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Abstract: This article provides an overview of pneumatic technologies in nineteenth- and early twentieth-century Western cities. As urban centres continued to grow and expand in the nineteenth century, networks of compressed air were introduced to provide public utilities and private services in a variety of domains, ranging from postal services to beauty parlours. Previously used in mining and large construction works, pneumatic technologies seemed to rival electricity towards the end of nineteenth-century in the provision of urban utilities. In the end, however, these technologies did not prove feasible enough to keep up with urban growth and expansion. Through an overview of compressed air applications as used in urban centres, our article provides an insight into the relationship between technological networks and urban modernities from the perspective of this relatively neglected urban network and technology.

10 September 2015

Paris

Dear Professor Ogborn,

Please find attached our revised article in light of the referees' comments. We would like to thank all three referees for the extremely useful comments they provided. We have tried to address them, and this letter details the changes we made to the paper.

A common concern among the referees had to do with the status of technology and understanding more about technological change through our empirical example. Ref-1 suggested that we engage with some of the related literature. We have done this, and now the paper has more general messages to deliver rather than remaining limited to a description of pneumatic technologies. These have to do with the merits of not limiting analysis to mere technological aspects, and the usefulness of taking into consideration auxiliarytechnologies which might end up in 'failure' – rather than focusing on innovation and success only.

Addressing this issue also helped us to clarify our approach, which was highlighted by Ref-3. We are now clear that our analysis is not undermined by technological determinism, that we consider cultural aspects as well, and more sensitive to the broader context (which were also highlighted by Ref 1 and 2).

The major change followed from this position: that the disappearance of pneumatic networks had to do not merely with technological limitations and rapid urban change, but also withdominant urban imaginaries about urban modernity, and concerns about giving access to underground. The list of references on urban modernities provided by Ref-1 was very helpful in developing these aspects of the article. Also, the point made by Ref-2 about the representations of this technology led us to a film by Truffaut, which we have used to illustrate our point about the place of pneumatic networks in the imaginary. We have also greatly benefited from the formulations of Ref-1 and Ref-2 on (in)visibility and benign neglect, and of Ref-3's recommendation to consider these networks in relation to urban modernities.

Ref-3's comments also encouraged us to signal these arguments early on in the paper, and develop especially the first and the last sections.

We brought in an article by Atmore (2004) to make one of our points more clear: that these technologies were at the time a real alternative. Retrospectively, they do not seem to make much sense, given the limitations, but in the nineteenth-century this was not yet definitive.

We realised also that we had introduced some confusion regarding London and Paris. The difference is not, as Ref-1 pointed out, only down to private versus public organizational structure. We are now more clear on this (e.g. Paris system benefited largely from the existence of vaulted sewers and a more compact urban pattern).

We hope that these changes are satisfactory. We are grateful for the very constructive remarks and suggestions.

Yours sincerely,

Prof. Mustafa Dikeç (corresponding author)

and

Dr Carlos Lopez Galviz

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*Title page with author details

'The Modern Atlas':

Compressed air and nineteenth-century cities

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Highlights for 'The Modern Atlas':

- Pneumatic technologies were significant parts of nineteenth-century Western cities
- Compressed air competed with electricity as motor power
- Pneumatic urban networks were part of urban modernities, but remained obscure

'The Modern Atlas'

Abstract: This article provides an overview of pneumatic technologies in nineteenth- and early twentieth-century Western cities. As urban centres continued to grow and expand in the nineteenth century, networks of compressed air were introduced to provide public utilities and private services in a variety of domains, ranging from postal services to beauty parlours. Previously used in mining and large construction works, pneumatic technologies seemed to rival electricity towards the end of nineteenth-century in the provision of urban utilities. In the end, however, these technologies did not prove flexible enough to keep up with rapid urban growth and expansion, nor were they able to become glorious symbols of urban modernity. Through an overview of compressed air applications as used in urban centres, our article provides an insight into the relationship between technological networks and urban modernities from the perspective of this relatively neglected urban network and technology.

Keywords: compressed air; ~~pneumatic technologies~~; ~~urban networks~~; Paris; ~~Victor Popp~~

'The Modern Atlas':

Compressed air and nineteenth-century cities

> Compressed air, though as old as the hills, is a new thing in its usefulness to mankind. This century, and we may also say this decade, is the compressed air era, and yet the useful application of this power has become so general, that we appear to be only beginning to enter this wide field of usefulness.[1]

~~Pipe dreams~~

In 1900, Charles Emory Smith, the then postmaster-general of the United States, predicted that by the end of the decade the pneumatic postal tube system would extend to every house for the immediate delivery of mail following its arrival in cities.[2] It turned out that his prediction was not quite accurate – far from it. By 1918, it became clear that the future of mail delivery in the USA did not lie in pneumatic tubes, and the system was gradually suspended in the following years. Smith's prediction~~,~~ ~~however,~~ was not so ~~much~~ off the mark ~~either~~. In the late nineteenth and early twentieth century~~,~~ the use of such networks in cities of Western Europe and the United States was hardly uncommon. Pneumatic technologies were perceived as a developing and promising technology for the future. It was, contemporaries observed, ‘The Age of Compressed Air’. Compressed air was ‘The Modern Atlas’ that sustained the industrial world upon which one ‘revelled in dreams of pneumatic enthusiasm’.[3]

Insert Figs 1 and 2 here

The glory days may be over, but pneumatic technologies are far from dead. Several small cities in France opt for pneumatic recycling systems in newly built areas (Saint Ouen, Romainville). There are also signs that some of the dreams of the pneumatic enthusiasts may be materializing. Since 2003, a system called Pipenet has been developing to propose a more environmentally friendly and cheaper alternative to freight transport.[4] In 2013, the French car manufacturer Peugeot revealed its new hybrid engine using fuel and compressed air, which is expected to reduce fuel consumption and be ready for commercialisation by 2016. The MDI (Motor Development International), another French Company, has been developing compressed air cars for more than two decades, and has recently signed a licence agreement with the Indian automotive manufacturing company Tata Motors to produce and commercialise compressed air cars in India, notably its AirPod model.[5] Hybrid technologies constitute one of the key alternatives that car manufacturers continue to explore in order to preserve their share in the future of sustainable mobilities.

In this article, we explore the contribution that a brief survey of pneumatic technologies in nineteenth- and twentieth-century Western cities has to make to our understanding of the consolidation of urban networks. Whereas transport, telecommunications, electricity, sewers, and, more recently, water have received due attention by historical geographers, historians of science and technology as well as cultural historians, scholarship on compressed air has been predominantly the field of practitioners and enthusiasts, who highlight the minutiae often to the expense of context and analysis.[6] One of our aims is to contribute to redressing this balance through a close examination of pneumatic technologies that traces their emergence, development and final disappearance. In so doing, we wish to explore whether and how the 'cities of air' might supplement the better-known 'cities of light', with Paris being the most iconic example. As the article will show, Paris and other cities were cities of air too, where pneumatic systems compressed, distributed and sold air in a way analogous to public utilities. Furthermore, pneumatic technologies contributed to and were part of the specialisation of uses that was characteristic of the proliferation of urban networks. A detailed characterisation of that process in European and North American cities will provide unique insights into the relationship between technological networks and urban modernities.

Technological networks and urban modernities

The rise of the telegraph, and later telephony, developments in postal services and urban transport, the planning and construction of sewers as well as the provision of public utilities such as gas and water have been central to studying the development of networks of infrastructure in cities.[7] Urban networks were, and remain, visible and invisible; overground and underground; fixed yet growing; privately-funded and publicly-operated or a combination of both; giving comfort to city dwellers, but also making them vulnerable.[8] One of the significant aspects of the planning, building and maintaining of these networks lies in their being an expression of and a means for the modernisation of cities, a process that is gradual and piecemeal, juxtaposing new and old.

As Richard Dennis argues, modernisation involves a 'marriage of technology and myth-making' in the sense that ideas around transport infrastructure, for example, often draw on notions such as progress and improvement.[9] True, the emergence of tramways, the wide-spread use of bicycles and, gradually since the opening of the Metropolitan Railway in London in 1863, underground railways, did transform the urban experience of nineteenth-century cities, but an important part of that experience included the vast majority of people that continued to walk, negotiating their way amidst horses, animals, carts and other vehicles in generally overcrowded streets and thoroughfares.[10]

Change also involved regulation, whether this was in the form of directing public behaviour on streets and markets, encouraging co-ordination in the provision of public utilities that were often built by private companies, and developing the regulatory frameworks to support the effective governance of infrastructure.[11] Building networks was supplemented by building upwards, following important innovations in steel-frame structures and hydraulic lifts, both central to the now familiar skyline of cities such as Chicago, Boston or New York. Moreover, cities became places where the pace of change seemed to accelerate and technological innovation thrived as it has been explored in the 'urban histories of technology' by Mendelshon, and others.[12]

The modernisation of cities, the building of new networks and the upgrading, maintenance, reuse or closure of old infrastructure are all part of the same process. As Graham and Marvin suggest: 'Networked infrastructure [...] provides the technological links that make the very notion of a modern city possible.'[13] Modern cities, in the late nineteenth and early twentieth centuries, provided the quintessential arena for the consolidation of these networks. Technologies undergird the transformation of cities, but so do cities structure the conditions under which technological innovation and development might evolve.

'To think in terms of networks', Osterhammel argued, 'was a nineteenth-century development'.[14] Following the work of Matthew Gandy, we relate the 'modernisation' of cities in nineteenth century to the development of technological networks. Pneumatics was a network-creating technology, and was thus associated with what we call urban modernities, which we see as a 'technopolitical field' that includes ideas about and images of the city.[15] The importance of imaginary in shaping socio-spatial configuration in cities has been noted by several scholars.[16] Urban modernity in the nineteenth and into the twentieth century was closely associated with advances in science and technology, which found a prominent place in cityscapes. As Kaika and Swyngedouw argue, during this period of modernisation, urban networks were celebrated as glorious symbols of modernity and were proudly displayed in urban spaces. After the war, however, they started losing their place in cityscapes and came to be seen as a mere engineering matter best kept out of sight. This shift from being civic symbols of modernity to engineering problems led to their disappearance not only from cityscapes but also from urban imaginaries.[17]

In the case of sociotechnicial transition, Elizabeth Shove argues that the focus is for the most part on the introduction of new technologies, and how this implies the death or demise of other networks.[18] Our story is not one about a new technology replacing the old. It takes place in a period of experimentation with different technologies in an age fascinated by technological innovations and networks,[19] where several technologies – electric, pneumatic, gas – ~~that~~ were competing with each other. Pneumatic technologies deployed in urban space captured the imagination of inhabitants, in Paris in particular. However, their shortcomings undermined confidence in them in the early periods of experimentation, and they did not have the same versatility and 'visibility' as electricity. The pneumatic pipes were relegated to the underground where they did useful work, while electricity lit up the streets (gas as well but this is not covered in this article), giving it, as it were, a more prominent ~~display and~~ place in the urban landscape and imaginary. Perhaps exemplary here is a scene in François Truffaut's 1968 film *Stolen Kisses*, one of the later representations of ~~this~~ technology in film where the camera follows the rusted pipes in the dark sewers while a canister with a letter in it travels through them ~~–~~ very convenient network, but not a particularly glorious image. Partly because of its relative safety and 'invisibility', compressed air was not as fascinating as electricity or gas, and was therefore more susceptible to benign neglect.[20] There is also evidence from Paris that suggests that electricity was seen somewhat more 'scientific', an example of which was the Paris Observatory scientists' preference of electricity over pneumatics for the regulation of the city's clocks.

By examining the introduction of compressed air into the fabric of late nineteenth and early twentieth-century cities we can characterise the relationship between technological change and urban growth. New technologies required a market to succeed. That market was, in cities, plural, generally open and 'splintered' in a wide range of uses and applications. It was in cities that electricity, for example, generated and built upon a significant market of hotels, shops, theatres, fashionable restaurants and middle-class households, which used the new technology to lure their customers and users into a new sense of being modern. By contrast, compressed air was a technology whose applications tended to be niche, limited to specialist services such as the post and time regulation.

The inroads that the advocates and businessmen behind compressed air carved were modest by comparison with electricity. The scale of the plans and the actual infrastructure that they built were not based upon the 'culture of invention', which might have been apparent through the experience of AIG in Berlin, or that of Thomas A. Edison in Menlo Park. Nor did compressed air create a system combining invention and science, on the one hand, and manufacturing and distribution, on the other – at least not during the period considered here and certainly not in a way that would make it comparable to contemporary developments in electricity. Pneumatic tubes were not the stuff behind ambitious schemes such as 'Superpower', northeast of the United States, which 'called for the construction of privately funded Superpower plants of 60,000-to-300,000-kilowatt capacity to be interconnected by transmission lines of 110,000 to 220,000 volts'; or, Gifford Pinchot's giant plant in western Pennsylvania with a similar output and 200 miles to cover; or, Henry Ford's increasingly decentralizing model, started along the Rouge River in his Dearborn farm, soon expanding with 'assembly branches in ten countries and assembly or service branches in thirty-four American cities' by the mid 1920s.[21] Furthermore, the role that patents and intellectual property played in the legal and commercial applications of electricity has no equivalent in compressed air, or, at any rate, none that we have seen in the period covered in this article.[22]

When seen through the lens of compressed air, the technological change that we might associate with steam or electricity and its relationship to cities looks different. It reveals what contribution supplementary and auxiliary technologies made to the modernisation of cities, stressing the conditions under which technological innovation and development might evolve in contexts that are specifically urban. Developments in compressed air during the nineteenth and twentieth centuries were part of the larger process of differentiation, consolidation and transition of technological networks in cities. This is a process that we know well in relation to water, sewers, electricity, transport, postal services, and more, but not in relation to supplementary technologies such as compressed air. This focus seems to us important in two respects. First, it gives technological change a spatial dimension in a way that echoes the location and places of knowledge that Ophir, Shapin and Schaffer have foregrounded in science.[23] The introduction of compressed air in cities contributed to forging a new geography of networks that connected (and, therefore, also separated) specific places such as hotels, banks, railway stations, and post offices across cities as diverse as London, Paris, Boston, Chicago, New York, Berlin, Vienna and Prague; and it did so differently, but also with some similarities between cities. Second, the focus on compressed air highlights the joining of the twin forces of diversifying and specialisation. In other words, compressed air was suitable for some but not all of the small-scale industries and businesses that had a foothold in cities. It represented advantages, notably its safety, its cleanliness, and its ease of operation and maintenance which made skilled labour redundant, thus saving costs. Among the limitations there were the capital needed to meet the costs of first installation and the comparatively high rate of power loss when the air compressed was transmitted at a distance.

In addition to providing a survey of these neglected pneumatic technologies in cities, our aim is to show what the development of supplementary and auxiliary technologies reveals about the larger process of modernisation in cities. The ‘rise’ and ‘fall’ of compressed air resonates with the significant role that urban populations and urban commerce have had in the shaping of technologies in European cities, as shown by Hård, Misa and others.[24] Concentration and density were important factors in the geography of compressed air; in how compressed air was produced and distributed;

and in who were the ‘air’ customers whether in the bourgeois residences and small workshops and businesses of cities like London and Paris or in the tall buildings of Chicago and New York. Pneumatic networks produced ‘cities of air’ that stood side by side with the better-known cities of light, not least in Paris. Safety and hygiene, adaptability to the scarcity of space that was (and still is) characteristic of cities, and being a relief to overcrowded services supported by other technologies, are all part of the story that tells us exactly how and where air met light.

The precise ways in which pneumatic technologies were introduced into nineteenth-century European and North American cities will show the extent to which compressed air, very much in line with other technologies, supported and contributed to the specialisation of a wide range of services each based upon specific needs. To a degree the developments that are examined in this article show technology as contingent ‘born out of conflict, difference [and] resistance’, and as being permeated by strategies in which actors and contexts ‘are recursively implicated’.[25] The production of compressed air required the construction of large buildings to house large machinery, from which an intricate network of pipes, valves and regulators originated, connecting homes, public buildings and other places to an operational system. The social edifice of modern lives founded on regularity, reliability and comfort was based upon this kind of infrastructure. In some respects, the buildings where compressed air was produced embody the dialectical relationship between the invisibility of infrastructure and the monumentality that is at the heart of urban networks.[26]

The cities where compressed air was used, in this article limited to Europe and North America, determined the kind and scope of the pneumatic systems that were built. Questions around efficiency and productivity as well as safety, ease of use and maintenance took on a different dimension in cities. Using compressed air in, for example, mines or in large infrastructure projects like bridges represented unquestionable benefits, but the question remained as to whether and how those benefits translated into urban contexts. At the same time, plants, pumps, tubes and reservoirs provided a most welcome relief to the intensification of communications, ~~notably,~~ postal services and urban transport, ~~in cities.~~ However, ~~although~~ pneumatic technologies ~~proved useful in mines and large infrastructure projects, as well as in the earlier stages of the expansion of urban communication networks, they~~ could not match the dynamism of urban growth. As we ~~will see later on in the article~~, expanding ~~them~~ to match urban growth was both economically and technically demanding ~~– not impossible technologically, but technology was one aspect of the problem~~. Pneumatic technologies also did not have the same versatility and especially visibility as their main competitor, electricity, and did not become prominent symbols of urban modernities. Before moving on to the technical details of such systems, however, let us first get a sense of the origins of compressed air technologies.

Pumps, tubes and reservoirs: origins and uses of compressed air

The uses and applications of compressed air have a long history. From diving bells to early submarines, including Bushnell's designs during the American war of independence, through to ancient pumps, pneumatic engines for mining and the air-pump controversy between Thomas Hobbes and Robert Boyle, the history of compressed air has been both ubiquitous and overlooked.[27]

Among the earliest uses of compressed air we find the 'air treading bags, the wooden cylinder and piston, and the Chinese wind-box', which, according to a contemporary account, were still prevalent in China, India, Burma, Borneo and Madagascar at the turn of the 20th century. Compressed air and hydraulic pumps were prominent in the intricate and often extraordinary mechanisms that Egyptians used in their temples. Other applications and experiments included Ctesibius's wind guns in Alexandria around 120 BC, perfected ~~over fifteen centuries later~~ ~~through the pneumatic gun~~ by Marin in France and Guter in Nuremberg, ~~both in the seventeenth century~~; Otto van Guericke's compressed-air and vacuum pump; Denys Papin's experiments with 'an air pump driven by a water wheel' that was to allow motive power to be transmitted at a distance; 'the pneumatic pumping engine at the mines of Chemnitz, in Hungary, erected by M. Hoell in 1755'; the rather simple, elegant and successful experiment with air pumps connected to air bags, which allowed the recovery of sunken vessels by Professor St Clair, in Edinburgh in 1785; Medhurst's pneumatic tube system for the conveyance of people and parcels patented in England in 1810, discussed below; Baron von Rathlen's compressed-air vehicle, reported to have reached 12 miles per hour in 1848; John Gorrie's USA patent from 1851, which provided the basis for the use of compressed air in refrigeration, instrumental in the transport of food and other perishables a few decades later; postal services, first in London and soon after in use across main cities in Europe and the United States; compressed-air locomotives and cars for mining but also for urban transport; and a broad range of equipment for the construction industries, both structural and ornamental, as well as specialist tools whose applications ranged from medical instruments to artist's tools and domestic cleaning.[28]

At the turn of the 19th century, advocates of pneumatic technologies considered compressed air to be a sound alternative when contrasted with steam-operated machinery, and, later on, as a firm competitor against the luring appeal of electricity. A key difficulty was securing the capital, which was deemed too high when the initial investment in machinery and infrastructure and the prospective returns were compared. George Medhurst's 'invention of machinery for the rapid conveyance of goods and passengers by air' in Britain is an early example of that trend. His 1810 patent suggests that Medhurst had two systems in mind: one for light parcels and letters and another for heavier loads. Both posed different challenges and involved different kinds of infrastructure. At the same time, they both provided an alternative to existing means of transport, that is, roads and canals, particularly in relation to the labour needed in their operation and the constant disruptions to their services caused by frost, wind and rain.

'By forcing the air through the tube with a pressure of three ounces per square inch for every ounce weight in motion', a packet of letters, say, could be transported at up to one hundred miles per hour. The key was for the tubes to be of a uniform dimension and be laid avoiding ~~sudden curvatures~~. Part of the system were the 'air-tight rooms' distributed along the tube network. This is where the letters and parcels would be propelled to from their places of origin reaching their final destination in stages through a succession of these rooms. 'If', on the other hand, Medhurst wrote,

> A tube or tunnel is built of brick, stone, timber or iron, of twelve feet area, upon or under ground from one place to another in a line as straight as the surface of the country will permit; and a four-wheeled carriage is fitted to run within it upon an iron road, so that no considerable quantity of air can escape between the sides, such carriage loaded with one ton weight of goods, and weighting itself ten hundred, will be impelled upon level ground with the velocity of 20 miles per hour by a pressure of air against it of 220lb. which is two ounces per square inch.[29]

In other words, it was the rapid, certain and reliable transport of goods that required new infrastructure. Interestingly, the system combining a 12-feet tube, a wheeled carriage and an iron road uses the very same principle (and dimensions) ~~of~~ the system built by the Pneumatic Dispatch Company in London, which we discuss below. Perhaps more importantly, Medhurst's method provided the foundation for Peter Barlow's 'subway omnibus system' (1869) whose infrastructure was perfected by James Greathead, and upon which the City and South London (1890), and later Tube lines were built.[30] Incorporating a new technology of traction, namely electricity, Medhurst's ideas for the transport of light goods and parcels would become the very basis for the infrastructure moving millions of passengers across London in the twenty-first century.[31]

Medhurst was a mechanical engineer and clockmaker apprentice (in Clerkenwell, London). His *Calculations* and pamphlets – three that we know of from 1810, 1812 and 1827 – contributed to a body of work that later authors could build on, leading to experiments such as the successful demonstration in Southwark, London, of the Samuda Brother's first atmospheric railway in 1839, the very fundaments of which followed Medhurst's principles. Part of redressing the balance in the historiography of compressed air lies precisely in highlighting the kind of precedent that Medhurst's work provided for future transport in London which, incidentally, enables us to move beyond his rather misleading characterisation as 'an obscure London instrument-maker'.[32]

Insert Fig. 3 here

Similar in conception and scope to Medhurst's ideas was John Vallance's pneumatic system, which proposed to use a cylinder for the conveyance of goods, largely coal, in South East England. Despite the local support after the successful trial of a scale model, the system was never built. As Vallance explained in his response to criticisms: 'the experience we have as to conveying both water and gas through pipes, proves that we certainly may send common air through a tube or tunnel extending from Brighton to Shoreham Harbour.'[33] According to Vallance, facilities of communication might become public utilities, something that was particularly important in cities. After all, the transport of heavy goods such as coal, but also of letters, parcels and people, included higher frequencies, larger loads, often requiring speedier deliveries, where more people lived and worked. A key question was refining the needs that might shape a promising market vis-à-vis securing the investment to finance the building of a pneumatic system. How to ensure that the air compressed would travel long distances without loss of power and capacity was central to the process.

Late in the 1830s, French engineer Andraud conducted a series of experiments with the aim of using compressed air as a motive force that could be stored and transmitted remotely.[34] Andraud tested his ideas with a railway car in Chaillot, France, in 1840, which, a contemporary rapporteur commented, achieved little by way of its potential widespread use. The rapporteur, A. Pernolet, was an engineer versed in the theories developed in German, English and American publications, who also visited key sites including the collieries of Wales, Lancashire, the Newcastle Basin, the royal mines of Saarbruck, in the Ruhr Basin of Austria and Belgium, and the tunnels of Mont Cenis and Saint-Gothard. In Pernolet's view, the experiments of another engineer, Triger, in the mines of Chalonnes in 1845 constituted the first successful practical application of compressed air for producing motive power remotely.[35] Moreover, compressed air was 'the only agent of transmission that could be kept separate from the motive power it transmit[ted]', allowing the storing of part of the power produced, so that it could be released in fractions and at intervals by using regulating valves. The economics seemed also favourable. Pernolet estimated that the cost of producing 20 horse-power by steam employing 200 men was 54 francs per day. By contrast, one person's labour using compressed air would produce the same 20 horse-power at 0.27 francs for 12 hrs or 0.22 francs per day.[36] Rationalisation of labour involved making the work of men more efficient, but also redundant.

Efficiency in terms of energy and capacity transmission was important and often explained by reference to four agents: steam, electricity, water, and air (compressed or rarefied).[37] Steam had dominated for more than a century. It did not cost much, but it was not very efficient especially if it had to be transmitted over a distance, which tended to restrict its application to urban networks. Steam was not a very handy technology for use in galleries either, nor for portable tools, and was difficult to maintain. Hydraulic machines that used pressurized water had much better efficiency, but this method, like steam, did not work well with portable tools. Freezing was a problem, so was the high cost of initial installation. Electricity seemed like the most convenient system, but it required specialized personnel, which made its use on construction sites less practical. Electricity could not be used in mines because of the difficulty of mounting the necessary equipment in galleries and the risk of explosion, nor for powering machines; or in manufacturing or distribution sites with inflammable and explosive materials. By contrast, there were no steam, water or cables on site when compressed air was used; the diameter of tubes and pipes was reduced; ~~no heat was caused by steam, nor seepage observed in water mains~~. The combination of these comparative advantages made compressed air a safer technology for mining from the outset.

As important was the location where applications of compressed air would take hold, whether it was in remote and inaccessible mountain sites or in the immediate vicinity of cities where other technologies might provide a sound alternative. For later commentators, from early on compressed air was 'used for mining and tunnelling, for which no other power was available, and in fact in all the early uses of compressed air it was only used where it was considered a necessity regardless of expense, it having always been termed an expensive power'.[38] As another observer put it:

> To those familiar with compressed-air practice in the United States, it would seem that the possible economies and the best efficiencies have been worked out and adopted quite slowly, if not almost with reluctance. And yet the period covered from the beginning of the modern, and now general, employment of compressed air for power and other purposes is not much more than a quarter of a century. *It was adopted at first upon compulsion and not by choice*. For the driving of rock drills in tunnels and mines there was no other means in sight, and its employment became imperative also for resisting the inflow of water where men were employed below water level, for example in the sinking of caissons for bridge piers and other foundations.[39]

The pace of inventions and improvements on existing technologies ran parallel, often intersecting with, the specialisation and spatialitation of uses, industrial, domestic and otherwise. Moreover, the successful application of compressed air was ~~somewhat~~ a compromise between costs and efficiency, on the one hand, and the limitations of existing technologies, on the other. Specialisation followed from this, so that, at least three types of infrastructure used compressed air by the third quarter of the nineteenth century: tunnels, underwater works and foundations by deep poles for bridges, particularly in unstable land. By the 1880s in France, for example, confidence had grown among engineers about the use of compressed air in the sinking of caissons and the foundations of bridges,[40] a trend that was repeated years later in the USA, as the commentary above explained. One of the most prominent and iconic examples of the use of compressed air were the foundations of the Eiffel Tower.

Insert Fig. 4 here

National prestige also became a factor determining the kind of developments in pneumatic technologies. A French commentator even claimed that compressed air was the only technology that would allow France to compete effectively in an international context, specifically with Britain and Prussia.[41] A vote of confidence was the teaching of compressed air at the prestigious École des Mines and École Centrale where 'the incontestable superiority of compressed air' by comparison to, say, steam engines, was the subject of theories and experiments concerning the transmission and distribution of motive power.[42] But there was sufficient room for collaboration too as the construction of the tunnel at Mont Cenis demonstrated, bringing together as it did the work of well-known experts such as Colladon (Swiss), Sommeiller (Piedmont) and Bartlett (England).

Despite important disadvantages when compared to steam and electricity, namely, installation costs, the relatively low productivity, and reduced capacity, compressed air became the most convenient technology for specific kinds of works. Using compressed air was practical, clean, simple, and easy to maintain.[43] At the same time, it seemed as if compressed air was a technology used by necessity rather than choice, and in those cases and at those sites where the disadvantages of other existing technologies became all too apparent. How, then, can we account for their use in cities?

As we will see, compressed air technologies made their entrance to urban contexts first as auxiliary technologies to relieve the burden on congested systems that were already in place and operational. The association of these technologies with cleanness and hygiene – compare air to steam engine or electricity, both of which evoked images of fire and smoke (although pneumatic technologies also used steam engines to compress air, burning fire was not present in the actual deployment of pneumatic tools) – was also part of the broader concern for sanitation in nineteenth- and early-twentieth century Western cities.[44] What made pneumatic technologies particularly suitable for urban networks was the ease of transmission of air, which, in the end, proved inflexible in urban environments that changed rapidly and in directions that were often unintended.

Cities of air

In its 1921 issue, the *Compressed Air Magazine* published a short piece with an alarming title: 'Air alleviates torture in Paris beauty shops'. The author of the piece reported on 'how compressed air is used to lessen the discomforts of ladies undergoing the painful process of the "permanent artificial hair wave" at the hands of the Parisian beauty experts':

> It is a tropical experience for the patient, for a great deal of heat is generated in the spools. The whole apparatus looks like some device of the Spanish Inquisition. This is where the compressed air comes in, for an operator stands beside the victim and blows a current of air from a rubber hose over the scalp to alleviate suffering. Every beauty parlor or barber shop in Paris may have compressed air at its command, for it is piped through the streets just as gas and water are in other cities.[45]

For the early advocates of pneumatic technologies one of the keys to unlock the potential of compressed air was to develop its production, distribution and consumption in a way similar to the provision of public utilities ~~much in the same way as the *Compressed Air* reporter recognised in Paris~~. By the mid-nineteenth century, a strong link had developed between compressed-air technologies and communications in cities, more specifically, urban transport and postal services. There was no shortage of projects and inventions proposing to connect the pneumatic telegraph to atmospheric railways and canals.[46] Successful applications of the pneumatic system would later include the delivery of parcels and light goods connecting railway termini to central post offices, banks, hotels and large buildings, in a way that was reminiscent of Medhurst's ideas. Compressed air allowed mail deliveries to avoid street congestion, making the laying out of pneumatic tubes, and the investment behind it, more attractive as it saved time and money. Large compressed air distribution centres were operational in cities by the end of the nineteenth century. In the UK, the General Compressed Air Company was serving both Birmingham and Leeds in 1885. In 1890, Paris was served by the *Compagnie Parisienne de l'Air Comprimé* with a network of 600 kilometres.[47]

But how was air compressed and distributed in cities and how did it compare with its direct 'urban' competitor, namely, electricity? Two aspects are important in answering this question: first, the actual production and distribution of compressed air and its relationship to efficiency, productivity, maintenance and safety; and, second, the extent to which compressed air served as an auxiliary to existing urban networks.

Pneumatic technologies either compress or depress air with the aim of obtaining a difference in pressure ~~within and outside~~ the transmitting tubes, making the pressure inside either lower (by sucking the air out of the tube, exhausting air and creating a vacuum) or higher (by pumping higher pressure air into the tube) than atmospheric pressure. The first is rarefied, the other is compressed air. ~~Both work on the same principle: making the air flow as a result of the difference in pressure at the two ends of a tube.~~ In terms of production costs, rarefied air was more economical than compressed air. However, there are several other reasons that made compressed-air technologies more convenient and economical. First, in the case of a leak in a tube laid in wet ground, the exhausted tube draws in water, which is not the case with compressed air. Second, air cushions in tubes work more efficiently and effectively with compressed air, allowing a better control of the speed of carriers when they arrive at their stations. Finally, the sending and receiving apparatus of exhaust systems require larger cylinders and pistons compared to those used in compressed air.[48]

As for its distribution, a contemporary account provides a comparative description of the process: Once the air has been compressed

> it is simply carried around in pipes, the same as steam or water, but being more easily handled than either, for no matter what the length of pipe, there will be no condensation as with steam, and no shock as with water. As to the distance that air can be carried, that depends entirely on the volume of air and the size of pipe, the only loss being reduced pressure at the end of pipe line, caused by friction if the pipe is not of sufficient size, but at this reduced pressure the air has a larger volume, so that the loss is not as much as the fall in pressure would make it appear.[49]

The inefficiency of using compressed air as a method for transmitting mechanical power was due to the energy that was lost during the compression and the relaxation of air. However, as Pernolet and others explained, compressed air also provided a reserve of potential energy that might be kept indefinitely if the reservoir was tightly closed. Compressed air was 'elastic and supple', and by using tubing that was easy and economical to install, it could be transmitted over long distances with minimal loss along the way.[50] Moreover, cities provided a somewhat ideal context for the distribution of 'the motive power among a large number of smaller workshops' whose economy of operation compared considerably better than the larger and medium steam engines that were in use.[51]

Productivity, especially when compressed air and electricity were compared, was another important aspect of their distribution. Transmission using electricity had a productivity ('*rendement*') of up to ninety per cent, whereas compressed air barely made it to over twenty per cent. However, machines using electricity were vulnerable when sudden fits and starts were involved in the working of tools used, such as tool used for fastening nuts or drilling. If the machine met a resistance that was higher than normal, either the electric fuses melted down or the motor was damaged. By contrast, machines using compressed air simply stopped, and could easily be re-started once the resistance was removed. This made the use of electricity inconvenient in tools for fastening nuts, hammer drills and, on a larger scale, boring machines. Apart from safety considerations, what made compressed air operated machines preferable over those using electricity was the simplicity of their construction as well as the ease of their installation, use and maintenance.[52]

The relationship between, on the one hand, efficiency and productivity, and, on the other, safety, usage and maintenance, provided a useful contrast of the differences between and the benefits of the two technologies. By the late 1890s, the assessment was generally in favour of compressed air:

> The difficulties encountered in electrical operations are numerous, and in many cases impossible to overcome. Everything must be guarded with the closest scrutiny, demanding the highest skilled and educated labour; lighting, moisture, etc., are constant causes of trouble; extreme care is required by the operators to avoid receiving the dangerous and often fatal current; the machinery runs at high speed, requiring buildings and foundations of the most substantial construction.
>
> Compressed air has none of these difficulties to contend with. The compressor is but little more than a steam engine with one or more extra cylinders and their valves, all of simple design; it runs at safe speeds, is clean, comparatively noiseless, and safe in every way, and the same may be said of the compressed air machine at the other end of the line, considered in itself.[53]

Victor Popp, the founder of the first city-wide distributor of compressed air in Paris, made similar observations about the advantages of compressed air over electricity. He maintained that electric cables were a constant source of worry for operators, and electric systems required a specialist crew for maintenance. Ceramic conduits proved inadequate and required constant replacement.[54] Compressed air, on the other hand, was good for its simplicity. It did not require an army of engineers, as electric systems did; 'an ordinary mechanic' sufficed. Another advantage was 'direct accumulation', whereby it was possible to store compressed air in the reservoirs of the factory, in the pipes, and in the containers of automobiles.[55] As an anonymous author observed:

> One of the most important advantages of compressed air is that it lends itself so well – incomparably better than any other system – to direct storage, which quality admits of holding in reserve great accumulations of energy with so much ease and economy. So far as accumulation of reserve power is concerned, electricity has incontestably shown itself greatly inferior to compressed air.[56]

Furthermore, the abrupt interruptions in the electric system caused damage to the machines, which was not the case when compressed air was used. Popp also argued that, economically, electricity and compressed air were equal. His assessment was based on the cost of providing energy for a kilometer of tramway traction, without considering the initial installation costs. The Popp-Conti company had invested in the compressed air tramway of Saint Quentin, the first of its kind in France. The system combined steam engines, boilers and compressors, which together operated a 7-km line with eight carriages of forty places each.[57] In short, the two qualities that made compressed air superior to electricity were, in Popp's view, practicality and security.[58]

Compressed air was thus stored, distributed, and mastered better than electricity, steam or water. This made pneumatic technologies convenient for use in urban networks, partly because of their association with security and hygiene; partly, because of the positive relationship between the availability of space and the size of the installations needed to compressed the air and distribute it: relatively small installations servicing areas where land was sparse. The other important aspect was the application of pneumatic technologies as an auxiliary to relieve the pressure on already existing urban networks, especially in those cases where it could also save time and money.

The pneumatic postal system started at about the same time in several capital cities of Europe from the 1850s onwards, London leading the way, followed by Paris, Berlin, Vienna, Prague and towards the end of the nineteenth century and early twentieth century on the other side of the Atlantic, in Philadelphia, Boston, New York, Chicago and Saint Louis. The reason for recourse to this technology was the burden on telegraphy networks. '[T]he telegraph networks of the 1850s', Standage writes, 'were subject to congestion as the volume of traffic mushroomed, and key network links within major cities became overloaded'. The use of vehicles for transmitting telegraph messages caused delays because of traffic congestion, and the use of messenger boys, as it was done in London, did not inspire public confidence in the system. The Electric Telegraph Company in London was the first to use a pneumatic system to transmit telegraph messages between different offices, which then installed similar systems in Liverpool, Birmingham and Manchester.[59] The business opportunity seemed lucrative, and the London Pneumatic Dispatch Company was created in 1859 for the pneumatic transmission of mail, parcels and light goods.[60]

The first section of the London Pneumatic Dispatch Company was opened in 1863 covering the distance between the Eversholt post office near Euston Station to the headquarters of the General Post Office (GPO) at St. Martin's-le-Grand. It ran from Eversholt street to Drummond street, continuing down Hampstead Road and then Tottenham Court Road all the way to New Oxford Street, from there turning east under Holborn Street, passing below Farringdon Street to reach Newgate, and finally to its home at the GPO headquarters near Cheapside at St. Martin's-le-Grand.

The tube was four feet high and four and half feet wide, and it served to transport both mails and parcels between the two offices using pneumatic pressure. The central station was located in High Holborn, where the motive power was centralised and contained. The air was sucked out from in front of the cars carrying the parcels~~. The cars carrying the parcels were drawn by suction (the air was sucked out from in front of them), reaching~~ speeds as high as thirty-five miles per hour. The journey from one end to the other took nine minutes. According to the account of an engineer who worked for the Company from 1869, the carrier cars reached speeds of sixty miles an hour, and it was not unusual for them to shoot people through the tube~~; he~~ himself had made the journey, which was exhilarating, especially on the hottest of summer days, 'the air being fresh and cool' inside the tube.[61]

When the line was first opened, it was greeted with enthusiasm: 'Between the pneumatic dispatch and the subterranean railway', that is the first section of the Metropolitan Railway, which opened in January the same year, 1863, 'the days ought to be fast approaching when the ponderous goods vans which now ply between station and station shall disappear for ever from the streets of London'.[62] The prospect was both good and lucrative.

However, leaks were a constant problem: 'The insuperable difficulty lay apparently in the impossibility of rendering the tunnel sufficiently air-tight. Leakages of various extents prohibited the creating of a working vacuum'.[63] The Company went into liquidation in 1875, and the line forgotten until George Threlfall, a consulting engineer, came upon it by chance in 1895. According to his estimations, after a fair amount of investment, the disused tube could be put to working order for hosting cars propelled by electricity. The commercial value of the tube lay in the fact that '[p]ractically all the heavy post to the north of Great Britain passe[d] through the Euston Station' and the use of vans for transporting post was both time consuming and inconvenient (heavy traffic), taking twenty-four minutes at the best of times, ~~or double that time depending on traffic and the weather~~. The prospects of turning it to a profitable utility were good for it was 'a gold mine extending from the G.P.O. at St. Martin's-le-Grand to Euston station'. Goldmine or not, the system was unused by 1900 when a different observer asked: 'Is there any other city in the wide world where a cast iron tunnel, two and three-quarter miles in length, could lie disused, unknown, lost to the memory of all but a few scientists, for over thirty years, excepting London?'[64] 'That a privately owned tube should be forgotten is not remarkable', would be the (indirect) response of *The Times* nearly four decades later, conceding that 'it [was] a strange indication of the short memories of Londoners'.[65]

Across the Channel, Paris also introduced a pneumatic network for the delivery of messages, '*Le pneu*', whose service started in 1867 for the transport of urgent letters. As in London, it was originally conceived as an auxiliary to the over-burdened electrical telegraph system. Unlike London, however, it was a state-owned network, it worked with compressed air and was hugely successful, developing into a vast network that remained operational until 1984. The Paris system benefited greatly from the already laid out infrastructure – Haussmann's vaulted sewers, where the tubes could be placed – and it was more compact compared to London, which was an advantage for this network. Furthermore, '*le petit-bleu*' – the folded blue stationary for the messages sent by this system – quickly entered the imaginary Parisians, giving rise to expressions such as '*attraper un bleu*' (receiving a message via pneumatic post).[66]

The decisive moment for installing the Parisian network came when the telegraph lines became too busy and there was a shortage of personnel during peak hours. A first response to this congestion was the putting in place of horse-pulled cars that operated every fifteen minutes between the post office at Grenelle (where the ministries were located) and the Bourse (a distance of three kilometres covered in about fifteen minutes). The test line of the pneumatic network was installed in 1866 between the Bourse office and a branch office at the Grand Hôtel (Boulevard des Capucines). When this proved satisfactory, a tube was laid to connect the two main telegraph offices, one at the Bourse, the other at Grenelle, which eventually led to the creation of a city-wide network starting with the laying down of tubes in the sewers from 1868.

The transported objects were placed in cartridges. Each office had a sending and receiving apparatus. Each cartridge contained approximately thirty-five letters. The system was both rapid and effective. It delivered the letters faster than the horse-pulled cars, and its output was higher compared to the telegraph over the same distance. The network used two already existing urban systems. One of these was the sewers, which made the initial installation relatively easy and cheap. The second was the already operating system of post offices, which were now linked with a pneumatic network. The network, though efficient, required a high number of personnel for surveillance, maintenance and repairs.[67]

Insert Fig. 5 here

Soon proposals were put forward to use compressed air for transcontinental communication. Among them was J. B. Berlier’s *The Pneumatic Transmission of Messages and Parcels between Paris and London, via Calais and Dover* (1885). Berlier's scheme consisted in laying 'two pneumatic tubes [...] between Paris and London, which would serve for the transmission of letters, telegrams and parcels, weighting not more than 5 kilogrammes, or 11lbs.' The total distance was 475 kilometres and followed the existing railway lines. According to Belier's estimates, parcels, letters and telegrams would be delivered by six trains an hour in either direction, each covering the entire distance in one hour. The capital required was around £1,360,000, with an expected annual dividend of 4.90 per cent, based on 300 working days per year.[68] Whether appealing or not, the scheme did not take off.

The advantages that compressed air represented for postal services made the system relatively popular. 'In 1872 [the US] Congress appropriated $15,000 for a pneumatic dispatch tube between the Capitol and the Government Printing Office in Washington.'[69] There were pneumatic postal services in Vienna since 1875 and Prague since 1899.[70] By the late 1890s, other pneumatic postal services included the Batcheller system in New York and the Bostedo Package and Cash Carrier Company in Chicago.[71]

Implementation was also subject to the politics of the technologies used. The first experimental service tried in Berlin in 1865 concerned two different administrations, the Royal Prussian Telegraph and the Post Office. Differences were solved in 1876, after the death of von Chauvin, director of Telegraphs, when the renamed Rohrpost was extended to twenty-six kilometres. The Rohrpost had thirty-eight stations by May 1888, ninety-four in 1936, remaining operational until 1963 when it was closed.[72]

By 1900, a committee reporting on proposals for pneumatic tubes for mail in twenty-seven cities in the USA suggested that compressed air served a very specific purpose, namely, first-class mail, and only in those cases where there was a market for this service could the costs of infrastructure be justified. Out of the eleven cities the committee reported on only in New York, Philadelphia, Boston, Chicago, and St Louis was the system deemed justifiable when the costs and expected revenue were compared. The committee also advised proponents to incorporate 'moderate charges for operation and equally reasonable cost of construction' into their bids in order to avoid the inflated estimates of initial costs.[73]

Specialisation, as exemplified by the use of compressed air in first-class post, was also apparent through the introduction of red mailboxes (Rohrpost) specifically for pneumatic postcards, which were introduced in 1879 in Vienna in an attempt to boost low usage: two items per station – total of ten- per day during the first year of operation. Similar was the special stationery including letter sheets, envelopes, post cards and letter cards, which were made to special sizes so that they fitted the tubes without exceeding the weight limit of ten grams. By 1913, there were over fifty post offices connected across Vienna's pneumatic system, which remained in operation until 1956.[74]

Given its relatively widespread use, the pneumatic postal system would become iconic of a service that brought air, not light, to cities. After several decades of operation, the Paris network continued to impress visitors who contributed to the myth of the French capital being '*a city of air*' through their reports:

> Paris is rightfully boastful of her air – her sparkling, refreshing air. But below ground, she is also a city of air – compressed air, ready to do man's bidding. In short, Paris is the only place in the world where compressed air is a public utility

like gas, electricity, and steam: where compressed air is carried from one end of the metropolis to the other in a vast network of piping, beneath the city streets, to do a multiplicity of services.[75]

Insert Fig. 6 here

Diversifying supplemented specialisation as the Parisian experience demonstrated. By 1894, the *Compagnie Parisienne de l'Air Comprimé* had two factories for compressing air, one at rue Saint-Fargeau and the other at the quai de la Gare, totalling 13,000-horsepower; a compressed air tube network of 168,500 metres underground, of which 66,500 was for distributing time and 102,000 for distributing motor power; 7,400 pneumatic clocks or dials; and sixteen cold rooms under the ground at the Bourse du Commerce. As the Company's founder put it:

> The compressed air tubes arrive in homes exactly as gas pipes do, and it is a simple pipe with an ordinary tap, which delivers motor force constantly to the consumer in the form of compressed air, that is, in a handy, clean, absolutely harmless, and even healthy form, that is immediately usable in a multiplicity of ways, which also has, furthermore the advantage of being cheap.[76]

Insert Figs 7 and 8 here

This meant that Parisians used compressed air in at least three respects: as a motor force (from moving hands on clock dials to sewing machines and heavy machinery); for ventilation (for both industrial and residential premises); and for refrigeration (cold room for storing meat and other perishables).

Compressed air was also central to engineering projects such as the Nord-Sud line, built in the mid 1900s in Paris as a complement to the Métropolitain, and the completion of the tunnel across the Hudson River in New York, despite setbacks and the 'nonchalance' and obstinacy of Colonel Haskin and others.[77] Unsurprisingly, companies often sought to expand their markets by devising new applications for the technologies they used. This was true of Popp's company, but also of several others, including the *Compagnie Parisienne du Gaz*, which in 1896, experimented for the first time in France with a 'vehicle by mechanic traction' of the kind tried already in Blackpool in the UK, Criesfield in the USA and other places in Germany.[78]

The very mechanical effects of compressed air would even give the owners of cafes along the grand boulevards of Paris the support they needed in order to run their businesses more effectively and economically, at a time when electric networks were neither extensive nor reliable. Café owners had compressed air motors in their basements ~~for the dynamos~~, producing four to ten horsepower. They soon realised that the air released from the machines could be used to keep beverages cold. However, the expansion of the air, while cooling the surrounding ~~temperature~~, also froze up any moisture that remained in the air. Since the compressors used water as an intermediary, they produced vapour which then ~~used to~~ condense in the tubes and the connected machines, also freezing up the exhaust.[79] When compressed air is released, it absorbs heat from surrounding objects during its 'relaxation' or expansion, which is why it was also used for refrigeration.[80] The real boom in the use of compressed air technologies came after 1884 with the construction of machines that could compress '*à sec*'. According to Champly, it was '*la compression à sec*' that allowed the *distribution of compressed air* in cities'.[81] Why, then, did this technology fail to compete with electricity and survive as an urban network?

Conclusion

Paris, after all, became not the 'city of air', but of light. She was both, of course; the two technologies were not mutually exclusive. But the significance of air being compressed, distributed and consumed in Paris, and in the several other cities we have discussed, has been overshadowed by our enchantment with light.[82] Pneumatic technologies have been marginal to our understanding of the transformation of western cities in the late nineteenth and early twentieth centuries. The acceleration of change, 'new engineering knowledge', and 'capital availability' that might have given rise to the building of infrastructure in North American and European cities during this period does not take into account developments in compressed air.[83] Yet, cities of light were also cities where air was compressed, distributed and consumed in a variety of ways, using existing networks, but also building new ones, contributing to the specialisation and spatialisation of uses that different technologies exemplified.

Similarly, our fascination with electricity has led to trends in historiography that take little account of the work of figures such as George Medhurst ~~and others~~.[84] Medhurst's ideas about the transport of people, letters, goods and parcels, provided the conceptual basis for future developments in urban transport in London and, by extension, in several other cities. Pneumatics, not electricity, paved the way for future advances in urban transport and urban infrastructure. The comparative differences that made compressed air the technology of choice for the wide range of uses that have been discussed in this article were the result of contrasting two inter-related elements emerging during the process: the urban development of other technologies, notably steam and electricity, and the possibilities provided by the available spaces where air could be compressed and by other infrastructural networks that allowed the compressed air to be distributed. At the same time, the intensification of communications was greatest in cities. Higher frequencies, larger, heavier, lighter or smaller loads traveling longer distances, and speedier deliveries were conditions that cities imposed on services such as urban transport and the post. The question was how to turn these services into public utilities. One alternative that advocates of compressed air found was for the technology to function as an auxiliary to networks that were pressed or had reached their limits, notably the telegraph and the post.

But providing merely an auxiliary function to overburdened networks using other technologies was not adequate for the survival of pneumatic technologies in urban networks. Nor was is adequate to elevate such technologies to glorious symbols of urban modernity. The development of pneumatic networks were intimately bound up with urban development, but they were, in the end, unable to match the dynamism and pace of urban expansion. Even in Paris, which was the 'showcase' of pneumatic technologies, compressed air networks could not compete with other technologies. One of the reasons why pneumatic technologies developed in Paris was that the city was rich in construction sites that required machinery using compressed air because of large-scale public works. In the last two decades of the nineteenth-century, ~~the Paris~~ underground was home to up to five different pneumatic networks, including time distribution, postal service, draining, and motor force, using either compressed air or rarefied air.[85]

However, one of the main disadvantages of pneumatic networks was (and still is) that, whatever the function of the network, its size is limited because of the nature of this technology. To have sufficient force in the networks inhibits the use of large pipes and the spread of the network over long distances. Furthermore, the pipes ~~tend~~ to reduce in diameter as the distance grows to keep the force constant. This makes the extension of the system by branching out difficult, indeed impossible, unless several power stations are constructed along the network, which, in turn, is costly. As Poujol argues, pneumatic networks in constantly changing or expanding urban systems are not easy or feasible. This was one of the advantages of electrical networks: it was possible to make interconnections over long distances in a way that pneumatic networks did not allow. Extension is difficult or indeed impossible in pneumatic networks after a certain point. The technical aspects represent important advantages, but it is their limited field of action that poses problems.[86] By the early 1890s, current transmission over distance between cities had became feasible, something pneumatics could not do.

Pneumatic technologies also take up ~~bigger~~ spaces, which is a problem in dynamic and popul~~ar~~ cities where land values are high – London, for example. Networks combine three features: generation, storage and transmission.[87] Pneumatic networks were ~~not terribly efficient~~ in the latter, which meant that they could not be too far away from the urban centres they were serving for the former two. Given the inefficiency of long distance transmission of compressed air, production and storage facilities had to be nearby. As noted above, the production and storage of compressed air required the construction of large buildings to house large machinery, which took up vast spaces and was was prohibitive in cities with high property values.

We agree with Atmore that the 'failure' of compressed air technologies – in his case, the failed attempt to introduce atmospheric railway traction in the UK in the 1840s – cannot be attributed merely to technical problems. It is equally important to take into consideration how people think about those technologies, what place they have in imaginaries. ~~In Atmore's case, he~~ attributes the failure to introduce pneumatic railways in the UK in the 1840 not merely to 'mechanical obduracy', but to the collapse of the railway mania ~~following – the 'railway bubble' burst~~ in 1845 ~~– in the same period,~~ which made experimenting with new technologies more risky and less desirable. Moreover, the steam locomotive was deeply 'entrenched in the Victorians' perceptions of themselves'.[88]

The mechanical difficulties facing pneumatic technologies in cities were not, to a certain degree at least, insurmountable. These were, like electricity, network-creating technologies, and it is here that the main difficulties facing the urban applications of these technologies lay ~~–~~ not because the applications were mechanically poor, but because the network was not as flexible as it should be in rapidly changing context. The production and storage facilities required space at a time when urban space was becoming more valuable. Furthermore, the setting up of the network was not only costly but disruptive in already congested cities. Paris was at an advantage~~,~~ because ~~the infrastructure was already laid out by the sewer system~~. In London, on the other hand, just laying the pipes was a problem. As the Parliamentary debates show, when the idea of 'reviving' the Pneumatic Despatch Company came in the early twentieth century, there was great concern about 'the grave evils arising from the construction and maintenance of a new and extensive system of underground tubes', as the Postmaster General Lord Stanley put it. There was also concern, in London as well as in Paris, of granting access to the underground to private companies.[89]

Paris, compared to other cities where pneumatic technologies were employed, had the advantage of being compact and having an infrastructure to house the pneumatic pipes. But, as the city grew and changed, questions of scale and flexibility arose, to which pneumatic technologies could not provide a satisfactory answer. The characteristic growth of late-nineteenth- and early-twentieth-century cities became the force that pierced the pipes through which the dreams of compressed air travelled. There was also concern, as noted, about opening the underground to private companies. In the nineteenth century, it was still possible to consider alternatives to electricity, and pneumatics was a contender. However, by mid-twentieth century, what the pneumatics were doing but electricity could not was either no longer necessary in most urban contexts (such as post service in the US cities) or were not necessarily glorious symbols of urban modernity (digging roads, for example). Furthermore, pneumatics never had ~~the~~ place ~~of pride~~ in urban imaginaries. While they did useful work in cities, they mainly remained in obscurity, and lacked the versatility, flexibility and visibility of electricity. It is, after all, possible to imagine fin de siècle Paris without compressed air, but not without its lights.

Notes

[1] Anon., Men prominent in compressed air development, *Compressed Air* (1898) 3: 437

[2] Charles Emory Smith, *Pneumatic-tube service. Report of the post-master general [Ch. Emory Smith] to Congress* (Washington: U.S. Government Printing Office, 1901).

[3] Anon., London's lost tunnel, *Compressed Air* (1900) 5, 2: 925.

[4] See, for example, 'Put that in your pipe and poke it', *The Economist*, 8 January 2011, page 73; O. N. Egbunike and A. T. Potter, 'Are freight pipelines a pipe dream? A Critical review of the UK and European perspective', *Journal of Transport Geography*, (2011), 19: 499-508.

[5] 'Peugeot veut faire rouler ses voitures à l'air comprimé', *Libération* 23 January 2013 online edition http://www.liberation.fr/economie/2013/01/23/peugeot-veut-faire-rouler-ses-voitures-a-l-air-comprime_876068 (last accessed 25 November 2013). 'MDI's air engine technology tested on Tata Motors vehicles', Tata Motors press release, 07 May 2012, available at http://www.tatamotors.com/media/press-releases.php?id=750 (last accessed 25 November 2013).

[6] The magazine *Compressed Air*, founded in 1896 and running to the 1960s, used throughout the article, illustrates this point.

[7] Thomas P. Hughes, *Networks of power: electrification in Western society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983); F. Caron *et al*. (sous la direction de), *Paris et ses réseaux: naissance d'un mode de vie urbain XIXe-XXe siècles* (Paris: Bibliothèque Historique de la Ville de Paris, 1990), K. Bowie and S. Texier (sous la direction de), *Paris et ses chemins de fer* (Paris: Action Artistique de la Ville de Paris,

2003); R. Dennis, *Cities in Modernity Representations and Productions of Metropolitan Space, 1840-1930* (Cambridge: Cambridge University Press, 2008); S. Guy, S. Marvin and T. Moss (Eds.), *Urban infrastructure in transition: networks, buildings, plans* (2001); P. Dobraszczyk, *Into the Belly of the Beast: Exploring London's Victorian Sewers* (Reading: Spire Books, 2009).

[8] Joel A. Tarr and Gabriel Dupuy (Eds.), *Technology and the Rise of the Networked City in Europe and America* (Philadelphia: Temple University Press, 1988), see especially the Preface xiii-xvii.

[9] Dennis, *Cities in Modernity*, 14; see also Chapter 2.

[10] London and Paris are typical examples; see Th. Barker and M. Robbins, *A History of London Transport. Passenger travel and the development of the metropolis. Vol. 1* (London: George Allen & Unwin Ltd, 1963); A. Passalacqua, *L'Autobus et Paris* (Paris: Economica, 2011).

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[13] S. Graham and S. Marvin, *Splintering Urbanism: network infrastructures, technological mobilities and the urban condition*, London, New York, 2001, 13.

[14] Jürgen Osterhammel, *The Transformation of the World: A Global History of the Nineteenth Century* (Princeton: Princeton University Press, 2014), page 711.

[15] Matthew Gandy, *The Fabric of Space: Water, Modernity, and the Urban Imagination* (Cambridge: The MIT Press, 2014).

[16] Maria Kaika, Architecture and crisis: re-inventing the icon, re-ima(in)ing London and re-branding the city, *Transactions of the Institute of British Geographers* 35.4 (2010), 453-474; Erik Swyngedouw, *Liquid Power: Contested Hydro-Modernities in Twentieth-Century Spain* (Cambridge, The MIT Press, 2015).

[17] Maria Kaika and Erik Swyngedouw, Fetishizing the modern city: the phantasmagoria of urban technological networks, *International Journal of Urban and Regional Research* 24.1 (2000), 120-138

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[19] Osterhammel, *The Transformation of the World*.

[20] We are grateful to the referees for suggesting this formulation.

[21] Thomas P. Hughes, *American Genesis A Century of Innovation and Technological Enthusiasm 1870-1970* (Chicago and London: The University of Chicago Press, 2004), 298-309.

[22] For a study of patents, state patronage and the work of William Thomson, later Lord Kelvin, see Christine MacLeod, 'Patents and State Patronage in New Technosciences, circa 1870-1930', *Isis* 103 (2012), 328-339.

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[25] W. E. Bijker and J. Law (Eds.), *Shaping Technology/Building Society Studies in Sociotechnical Change* (Cambridge, MA and London: The MIT Press, 1992), 9-10.

[26] Graham and Marvin *Splintering Urbanism*, 19-20.

[27] For the Hobbes-Boyle controversy see S. Shapin and S. Schaffer, *Leviathan and the Air-Pump Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton University Press, 1985).

[28] G. D. Hiscox, *Compressed Air Its Production, Uses, and Applications* (London, 1902), 15-28. Two other contemporary accounts are M.A. Pernolet, *L'air comprimé et ses applications production distribution et conditions d'emploi* (Paris, 1876); and Th. Simons, *Compressed Air a Treatise on the Production Transmission and Use of Compressed Air* (New York, 1914).

[29] G. Medhurst, *A New Method of Conveying Letters and Goods with great certainty and rapidity by Air* (London, 1810), 9-10. See also, *On the Properties, Power, & Application of the Aeolian Engine* (London, 1810); *Calculations and Remarks tending to prove the practicability, effects and advantages of a Plan for the rapid conveyance of Goods and Passengers upon an iron road through a tube of 30 feet in area, by the power and velocity of Air* (London, 1812).

[30] Barker and Robbins, *London Transport*; López Galviz, Mobilities at a standstill, 71-73.

[31] The majority of the Tube lines in London use a section of 11ft 8in in their tunnels. Though fascinating, tracing the connections between Barlow and Medhurst is beyond the scope of this article.

[32] John Vallance is condemned to the same obscurity as Medhurst by Henry Atmore in his otherwise informative article Railway Interests and the 'Rope of Air', 1840-8, *The British Journal for the History of Science* 37, 3 (2004), 260-61.

[33] For the list of seven reasons justifying his project see John Vallance, *A Letter to M. Ricardo, Esq. in reply to his letter to Dr. Yates, on the proposed method of pneumatic transmission, or conveyance by atmospheric pressure* (Brighton, 1827), 11-13.

[34] M. Andraud, *De l'air comprimé et dilaté comme moteur, ou des forces naturelles recueillies gratuitement et mises en reserve. Seconde édition augmentée d'une partie experimentale en collaboration avec M. Tessie du Motay* (Paris, 1840), see also *Chemins a Vent ou Locomotion par l'air comprimé (systeme Andraud)* (Paris, 1846). For a contemporary discussion of the work of Andraud and others see A. P. H. Gaugain,

Notice Historique sur l'emploi de l'air comprimé considéré comme force motrice et comme agent de locomotion (Paris, 1958), 9, 52-53.

[35] Pernolet *L'air comprimé*, 9.

[36] Pernolet *L'air comprimé*, 14-16.

[37] For a review of these technologies, see A. Grenon, *Manuel pratique de l'air comprimé* (Paris: J. Loubat, 1931).

[38] William Prellwitz, Compressed air: its production, transmission and use, *Compressed Air* (1897) 2,,7: 285

[39] Frank Richards, Things worth while in compressed air practice', *Compressed Air* (1911) 15, 6: 6059; emphasis added.

[40] See, for example, the reports 'Fondation à l'air comprimé. Emploi du caisson batardeau divisible et mobile', *Annales des Ponts et Chaussées* (1881) vol. I, 323 and vol. II, 103; also 'Fondations à l'air comprimé des jetees du nouveau port de la Pallice à La Rochelle', *Annales des Ponts et Chaussées, Memoires et Documents relatifs à l'art des constructions et au service de l'ingenieur* (1889) vol. XVIII, 455.

[41] Gaugain, *Notice historique*, 53.

[42] Pernolet *L'air comprimé*, vii.

[43] To show how easy it is to use this technology, Grenon indulged in a bit of condescension: 'pneumatic tools are, for instance, successfully used in mining operations in Africa by careless and inexperienced indigenous staff', *Manuel pratique*, 31.

[44] 'It is more than half a century since the properties of compressed air as a remedial agent were put forward as a theory and in practice in "compressed-air baths", and claimed to be especially useful in the treatment of pulmonary diseases and of dyspepsia'. Hiscox, *Compressed Air Its Production*, 775.

[45] Anon., Air alleviates torture in Paris beauty shops, *Compressed Air* (1921), 26, 3: 10019.

[46] A typical example is James Pilbrow's 1844 proposal for a pneumatic telegraph in combination with an atmospheric railway and canal. Science Museum Archives, J. Pilbrow, *Atmospheric Railway and Canal Propulsion and Pneumatic Telegraph* (London, 1844).

[47] Grenon, *Manuel pratique*.

[48] B. C. Bacheller, Recent progress in the development of pneumatic dispatch tubes, *Compressed Air* (1898) 3, 559.

[49] Prellwitz, 'Compressed air', 291-292. As we will see later on, the loss of pressure with distance turns out to be a disadvantage as it requires diminishing pipe diameters, which makes it inconvenient over large distances.

[50] René Champly, *L'air comprimé ou raréfié : production – emplois* (Paris: Dunod, 1929): xv.

[51] Pernolet, *L'air comprimé*, 17-18.

[52] Champly *L'air comprimé ou raréfié* , xv.

[53] 'Compressed Air vs. Electricity', *Compressed Air* 1, 12 (February 1897), 179-80.

[54] See ‘Les canalisations electriques a Paris’, *Revue Universelle des Inventions Nouvelles et des Sciences Pratiques* (1895), 1, 188-89.

[55] Victor Popp, *L’air comprimé à Paris : sa production, ses applications et son prix de revient* (Paris: E. Bernard et Cie, 1894), 32.

[56] Anon., Popp compressed air motors for tramway traction, *Compressed Air* (1899) 4, 6: 720.

[57] See ‘Installations des Tramways Popp-Conti a Saint Quentin’, *La Vie Scientifique* (1896), 1, 325.

[58] Popp, *L’air comprimé à Paris*, 34.

[59] Tom Standage, *The Victorian Internet: The Remarkable Story of the Telegraph and the Nineteenth Century’s Online Pioneers* (London: Phoenix, 1998).

[60] See ‘Early Pneumatics', *Compressed Air* 1,3 (May 1896), 4-5.

[61] *Ibid*., 926.

[62] *The Times*, 10 February 1863, 5.

[63] Anon., London’s lost tunnel, *Compressed Air* (1900) 5, 2: 926; Standage *Victorian Internet*, 93.

[64] ‘London’s lost tunnel’, 927, 923

[65] ‘London Railways of the Past’, *The Times*, 1 September 1938, 8.

[66] Molly Wright Steenson, Interfacing with the subterranean, *Cabinet* 41 (2011), 82-86.

[67] Thierry Poujol, *Des réseaux pneumatiques dans la ville : un siècle et demi de techniques marginales* (LATTS: Noisy-le-Grand, 1986). Neuilly-sur-Seine to the west was the only place outside of Paris that was connected to this network (in 1914).

[68] J. B. Berlier, *The Pneumatic Transmission of Messages and Parcels between Paris and London, via Calais and Dover* (London: 1885), 2-10, 11-17.

[69] *Compressed Air* 1, 12 (February 1897), 174-77

[70] C. Tobitt and A. Taylor, *The Pneumatic Post in Vienna, vol. 1* (Stokesley, UK, Austrian Philatelic Society, 2005).

[71] *Compressed Air* 2, 12 (February 1898), 371-73.

[72] Neil Smart, *The Berlin Rohrpost* (Sway, Hants: Germany and Colonies Philatelic Society, 2003), 1-10.

[73] *Pneumatic-tube service. Report of the post-master general* 1901, 35, 29-33, 34.

[74] Tolbitt and Taylor, *Pneumatic Post*, 6, 53, 7; see also the subsequent table that lists all stations up to the 1950s, pp. 10-15.

[75] Ben K. Raleigh, and A M Hoffmann, Paris has reason to be proud of her pneumatic mail-tube system, *Compressed Air* (1925) 30, 2: 1141.

[76] Popp, *L'air comprimé à Paris* 5-6, 10.

[77] A serious accident occurred during the sinking of the caissons for the Nord Sud line under the Seine on 23 December 1907 that killed five workers and flooded the existing works. See, for example, the brief note in *Compressed Air* (February 1908), 13,2: 4763. For a fuller report on the progress of the construction of the line see 'Caisson Work for the Paris Subway', *Compressed Air* (December 1907), 12, 10: 4655-4657. On the Hudson Tunnel see, for example, Timothy R. White, Crossing oceans to cross rivers: tunneling the Hudson in the late 19th century, C. López Galviz and S. Merrill (Eds.),

Going Underground: New Perspectives (London: London Transport Museum, 2013), 56-63.

[78] See 'Les Tramways a Gaz', *La Vie Scientifique* (1896) 1, 489-92.

[79] Prellwitz, 'Compressed air'; Champly *L'air comprimé ou raréfié*.

[80] The compression air heats the air up, but this accumulated heat must be evacuated during the compression process. Champly, *L'air comprimé ou raréfié*.

[81] *Ibid*., page xvi, emphasis in original.

[82] Two key works illustrate this: W. Schivelbusch, *Disenchanted Night. The Industrialization of Light in the Nineteenth Century*, University of California Press, 1988 and J. Schlör, *Nights in the Big City Paris, Berlin, London 1840-1930*, London, 1998.

[83] Important as their work is, Tarr and Dupuy cover transportation, water systems, waste disposal, energy, heat and power, and communication, without a mention of pneumatics or compressed air.

[84] While Medhurst is often cited in most of the histories of compressed air, no academic articles, apart from Atmore's, appear to have discussed his work in the context of histories of technology and science (see for example, Pernolet, *L'air comprimé*; Hiscox, *Compressed Air*; also see *Compressed Air Magazine* for articles charting the history of pneumatics).

[85] Poujol, *Des réseaux pneumatiques* 1986: 127-28.

[86] Ibid.: 130.

[87] Osterhammel, *The Transformation of the World*.

[88] Atmore, Railway interests, page 279.

[89] For London, see Parliamentary Debates (*Hansard*), House of Commons, vol 143, 29 March 1905; for Paris, see 'Le sous-sol de Paris aux Allemands', *La Croix*, 22 February 1893, page 2.

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'The Modern Atlas':

Compressed air and nineteenth-century cities

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The research on which this paper is based is part of the project 'Pumping time: geographies of temporal infrastructures in fin de siècle Paris', funded by the Arts and Humanities Research Council (grant number AH/H39414/1). We gratefully acknowledge this support. We are also grateful to the three referees and to Jonathan Rutherford for their constructive comments and suggestions.

Figure 01

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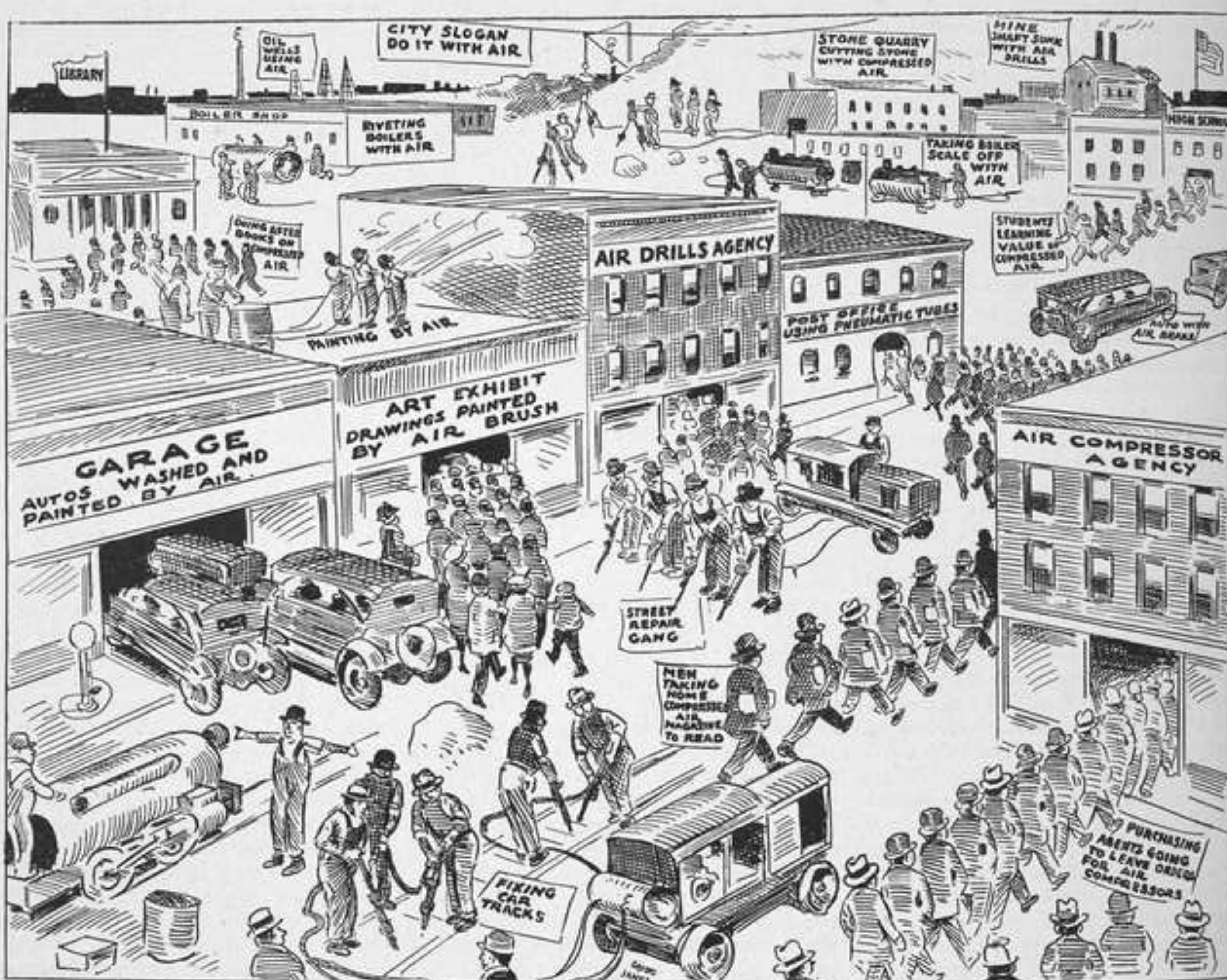

THE AGE OF COMPRESSED AIR

Figure 02
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Figure 03
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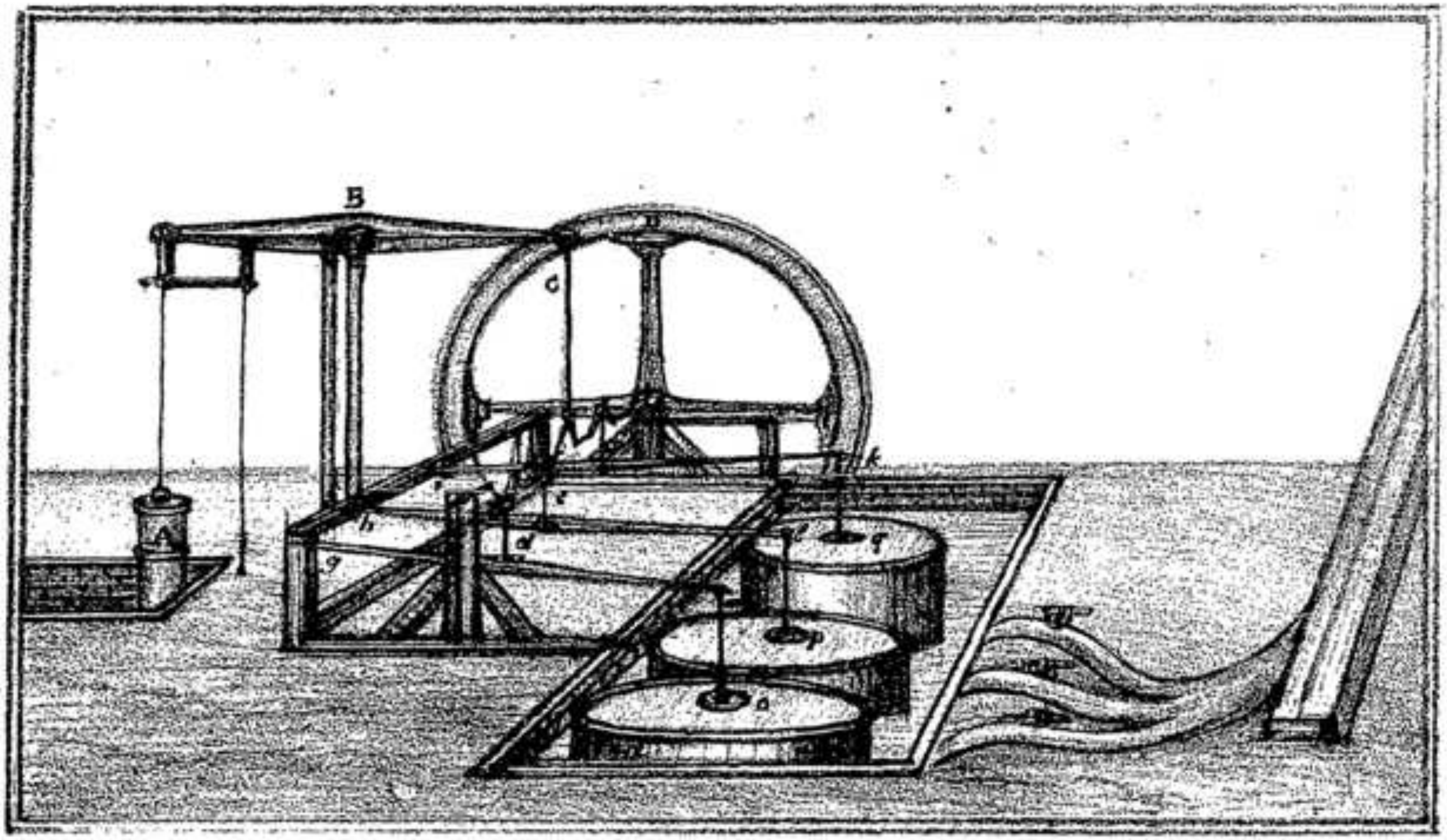

Figure 04
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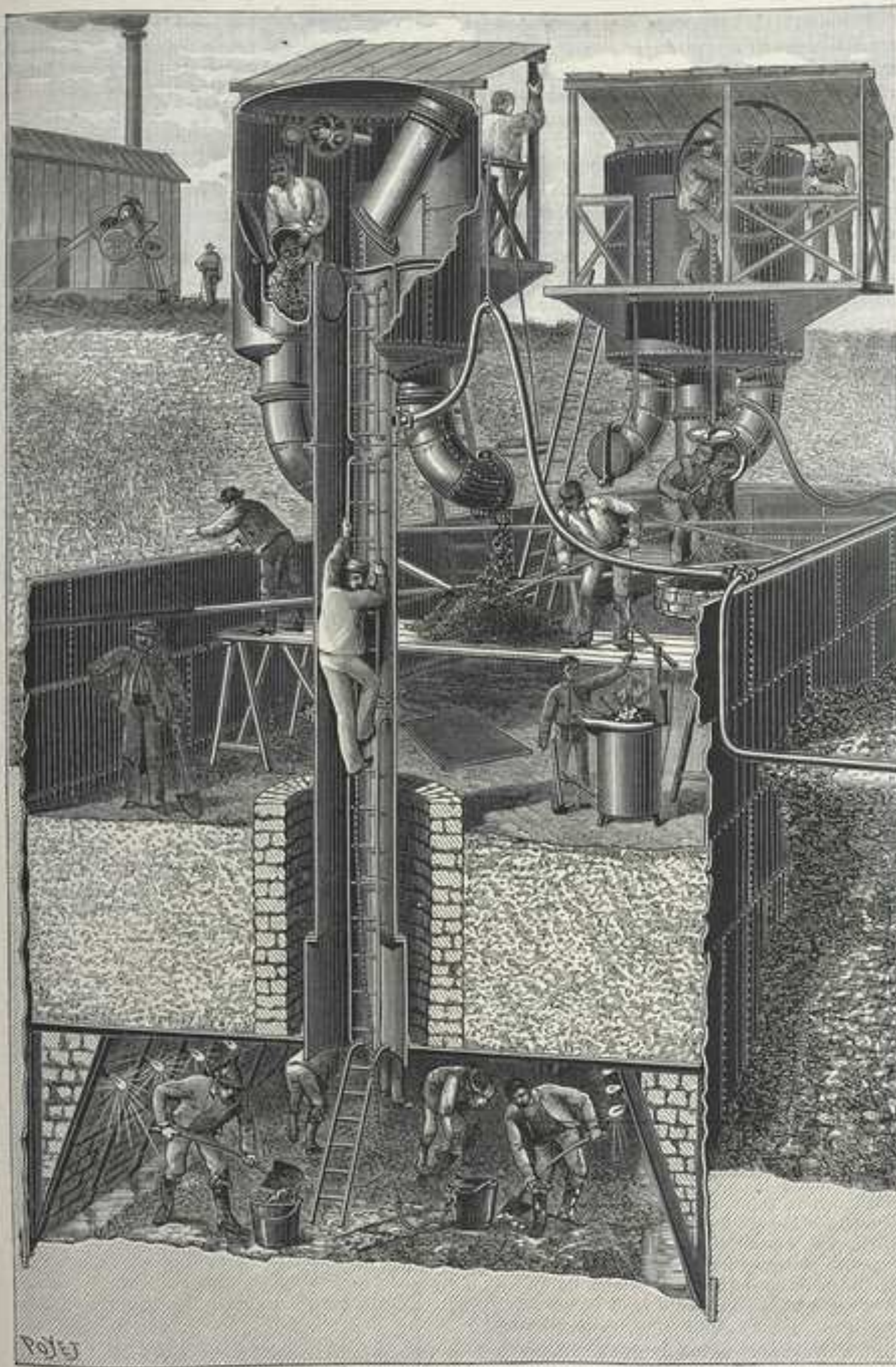

Fig. 2. — Vue d'un caisson pour la fondation de la tour Eiffel par l'air comprimé. — Coupe montrant le travail souterrain et les tubes d'accès et de déblaiement.

Figure 05

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LES CANALISATIONS ÉLECTRIQUES A LONDRES ET A PARIS

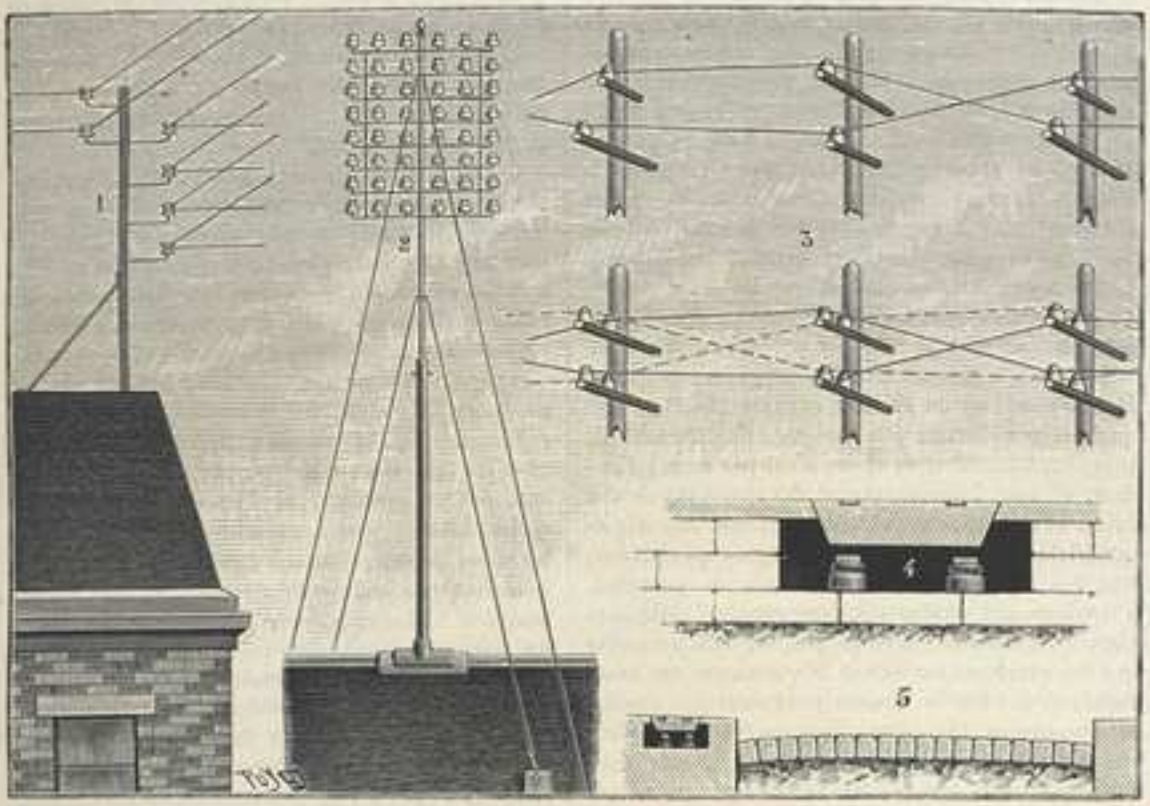

Fig. 1 à 5. — Différents systèmes de canalisations électriques aériennes et souterraines à Londres.

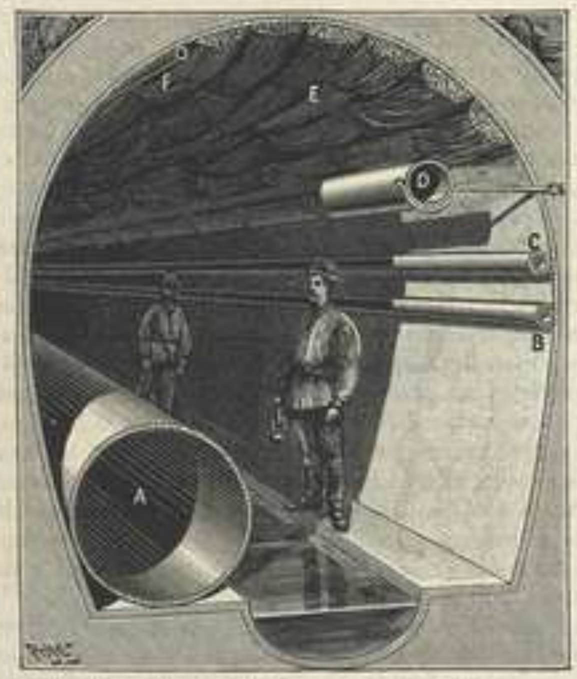

Fig. 6. — Coupe d'un égout de l'avenue de l'Opéra, à Paris, montrant les canalisations électriques.

Au moment où plusieurs compagnies vont bientôt commencer à Paris des installations d'éclairage électrique, il n'est peut-être pas inutile de présenter quelques considérations sur les canalisations électriques, et de passer en revue ce qui a été fait jusqu'ici à ce sujet.

Nous parlerons d'abord des canalisations dans la ville de Londres. Toutes les canalisations étaient jusqu'à ce jour *aériennes*. Sur le toit des maisons sont fixés des poteaux en fer (fig. 1), avec des isolateurs en porcelaine sur lesquels viennent passer des fils dans toutes les directions. Il n'est pas rare de voir sur un même support des câbles destinés à la lumière et des câbles destinés aux services télégraphique et téléphonique. Les câbles destinés aux courants alternatifs de haute tension (2400 volts) sont également placés de la même manière. Nous citerons principalement les câbles de la station de *Grosvenor Gallery* (système Ferranti) qui sillonnent Londres en plusieurs sens et s'étendent dans un cercle qui a un rayon de 4 km. La station d'*Oxford Street* par transformateurs Mordey (2400 volts) a également ses câbles placés sur les toits. Les propriétaires se sont volontiers prêtés aux circonstances et ont accordé les permissions nécessaires, le plus souvent sans accepter de redevances, quelquefois pour des sommes infimes. En effet, ils étaient jusqu'ici les seuls maîtres d'accorder ou de refuser

Figure 06
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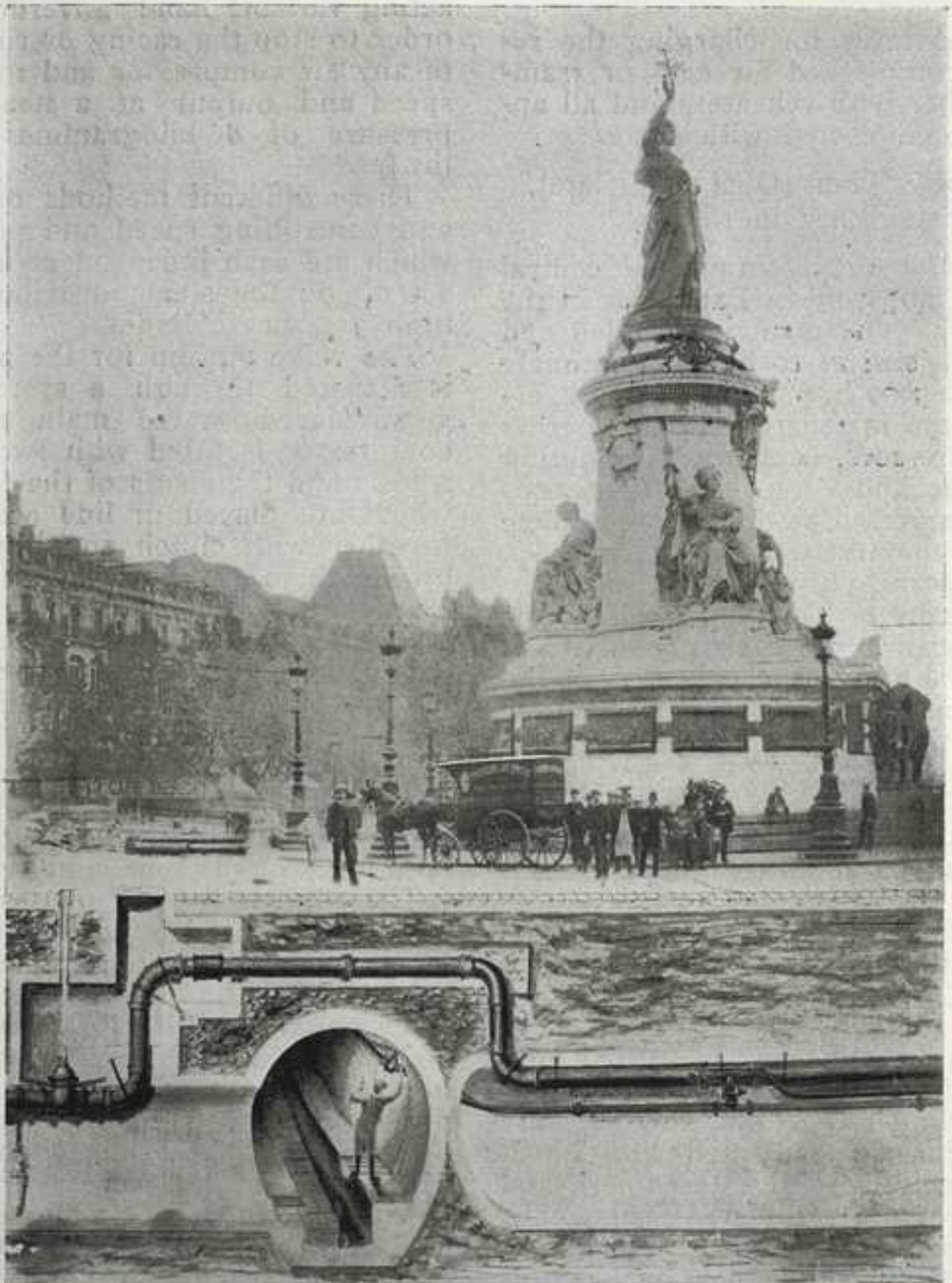

PLACE DE LA REPUBLIQUE, PARIS, SHOWING THE COMPRESSED AIR MAIN PIPE LINE.

Figure 07
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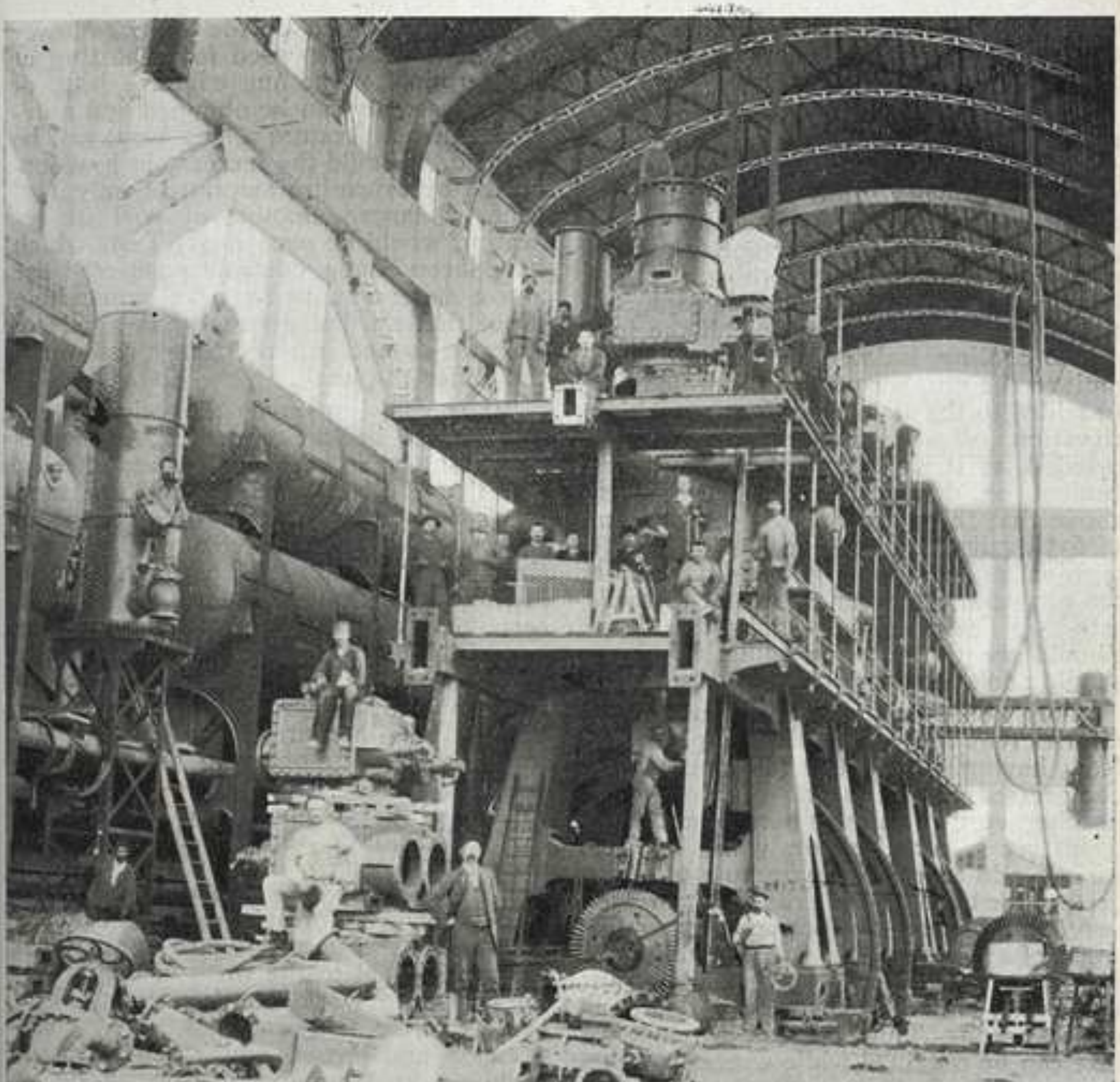

AIR COMPRESSORS AND AIR STORAGE RESERVOIRS.

Figure 08
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Fig. 3. Vue d'une horloge pneumatique à Paris, place de la Madeleine (d'après nature).

'The Modern Atlas'

Captions and sources for figures

Figure 1: The age of compressed air

Source: *Compressed Air* (April 1922) 27, 1: 120.

Figure 2: The Modern Atlas

Source: *Compressed Air* (February 1920) 25, 2: 9557.

Figure 3: Medhurst's Aeolian engine

Source: G. Medhurst, *On the Properties, Power, & Application of the Aeolian Engine* (London, 1810), insert between pp. 14 and 15.

Figure 4: Foundations of Eiffel Tower

Source: *La Nature* (1887), 1: 409.

Figure 5: Electric lines and pneumatic tubes in Paris sewers (Avenue de l'Opéra). A, B and C are for water, D is for compressed air, E for telegraph and telephone lines, and F for pneumatic clocks. Note that although it is not depicted, the sewer should also contain a pipe for the pneumatic post, which is acknowledged in the article accompanying this image.

Source: *La Nature* (1889), 1: 165

Figure 6: Place de la République, Paris

Source: *Compressed Air* (September 1899): 744.

Figure 7: Victor Popp's compressed air factory

Source: *Compressed Air* (September 1899): 742.

Figure 8: Pneumatic clock at place de la Madeleine, Paris

Source: *La Nature* (1880), 1: 409.