing in Gothic windows is always kept in place by iron glazing bars.
(2) In fully developed tracery the pillars are stone bars kept in place by iron crossmembers. Larger tracery windows cannot be built without such crossmembers.
(3) Some of the iron window crossmembers penetrate through the pillars, enclosing the whole building structure as a ring beam. These ring beams are often located at distinct points, for instance, at the level of the bases of vaults and are distinguished from ordinary sash bars chiefly by their larger cross sections.

Ste.Chapelle of Paris, a building constructed in the High Gothic period (1243-48), consists chiefly of three materials: stone, iron and glass. Each of these materials makes decisive contributions to the design of the building.
In the choir hall of Aachen Cathedral, which is over 100 years younger than Ste.Chapelle but yet can be compared with it, several layers of window trusses extend around the whole building as ring beams. One of these anchors was stressed by visible iron bars right across the room.

That there are also iron dowels and clamps in Gothic buildings goes without saying, but in these cases iron could also be replaced by different materials (for instance, there are wooden dowels and animal bones used as dowels in vault ribs in the late Gothic period). The "Maßwerkschleier" (tracery veil) of the front of Strasbourg Cathedral needs to be anchored to iron members.
In a slightly simplified way the situation may be summarized as follows: Romanesque buildings could do almost entirely without iron, in the Gothic style designs were developed which could be implemented only by the use of iron.
Gothic buildings used iron in considerable quantities. Hence, it must be assumed that also the production of iron had expanded greatly since the 12th and 13th centuries. References in the literature on ironworks in the Middle Ages have been studied by Rolf Sprandel. He was not familiar with the problem associated with building construction to which we are referring. But his results are all the more important for our problem. Let me refer to some of them by quoting them as theses:

(1) Intensive prospection for ore can be found in various regions of central and western Europe since the 12th century.
(2) Since the late 12th century there have been documents about iron trade.
(3) Because of the monasterial principle of self-supply especially Cistercian monasteries intensified their production of iron. But some monasteries produced so much more than they needed for their own uses that they could supply the market.
(4) Legal standards were developed in that period which allowed ore to be mined and worked irrespective of ownership of land. This established a condition for entrepreneurial iron production in addition to production by the landlords.
(5) Since the 13th century water power has been used for iron production, either to drive hammer mills or to operate bellows.These bellows are used to create temperatures in the furnaces sufficient to really smelt iron and therefore constitute a first step in blast furnace technology.
(6) As a result of denser population and increased land use further preconditions of iron production are created after the 12th century. For instance, ore seems to have been mined on a larger scale in the Erzberg region of Styria, which used to be an important place of iron production in prehistoric times, only since the 12th century. Before that time, the region was so sparsely populated that iron smelting continued to exist only on a very small scale.

All indications seem to point in the same direction: after the 12th century iron was produced in larger quantities than before and has been used since as a major building material in architecture.
The examples found in the French High Gothic period, and the German examples dependent on them, show an increase in building height, a more frequent use of skeleton structures, both made possible only through the use of iron. In Italian Gothic buildings we find very different styles and trends, but again there are buildings which employ and need iron.
Arena Chapel of Padua (1303-05)or Loggia dei Lanzi of Florence (1376-81) were designed for iron anchor beams. We are familiar with the Palazzo della Ragione of Padua in the form in which it was rebuilt in the years until 1435 after the fire of 1420 (the renovation following the flood disaster of 1759 seems to have preserved that design). The huge shape of a drum with hips at the narrow sides is held by iron anchor beams. The original building constructed in 1306 may still have contained timber beams as tension bars. A clear reference to such replacement of timber beams by iron tension bars exists for the Nuremberg Townhall. The building of 1332-40 had contained nine anchor beams to hold the wooden barrel, which were replaced by three iron bars in 1520-21. Comparison of this room with a room retaining the timber anchorage of the barrel (for instance, the Hotel Dieu of Beaune or the Holy Spirit Hospital of Lübeck) shows what the iron anchors achieved: in one case, the wooden barrel is closely drawn towards the room, in the other case it is clearly separated.
The choice between timber beams or iron rods as anchors also existed in basilica church buildings. The retention of "Romanesque" beams in Gothic buildings, for instance in Venice or in Northern Germany, is probably due to the fact that brick buildings required more reinforcement because of the greater elasticity of their walls. This was particularly true in view of the uncertain conditions of foundations in Venice.This comparison hardly contributes to our question relating to iron.

In early Italian Renaissance buildings we find as a sort of leitmotif the slender, wide-span colonnaded arcade. In Brunelleschi's Ospedale degli Innocenti of Florence the loggia is supported laterally by solid

fields of wall. Accordingly, no tension anchorage was required in the facade. However, the shear stress exerted by the arches of the loggias required rear anchorage of each column. In many 15th and 16th century loggias tension bars are used quite naturally in every arcade and every arch support. Comparison with an arcaded courtyard in Istanbul, which has timber beams as rear anchors, shows how badly the early Renaissance period needed iron to implement its design concepts.

Buildings of the High Renaissance period in Rome had less graceful forms than Florentine early Renaissance buildings, but were not solid enough to do entirely without anchors (for example, Palazzetto Venezia of Rome).

Besides the open, natural exposure of iron anchors most clearly seen in halls with semi-circular vaults (for exemple, Naples, Ospedale della Pace) there is also the use of iron in a more clandestine way. For example, I should like to refer to the most important dome buildings of the 15th and 16th centuries: in the dome of the Cathedral of Florence radial iron ties are installed in the liernes. They were needed because the flat arches connecting the corner ribs hold these liernes only on the upper sides. The iron ties included the whole cross section into the static system. However, this is merely an interim design. As soon as the individual ribs had been run through to the final ring, the vaults were self-supporting and no longer needed any tangential arches.

From the beginning, the dome of St.Peter's Cathedral in Rome had contained iron ring beams in the area of the static impost.
Both possibilities of using iron, either visibly or invisibly, also occur in Germany in the 15th and 16th centuries. For instance, at the Breisach jube (1496) the playful, light architecture is held by a visible tensile iron bar. On the tabernacle by Adam Kraft in Nuremberg's St.Lorenz Church (1493-96) the helical Gothic spires of the so-called crown of thorns are made of small pieces of stone threaded on bent iron bars. The rolled tip of the tabernacle is designed much in the same way, also employing iron reinforcements. In this case, the iron remains invisible. It is merged with the stone so as to form a unit. In the Vladislav Hall of Hradčany Castle of Prague (Benedikt Ried,1493-1502) the iron structure of the anchors and the stone closure of the room are developed independently without any visible reference to each other.

Up until the 18th century no major new material can be found on our subject. It appears as if iron were used more sparingly in building construction. After the mid-18th century we find another wave of the use of iron in architecture.
The plan drafted by Franz Ignaz Neumann to construct a vault over the monasterial church of Neresheim, which had been left incomplete by his father (Balthasar Neumann, who died in 1753), provided for large numbers of iron reinforcements in the walls. Here again we find the phenomenon known from the Gothic period that ring beams are carried right through the window openings and simultaneously serve as window trusses.
Franz Ignaz Neumann also planned a western wing for reconstruction of the partly destroyed Speyer Cathedral which, for lack of money, was implemented only on a reduced scale. These plans also show extensive iron reinforcements in the walls. As far as the building was actually constructed, they were certainly put in place according to plan. Also the rear anchorage of the walls of the aisle to the nave was implemented as shown in the plan. However, the project of a solid roof on the aisle was not implemented; of course, it could have been done only with iron reinforcements. In the Cathedral of Mainz and its reconstruction, Neumann did in fact build such solid roofs. Neumann

always used invisible iron structures. For the nave of the Speyer Cathedral he developed a roof structure which accomodated, in the roof space above the vault, the rear anchors taking the thrust produced by the vault. In this way he avoided the appearance of visible iron anchors in the western part of the nave he had rebuilt, which anchors had been installed in the Romanesque eastern trestles instead of the original anchor beams after the destruction in 1689.

Naturally, F.I. Neumann was not the only 18th century architect to use iron in this way. The roof Küchel designed for the nave of Bamberg Cathedral is very similar to the Speyer roof. After destruction of the Stuttgart New Palace in the Second World War it became apparent that the parts built by Leopoldo Retti had been erected in simple brickwork, while the urban wing built by Philippe de la Guêpière after Retti's death used strong iron reinforcements in the brickwork.
Especially this comparison of the same piece of architecture, once without iron, once with iron reinforcement, shows that 18th century architecture is not about building structures which could not have existed without iron. But a number of engineer-architects in the 18th century preferred the use of iron, especially when building rooms, such as the White Hall of the Stuttgart Palace or the nave of Speyer Cathedral, without any visible anchor beams or when building solid roofs in Mainz in such a way that outwardly they could not be distinguished from conventional timber roof structures.

Iron as an integrating part of architecture can be found in some examples of Romanesque building (Verona, St. Zeno), as a major element of the Gothic style of building, whose characteristic structures stem from the very use of iron, next in the arcades of the early and High Renaissance periods and, finally, in the engineer-architects of the late Baroque style. In some of these examples, visible anchor beams were used, in others invisible reinforcements; in some cases, the anchor beams were disguised as window trusses.
If one attempts to find a common denominator for the various phenomena and types of use, one must first of all say that iron is always used as forged iron bars of round, square or flat rectangular cross sections. In no case is this real iron architecture, but always mixed building construction of stone with iron or timber with iron. In any case, iron plays a special role in these designs. It must accommodate tensile forces, sometimes even shear stresses, whereas stone takes up compression forces.

Iron architecture of the type to be discussed at this colloquy has been in existence since designs and structures of iron were developed so as to be able to accomodate also compression stresses.

Reinforced concrete, however, returned to the design principle we have been able to observe and trace since the 12th century. Also reinforced concrete is a mixture of stone and iron in which iron is responsible for accommodation of the tensile stresses, and concrete, a manmade type of stone, accommodates compression forces.