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## **Solidifying Grounds: The Intricate Art of Foundation Building**

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### **Abstract**

Modern thinking about the ground tends to take it as a purely material base for the unfolding of history and ideas emerging on its surface. In this article, I question above-ground visions of city building by drawing on both the history of ground engineering and ethnographic fieldwork carried out in Paris with geotechnicians. I address the difficulties that theorists have faced over past centuries in modelling soils, and the contemporary practice of building piles underneath buildings to anchor them. From this unfolds an understanding of the ground as a geosocial formation produced through an equilibrium between forces and materials in which buildings become participants, rather than a solid base upon which they stand. Looking at the activities of foundation builders, we find that the inertia of the urban soil no longer betokens an absence of activity or movement, but is rather a continuous achievement, a slow and dangerous process of balancing tensions.

### **Keywords**

architecture, geosocial formations, ecological anthropology, foundations, ground, solidity, tectonics

### **Introduction: A Drifting Church**

In 2014, a note pinned to the door of the little church of St-Germain de Charonne, in the 20th arrondissement of Paris, advised that the church was in danger of collapse after significant faults had appeared in the stones and the masonry: it would have to be closed for extensive work on its foundations. The church had been built in the 12th century. At the time, it was at the centre of the small village of Charonne, which was absorbed in 1859 as Paris sprawled out. Because it was built on a hillside, on a clayey soil layer, the church had suffered from stability issues in the past. Flying buttresses added to its down-facing side in the 19th century show that villagers of earlier centuries had already had to address this problem.

After the Second World War, however, the Belleville Hill, just behind St-Germain, was intensively urbanised, and hundreds of large buildings replaced the workers' houses and former fields, putting further pressure on the soil. From the early 2000s, cracks began to appear more frequently in the church, and they eventually became so large that the church had to be closed. As a geotechnical study showed, the destruction of older buildings that had held the ground in place, coupled with the addition of the new surrounding constructions, had caused the ground

layers beneath the church to slide downward at an unprecedented rate. Engineers were immediately brought in to save St-Germain, and works were initiated to improve rainwater drainage on the slope above the church, so that less water would soak into the clay.

This made little difference, and the engineers had to take drastic steps: they drilled long, thin holes under the church, down to the bedrock 10 metres beneath the surface, into which they injected high-pressure cement slurry to form ‘soil-concrete’. The piles now firmly anchor the church in deep rock layers, and the City Council was proudly able to announce that ‘these measures will allow St-Germain to remain in good shape for many more centuries’. It will stand as a hybrid legacy of stone and concrete for future generations.

As for the clayey layer, it will boldly continue on its downhill trajectory, under the combined pressures of gravity and load, and the liquefying effect of rainwater pouring into the soil. It takes only a small leap of imagination to compare the church, now resting on 190 underground piles, to the swamp pile dwellings that exist in many countries. In this case, however, the fluid element is not a river or a lake, but a slowly sliding layer of soil.

This example aptly captures the tensions between solidity and fluidity, and between surface and material medium, that I wish to address in this article. Since modern times, the ground has been understood as a blank canvas upon which human projects materialise, a surface that can be apportioned by cadastral surveys, and a solid base carrying immobile buildings. As geographer Stephen Graham puts it:

Of all things, modern humans tend to naturalise the ground, seeing the terrestrial platform beneath their feet as some immutable and natural product of geological processes working over unimaginable time horizons. Such an understandable tendency leads to an overwhelming sense of ground as an inherently horizontal phenomenon – the very surface of the earth stretching to and beyond the horizon (Graham, 2016: 282)

In recent years, this surface bias has been challenged by a wide array of scholarship ranging from ethnographic studies of how surfaces are imagined, produced, and lived (Coleman and Oakley-Brown, 2017; Anusas and Simonetti, 2020) to more general critiques of how ontologies of space as a flat, regular surface that affords mapping have been key to modern projects of territorial occupation and colonisation (Massey, 2005; Highman, 2017). In the fields of urban geography and anthropology, several scholars have in turn focused on the study of the ‘volumetric city’ (McNeill, 2020) by taking into account the vertical and voluminous extension of built space both upward and downward, highlighting the three-dimensional nature of modern territorial governance (Elden, 2013; Bille´ and Battaglia, 2020).

At the same time, a series of discussions within the posthumanities and the new materialisms have drawn new scholarly attention to the vital materiality of the ground through works that examine how the becoming of human societies, identities and practices entangles and concretes with that of dynamic geological strata. In a recent special issue of *Theory, Culture & Society*, Nigel Clark and Kathryn Yusoff (2017) called to extend the impulse brought in social theory through the new materialisms – which often focus on the sensorial and performative aspects of organic processes such as plant or bacterial life (Coole and Frost, 2010) – to the vitality of the earth itself, ‘the basal depths and lumpen masses of the inorganic, the

mineral, the geologic’ (Clark and Yusoff, 2017: 16). This move resonates with other recent proposals within STS (Kinchy et al., 2018) and the environmental humanities (Puig de la Bellacasa, 2014) to acknowledge soils and subsoils as more than a set of inert resources for human use and extraction, and to approach the flows of the earth ‘on their own terms as multidirectional and non-utilitarian, and productive of social expressions on the surface’ (Yusoff, 2017: 113). Drawing on the geophilosophy of Deleuze and Guattari, Clark and Yusoff’s (2017) call to examine ‘geosocial formations’ focuses on the formative forces in which both the social and the geologic come into focus, and thus redirects scholarly attention to how specific configurations of contact with the ground and its ecologies afford certain social and political forms.

Drawing on these approaches, this article focuses on the city and its ground as such a geosocial formation, examining how the solidity of the urban ground and the processes that aim to make it ‘just space’ are performed through mundane building practices. To do so, I examine foundations and those who build them. The task of foundation builders is to stabilise the ground upon (or rather, in) which buildings are erected. They generally prepare the terrain before architects and builders start working on the site. It is their work – and, I argue, its invisibility – that sets the stage for the idea of the building site as an appropriable *terra nullius*. So long as the work is carried out properly, one cannot even think of the ground as anything other than a stable, solid base. The development of the discipline of ground engineering is ‘foundational’ to modern urbanism and can be understood in relation to other forms of state and technocratic power developed in the modern era. It is therefore intertwined with the history of how modernity probed and reorganised the subsurface, not just for mining (Kinchy et al., 2018), but also to establish the forms of dwelling of modern daily life.

Foundation builders, however, take us to a world that is very different from that of the city’s surface and its cadastral plan. Not only is their ground heterogeneous and always local – especially in cities – but it also blurs the boundaries between solids and fluids, always transitioning between phases, and its properties and behaviour cannot be predicted by mathematical models. Their approach thus also carries a message for anthropology, a discipline whose own engagements with materiality, as Stuart McLean notes, ‘have shown an overwhelming predilection for solids’ (2011: 591), leading to a preference for object and artefact-centred approaches, where the analysis focuses on ‘what

people do with objects’ (Miller, 1998: 19). As a result of this, anthropology often takes for granted the idea that the earth is the stable ground of dynamic human experience or social processes (Ingold, 2004). To approach the ground as a solid-fluid, by contrast, provides us with an entry point to peer beyond the cultural significance of the ground, and approach it as a reality that both precedes and exceeds human presence (McLean, 2011; Clark et al., 2018). As Simonetti and Ingold contend, examining solid-fluid materials is to address how ‘persistence in life is still subject to flow which, although it might pass unperceived to the naked eye, is inevitable given sufficient time’ (Simonetti and Ingold, 2018: 28). Hence, whereas solidity and fluidity, or immovability and movement, are often conceived as opposites (Kyriakides, 2014), the work of foundation builders invites us to interrogate the stillness and apparent solidity of urban ground, and to understand it not as the absence of movement, but as a performance that

congeals material, undergoing slow and uncertain solidification, into an apparently static form. The ground does not just ‘resist’ human attempts to know it or control it. Its solidity is always a temporary achievement in which materials have their say, and it must be reached by working with the ground through skill and technical detours.

The first part of the article sets out from the histories of geotechnics and stabilisation. I first examine how prominent soil engineers have constructed a narrative of their own discipline that links teleological chronologies about the mastery of the ground to ideas of permanence, memory, and civilisation. I then explore how this idea has been constantly frustrated by the uncertain materiality of the ground, as I describe a double-sided controversy, at once theoretical and practical, which looms over whether an overarching theory of soils should be based on the model of solids or fluids, and whether theory or experience should be privileged in approaching their uncertain materiality.

In the second part of the paper, I turn to my ethnographic research among ground engineers in the Paris area to describe some of the pragmatic and productive dimensions of soil stillness, or how soils can ‘remain at rest’, to use an expression by the physicist Coulomb. I first show that many engineers consider that their expertise applies to specific local soils, and I describe the highly complex and heterogeneous set of geo-infrastructure strata that make up the ground in which they operate. I then describe the case of a specific construction site where the unexpected flooding of the foundation pit revealed some of the many underground forces that must find a balance to achieve temporal ground stability. I conclude by considering how recent conceptualisations of architectural practice as a tectonic practice related to weaving can be applied to foundations and the ground itself.

### **Civilising the Ground: A Teleological View on Soil Mastery**

Despite its important role in modern architecture and town planning, foundation building is seldom addressed in conventional histories of architecture and is never considered a creative activity. Writings on architecture and city-building commonly depict the evolution of architecture as a gradual emancipation from the ground, starting with troglodyte dwellings and ending with modern skyscrapers. They stress the prowess afforded by technologies such as vaults and metal structures that have allowed for increasingly aerial forms, seemingly releasing architects’ creativity from the constraints of gravity and the weight of structures, and describe buildings as though they were monuments built out of pure ideas and knowledge.<sup>1</sup> With this gradual emancipation from the ground, the latter appears merely as a blank canvas on which to materialize human projects, the surface of a mineral, compact and solid world, to which buildings are fixed.

What little room is left for the ground in the history of architecture and urbanism relates to a wider separation between that which stands above the surface of the earth and that which

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<sup>1</sup> This corresponds with trends in recent building fashion, in which plinths and other works that regulate the structure–terrain relationship tend to be hidden away, so buildings appear simply placed on the terrain, or even detached from it (Diethelm, 2005).

unfolds below, between the physical world of the soil and the aerial realm of ideas. For Tim Ingold, these traits are characteristic of the modern conception of the city: ‘With their feet on the ground and their heads in the air, human beings appear to be constitutionally split between the material and the mental’ (Ingold, 2011: 74). The ground, therefore, becomes backgrounded (Meulemans, 2020) not only as a blank canvas on which to erect buildings, but also as a purely material base for the deployment of the life, history and ideas emerging on its surface.

However, long before geography underwent its recent vertical turn, several ground engineers had produced essays or historical accounts of their own discipline, often with the view to give foundations their rightful place in architectural culture. Among these insider historians, one of the most prominent and influential was Jean Kerisel (1908–2005), a respected French professor and foundation engineer who worked as Director of Construction at the ‘Ministry for the Reconstruction of France’ following the Second World War, tasked with rebuilding French cities destroyed by the bombings. In the 1980s, while working as a consultant for the construction of Cairo’s subway system, Kerisel became passionate about Egyptology and archaeology. He began to promote the role of geotechnicians in saving ancient monuments, and subsequently wrote several books on ancient earthworks and foundations. His fascination for buildings that had stood for thousands of years is most evident in these works. For Kerisel, it is their sound foundation design that has enabled the pyramids to stand the test of time and perpetuate the achievements of their ancient builders. More generally, he insisted that the material culture of civilisations should be measured not only by the monuments they produced but also by their foundations. In his eyes, a civilisation that neglected its foundational basis could only be decadent. ‘Many a proud fortress and many a great city’, he asserted, ‘have long since crumbled through being badly founded. Those ancient structures still standing carry a message, which it is for us to decipher’ (Kerisel, 1985: 3). He went on to review the architecture from the era of the last French kings, Louis XV and Louis XVI: they had commissioned monuments such as the Pantheon, meant to impress the people and show off their might, but the foundations were often neglected, leading to many embarrassing structural problems that undermined their monumentality. To Kerisel, this epitomised the decadence of the French court, whose engineers, blinded by their grandiose ideas, neglected unglamorous topics such as the ground; it is no wonder that such bad monarchs were overthrown by a revolution.

The passage of time, and the inexorable attrition of the ground, decide which civilisations leave a mark, and which do not. According to Kerisel, it is the ‘test of time’ (*l’oeuvre du temps*) that separates ‘civilised ancient peoples’, whose achievements we can still admire today because of their sound foundation design, from others who disappeared without trace. Foundations, for him, are like milestones along a continuum from savage to civilised peoples, a crucial element in the rise of humanity above the whimsicality of nature, as earth engineers set out to create a customizable topography, performing an appropriable space by overcoming the limitations of landscapes. Kerisel’s arguments for restoring the honour of foundations are perfectly aligned with canonical formulations of history and progress in Western modernity: notably, the idea that the evolution of human societies progresses from volatile nomadic groups to well-founded sedentary civilisation. His ethnocentric reading of the ‘achievements’ of peoples is both teleological and retrospective, positing that their key motivation is to leave a trace for future generations. It thus also reveals a profound aspiration, by those who define themselves as

moderns, to leave a mark that will identify them as drivers of progress. Emancipation from the ground, it appears, is also emancipation from time and death, and this can be achieved through sound foundation design.

Despite its frustrated attempts to find a place in the grand narrative of modernity, however, the practice of foundation building itself is not quite ‘founded’ on rational scientific premises. In order to understand what underpins such practice, I will now turn to the history of foundation building, which turns out to be as turbulent as the material (soil) it is dealing with.

### **Solid-Fluid Controversies**

Far from Kerisel’s hope of developing a teleological narrative of human mastery of the ground, the history of foundation building is as convoluted as the ground itself. First of all, it seems that in western European countries, hopes of building a solid base for cities and buildings are themselves fairly recent. Historian André Guillerme (1991) explains that most premodern cities could only expand as far as they could find solid ground; their expansion was halted by any marshland, peat or sludge lying on the fringes of human settlements. There were exceptions – one only has to think of Venice or Stockholm – but the dominant model of ground-city relations was what Guillerme calls the ‘iceberg’ model, whereby the shape and extent of the city directly reflected that of its subsoil.<sup>2</sup>

In the 18th century, engineers endeavoured to understand the instability of the ground as they built canals and fortifications. For over a century, the question that preoccupied most engineers was how to prevent the earthen walls of fortifications from collapsing after heavy rain. In many ways, the emergence of ground engineering as a discipline coincided with that of modern states and their techniques of bureaucratic spatial discipline. Its early specialists were engineers in charge of building roads, fortifications, ports, dikes, and canals. In the 19th century, they were joined by builders of railways, earth dams, and large-scale irrigation works in the colonies. The vast majority of these projects served the establishment of modern centralised states and the associated commercial, military and administrative institutions. As Alec Skempton (1985) remarks, ground engineering long existed as a series of distinct disciplines, such as earth-pressure theory, the physics of sands, the physics of ‘semi-fluid’ clay, or the practical knowledge of land subsidence. The term ‘soil mechanics’ only appeared in the 20th century, and its use became widespread with the translation of Karl Terzaghi’s treatise *Erdbaumechanik* (1925).

The modern history of foundation engineering is marked by an unresolved controversy surrounding the very nature of soils and the possibility and utility of establishing a general and predictive theory of their behaviour. From the 18th to the mid-20th century, engineers sought

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<sup>2</sup> Guillerme explains that before the 17th century, ‘The history of soil mechanics – or soil hydraulics as we might better call it – follows the development of cities, stopping at the still uninhabitable peat bogs of Caen, stumbling over the mud of the ports of Toulon and Bayonne, the marl slopes of the cities of the Jura, the swamps of Lille and Be’thune, trampling over the banks of the Seine and the Meuse, but spreading easily on rock and incompressible tuff. The city, like an iceberg, directly reflects the behaviour of its subsoil’ (Guillerme, 1991: 212, my translation).

to establish a general theory of soil behaviour in relation to buildings. The aim was to isolate universal laws that could provide a rational basis for building foundations. Such theories had been successfully established for other materials, thus facilitating their large-scale use. As Reint De Boer (2005) notes, materials such as ceramics or concrete could be modelled ‘ideally’ as if they were solid and devoid of internal structure. With such models, the mechanics of classical continuous media was able to obtain highly satisfactory results.

One of the main problems that foundation theorists encountered was in deciding whether soils should be understood as fluids, solids, imperfect fluids, or semi-fluids. In the 18th and 19th centuries, military engineers tended to approach ground stability issues by analogy with the laws and axioms of hydraulics. Reinhard Woltman (1757–1837), a German harbour builder who developed an independent theory of earth pressure and wrote treatises on the building of retaining walls in the late 18th century, studied how mud and other mixtures of solids and fluids behaved as a liquid mass (De Boer, 2005). The mathematician Gaspard de Prony (1755–1839) regarded earth as an imperfect fluid which should be studied through the lens of hydrostatics (Guillerme, 1991), while the physicist Jean-Baptiste le Rond d’Alembert (1717–1783) – co-editor of the *Encyclopédie* – considered that there were only solid-fluids, or to be more precise, an infinity of shades between solid and liquid states.

The question of how to model the ground was never definitively answered. In the 1950s, when soil mechanics became an institutionally and epistemologically stable discipline, there was still disagreement as to whether mixtures of clay and water should be treated as a two-phase system (which would mean that the laws of mechanics that apply to liquids and solids could be applied to the soil’s separated constituents), or as a continuum, an intrinsically solid-fluid media that required a radically new approach. The debate has occasionally resurfaced until the present day, as new attempts to approach soils as ‘porous media’ (materials that intrinsically mix gas, liquids, and solids) have emerged (De Boer, 1996). Similar debates around the solid or fluid nature of a particular material exist in other fields, for instance in relation to the movement of glaciers (Simonetti and Ingold, 2018). As in these other fields, it has seemed difficult for scientists to reconcile fluidity and solidity, properties referring to idealised materials that, in the real world, cannot be kept apart. The intermediary states of soils and their recalcitrant materiality stood in the way of attempts to build universal axioms through abstract reasoning.

### **Knowing Soils through Theory or Experience?**

Since the 18th century, the long-standing debate around the theorisation of soils has been carried on hand in hand with another debate, concerning the relative priority to be accorded to theory and experience. Opposing ambitions to theorise, many engineers have defended a practical approach based on in situ experience. They consider that soils are so complex, as well as place- and project-specific, that their properties can never be fully grasped by theory. In practice, they argue, abstract mathematical laws assumed to be universally true are only applicable in a few very peculiar contexts, such as of volcanic islands in the Caribbean, or alpine regions – both of which, in the revolutionary times of the 18<sup>th</sup> century, were being fortified, and



where the theorists who had formulated mathematical laws for soils had sometimes worked for the military.

The engineer Jean-Henri Mayniel (1760–1809), for example, also a fortress builder, who worked for Napoleon in newly conquered land with unfamiliar soil, wrote a treatise in 1808 in which he pointed to the limits of laboratory tests, rejected normalisation, pressed engineers to favour field experience over theory, and encouraged them to consider the worksite itself as the only trustworthy laboratory. As André Guillerme (1991) has shown, the discipline's major theorists – people like Charles-Augustin de Coulomb (1736–1806), who first theorised how cohesion and friction informed the 'rest condition' (1776) of the ground in the late 18th century – were both respected for the elegance of their equations, and regarded with suspicion by engineers who found their laws of little use in the field. Even positivistic historical accounts such as those of Alec Skempton, who described the history of ground engineering only from the standpoint of its theoretical advances, stated that these advances could only be based on soils so abstract and refined that they were of little interest to builders.

This debate continued well into the 20th century. Karl Terzaghi, the Austrian engineer considered to be the founder of modern soil mechanics, was particularly dubious about theory. After 1937, he completely stopped his theoretical research and worked only on practical problems and observational methods. He often said that theory had reached its endpoint; everything that was needed was known. He castigated foundation theory for reasoning only with ideal materials, when in practice the materials that make up the ground are not artificial and cannot be made to fit the models. This, to him, set ground engineering apart from other branches of civil engineering. Terzaghi's books and conferences brimmed with exhortations to prefer practice over theory, and are still abundantly quoted in today's training manuals in the field. Consider this excerpt, for example, regularly cited by engineers in publications ranging from dissertations to Facebook pages:

to acquire skills in the field of foundation building, you really have to live with the soil. You have to love it and observe its performance, not only in the laboratory but also in the field, to become familiar with its many properties that are not revealed by boring models (Terzaghi, 1957: 55)

Of course, theoretical and positivistic approaches also had their advocates, and the differences in perspective sometimes escalated dramatically. In his book *The Engineer and the Scandal* (2005), Reint de Boer relates an argument that broke out in the 1930s between Terzaghi and Paul Fillunger, an engineering professor at the same institute in Vienna (De Boer, 2005). Fillunger was an advocate of modelling, respected as a fine theorist in the field of mechanics, and now mostly known as a 'precursor' of porous media theory (De Boer, 1996). He posited that experience was subjective and unreliable, arguing that soil properties should be objectively measured using instruments, and that robust models should be developed to predict the behaviour of soils. He accused Terzaghi of being an imposter, a bad theorist who had not read or understood Coulomb, and with a poor grasp of mathematics and mechanics. In his reply, Terzaghi consistently insisted that soil mechanics should serve to solve practical problems rather than theoretical ones. The dispute soon reached the Austrian news, at which point a

commission of experts was set up to settle the conflict. When the commission voted in favour of Terzaghi, Fillunger committed suicide with his wife.

The feud between Fillunger and Terzaghi is often framed as a battle between a ‘theoretical’ and a ‘practical problem-solving’ approach. Soon after the tragic end of the affair, Terzaghi moved to the United States, where he worked with his pupil Arthur Casagrande to develop the first training in soil mechanics at MIT, establishing his practical approach, which left ample room for each engineer’s flair, as the basis for the training of every subsequent generation of ground engineers. Is it because of the circumstances of its establishment as a discipline by strong characters like Terzaghi, as de Boer (2005) claims, or because of the very nature of its topical material – the ground – that geotechnics has remained so allergic to models?

### **An Ethnography of Foundation Building**

Let us now turn to the second part of this article and examine the kind of experience, skill and adaptability that Terzaghi was referring to by returning to Paris – a city that has long defined itself as the ‘capital of modernity’ (Harvey, 2003) – to examine how foundation builders deal with the ground in practice.

In the past three decades, several theorists have reconceptualised architecture and building practice as poetics of construction rather than disciplines premised on space and form. One of the most influential of them is Kenneth Frampton (1995), who draws on Gottfried Semper’s *Four Elements of Architecture* (1989 [1851]) to explain that architecture boils down to two canonical ways of making: *tectonics* (from *tekton*, the Greek word for carpenter) relates to the art of jointing and textile weaving, while *stereotomics* (from *stereos*, solid, and *tomia*, to cut) relates to the practice of cutting stones and to the piling of mass elements such as rock or earth for solid construction. Foundations, in both Semper’s and Frampton’s writings, belong to the stereotomic realm, and appear massive and solid. In opposing the stereotomic to the tectonic, they still view the ground as a solid undifferentiated mass, as opposed to what is constructed over it.

Tim Ingold (2007), on his part, also draws on Semper’s ideas to propose that we think of buildings as woven with lines rather than built from discrete blocks. He thus formulated a conception of the surface of walls or roofs not as a boundary of separation but as a zone of interpenetration in which lines converge, diverge and intermingle. For Ingold, thinking of surfaces in this way also means reconceptualising the ground not as a platform for the enactment of human affairs, but first and foremost as the place where earth and sky engage in a continuing dialogue. In this view, the ground is indeed a dynamic interface of exchange rather than a solid mass to be sculpted into shape, a weaving of lines where living materials mingle and grow. If this is the case, can we still think of foundation building as a stereotomic discipline? In the rest of this article, my aim is to build on Ingold’s idea of the ground as a place of interpenetration, and ask: What if it is tectonics *all the way down*? What if the foundations are woven too?

## Locality, Climate and the Built Environment

Between 2015 and 2019, I conducted ethnographic fieldwork with ground engineers and technicians who work with the ground of Paris. I shadowed them as they went out into the field to monitor construction sites, when they discussed plan modifications with their clients, when they took soil samples in the field, and when they analysed and discussed these samples at the laboratory.<sup>3</sup> Many of them frequently mentioned the attention and even passion they had developed for the local vices and virtues of the soils with which they had to work. They sometimes said that their job was linked to a particular ‘terroir’, and I was often struck by the local nature of their knowledge of the ground. As one builder explained, ‘Here in Paris, we know our clays, we know our silt [...] When I talk to contractors on a construction site, we do not use the vocabulary of geotechnics, but talk about the “green layer”, and we all know what that means in terms of solidity and risks of collapse’. He then asserted the importance of his experience of the place, its layers and the materials from which it is made. Like the Napoleonic fort builders, if he were to work in a different place, he would not immediately know what to expect. The relation of these geotechnicians to the ground rarely abided by the purported canon of the ‘engineer’, which Lévi-Strauss (1966) described as basing their approach to making on holistic totalising systems that keep them exterior to the material world to which their action applies.

To a depth of about 50 metres, the Paris Basin is made up of many different geological strata, formed by cycles of compression and relaxation of the earth’s crust, marine sediment deposits, the vagaries of the meanders and tributaries of the Seine, and, of course, over two thousand years of human dwelling. Its ground is the product of a web of unstable geological and anthropogenic layers, all formed through the interplay of water, air, and life both above and beneath the surface. Many scholars regard Paris as the archetype of the modern rationalisation of urban space, a result of massive transformations driven by the desire to refashion the environment to suit ‘human’ (in fact, modern European bourgeois) needs (Gandy, 1999). However, unlike the part of the city we see above ground, underground the city has never been modernised. Still today, those who build and repair networks and other subterranean infrastructure refer to it as an indescribable chaos.

When digging in urban settings, workers first encounter several metres of ground that has little to do with long-term geological processes, and that results instead from accumulations of urban occupation debris – geotechnicians often call this ‘made ground’, but other designations include ‘technosols’, the ‘rubble blanket’, the ‘pipesphere’ or the ‘archaeosphere’, depending on the concerned professional area (see Edgeworth, 2017, for a review of these). In Paris, several districts rest on top of up to 12 metres of fill and foundation remains from various eras that

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<sup>3</sup> Ethnographic fieldwork and interviews were carried out discontinuously but totalled a period of about 15 weeks, half of which was spent in residency at the Conservatoire des Arts et Métiers, a historic research and training site for soil engineers in Paris, where I was able to pursue archival work, attend geotechnical courses, and participate in the development of a video installation on the Paris subsoil with artist Anaïs Tondeur (see <https://anaistondeur.com/is-paris-floating>). The rest of the fieldwork was carried out with the engineers and technicians of two geotechnical offices – one private, the other public – both in the field and in their laboratory work. For a description of how technicians understand soil layers by ‘abducting the granular’ in laboratory work, see Meulemans (2019).

piled on top of one another as the city rose up on ground of its own making. On top of working and abandoned pipes and cables, this made ground contains materials such as brick, concrete, glass and plastic fragments, the proportions and qualities of which are so heterogeneous that it is nearly impossible to predict its behaviour. Underneath this made ground layer, three of the main geological strata of the Paris Basin are of gypsum and limestone, both calcareous minerals formed during the Eocene, when the region was a large and shallow tropical lagoon subject to strong evaporation, which allowed minerals to precipitate. Over the centuries, these strata were quarried for construction materials used in building the above-ground city: gypsum to make plaster; limestone as building stone. This resulted in a 200-km-wide network of abandoned underground quarries still in place underneath the city – and still partly uncharted. The problem is that these calcareous minerals are easily eroded by water and pollutants, thus leading to the formation of sinkholes – the sudden collapse and subsidence of the ground surface. Urban sinkholes can be caused by such a trivial thing as a water pipe leakage, and the extent of current anthropogenic changes to local geologies and hydrologies mean that they are quickly becoming ‘an emerging anthropocene hazard’ (Dixon et al., 2018). After the deadly collapse of Denfert Street, in 1774, due to a sinkhole in the limestone strata, the authorities realised that entire districts had been built upon ground that was full of holes. This led to the creation of the General Inspectorate of Quarries (IGC) in 1777. This municipal department, which is still highly active today, surveys, maps, maintains and fills the many human-made and naturally occurring cavities under the city. The titanic work to consolidate these cavities as they deteriorate is sometimes described as the most important urbanism work in the history of Paris (Thomas, 2015), along with the far more famous works of Haussmann and the digging of the metro system.

The climate also continues to interact with the ground, despite engineers’ most concerted attempts to separate the sky from the ground through soil sealing (see Meulemans, 2020). The city remains porous; leaks from water networks are frequent and can deeply erode the ground without the leaks being discernible on the surface – until, of course, cracks appear. Moreover, the IGC regularly monitors ‘underground floods’, which are rather different from what is commonly understood as a flood. IGC engineers explain that the River Seine has a memory: it tends to return to its ancient bed. Long before water floods the surface of the streets, it first spreads underground, infiltrating the soils which, because of the ancient passage of the river, have retained a particular porosity. The Paris subsoil is thus haunted by an underground ghost river, an old passage that calls the water back as soon as it escapes from its usual course. This also contributes to the dissolution of gypsum, posing a major threat to the stability of the ground.

Finally, groundwater tables have been rising and falling over the last 150 years. Between the 19th century and the 1970s, groundwater tables went down 15 metres because of factories that pumped water directly from them (Barles, 1993). With the demise of industry, however, pumping stopped, and water rose again, leading to inundation and structural problems in cellars and underground car parks that had been built in ground that was far drier than it is today. In the past few years, these effects have been compounded by increased spring rain episodes due to climate change, and by the monoculture of corn in the surrounding countryside, which soaks up rain before it can penetrate the deeper ground.

This has resulted in a chaotic rise and fall of underground water tables, causing the underground wooden piles that support many pre-20th-century buildings to rot. That is why, for example, between 2001 and 2004, the 3400 oak trunks that supported the Grand Palais had to be supplanted by 1800 concrete replacements (Grand Palais, 2012). This messy and highly unstable meshwork of debris, infrastructure and geological strata which all leak into one another is what geotechnicians call their ‘terroir’. Let us now turn to how they work with this in practice.

### **A Flooded Pit: A Foundation’s Intertwinement with Its Environment**

In recent years, anthropologists of architecture have set out to investigate structures not after the fact of their construction (as a finished object), but in the process of their designing and building. In her account of the material, cognitive and cultural dynamics at play in architectural design processes, Albena Yaneva has shown how the building itself can ‘guide, afford, redirect and facilitate to a greater extent the course of this process instead of being passively submitted to renovation interventions’ (Yaneva, 2008: 10). She therefore stressed the disobedient nature of the building and its capacity to ‘surprise’ its makers and to force them to reorient their well-prepared plans. Similarly to what Yaneva describes, foundation builders need to be attentive to more than just a messy yet static geo-infrastructure substrate. They also need to be mindful of its ongoing transformation within the worksite’s environment. To give an example, I shall describe a site I visited with Aleandra, an engineering geologist working for one of the main Parisian geotechnical design offices. With her team, she had designed plans for the building of the earthworks based on her knowledge of the district, backed up by laboratory tests of soil samples taken from the site. But she knew that soil rarely does what is expected of it, and fully expected that the plan would need adapting in situ.

A few days earlier, as the workers were digging, the bottom of the pit had begun to flood. This is very common when digging in cities, and cannot be predicted. As Aleandra explained to me, this has to do with the porosity of the city itself: ‘Water soaks through gardens, football fields and the like, and even through the pavement, then it gets trapped between constructions, and we release it as we dig’.

Such leakages are not only problematic for the diggers but also dangerous for buildings around the excavation site: as it flows, the water carries along soil particles, leading soils to settle, which causes irregularities and cracks in the buildings they support. Thus, as Aleandra put it, ‘in all the earthworks we do, we impact the ground and its equilibrium; we can always incidentally cause, cut or reorient water flows. We create voids that cause movement.’ The same goes when builders use vibrating devices to compact earth materials, which modify how grains assemble, change the balance of the soil, and can cause irregularities in neighbouring buildings. Because of this, Aleandra and her colleagues sometimes pump water *into* the surrounding area to maintain an even amount of ground water, while at the same time removing it from the worksite.

The way Aleandra described her work made it clear that every move can backfire. In order to manage the vagaries of the ground, engineers often inject concrete, synthetic resins, and other materials under buildings to solidify the earth – as they did underneath the church of St-

Germain. However, these injections, along with other deep foundations, also disturb the pathways of water and often have unexpected consequences. On a different worksite, a geotechnician working on a large development project which involved the construction of several buildings (and as many foundations) explained to me that ‘it is as if we had built hundreds of small underground dams’, which funnel water, accelerate its course, and exacerbate underground erosion and dissolution processes. As in the example of the church, with which this article began, events such as this one can be described as moments of breakdown, when ‘The normally invisible quality of working infrastructure becomes visible’ (Star and Ruhleder, 1996). In this case, the working infrastructure is the ground itself, which suddenly no longer appeared as an object, let alone a stable one, but as a node of flows and forces in precarious equilibrium that could tip over at any moment.

### **Conclusion: Weaving the Ground**

Let us conclude by returning to the modern city. As we have seen, approached through the prism of its unsettled grounds, it appears far less solid than one might first think. Paying attention not just to city grounds’ volumetric organisation but to the stabilisation of this ground reveals a different picture of the city: as if its buildings were afloat like a fleet of ships, or standing on piles, amidst the semi-liquid element of its soils, conveying the image of modern-era stilt-house settlements.<sup>4</sup>

Unsettling claims of sovereignty and fictions of a stable ground, the story of the stabilisation of the city’s grounds therefore takes the focus away from humans, who appear not as almighty architects shaping matter at will, but as having to engage with and follow materials in order to reach a fragile equilibrium between the soil’s various forces and materials, by becoming immersed in the activity of the site – what Terzaghi referred to as ‘living with the soil’ (Terzaghi, 1957: 55). Herein lies the great paradox of earthworks and foundations. They lie at the basis of the modern project: once they have been well installed, they allow modern rationality and axioms to unfold in a world that can be ordered and governed. And yet, they themselves cannot be built by following these principles. Geotechnicians do not take the world as raw matter expecting human agency to bring it into form, but interact with soils in ways that are more akin to what Jason Cons calls a ‘damp ontology: an analytic of terrain, volume, and movement which foregrounds not just liquidity, but its emergences, disappearances, and oozings’ (Cons, 2020: 207). In this sense, the crafts needed to lay the very foundations of modernity are themselves rather anti-modern.

In conclusion, to describe the work through which these flows are made to congeal into a more viscous, slow-moving, even static form, let us return to Ingold’s (2007) proposal to view architecture as more akin to the activities of weaving and splicing than to the assembly of

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<sup>4</sup> This image is strikingly rendered in David Macaulay’s illustrated book *Underground* (1976: 8–42), which offers a particularly revealing presentation of the main types of foundations that can be found in a modern city. In many respects, the vocabulary of foundation building is reminiscent of fluvial and maritime worlds. Hence, engineers regularly use cables to ‘anchor’ buildings so they do not slide. Many buildings lie on ‘floating foundations’, others on ‘bearing piles’, and still others on concrete ‘piers’.

elementary solids. As Ingold argues, the underlying principle of rope making – the joining and twisting of reeds against their natural bend – is the polar opposite of block-type construction: the parts of the rope ‘are not elementary components but ever-extending lines, and its harmonies reside in the way each strand, as it issues forth, coils around the others and is coiled in its turn, in a countervalance of equal and opposite twists which hold it together and prevent it from unravelling’ (Ingold, 2015: 11). The core of rope making is to get the forces internal to materials to cancel each other out and bring them into a coherent thread.

Human constructions, as we see from this example, are not simply placed on the ground of the city. They become an integral part of the ground’s substance and modify the existing equilibrium between its compositional forces. They inevitably participate in underground currents of materials. The unpredictability of the soil thus stems from the fact that it does not have an independent existence, as in a laboratory, but continuously interacts with the climate, the surrounding buildings, and the excavation itself. Suspended in liquid-solid indeterminacy, caught in a field of forces where flows and resistance are omnipresent and can manifest in a range of ways, soil is constantly in the process of becoming something else, more or less rapidly, depending on the factors discussed above. There is no opposition between solidity and fluidity in soils, nor between flow and immovability. There is only an ecology.

From this perspective, the ground is never inherently solid or liquid but becomes a specific gathering of materials that intertwine into a more or less ephemeral form. This also implies that the ground, understood in perpetual solid-fluid becoming, cannot be worked upon as if it were a stable object: it is only possible to work *with* it, to follow it. As Ingold explains, to follow materials is to enter a world in which the forms of things do not exist but occur, or ‘take place’ as entanglements of relations. This means ‘shifting the focus from readymade objects to processes of generation and dissolution [. . .] attending not to the materiality of things but to materials-becoming-things’ (Ingold, 2011: 179). Foundation builders need a feel for materials to appraise the polymorphy and the potentialities of each piece of ground. Their skill lies in allowing themselves to be affected (Fox Keller, 1983) by the materials encountered, to follow their local accidents and imperfections, rather than imposing a rigid, pre-planned form. This work is done close up, on the worksite, far from the distant gaze of the modeller.

In his grand narrative of the history of foundation building, Kerisel (1985) noted that the foundations of the ancient ziggurat of Aqar Quf, near Baghdad, include reed mattresses placed between layers of sand and gravel at regular intervals. These not only enhanced the cohesion of the earth materials but also acted as drains for the dissipation of excess porewater pressures that built up over the course of the construction process. For Kerisel, of course, weaving was characteristic of ‘primitive foundations’, but drawing on Ingold’s definition of rope making, it appears that perhaps even modern foundation building, understood as the occupation of solidifying grounds through an equilibration of forces, has retained this quality, and can be thought of as nothing less than weaving the ground.

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