THE EMPLOYMENT OF METAL CONNECTORS IN ORDER TO BIND THE ASHLARS OF STONE FACING IN MONUMENTS FROM 1ST TO 20TH CENTURY

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ABSTRACT

Architecture, through the centuries, had always made use of iron not only for gates, staircases, banisters and railings, but also for firming buildings, connecting stones or timber among them and linking together distant parts by means of bars. In the most ancient buildings metal was used with more thriftiness than today's and, at any rate, it was never employed in sight. We can find only some bronze harpoons, iron bars and cramps hidden in architraves, drip-stones and vaults (Milizia [6]).

The walls of the Concord temple in Agrigento show an example of this kind of building. Rows, formed by equal dimension stones cut out carefully, are connected with copper pivots; the execution of this masonry is so perfect, that after making arcades in side walls many centuries later this didn't cause detachments on the top of the wall (Sganzin [5]). In gothic buildings, on the contrary, using iron became very plentiful: there is no stone not sealed with lead and iron cramps. The explanation of this is given by the great length of the arches' and vaults' piers and to have to endure thrust of the high and daring cross-vaults. The use of iron cramps was sometimes excessive and so blamed: indeed Vignola said "buildings must not to be supported by iron bars".

In sixteenth and seventeenth centuries iron was employed abundantly, especially for iron bars: for instance, Corsini palace in Albano has every room hooped by four great iron bars. With regard to this, Milizia maintained that " well-made buildings don't need these connections, which are nothing but remedies for old and ruined buildings" (Milizia [6]). Approaching today's, on the contrary, also maybe for building contractors'greediness a new straightforward and cheap but essentially faulty way, unknown in ancient times, of putting ashlars was accepted, by means of wood wedges. By this way followed the repeated settling of the French Pantheon'pillars, so great settlings to cause pillars' reconstruction (Sganzin [5]).

Nowadays, owing to using reinforced concrete in buildings and regarding to an ever greater attention to costs, the use of stone-buildings has come down remarkably and it is reducible almost to an aesthetic function. We employ thin slabs, so even more easily to fasten them to the walls by means of screws and pouring out liquid cement mortar in the interstices (Donghi [4]).

BRICK-MASONRY AND FACINGS

Treating of brick masonry we call "heads a brick's less area faces"; bricks "as like as stone ashlars can be placed in order by courses or horizontal rows, usually flatly, that is with the largest face placed horizontally, and, according to the bricks' heads will be normal or parallel to the wall front, we can say that bricks are placed *longwise*, *by thickness* as from *a* (figure 1), or *by key*, *by head*, as from *b* (figure 1).

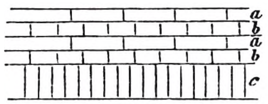


Figure 1

a, longwise bricks; *b*, bricks by key; *c*, bricks-on-edge course

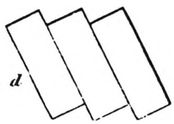


Figure 2

d, herring-bone bricks

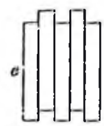


Figure 3

e, toothing bricks

When placed with the largest face upright we say that bricks are on *edge course*; if then the bricks-on-edge-course largest faces will fit together, we'll have an edge course, as from *c* (figure 1).

We have *herring-bone* bricks or *diagonal* courses when bricks forming a 45° or 60° angle to the wall front (*d*, figure 2); *toothing* bricks, if the bricks stick out one another (*e*, figure 3).

To setting the thickness of the walls must be aware that it takes in exactly a whole number of brick heads, adding the mortar thickness for each one. Walls are just named by the number of the brick heads, so there are one, two, three, exc.-heads walls (Donghi [4], Sganzin [5]).

Two following rules exist about brick-laying: 1) horizontal joints must be held by only one plane all along the length and the width of the wall; 2) vertical joints of two laid one upon the other courses must not ever coincide one with the other, but they must be offset and, if possible, crossing the wall all along its width. Usually, one centimetre in thickness for the vertical joints and 1.2-1.5 centimetres for the horizontal joints are fixed.

To carry out a regular connection are indispensable *three-quarters* and *half* brick pieces. It is necessary, too, to make sure that in ever external course there is the higher possible number of whole bricks and a strictly necessary number of three-quarters and half bricks to obtain the connection.

Every stone or brick facing should be carried out at the same time with the masonry to prevent detaching of the parts for the reason of different settlings. It is essential to find a remedy for it with the application of a thin and less contractible mortar."

If it is demanded to face a plastered brick wall with, for example, thick sandstone ashlars we should employ 6 cm in thickness, but by the corners and everywhere requiring more resistance employ 12-18 cm, the walls fitting according to these thickness (figure 4). Upper and lower face of each ashlar should be 1.5 cm in width fluted only, to receive putty or sealing mortar; vertically flutings can be wider. Stones' back faces can be left as unrefined as from the quarry, ashlars putted one on top of the other, dryly, with little lead plates interposed and connected to the masonry by 4 mm in side square section spikes with 10-12 cm in length. By the corners, pieces can be directly connected by fused bronze spikes in vertical joints (figure 5).

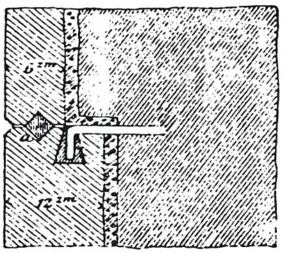


Figure 4

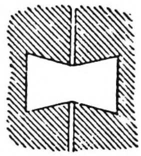


Figure 5

For little thickness we shouldn't employ zinc plated iron, to avoid rust. Spikes can be plastered in the masonry and sealed with lead in the sandstone. To seal the joints we can use water lime mortar, excluding cement, greasy lime and plaster.

Empty spaces that eventually can form during cutting out the wall behind the facing must be carefully filled with little pieces of broken bricks and mortar (Donghi [4]).

STONE-MASONRY AND FACINGS

As regards ashlar masonry, let's divide in pieces forming these walls: "flat horizontal faces, called *upper bed* and *lower bed;* external surface or *front;* joining surfaces or *joints*". Worked stones are placed in order, usually, by horizontal layers named *courses* or *rows* and, as like as brick walls, longwise or by head.

Nowadays, walls consisting in ashlar only are seldom built owing to very high costs, so ashlars are employed in facings or like special pieces as architraves, window-sills, pillars, columns, bases, shelves, exc. (Donghi [4]). "On the contrary, stone-built throughout walls, called *megaliths,* lie in times past. Those used in ancient buildings differentiate from today's ashlars, besides dimensions, for using mortar in stucco-works, rather than for connections.

The ashlars are connected among them, or to the rest of the masonry when it isn't stone-built throughout, by means of toothings. However, to obtain a more solid connection we resort to dowels, pins, spikes, iron or wooden or stone keys.

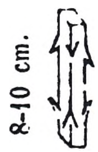


Figure 6
Iron dowel

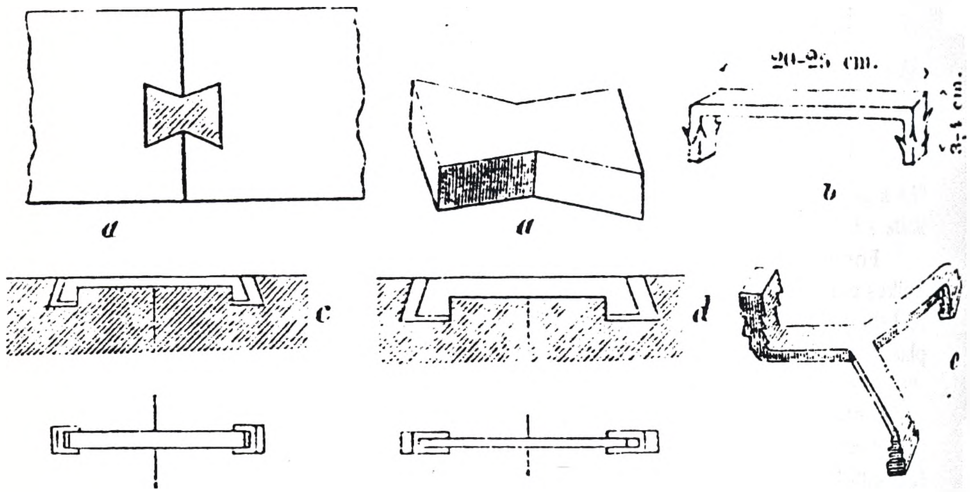
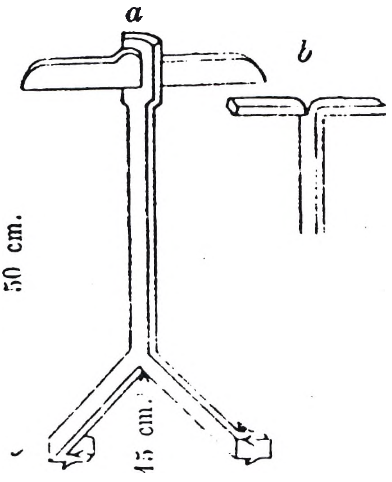


Figure 7
Spikes or iron cramps connecting ashlars



Generally, we have 2-2.5 cm in side square section iron dowels (figure 6); spikes or *cramps* (figure 7: *a, b, c* and *d*) can be made with flat or by thickness iron (there are L-shaped cramps in the marbles of Guarini's Saint Lawrence's church and straight cramps in the ashlars of Guarini's Holy Shroud's chapel in Turin). We have, as from *a,* a swallow-tailed cramp used for to join two ashlars from the same row. As from *b,* we have a flat iron cramp with upright teeth armed with points. We can also employ a flat cramp with smooth teeth but wedge-shaped, as from *c.* As from *d,* we can use a cramp on-edge-course with wedge-shaped teeth armed or not with points. As from *e,* a three-wings cramp can be employed to connect two or three ashlars from two rows laid one upon the other.

Simple or fork-shaped keys, as from figure 8*a*, are made with a 20-25 mm in breadth and 7-10 mm in thickness flat iron. It is advisable to make not removable keys to avoid forgetting to insert them in the lock; it is safer to divide in two parts the end of the key and then fold them in opposite ways (figure 8*b*). The thinner are the ashlars, the larger is the number of keys" (Donghi [4]). The employment of iron or copper bands fixed all along a row's upper bed is particularly recommended for masonry hit by sea-waves. Each ashlar forming the row is perforated by a vertical hole and by means of a bolt, crossing the band and the stone, ashlars can be considered united. To increase solidity we can extend, sometimes, the holes through one or two lower rows more, such that the lengthened bolt would bind them together (Sganzin [5]).

Non-monolithic columns or pillars can be connected by means of metal or wooden pins.

If we have a sandstone to face the masonry, and we should be afraid of the wall's behind thrust, like as, for instance, supporting-walls' thrust, we could connect the several ashlars leaving toothings at them (figure 9 *a*, *b* and *c*) always avoiding, however, to form acute angles.

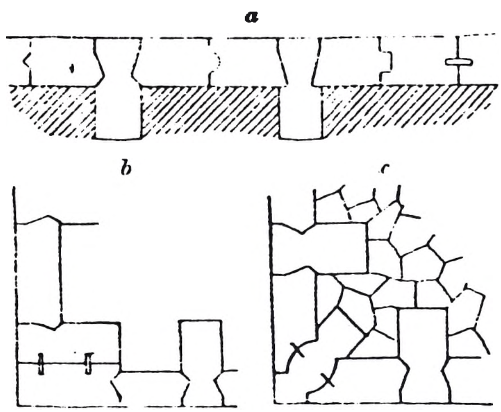


Figure 9
Facing swallow-tailed pieces connection
with cramps or various toothings

By the footings "we carry out a 12-15 cm in thickness facing, except by the corners which are formed with bigger ashlars. Normally, we alternate spikes with keys, so that the first and the second ashlar of one row are connected between them with cramps, the second and the third are fastened to the masonry behind with a fork-shaped key (figure 10), and so on" (Donghi [4]).

With regard to iron, Francesco Milizia reminded that iron employed in building "should be fire processed as less as possible, if we want to retain its mechanical properties. Incandescence deteriorates it: iron should be heated till the *cherry-red-heat.*

A bad practice can, however, damage the well fused iron too, that is to immerse the red-hot iron in water to handle it as soon as possible. The colder the water is, the less tough the iron is; by this way it should become vitreous and change its grain. Iron doesn't need much fire but much hammering: this increases the iron density, white-heat reduces it. The iron's variety depends on the way of manufacture process, rather than on its extraction place; hammering much and heating a little we make every iron well forged, whichever region of the world it comes from.

The best iron is nearly grainless and has a quite ashy-grey nerve. Half nerve and half grain is the iron preeminently. Nerveless and coarse grained iron is the worst and it should be proscribed" (Milizia [6]).

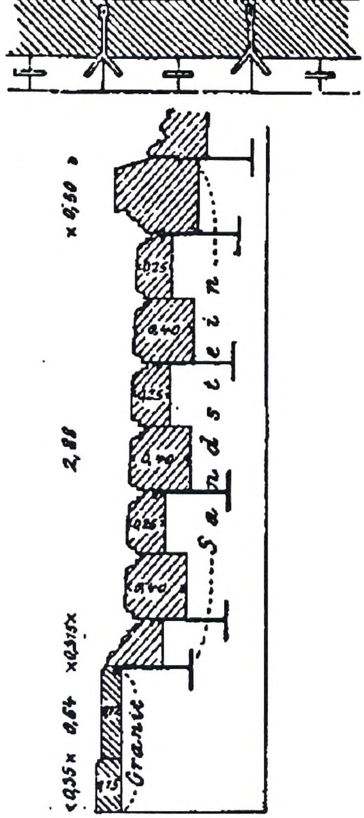


Fig. 10
Footing ashlar facing
(*Granit,* granite; *Sandstein,* sandstone)

These irons are kept in the holes made on purpose in the ashlars and becoming wide towards the inside by means of lead, sulphur, cement, plaster or iron filing putties. Usually, old lead is employed; it is poured into the interstices between stone and iron: when it get set we press it down, as like as iron filings putty, with a blunt iron or a hammer; sulphur must be heated over its fusion point til it gets brown, for, otherwise, it could form an iron sulphide and, dilating, chip the stone.

Seldom we use today plaster to fasten iron connectors on the ashlars: nay as cement strongly sticks to iron and preserves it from rust, we resort to cement. To avoid from rust anyway spikes, cramps, exc. should be tin-plated or zinc-electroplated.

Ashlars of stone facing are 12-30 cm in thickness when they're granitic or calcareous and 3-10 cm when marble. As from fig. 8, we can obtain connecting between facing and masonry, according to the cases, with cramps, keys, exc., as we said more above.

Frequently, we face masonry with ashlars whether throughout the front or baseboards, corners, drip-stones, exc. only. We have *right ashlars* when they present simple rectangle-shaped faces; *small pillow ashlars* when the jutting out parts are rounded; *unframed* or *rounded off ashlars* when there are two faces laid one upon the other with the borders linked together by means of any moulding; *diamond-point ashlars*, when we have quadrangular pyramid-shaped faces; *blunted ashlars* when the four edges of the faces are blunted; *unrefined ashlars* when faces are roughly chipped.

Some ashlars'forms in figure 11 are represented. We may not ever find ashlar rows with the same height (figure 11*c*) and stone-built rows throughout; sometimes brick-built rows alternate with them.

To avoid matter detachments or cracks owing to homogeneity lack among different materials make, when possible, the facing independent of behind masonry, fastening it, when the wall's construction is over, with little iron keys only (Donghi [4]).

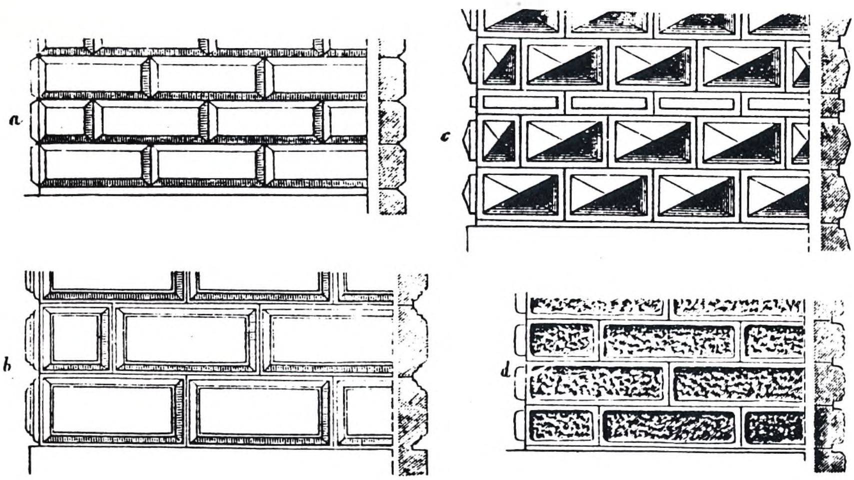


Figure 11
a, blunted ashlars; *b*, unframed ashlars; *c*, diamond-point ashlars; *d*, unrefined ashlars

ALTERNATIVE CONNECTORS

Iron, mostly at the seaside, increases in volume and causes by means of its expansion power, sometimes, a stone crack; to avoid it is recommended the use of bronze or copper; these are costly metals, however.

We carry out, ordinarily, cramp-iron's or pivots'soldering in the stones with lead. This means is the most solid, but it requires a considerable expense: we can replace it with vinegar-oxidized iron, sulphur and blends obtained by the fusion of sulphur with resin and sealing-wax (Sganzin [5]).

"We set ashlars through lime" not including any combustible element, as Palladio advised (Bertotti Scamozzi [2], Zorzi [3]) "mortar greatly added with plaster or pure plaster mortar too, applying two trails of mortar along the ashlars'side edges and then compressing these on the wall's surface highly damped. Empty spaces been left among the ashlars and the wall, are then filled with poured highly fluid plaster mortar. Big ashlars must be fastened behind with foundation screws plastered in the wall. Very expensive marble slabs can be sawed like a veneering and applied with plaster or putty on ordinary marble or sandstone ashlars, fastening them, then, to the wall " (Donghi [4]). See the columns of Holy Martyrs' church in Turin.

In imitation of the ancients, several constructors tried to increase buildings'solidity given by a mortar-bath, making inside fastenings through grooves and relieves made on the ashlars'faces. This means ran wherever masonry could be hit during the mortar's hardening (e. g., for those buildings exposured to the sea-waves), but it depended on the cutting out accuracy, such as to secure that each surface touched the other. It would be better to use plaster-cements or fused putty in horizontal joints (Sganzin [5]).

CONCLUSIONS

Due to the different use of metal connectors in order to bind the ashlars of stone facing in the different ages, it becomes very difficult to give a general rule for restoring or reinforcing those buildings.

$$\mathbf{Fe + H2O \Leftrightarrow FeO + H2} \qquad (1)$$

Passivation phenomenon: formation of iron oxide

We are only sure of the fact that, going back in old times, the quality of materials was very good. This is particularly true for iron, which was well forged and was always put in strategic places, well protected from water seepage; moreover, thanks to passivation phenomenon, a superficial formation of a very thin coat of iron oxide, as from eqn (1) (Brisi, Cirilli [1]) it could protect itself.

References

[1] C. BRISI, V. CIRILLI, *Chimica generale inorganica,* Torino, Levrotto & Bella, 1984; [2] O. BERTOTTI SCAMOZZI, *Le fabbriche e i disegni di Andrea Palladio,* Venezia, Alfieri, 1968; [3] G. ZORZI, *I disegni delle antichità di Andrea Palladio,* Venezia, Alfieri, 1968; [4] D. DONGHI, *Manuale dell'architetto,* Torino, UTET, 1906-1907; [5] G. SGANZIN, *Pubbliche costruzioni,* Venezia, Antonelli, 1847-1853; [6] F. MILIZIA, *Principi di architettura civile,* Milano, Ferrario, 1832.