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Engineers and Engineering History: Problems and Perspectives

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In past decades, the history of engineers and engineering has seen spectacular development. Despite this, major interrogations are still left unanswered. This article examines some of these pending questions, like the type of relation that exists between engineering knowledge and practice, or the complex articulation between continuities and discontinuities that characterizes engineering history. Finally, the article proposes to focus on engineering rationality as a possible way to address some of these issues. In order to do so, engineering rationality is not to be confused with some kind of generic and abstract logic. On the contrary, it must be historicized.

Keywords: Engineering; History; Science; Rationality; Education; Practice

Introduction

In past decades, the history of engineers and engineering has seen spectacular development. Studies of the engineering profession in various countries ranging from England to Russia, from France to Egypt have multiplied. Historians of science and technology have scrutinized engineering knowledge, as well as the various types of engineering realizations.

Despite this development, major interrogations are still unanswered. In addition, none have yet sufficiently explored some possible directions of development. Above all, the relations between engineering history and social history still represent an open-ended issue. What can we learn through engineering evolution that concerns society and culture at large? In the following pages, I would like to discuss some of these questions, as well as the perspectives of further inquiries that they imply. Among these perspectives, I will envisage in particular the interest of notions such as rationality and social imagination in order to understand some key features of engineers and engineering history.

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Engineers and/or Engineering History

Is the history of engineers primarily about the engineering profession and its evolution, or should it take into account its technical realizations such as infrastructures or machines? Although the question might seem trivial at first, the answers given to it are quite different from one author to the other. Whereas some historians have tried to articulate these two dimensions, many have devoted themselves exclusively either to the social dimension of the engineers' history, or to its technical aspects. In the French case, historians and sociologists, like André Thépot or André Grelon, have focused primarily on engineering institutions such as State corps of engineers, engineering schools and professional associations.[1] They have paid special attention to the sociological origins and trajectories of the engineers that they have studied without entering into the details of their realizations. Another series of contributions has dealt with these details. The historians of art and architecture Bertrand Lemoine and Bernard Marrey have described for instance the evolution of civil engineering, of bridge building in particular, while the historian of technology André Guillerme has analyzed the emergence and development of building technologies in the 19th century.[2] There are few relations between these two types of inquiries. Such a split is by no means a French specificity. The same divorce can be observed in the USA between studies of engineering institutions and social strategies, like Edwin T. Layton's classical analysis of the 'revolt of the engineers', and technologically-oriented accounts like Tom F. Peters' *Building the Nineteenth Century*.[3]

The lack of relations between these two fundamental aspects of the history of engineers is partly attributable to the extreme diversity of their jobs and realizations. Besides the distance that separates civil, mechanical or electrical engineering, engineers—since the second half of the 19th century at least—have occupied all kinds of positions between purely technical functions and management responsibilities. Engineering looks more like a continent marked by striking contrasts than like a unified field. On this continent, no self-evident link seems to exist between the organization of the profession and the various activities engineers are involved in. In this context, it may be tempting either to define the engineer through his social identity and aspirations or to limit oneself to a relatively narrow domain of technological expertise.

Although valid in themselves, these two options may generate however some dissatisfaction, just as the purely internal or external histories of science that have coexisted for a long time. Is it possible, in particular, to study the engineers without taking into account their competences and realizations? Various attempts have been made to justify such a choice. The American scholar Peter Whalley has argued, for instance, that the main characteristics of the engineer lies in his intermediary position between capital and labour, as a trusted employee, contrary to other categories of workers that do not benefit from a similar trust from the owners or managers of the company.[4] The observation is of course to a large extent true. The 19th-century French State engineers enrolled in the utopian and proto-technocratic Saint-Simonian movement were already persuaded that their mission was to act as mediators between capital and labour.[5] In the 1920s and 1930s, a similar idea was at the core of the technocratic ideals that flourished in both the USA and Western Europe.[6] The characterization, however, seems too narrow to apply to every situation, especially in countries where the State has traditionally been a massive employer of engineers like France or Russia. Once again, the engineers are spread on the surface of a continent that is not easy to map.

There are indeed questions that seem more relevant to the political and sociological realm than to the technological one. One could be tempted to examine, for example, the existence of national engineering traditions in such a light. The contrasts between British, French or German engineering professions are largely due to political and social factors, from the respective roles played by the administrations of these countries to the different conceptions of authority and hierarchy that permeates their industrial organizations. As we tried to show in a paper published a few years ago, the major difference between early-19th-century British and French engineers lay neither in their scientific training nor in the type of skills they displayed on the field.[7] It had more to do with the perspective these engineers assigned to their quest for technological competence and responsibility. Whereas British engineers tried to emulate the traditional professions, to appear as homologous to ministers, physicians or lawyers, their French counterparts were looking for a more authoritarian conception, seeing themselves as almost political figures in charge of the public good. In spite of its emphasis on their different attitude towards science, Edna Kranakis' comparison between American and French engineers leads to a very similar type of explanation.[8]

Nevertheless, is it possible to leave entirely aside the technological dimension of engineering when one deals with national engineering traditions? Tom Hughes' comparison between the development of electricity in the USA, UK and Germany tends to suggest the contrary.[9] Even if political and social factors play key roles, they are indeed intertwined with technological determinations. Despite what its name suggests, the so-called 'Social Construction of Technology' has shown that, while technology is socially constructed, technological organizations and objects often shape society and sociability. The 'Social Construction of Technology' is also about the technological construction of society.[10] What may appear as purely political and social factors is often linked to technological determinations. To return to the comparison between British and French early-19th-century engineers, their different aspirations had definitely something to do with the type of technological competence they had respectively developed. In the British case, the engineering field was marked by a continuity between civil and mechanical engineering, a continuity that limited somewhat the pretension of the engineer, since he appeared as a member of a larger community of technologists that included machine- and instrument-makers. In France, on the contrary, from fortification to bridges and highways, engineering was primarily defined through the design and realization of large, state-initiated infrastructures. The French engineers' aspiration to set the standards of public good was inseparable from their isolation from other technical figures, and their monopoly on large-scale infrastructures.

Knowledge and Practice

In order to throw some light on the difficult question of what exactly an engineer is, many scholars, instead of focusing on his social standing, have paid attention to the existence of a relatively formalized body of knowledge that is supposed to separate him from other technological figures. Indeed, from the Renaissance on, engineers have often insisted on the necessity to ground their practice on science. The title of the first major French treatise on fortification published by Jean Errard de Bar-le-Duc on the eve of the 17th century, *La Fortification Démonstrée* [Fortification Demonstrated] is quite revealing in that respect.[11] The desire to demonstrate is typical of the ambition to ground engineering on the firm soil of scientific knowledge. Throughout their long history, engineers have furthermore developed a science of their own, an engineering science the relations of which with mathematics, mechanics, physics and chemistry have been studied at length by a whole range of historians.

More generally, engineers seem definable by their ambition to take their decisions according to a rigorous set of criteria, some of these criteria regarding natural phenomena, others having to do with the economic feasibility of their projects. Authors ranging from Alfred Chandler to Hélène Vérin, or Theodore Porter, have stressed the importance of their contribution, not only to mathematics and physics, but also to the emergence and development of modern management and economics.[12]

The large number of studies devoted to engineering education—and to engineering schools in particular—is among the most visible consequences of the accent that has been put on knowledge as a crucial feature of the profession. Books and articles have been devoted in particular to the major French educational institutions: the École Polytechnique, the École des Ponts et Chaussées, the École Centrale, the École Supérieure d'Électricité and the Écoles d'Arts et Métiers, to name just a few.[13] Studies concerning engineering education in Spain, Switzerland, the Netherlands, or Egypt are also available.[14] The trend is less pronounced for sure in the UK or in the USA, the reason being the less determining influence of schools and diplomas on the structures of the profession. The study of engineering education appears nevertheless as one of the most developed areas in the history of engineers and engineering.

In most cases, this development has not addressed however the key issue of the relation between education and practice. More generally, the attention paid to the engineers' formalized knowledge, to engineering mathematics and mechanics, to engineering economical and managerial principles, has not been accompanied by a thorough investigation of their real impact on practice. Between the formalized knowledge that can be traced through courses and treatises, and the everyday decisions made by engineers, there must be for sure some kind of intermediate know-how. This intermediate level is still to a large extent unexplored.

How does engineering formalized knowledge relate to engineering practice? Various historians have tried to bring forward elements of answer to this pending question. Their answers have generally followed two different ways. The first one is to relate engineering knowledge to more fundamental cultural structures, structures that are supposed to govern both reflection and action. Michel Foucault's *episteme* and Thomas Kuhn's *paradigm* are among the possible theoretical models for these attempts to highlight the deep structures allegedly common to engineering knowledge and practice.[15] My past work on the French State engineers in charge of the construction of bridges and highways, *les ingénieurs des Ponts et Chaussées*, clearly belongs to that tendency, just as Konstantinos Chatzis study of the engineering practice of regulation in large-scale 19th- and 20th-century networks.[16] Hélène Vérin's broad picture of early modern engineering, *La Gloire des Ingénieurs* is also close to that orientation that she merges with philosophical reflections borrowing to the theories of decision-making and design initiated by Herbert Simon and pursued by the late Jacques Guillerme on the French-history-of-technology scene.[17]

A second way to treat the problem is to inspire oneself from deterministic sociological theories like Bourdieu's. Bruno Belhoste's recent synthesis on the scientific and technological curriculum at the Ecole Polytechnique clearly belongs to that second line.[18] His work is indeed strongly indebted to Bourdieu's notions of field and *habitus*. Instead of invoking deep cultural structures anterior to discourse and action, it relies on the assumption that education shapes the horizon of expectations of the individuals submitted to it, as well as their behaviour in the concrete circumstances of their practice. In his analysis of the technocratic orientation of the graduate of the Ecole Polytechnique, Belhoste is also close to some aspects of David Noble's work on contemporary American engineering, with its implicit criticism of the authoritarian streak at work in large sectors of the profession.[19] Deterministic sociological theories are hard to separate from political stances that still owe something to the former Marxist critique of science and technology.

In the domain of industrial organization, the study of hierarchy and the protocols of command it relies upon provide useful clues on how to relate engineering knowledge and practice. One of the major functions of knowledge is indeed to stabilize hierarchy and command. Command protocols bear as for them the mark of the know-how I mentioned earlier as intermediary between formalized knowledge and practice. In the work of Yves Cohen, one of the major French representatives of the domain, the role of formalized engineering knowledge is however downplayed, in spite of the key importance given to it by the forefathers of industrial organization like Frederick Winslow Taylor.[20]

Finally, the 'Science Studies' and the 'Social Construction of Technology' have perhaps brought the most convincing answer to the difficult question of the relation between engineering knowledge and practice. Abandoning all kind of *episteme*, *paradigm* or *habitus* in favour of a scrutiny of what actually happens on technological scenes, they have often convincingly described the interactions between knowledge, decision-making and realization. Michel Callon's and Bruno Latour's studies of the engineering of the electric vehicle and the mass-transit project Aramis are exemplary in that respect.[21] Instead of researching an overhanging point of view, they have adopted a more horizontal vision enabling them to grasp the chains, or rather the networks constituted by humans and objects, knowledge and actions.

One must however notice that these inquiries have been generally conducted on a very small scale, a scale reminiscent of the influence exerted initially by ethnomethodology on the nascent Science Studies. Above all, Science Studies and the Social Construction of Technology have focused on moments of change, on process of innovation rather than the long periods of stability that characterizes technological systems. In other words, the key problem of technological regulation has been left aside. Yet, just like the evolution of large technological systems, the history of engineers and engineering appears as a complex maze of changes and continuities, of stability and instability.

Continuities and Discontinuities

At this stage, it is perhaps necessary to review briefly the major articulations that are currently put forward to evoke engineers and engineering history. Let us note from the start that some of these articulations, like the 18th-century trend towards professionalization do not correspond to a clear-cut technological change. The often-indirect nature of the links between engineering transitions and technological change adds a supplementary degree of complexity to the history of the engineers.

A first way to structure this history is to observe the successive steps leading to the contemporary engineering continent. One considers generally that the first recognizable figure of engineer emerged at the Renaissance, at the intersection of two traditions. The European Renaissance engineer was the inheritor of both the medieval tradition of master-builders and specialists of war engine, and of the Antique ideals conveyed by Roman monuments and by books like Vitruvius' 10 books on architecture.[22] At the time, the engineer appeared as an isolated figure, an artist working for kings and princes, like his fellows artist painters, sculptors or architects. He will keep that status until the second half of the 17th century, when great territorial states like France will begin to organize their military engineers in corps, thus paving the way for the emergence of a profession.

In this perspective, the gradual professionalization of engineers represents the next step. In France, as I just said, professionalization occurred through the creation of State corps of engineers, and schools preparing to these corps, in England through professional associations. The process began earlier in France, since the corps of military engineers was organized in 1691, the *Ponts et Chaussées* corps in 1716, while the first English engineering association, the Society of Civil Engineers chaired by John Smeaton was created in 1771 only, and the second, the Institution of Civil Engineers in 1818.[23] Globally, between 1750 and 1850 the engineering profession emerged. From one country to another, its organization followed generally either the French or British model. Countries like Spain or Russia followed the French State-based model. Others like Belgium took after its British rival. The USA, as for them, imported the two models. It led to the coexistence of military corps of engineers, and civil engineers organized through associations similar to the British Institution of Civil Engineers.[24]

From the 1850s on, the engineering profession was marked by an increasing diversity. In France, civil engineers developed beside State engineers. Above all, mechanical engineering gradually separated itself from civil engineering.[25] Later in the 19th century, it was the turn of electrical and chemical engineering to emerge. This process, which continues today, was to create the engineering continent I have repeatedly alluded to.

The growing number of engineers turning towards managerial functions further accentuated such a diversification. The alliance between engineering and managerial responsibility was already discernible in France towards the middle of the nineteenth century. A similar phenomenon could be observed in the USA where engineers began to occupy managerial functions in major railways companies.[26]

After the professionalization and diversification of the engineers, their growing number was to transform them gradually into a massive labour force. New emerging industrial powers as if Germany or the USA took that step early in the 20th century. Countries such as France were to imitate them after World War II only. The result was a gradual erosion of the prestige of the engineering profession compared to rival figures like physicists.

The evolution leading from the engineer artist to the massive twentieth-century engineering labour force is only one possible version of engineering history. A study of the art of the engineer reveals other key episodes like the declining importance of fortification at the beginning of the eighteenth century, or the emergence of organizational practices like scientific management towards the end of the 19th century.

A study of engineering knowledge should be as for it organized around other episodes like the transition from a geometric knowledge to a calculus-based between 1750 and 1850, and the gradual connection between this new calculus-based engineering science with economics that occurs during the same period.[27] A shift of a similar importance has probably occurred in the past decades with the development of computers. Digital culture has affected engineering science to its very core.

In short, there are many ways to construct plausible histories of engineering. Some episodes of these various histories coincide. The French 18th-century professionalization, for instance, was contemporary with the shift of engineering knowledge towards calculus. This coincidence does not always mean that the episodes are connected. One may wonder for instance whether the 18th-century professionalization had really something to do with the shift towards a calculus-based engineering science. Doubt increases when one remarks that the English path towards professionalization ignored such a coincidence.

The most surprising aspect of engineering histories is its lack of systematic link with the general history of science and technology. The scientific revolution has almost no incidence on engineering evolution, even if some of its most prominent figures, like Galileo, have links with the engineering culture of their time. More surprisingly, the relations between the first industrial revolution and the professional history of engineering are far from being straightforward. In Britain, as in France, the initial trend towards industrialization does not rely on engineers but on inventors and entrepreneurs like James Watt or Matthew Boulton. Surely, these links become more evident with the second industrial revolution, through problems like control that represent major concerns for late-nineteenth-century entrepreneurs and engineers.[28] There are however other episodes of industrial change in which the engineering dimension is negligible. The periods of change in the engineering profession do not necessarily coincide with all the episodes of accelerated scientific and industrial transformation. Actually, it is often easier to relate engineering history to political and social issues than to purely scientific and technological ones. In the 18th and early 19th centuries, for instance, the history of French engineers is closely related to the development of the modern French State and administration. Later in the 19th century, this history becomes part of the evolution of the French business elite if we are to follow historians like Christophe Charle.[29]

Political and social questions like the emergence of technocratic ideals cannot be studied without reference to engineering history. More generally, if the scientific and industrial pace is often distinct from the rhythm of transformation of the engineering profession, the latter is inseparable from what we tend to call 'rationalization', after Max Weber.

The relative autonomy of engineering history or of some of the possible histories of the engineering profession, art, science and realization, from the general scientific and industrial pace is not the only problem faced by the historian. Engineering history, or rather histories, is also marked by a complex maze of discontinuities. It is not easy to consider simultaneously the artist engineer of the Renaissance and the employee of one of today large corporations. Even if one limits oneself to the modern period, engineering history seems marked by discontinuities that are not easy to overcome.

There are, however, elements of continuity. Key institutions like the Ecole Polytechnique, in the French case, are among them, just as the State corps of engineers that still give to the French engineering scene its distinctive flavour. Cultural attitudes also play a role. The heritage of military engineering and its conception of mathematics as the very science of action, a conception the influence of which can be traced in the writings of Descartes, still colours French engineering education and practice. It explains the role that is still devoted to mathematics in French engineering curriculum. In France, an engineer is first somebody who has studied mathematics, a definition that would seem strange in countries like the UK or the USA.

Technological traditions offer also elements of continuity. In civil engineering, earthwork represents clearly a French obsession, from fortification to freeways. Whereas an Italian engineer will often privilege a solution based on a bridge, his French colleague will first examine whether it is possible to cross with earth-moving.

In conclusion, with all its complexity, the history of engineers and engineering seem to leave two questions unaddressed. The first one lies, strangely enough, with the often-indirect connection between engineering evolution and global technological change. It raises the issue of the exact contribution of engineers to the dynamic of technology, past their role as inventors, designers, or managers. A second question regards the ways one can make sense of the complex maze of continuities and discontinuities that characterize the history of engineers and engineering. Is there coherence somewhere in this overlap of long-standing traditions and spectacular transformations? As we have seen, neither the engineers' social standing nor their formalized knowledge seem fit to provide it. Their practice is as for it too diverse for that purpose. In the last section of this paper, I would like to explore another path towards a comprehensive interpretation of engineers and engineering history.

Rationality, Social Imagination and Ethics

Although the study of practice has become a sort of watchword in contemporary history of science and technology, I am not sure that it can provide a general guideline for the study of engineers and engineering. Beside the extreme diversity of the engineer's activities that I have already mentioned, another reason to distance oneself from this orientation is provided by the engineers themselves. From the Renaissance on, engineers have almost constantly stressed their difference with according to them down-to-earth practitioners. Their various sciences, their aspiration towards managerial responsibilities, converge on that point.

The only common denominator to all the species of engineers that can be found throughout the centuries and in the various domains where actors consider themselves and are considered by others as engineers is perhaps the idea of a specific kind of a reason at work in their endeavours. Beyond its scientific connotation, the claim of Jean Errard de Bar-le-Duc to 'demonstrate' fortification is quite typical of this quest for motives, for a specific kind of reason that would distinguish the engineers from other figures.

It is thus tempting to define the engineers through a certain kind of rational argumentation, either in design or in decision-making. In other words, the identity of the engineer might very well like in a certain type of rationality, before the knowledge he makes use of.

The everyday confrontation with representatives of the profession at large may reinforce this point of view. For what civil and electrical engineers, engineers engaged in purely technological enterprises, and managers seem to share is a certain attitude, patterns of thought and action like the systematic decomposition of a complex problem into more elementary questions, or even a certain rigidity when dealing with issues to which clear-cut distinctions do not apply—social issues, for instance.

At this stage, it is necessary to avoid to pitfalls. The first one lies in an over-intellectualized conception of rationality. As far as engineers and engineering are concerned, rationality appears primarily as a guideline for action. Although engineering knowledge bears its imprint, it reveals itself primarily through the concrete practice of design, technological development and decision-making rather than in purely discursive structures. Thus, it might enable to overcome the gap between knowledge and practice.

Suggested by the engineering literature itself in its desire to appear as scientific, a second pitfall consists in sticking to a fixed, ahistorical conception of rationality, as if engineers had stuck, throughout their long evolution, to the same principles of choice and action. To demonstrate, something did not have the same meaning at the end of the 16th century, by the mid 1850s or today. Although the study of rationality may smooth out part of the discontinuities and breaks of engineers and engineering history, it does not erase some of its most fundamental transformations.

This last point suggests that rationality is not to be confused with logic at large. Contrary to logic, rationality is permeated by all sorts of historically determined factors like the representations of nature and man that prevail in a given society.

In the same line of thought, contrary to a long tradition in the social sciences, when confronted with science and above all technology, rational behaviour cannot be separated from the objectives it aims at. The distinction between the rationality of the ends, and the rationality of the means employed towards them, seems to me hard to sustain in the case of the engineers, despite a long tradition interpreting technology as the realm of an instrumental rationality impervious to its real ends. On the contrary, ends and means are in constant interaction.

This constant interaction means that rationality is not synonymous with a crystal-clear attitude consisting in the determination of the most appropriate means towards an end, whatever it is. In other words, rationality cannot be reduced to a sort of calculation. Ends and means do not follow similar paths. They are often somewhat contradictory. Their interaction is synonymous with perturbations that transforms rationality into something more muddy, so to say, than what one might expect a priori.

Another reason for this muddy nature lies in the fact that the engineer's rationality is not a pure individual conduct. It emerges in a context of interaction with other partners. Beside the other engineers, it has to take into account the existence of entrepreneurs and workers, even if it tries to set its own agenda. Rather than the result of a solitary exercise of the mind, rationality is the product of interaction, communication, and conflict.

For all these reasons, rationality is permeated by a whole set of elements that are usually considered as irrational. It includes desire and even impulses towards certain ends. It must allow for the uncertainties of communication and for conflict. Once again, rationality is neither crystal-clear nor straightforward. It appears often through ambiguous and twisted courses of action.

Let us not forget in passing that, as Hélène Vérin has brilliantly shown, trick and deceit were not foreign to the initial definition of the engineer.[30] With its use of technology as an almost counter-natural power, engineering had something to do with cheating, especially in the conduct of war, contrary to the frank and open attitude of traditional chivalry. In that respect, the engineer was comparable to Ulysses, wandering in a strange and threatening world the dangers of which he had to conjure through tricks like the Trojan horse.

Now rationality has something to do with the adaptation of means to ends, even if this adaptation is seldom a pure matter of optimization. In the case of the engineers, the means have been abundantly studied, even if their mobilization has often been described as a smoother process than what it is in reality. Here I would like to elaborate rather on the ends. For it might very well be the ends that singularize the engineers rather than their mobilization of scientific and technological knowledge. Behind the ambition to 'demonstrate engineering' lies, perhaps, a relatively specific type of ambition, an ambition extending far beyond the simple desire to gain or maintain one's social status and power.

This ambition might account for the recurring links between engineering conceptions and utopia from the Renaissance to the present. Strangely enough, the figure of the engineer has been often associated with utopian dreams, from the fantastic machines of 16th- and 17th-century utopian narratives to the technocratic streak of many 20th-century fictions. From the 19th century on, engineers have been furthermore associated to many utopian movements, Saint-Simonianism and Fourierism for instance.[31] Once again, the ends may play a more important role than what is usually assumed.

What is the aim of technology for engineers, beside of course their self-promotion? One might be of course tempted to interpret it in very general terms, after Heidegger or the School of Frankfurt, as an almost metaphysical quest for domination. When they were not sticking to the old anthem of the progressive hero devoted to public good, historians of engineering have often, implicitly or explicitly, given into that sort of perspective, the engineer appearing then as an almost Faustian villain.

Leaving that dramatic angle aside, I would like here to pay attention to another dimension of engineering, namely its belief in a natural order that should be a permanent source of inspiration for men and their organizations. To be more specific, engineers have generally seen themselves as mediators between nature and man. Their task was supposed to make nature exploitable, thus humanizing it to a certain extent, while importing into the human realm principles of productivity present in the natural world.

Another general characteristic of engineering lies in its systematic use of images and metaphors in order to formulate what this general role of mediation means in practice. Engineers have always made an intensive use of visual references borrowed to the natural or the human worlds. Plants, animals, skeletons and machines come to their mind when they try to approach what they aim at. Their utopian production is revealing in that respect with its abundance of organic or mechanical references, from the circulation of blood as a metaphor of infrastructures networks to the various motors supposed to bring a new prosperity to mankind.[32]

At a given time, one can call imagination, *imaginaire* in French, the system of these images. Since it deals primarily with nature and society, the engineer's imagination is intimately linked to the system of images that prevail in the society of which he is a member. In other words, the engineer's imagination appears as a component of social imagination.

Social imagination plays two roles: a role of justification of the present state of society, and a role of exploration of a different and better future. On the one hand, it functions like ideology, on the other it is close to utopia, according to Karl Mannheim or Paul Ricœur interpretations.[33] Engineers' imagination functions in the same way. It is both a factor of stabilization and change.

Rationality is inseparable from imagination. At the intersection of the two, one finds among others the key notions of effectiveness and efficiency. Contrary to what most engineers postulate in their desire to ground their practice on an indisputable science and on a ahistorical rationality, effectiveness and efficiency are culturally constructed notions. Just like mathematicians, who do not consider that all demonstrations are equivalent, engineers at a given time are more prone to certain solutions than to others. The best solutions supposed to be both effective and efficient are inspired by representations of what really matters in the physical world. Thus, the history of the successive engineering conceptions of efficiency and effectiveness are inseparable from these representations that we usually call nature. Despite Bruno Latour's call for a radical critique of the very notion of nature, it is probably impossible to get entirely rid of it since it enables professional figures like engineers to give meaning to their endeavours.[34]

In other publications, I have tried to sketch out some episodes of the history of effectiveness and efficiency.[35] I have in particular distinguished between a conception of effectiveness and efficiency, based on an architectonic vision of the world as well as on the key notions of order and proportion, which prevailed from the Renaissance to the mid eighteenth century. During the Enlightenment, this conception was gradually replaced by an interpretation of natural and social efficiency giving precedence to dynamic behaviour and flows instead of static equilibrium between causes and effects, the parts and the whole. If the first conception can be called Vitruvian, in reference to the principles contained in Vitruvius' ten books on architecture that influenced generations of engineers from the Renaissance on, the second is definitely analytical since it tries to understand dynamism and flow by their systematic decomposition in elementary sequences and operations.

Other turning points may be identified in the same way. The late 19th century 'control revolution' is clearly linked to that kind of shift. The digital revolution might very well, as for it, be related to a similar transition from one conception of effectiveness and efficiency to a new one based on the key notions of patterns and organization.[36] Patterns and organization could represent the contemporary equivalents of the Vitruvian guiding principles of order and proportion.

In each of these moments of transition, what seem at stake are changes in the representations of what is truly productive in both nature and human organization. However, the history of effectiveness and efficiency is probably not reducible to a mere question of changing representations. More generally, images are not what matters ultimately in the study of social and engineering imagination, for social imagination represents more than the collection of shared images that circulate in a given society. Social imagination is what holds together, what organizes and regulates the flow of these images. As such, social imagination does not represent something specific. If we are to follow the philosopher Cornelius Castoriadis, social imagination is structured around imaginary social significations, *significations imaginaires sociales* in French, that are not images but make the production and circulation of images possible.[37]

At that stage, and in the case of the engineer's imagination, I would like to suggest that this deep layer has more to do with ethical positions than with representations of nature and society. It is these ethical positions that generate representations of what is good, fecund and productive in the physical world, representations of what should be imported into the social realm. To come back to effectiveness and efficiency, their pursuit seems inherently ethical, at some level, just like the reference to justice among lawyers. In a way, the best manner to understand engineers and engineering might be to analyze them in the same light as the law and legal professions.

As a side consequence of such a perspective, one may finally wonder whether engineers and engineering are going to survive what has been often described, after Michael Gibbons, as a decisive change in the mode of production of science and in its relations with technology and industry.[38] For the short circuit between science and production that characterizes contemporary domains like biotechnologies is accompanied by the crisis of the ethical stance on which engineering has built itself. The question seems no longer to interpret the physical world, in search for principles of effectiveness and efficiency. These principles seem no longer a matter of interpretation. They are implicit to the scientific experiments and the manipulations that constitute the outcome of an advanced science in direct contact with industry. In other words, the type of mediation that was provided by the engineer seems irrelevant in certain domains. How will the engineering profession adapt to this new challenge? Its history has become inseparable from such an interrogation.

Notes

[1] See, for instance: Thépot, *L'Ingénieur*; Thépot, *Les Ingénieurs du Corps*; Grelon, *Les Ingénieurs de la Crise*; Grelon, *Ingenieure in Frankreich*; Grelon and Birck, *Des Ingénieurs pour la Lorraine*.
[2] Lemoine and Deswarte, *L'Architecture et les Ingénieurs*; Marrey, *Les Ponts Modernes*; Guillerme, *Bâtir la Ville*.
[3] Layton, *The Revolt of the Engineers*; Peters, *Building the Nineteenth Century*.
[4] Whalley, 'Negotiating the Boundaries of Engineering.'
[5] Cf. Picon, *Les Saint-Simoniens*.
[6] See Layton, *The Revolt of the Engineers*, and Brun, *Technocrates*.
[7] Picon, 'Technological Traditions and National Identities'.
[8] Kranakis, *Constructing a Bridge*.
[9] Hughes, *Networks of Power*.
[10] On that point, see, for instance, the various contributions to Bijker *et al.*, *The Social Construction of Technology*.
[11] Errard de Bar-le-Duc, *La Fortification*.
[12] Chandler, *The Visible Hand*; Vérin, *Entrepreneurs*; Porter, *Trust in Numbers*.
[13] Belhoste, *La Formation d'une Technocratie*; Picon, *L'Invention de l'Ingénieur*; Weiss, *The Making of Technological Man*; Ramunni and Savio, *1894–1994*; Day, *Education for the Industrial World*.
[14] See Velamazan, *La Ensenanza de las Matematicas*; Pfammater, 'The Making of the Modern Architect and Engineer'; Disco, *Made in Delft*; Alleaume, *L'Ecole Polytechnique*.
[15] Kuhn, *The Structure of Scientific Revolutions*; Foucault, *L'Archéologie du savoir*.
[16] Chatzis, *La Pluie*.
[17] Vérin, *La Gloire des Ingénieurs*.
[18] Belhoste, *La Formation d'une Technocratie*.
[19] Noble, *America by Design*.
[20] Cohen, *Organiser à l'Aube du Taylorisme*. See also Cohen's introduction to 'Organiser et s'Organiser Histoire.'
[21] Callon, 'Society in the Making.'
[22] Gille, *Les Ingénieurs de la Renaissance*, 19–27.
[23] Watson, *The Smeatonians*.
[24] Wisely, *The American Civil Engineer*.
[25] Cf. Parsons, *A History of the Institution of Mechanical Engineers*; Sinclair and Hull, *A Centennial History*.
[26] Cf. Chandler, *The Visible Hand*.
[27] We have studied that question in Picon, *L'Invention de l'Ingénieur*, as well as Porter, *Trust in Numbers*.
[28] Beniger, *The Control Revolution*.
[29] Charle, *Les Elites de la République*.
[30] Vérin, 'Le Mot: Ingénieur.'
[31] On the relations between engineering and utopia, see Segal, *Technological Utopianism*; Picon, 'Technique,' 241–6.

[32] The invention of such a motor was for instance Rudolf Diesel's initial aim. Thomas, Jr, *Diesel*.
[33] Mannheim, *Ideology and Utopia*; Ricœur, *L'Idéologie et l'Utopie*.
[34] Latour, *Politiques de la Nature*.
[35] Picon, 'Towards a History of Technological Thought'; Picon, 'Imaginaires de l'Efficacité.'
[36] This perspective is for instance suggested by Martin, *The Organizational Complex*.
[37] Castoriadis, *L'Institution imaginaire*.
[38] Gibbons *et al.*, *The New Production of Knowledge*. For a nuanced discussion of this change, see Pestre, *Science, Argent et Politique*.

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