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Old brickwork chimneys: structural features and restoration problems

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Abstract

The traditional masonry chimneys forming part of the first industrial installations in Italy, as of the second half of the nineteenth century, are replaced nowadays with constructions of engineering design and dimensions that benefit from tried and tested construction methods and satisfy specific standard requirements. A considerable number of older structures remain, however - mainly brickwork chimneys, some of which are surprisingly high (up to 70 m) and of remarkable architectural design - in certain areas of northern Italy that were among the first to be involved in industrial activities of various kinds.

As part of several schemes to restore and qualify some of these industrial complexes, this study proposes to analyse the type and structure of chimneys built between the 1870s and the first decades of this century, mainly in the Piedmont and Veneto regions, with a view to outlining potential codes of practice for their restoration. Starting from an examination of their technological and structural features, and restoration problems, the analysis aims to prompt proposals for action capable of complying with a restorative spirit while also ensuring that the buildings are made safe and stable.

1 Introduction

The problem of the chimney (and of the brickwork chimney in particular) is surely a typical example of the many "emergencies" posed by our historical buildings. The evolution in the methods employed in its making went hand in hand, in Europe, with a progressive transformation of the urban and rural landscape as a result of industrialisation. What's more, the chimney's design and construction often reveals the independent cultural roots of a given geographical area - tangible signs of the local artisans' skill, based merely on a few elementary rules, refined over decades of experimenting and handing down the benefit of experience from one generation to another.

In Italy, the first masonry chimneys for brick and lime kilns date back to the first half of the nineteenth century, and sometimes even to the end of the eighteenth. It is from these early experiences that a sophisticated chimney-building technology was developed and, from the mid-nineteenth century to the early years of the twentieth, this was progressively adapted to the demands of various kinds of industry, borrowing from experience already acquired in more-industrialised countries, such as Switzerland, France and Germany (where standard dimensional requirements had been laid down already in 1876).

Very often, what is most surprising today in many abandoned industrial areas is the remarkable height of some of the surviving nineteenth-century brickwork chimneys, and especially the extremely valid methods used in their making. Several unique models, based on different architectural types and construction methods, stand as proof that the admirable concepts behind their building were already considered as quite normal in their time, and relied on methods which were only formalised, circulated and discussed by the building manuals and technical literature towards the end of the last century. In northern Italy, and in the Veneto and Piedmont regions in particular, the perfection acquired in chimney construction technology benefited from two favourable conditions: the availability and relatively low cost of bricks and of lime suitable for the preparation of good-quality mortar, and a solid masonry-building tradition which had always had to deal with matters such as controlling the thickness of the wall facing and achieving particularly slim structures. It is hardly surprising, therefore, that the installations giving added value to the nineteenth-century industrial developments in these regions were made, up until the eighties at least, of load-bearing masonry - not only for the partitions and vertical walling elements, but also for the factory structures used for ventilation or for extracting gas or smoke. In addition, the close link persisting between the factory and the agricultural world ensured that there was a reliable source of virtually stable local artisans who were capable of perfecting chimney construction technique along the lines of the utmost simplicity in building methods and the best possible durability.

Brickwork chimneys were slowly and progressively abandoned by the industry as a direct consequence of a drastic drop in demand after the Second World War, following the introduction of forced-draught technology which soon led many entrepreneurs to lower the height of their factory chimneys - or even to demolish them altogether. Metal chimneys with forced draughts were cheaper and easier to build and took up less space, so they were generally preferred for modest needs, whereas higher-performance chimneys were made of reinforced concrete, which can easily overcome the technical and structural problems posed by brickwork chimneys. At the same time, many nineteenth-century industrial plants were becoming obsolescent and their chimneys with them. In the absence of the routine maintenance which had kept them in good working order over so many decades, the brick chimneys soon aged, often deteriorating to such a degree that they were no longer structurally safe [1].

Little remains of the numerous chimneys illustrated in paintings and drawings of the past, which showed a nineteenth century northern Italian industrial landscape concentrated around the edges of towns, along torrential rivers and canals (which provided the Italian industry's main source of energy for many years), along the Venice lagoon coastline, or isolated in open country, often annexed to stately homes or farmsteads, usually close to the raw materials involved in the industrial process (clays, mulberry crops, tobacco) or alongside tanning plants or textile mills [2]. The few chimneys that survive as rare examples of what was once a common sight in industrialised areas are generally lower and have been heavily repaired, or even totally rebuilt. It would be impossible to reutilise most of the chimneys that still characterise many industrial installations originally built inthe nineteenth century, but a number of chimneys could be restored and their structural features safely preserved for the future.

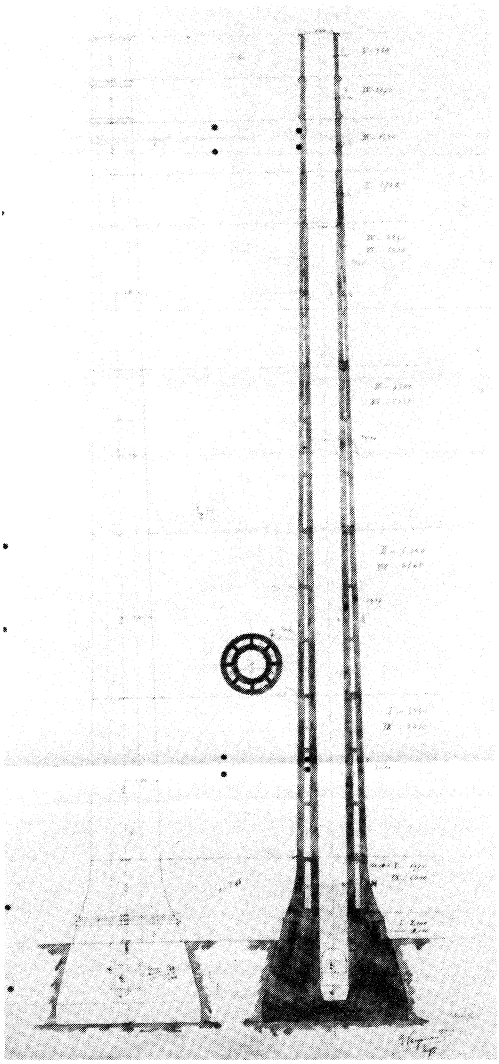

Figure 1: The "great chimney" (44 m high) at the Rossi woollen mill at Schio (Vicenza), from 1888. From the archives of the Lanificio Rossi, Schio.

After witnessing the destruction in recent years of a great number of chimneys in some of the most famous industrial areas of northern Italy, the present authors are now researching how to reinstate the heritage of surviving buildings, also taking into account a growing demand for action to preserve

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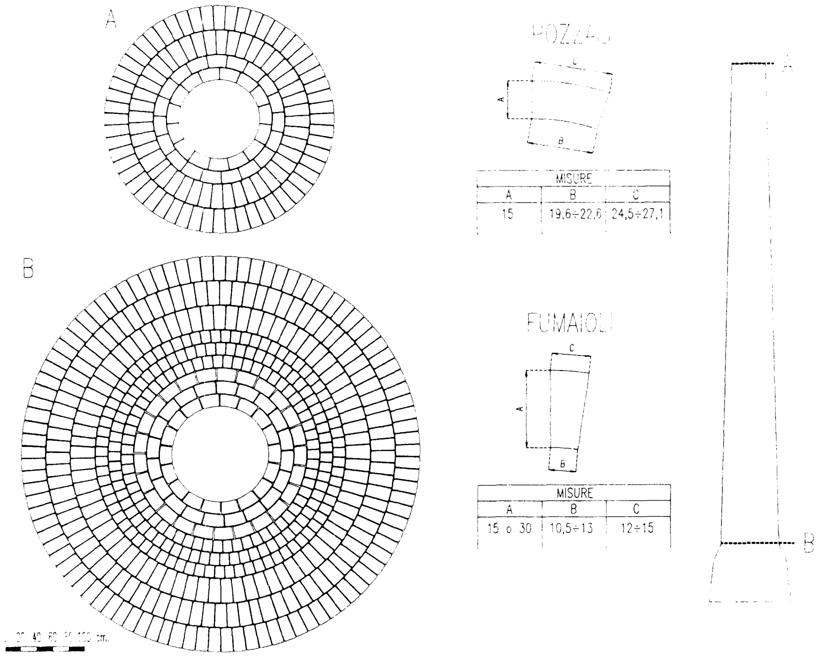

Figure 2: Reconstruction of the bond arrangement of a typical single-stack brickwork chimney for a 43 m high brick-baking kiln.

more recent structures (built in the last 50-70 years), especially when such intervention seems economically worthwhile as part of a scheme to restore an industrial plant to practical use.

2 Aspects of typology and construction

In Italy the first chimneys were introduced as a result of the installation of Hoffmann continuous furnaces in metal-working plants and for the production of coal gas, or with the rare steam engines. They became widespread about 50 years later than in other parts of Europe and in an atmosphere of strong resistance to innovation. Steam as a source of energy was mainly used in textile plants where admirably-made chimneys often still stand today, albeit in a state of disrepair.

Towards the end of the last century, there were signs of remarkable imagination in the design and building of some chimneys, thanks partly to the improved methods used by the brick and binder industry and partly to the creation of solid scientific foundations for the work of structural design. The phenomenon is particularly noticeable in the most rapidly-developing areas, which proved remarkably fertile in technological terms. This is apparent in Piedmont, in several examples constructed along the characteristic lines of the Antonellian school's brickwork skeleton, e.g., the chimney at the Turin old peoples' home, built in 1887 by one of Antonelli's disciples, Crescentino Caselli, is not particularly tall (41 m), but is suspended off the ground, supported by four hollow brickwork columns.

Despite its important technical implications, the building of chimneys in the area and during the time considered in the present study was scarcely concerned with matters of engineering competence. The particular structural features of the majority of these chimneys stem from the use of standardised codes of practice coupled with a solid artisan tradition for brick-laying, and the global quality of the masonry work and its structural reliability were the outcome of the care and precision that went into the various stages of its making [3].

Special precautions were taken in making of masonry walling to make the best possible use of the way the chimney behaved in relation to any tensile stresses resulting from the effects of the wind and the temperature differences between the inside and outside of the chimney. Great attention was also paid to selecting and preparing the raw materials (bricks and mortar), to selecting a bond comprising strain-resistant elements that were made to measure in suitable forms, to containing the thickness of the horizontal and vertical joints, and to constantly checking the geometry of the stack during the construction process [4,5].

The height of the chimney depended on intrinsic functional demands and the local weather conditions, taking into account the output of the furnace or boiler, the resulting volume of fumes or dust needing to be disposed of, and also its toxicity. The natural draught was improved by incrementing the temperature difference between the inlet at the bottom and the outlet at the top of the stack. The temperature gradient naturally also depended on the local climate, which was linked to the latitude and local wind conditions. The older chimneys had to be higher because they could only rely on natural draught, and chimneys built in the plains were usually taller than those in the foothills, because the latter benefited from the advantage of discharging gases into ascending air currents.

The chimneys at the Veneto factories were usually around 25-30 m high, with occasional cases of over 40 m (Fig. 1), and with the exception of two chimneys at the Trevisan furnace in Villaverla, which were built 70 m and 60 m high. In Piedmont, and particularly in the textile factories around Biella (an important study area in Italy, with an abundance of industrial findings), the heights of the stacks varied from 35 to 50 m, with exceptions of 60 and 63 m at the woollen mills of Veglio Mosso and Pianceri.

Standing on what was usually a polygonal foundation bed and usually built of bricks, sometimes of stone, and very occasionally of concrete, the chimneys were made exclusively of bricks, adopting either a single-stack solution, which was more widespread in the Veneto and Lombardy regions, (Fig. 2) or a double stack, more often seen in Piedmont (Figs. 3 and 4). The stack was usually

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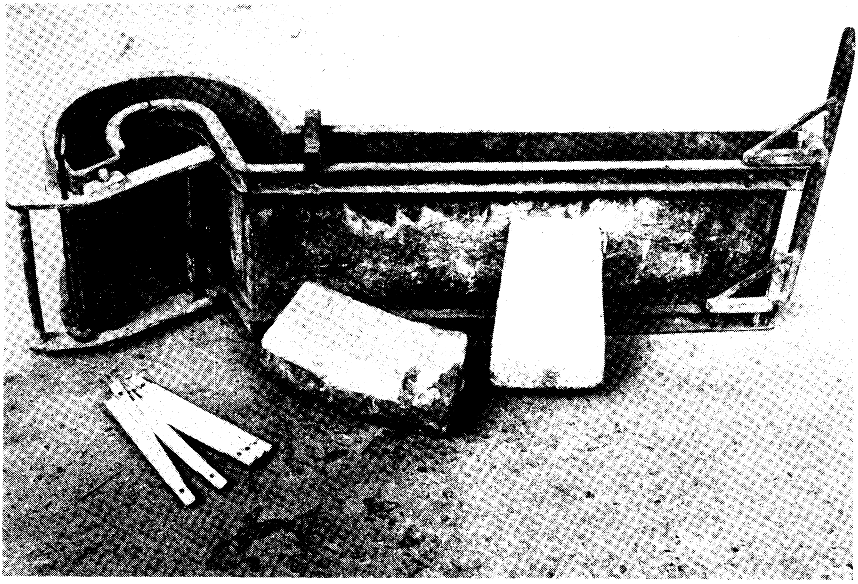

Figure 3: Common types of brick used in chimney construction: a circular-crown frustum brick and a radial brick. In the background: the mould used towards the end of the 19th century for preparing concrete quoins of various sizes using the Monnoyer system.

Figure 4: Reconstruction of the cross section through a typical double-stack chimney (Settimo Torinese, originally a tanning plant).

circular in cross section, but sometimes it was polygonal. The single-stack chimney had no inner lining; it was tapered progressively towards the top on the outside and had offsets corresponding to this progressive reduction in the thickness on the inside. The double-stack type had an outer wall of bricks, sometimes plastered on the inside, which not only protected the refractory material of the inner flue (which was more liable to wear because of the high temperatures involved), but also ensured the circulation of air which helped to reduce the temperature of the gases being discharged. In this second type, moreover, the cavity created between the inner flue (which had the same cross section all the way up) and the outer shaft (which was tapered towards the top) not only increased the draught, but also protected the inner flue from sudden temperature change. Structural stability was often ensured by radial ribbing which extended from the surface of the inner flue's extrados almost to the surface of the outer shaft's intrados, though never making contact. This ribbing was closed horizontally by bands of bricks arranged at regular intervals and served the purpose of creating sufficient slack for dilatation. As regular and frequent maintenance and repair work was expected to be necessary, ladders (made simply by walling in a series of "U"-shaped metal rungs on the inside or outside) provided access to full length of the chimney [6].

The chimney tops were often characteristic, with genuinely decorative crowns which sometimes took inspiration from Classic styles, though their handsome features were often combined with the practical utility of correcting gas or dust turbulence (thus preventing it from depositing on the masonry and giving rise to chemical deterioration processes, especially in the mortar of the outer shaft). In addition, a decorative chimney top was considered by the entrepreneur as a sign of prestige and distinction, to the point that the particular appearance of a given model often became a sort of "trademark" of the company concerned [7] (Figs. 5 and 6).

The bricks in the masonry forming the stack were always obtained from excellent-quality, well-baked clays, so that they would be sure to combine a reliable mechanical strength with durability. Visual inspection of a number of buildings that have been in use for over a hundred years, even in severe climatic conditions and despite our acid rains, has revealed bricks in remarkably good condition in the majority of cases: in a few, particularly difficult environmental situations, the bricks have deteriorated, usually in limited areas and only involving the uppermost layers, to a depth of a few millimetres.

Mortar was prepared with traditional air-hardening lime, obtained using lime from selected sources and integrating this with hydraulic compounds prepared according to what was locally available. The good mechanical properties and hydraulic features of the mortar would consequently be associated with the advantage of a growing resistance over time, thanks to the continuing reaction of calcium carbonate forming in contact with the carbon dioxide in the atmosphere. Air-hardening mortars were also particularly suitable - in working conditions sometimes involving even extremely high temperature differences - for coping with stress adjustments in the masonry

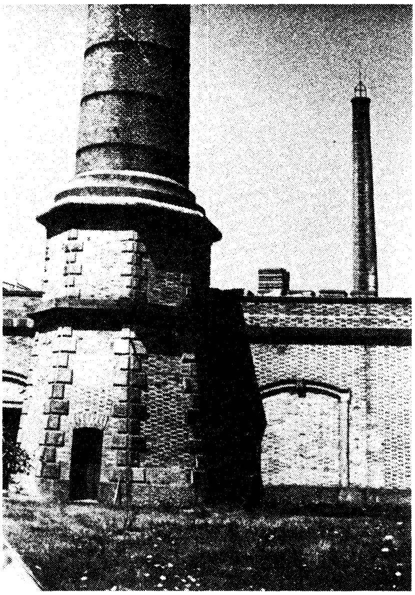

Figure 5: Traditional architectural influences of Mantua in the basement of the Sermide chimney (Moglia di Sermide, Mantua).

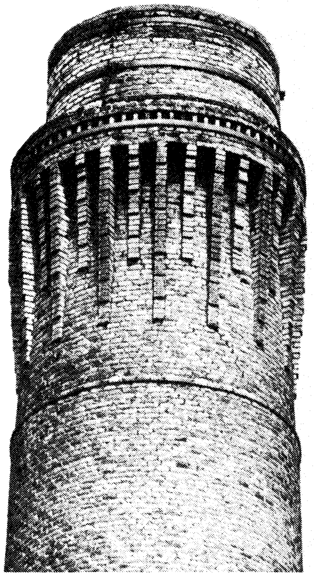

Figure 6: Detail of the top of a large-diameter chimney (Tortona, originally the Delle Piane textile factory).

without cracking.

From the point of view of the building methods involved, the dual-stack chimney was particularly demanding. The most complex aspect of the operation was certainly the construction of the outside tapered shaft: to ensure that the inner flue was encountered at the pre-established height called for the ability of a real master craftsman and, in the majority of cases, the chimney builders who were making a name for themselves in central and northern Italy towards the end of the nineteenth century were exactly that. In the Biella district, around the year 1890 for example, there were contracting companies specialising in the construction of chimneys and working together in associations. These were builders who had grown up in contact with master builders in foreign countries, especially in France, and who continued to use locally-obtainable materials and products (cements and limes, bricks of various shape and size) for decades, virtually up until the Second World War.

But certainly long before their time, there had been a strongly influential migration of furnace and kiln workers coming from Malcantone Ticino (Switzerland) and heading for the areas of northern Italy where the first brick kilns were in operation; these were artisans specialising in a given manufacturing process, but they were also competent builders of the early brick-baking kilns, and particularly of the relevant chimneys. From the end of the eighteenth century up until the start of the twentieth, there was a seasonal migratory flow from Malcantone to Lombardy, Piedmont, and the Veneto and Emilia regions. The artisan quality of this influence gradually faded, especially after the introduction in the mid-nineteenth century of the Hoffmann continuous kiln.

3 Recurrent problems and restoration criteria

The historical documents available on the functional problems of the old brickwork chimneys is very limited, usually merely a record of the most dramatic events, such as partial collapse or severe damage due to lightning, wind, earthquake or war, and usually followed by ample repairs or complete rebuilding. Though far from being well-documented, the repair and maintenance operations on the brickwork masonry chimneys were based on the maintenance routines typically performed on masonry works. This varied in relation to the extent of damage detected, ranging from locally replacing the mortar to inserting reinforcement elements (metal rings around the stack), straightening the shaft, reducing the height (depending on the use of the chimney), or reconstructing its damaged component parts.

Today, the problem of preserving these old brickwork chimneys and restoring them, possibly even for future use, calls for a new awareness and attention to modern-day safety demands [8,9]

The typical signs of deterioration in chimneys that are still standing are linked to their role in disposing of the smoke and fumes coming from the industrial plant below, but local climate also plays a major part, especially in the event of freezing and thawing cycles which can accentuate otherwise inflicted damage to the point of weakening the stability of a chimney left totally without maintenance, usually because it is no longer in use.

One or more of the following types of damage are commonly encountered, typically leading to the chimney becoming unsuitable for use:

- Effects of the disposal of smoke and fumes

  Damage to the chimney top, possibly leading to its deviating from the vertical axis, due to the chemical action of oxides in the fumes on the mortar on the inside and outside walling and of acid rain on the lime contained in the mortar.
  Crumbling effects in the mortar caused by the swelling of the reinforcement due to oxidation in the damp and acid microclimate.
  Localised cracking, especially around the top of the chimney, due to the temperature differences between the outside and inside of the chimney when it was in use. Left without repairs, these cracks facilitate the propagation of material deterioration, particularly in the mortar.

- Effects of the climate and ambient conditions
  Material damage due to freezing and thawing, especially when the chimney is out of use; this is usually located on the north-facing side and consists in

crumbling of the surface layers of mortar and exfoliation of the bricks, which often lead to a deviation from the vertical axis at the top of the chimney.
Localised cracking caused by lightning or strong winds.

- Extraordinary mechanical effects

  Mechanical effects of static disruption caused by wind, lightning, and earthquake, affecting the construction as a whole and capable of making it structurally unreliable, particularly in combination with other types of damage.

Locating and estimating the extent of the damage calls for a thorough analysis of the signs of deterioration and of their causes in order to suitably plan the necessary maintenance, bearing in mind the local environmental conditions and the predicted usage of the chimney.

As far as the methods for diagnosing the damage are concerned, recently-developed techniques that are now in widespread use for inspecting masonry structures on site are presumably suitable for examining these brickwork chimneys. These involve non-destructive or marginally-destructive investigations to establish the features of the materials and direct inspection of the cracking phenomena, but may also be extended to include an estimate of the compressive strength and elastic modulus of the walling with the aid of flat jacks.

The first, essential stage includes a visual inspection, accurately detailing all the structural features and damage, also with the aid of historical documents and using non-destructive or only marginally-destructive on-site tests (hole-drilling, core-boring, surveys of cracking phenomena, indirect sonic tests to locate gaps, thermographs, etc.). These investigations are often sufficient in cases of masonry retaining the structural continuity and homogeneity of the original, having undergone no improper repairs that might have disrupted its original equilibrium, and generally presenting lasting features. If the environmental conditions are not particularly severe (earthquake, wind, temperature differences, etc.) and the structure is not particularly slim, the necessary action may often be limited to a delayed overall maintenance, routinely followed up and involving cleaning, restoring pointing, replacing damaged metal elements, etc. (even if the chimney is not in use). The most common repair methods involve spot repairs on damaged mortar, localised replacements and even the partial reconstruction of severely damaged areas, the placement of additional reinforcement ribbing either at the top or covering the full height of the chimney, or the replacement of damaged reinforcement elements.

The second stage in approaching restoration work becomes necessary for severely damaged or particularly tall structures, or when the initial examination has been unable to deal adequately with all the problems emerging in terms of global stability and durability. It involves dynamic and static tests that may be destructive (e.g., taking samples of bricks and masonry on site), marginally-destructive (e.g., using flat jacks to establish the compressive elastic modulus and stress status), or non-destructive (e.g. sonic tests, used to establish the physical and mechanical properties of very compact and well-bonded walling). This experimental support is needed in some cases to provide quantitative indications as to the elastic properties of the masonry, for use in evaluating its safety and consequently deciding on the action needed to ensure overall structural stability (e.g., strengthening with reinforced concrete, steel, etc.).

Previous experimental results and our consequently better understanding of pre-modern load-bearing masonry enable us to better define its physical and mechanical behaviour, particularly as concerns the scarce contribution of the mortar to its elastic properties, the more limited compressive strength values than those of modern masonry structures, the lower values for its compressive elastic modulus and its greater ultimate deformation capacity by comparison with modern masonry. If such findings are also confirmed for the specific type of load-bearing masonry found in the old brickwork chimneys, the problem of restoration must be approached with great care and all due precautions, especially with a view to avoiding taking inappropriate action that might subsequently prove unsuitable for the characteristics of the original material, and consequently ineffectual or even harmful.

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