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CHAPTER 1

RENDERING

On Experience and Experiments

LUCIA ALLAIS

> The shades and shadows of architectural objects are architectural things, not mathematical things. . . . The fact that a draftsman of great skill and long experience will often make a very admirable drawing with poor instruments or materials is no reason why the beginner can do so.
>
> —Henry McGoodwin, *Architectural Shades and Shadows* (1904)

> I can't imagine that anyone without an architectural training could produce a good picture. . . . Often in our office it is not the computers that calculate the reflections, rather we do it ourselves by hand. . . . If I want shadows, I integrate these into the picture; if I don't, I move the sun.
>
> —Eric de Broche des Combes (2015)

Two lessons in architectural rendering, published more than a century apart, emphasize that when architects learn how to render, they are not only vested with a drawing skill but also implicated in a vast epistemic scheme that projects mathematics and its certainties onto buildings and their shadows. Today, digital renderings are the kind of image that elicit principled convictions. Commercial renderings, especially, images used to sell buildings, are seen as engines of superficiality because they are aimed at nonarchitects and also often outsourced to unseen software workers. "Architectural renderings are meant to seduce," reads a recent critique; they are "produced by people with no design training" who work in "image factories" creating "fantasies" unrelated to any "working building."[1] To preempt these critiques, architectural visualization firms reassure their clients that rendering is handiwork. In the 2015 interview cited above, Eric de Broche des Combes explains that in his firm, Luxigon (Figure 1.1), they do calculations "by hand."[2] These may sound like the modest words of an artisan, but they are

Figure 1.1. Digital rendering of Rex's design for the Calgary Central Library, 2017. Image and copyright by Luxigon.

a way to claim technical control far beyond architecture. Thus des Combes cannot resist adding that he is able to "move the sun," as if the goal of architectural rendering was not only the predictable appearance of buildings but the mathematization of the world itself.

Today the agent of this calculative power is imagined to be a computer. But the promise that rendering is a technique for channeling the forces of a possibly pervasive mathematical enslavement long predates the digital revolution. When the American architect Henry McGoodwin, who had trained at the École des Beaux-Arts in Paris, published a rendering manual in 1904, he assured his readers that shades and shadows of buildings were "architectural things, not mathematical things" and that he could manipulate them at will. Euclidian geometry was only an instrument, "a means having no greater architectural importance than the scale or triangle." To demonstrate his mastery, McGoodwin painstakingly drew figure after figure projecting the shadows cast by the sun onto the intricate outlines of the classical orders (Figure 1.2). Although these shadows had "form, mass

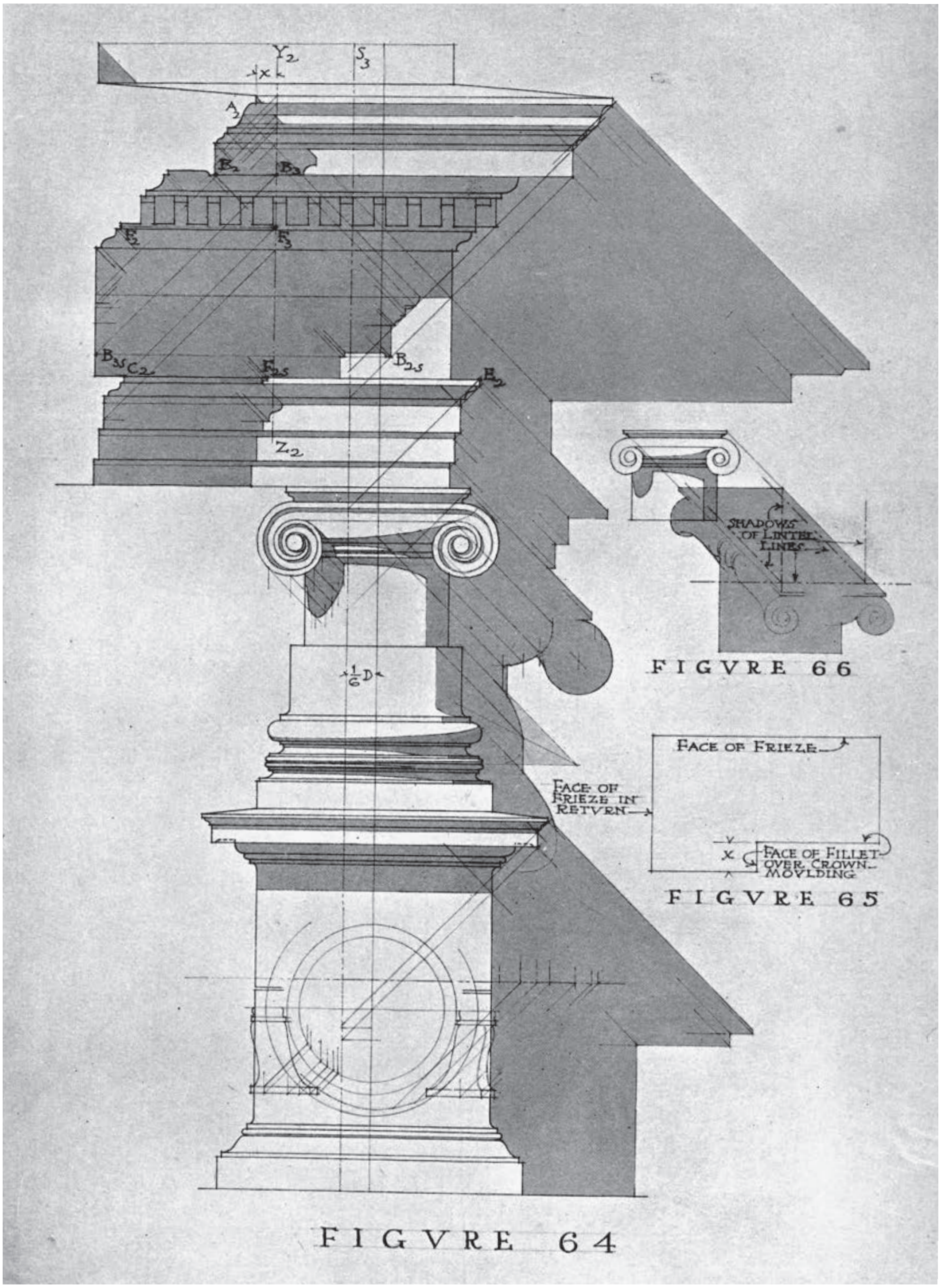

Figure 1.2. Shadows of a Doric order. Henry McGoodwin, *Architectural Shades and Shadows* (Boston: Bates & Guild, 1904).

and proportions" that could be immediately apprehended, McGoodwin cautioned against shaping them through intuition alone. For "inexperienced draftsmen," geometry was a tool that could substitute for the "great skill" of more experienced architects.[3]

Like his digital descendants, McGoodwin made a claim for rendering that was not so modest after all: a claim to have created, through architecture, a shortcut between two meanings of the term *experience.* When he spoke of shadows as having apprehensible form, he spoke of experience as given from external reality—as an *input* to the senses, we might say anachronistically. Whereas when he promised that "experienced draftsmen" would develop "an expressive 'touch' or technique," he described experience as something constructed through practice and repetition—as an *output* of the body.[4] To be less anachronistic, we could rephrase this distinction in terms of the philosophies of experience that proliferated in Germany and America around the time of McGoodwin's writing, from Wilhelm Dilthey to John Dewey and Edmund Husserl.[5] Architecture's shadows could be experienced by a passerby through *Erlebnis,* "a kind of passivity in activity," available in the lived moment.[6] But the painstaking experience of learning to draw delivered practical knowledge over time, what in German one would call *Erfahrung.* These two kinds of experience were increasingly split, philosophers warned. The promise of rendering, then, was to reconnect them, and it is a promise as alluring today as it was in 1904. Digital media enthusiasts claim that architects who use computer visualization can "empathize with the users of their projects," and especially those who "relate experientially and aesthetically to urban life as an interactive commodity."[7] Now that the public's senses have been habituated to digital media, the argument goes, every *Erlebnis* can become the input, and every *Ehrfahrung* the output, in an algorithm-fueled experience economy.[8]

Thus, our two rendering lessons lie on either side of a presumably irrevocable digital divide. But our computational vernacular, where terms like *input* and *output* evoke a world coursed-through with data and where "a rendering," or even "a render," has come to mean *any* computer-made image, is singularly helpful to flesh out retroactively how mathematics have inflected concepts of architectural experience and how design's labor has reflected notions of productivity. None of these oppositions map neatly onto one another—building / shadow, architectural thing / mathematical thing, architect / draftsman, *Erlebnis* / *Erfahrung,* input / output. An archaeology of rendering practices helps disambiguate the slippages between them. This essay offers one such archaeology: a history of rendering as a history of experience.

Existing histories of the architectural sciences have tended to distinguish between the shadow and the line—the former fuzzy and vague, the latter a tool of precision. Architectural historians have tied architecture's modernity to the development of linear graphic representation, specifically the "cult of the line" that was codified through the French tradition of *dessin* in the seventeenth century and achieved "hegemonic dominance" in nineteenth-century academicism, later migrating to the United States and beyond, through Beaux-Arts pedagogy and the artistic avant-gardes, after 1900.[9] In this account, lines contributed to architecture's scientific legitimacy, while shadows increasingly became a decorative flourish. The split between line and shadow is usually seen to originate with Leon Battista Alberti, who in 1452 defined "delineation" as the essence of architectural design. According to Alberto Pérez-Gómez, Alberti set the stage for a "loss of embodied experience" from architecture as "the sciences" increasingly encroached on design.[10] In his story, the line replaced a good kind of architectural mathematics (symbolic, poetic, metaphysical) with a bad geometricization of space (flat, secular, technological).

Yet computers have upset the old distinction between arithmetic and geometry upon which this line/shadow division was founded. As Friedrich Kittler and other media theorists have shown, the "code" that underlies digital culture is a written, nonvisual medium that can generate entire perspectival universes without using any lines at all—except a few lines of ones and zeros.[11] To account for this return of the digit, new histories have anchored Albertian *disegno* in a different historical arc that terminates in the digital present. Mario Carpo has argued that digital computation tools "unfroze" for architects the technological creativity and numerical "open-endedness" that had been latent in Alberti all along.[12] In his version of events, line and shadow are now equally obsolete because a deeper link between number and image, which the line could only ever approximate, has been recovered through the computer.

Such narratives of loss and recovery are of little use, however, for explaining the persistence of rendering and shadows in a history of architectural visualizations dominated by lines. As I want to show, it is the *operational* line that constitutes the architectural rendering's relevant legacy in digital culture today. In the training of architects, especially, rendering the shades and shadows of buildings has been an architectural technique for connecting professional experience to a sensorial world through threads of thinking and doing. By retracing this legacy, we will find not a gradual weakening of architecture's grasp on the real, nor its inevitable submission to mathematics. Rather, we will find a stubborn tendency of architectural visualization to be used and useful when the sciences have made claims on experience as a human faculty.

Architectural rendering, I will argue, has woven between experience as constructed and experience as received, and more specifically between the acquiring of disparate or discrete units of experience and the delivery of experience as sensible completeness. In this sense, an implicit phenomenology has driven the development of architectural rendering. I do not mean phenomenology as a design philosophy, for example, that of 1970s architects who wanted to accommodate the features of dwelling bodies, or that of recent proponents of embodied computation and its affordances.[13] I mean the formidable philosophy of experience that was invented by Edmund Husserl in the first half of the twentieth century, based on a study of mathematics. By his definition, phenomenology is a philosophical attitude to the real, which asks the mind to bracket off the question of whether things-in-themselves (say, buildings) exist, and instead directs the attention to phenomena as they appear, deriving philosophical principles about human cognition from the way these appearances are experienced. Historians of architectural drawing have referred to Husserl, but largely to borrow his idea that a "crisis" lies at the basis of the modern sciences. In Pérez-Gómez's aforementioned influential history, "a substitution . . . occurred as early as Galileo . . . of the mathematically substructed world of idealities for the only real world, the one that is actually given through perception, that is ever experienced and experienceable."[14] Instead, I propose to take the philosophical notions Husserl offered—wholeness, completion, and substitution—as technical and aesthetic tropes that have steadily characterized the making and recording of architectural shades and shadows across three supposed ruptures in architecture's history: the scientific, the industrial, and the digital. My goal is not to build a new grand narrative of architecture as a techno-science. It is to see architecture as a discipline through which scientific rationality has traveled historically, and where mathematics has resided as a kind of tradition. Husserl himself set the stage for this historical interpretation in "The Origins of Geometry," where he described geometry as a historical tradition, whose self-evidence relied on the "sedimentation of truth-meanings"—or, as Jacques Derrida put it, a "tradition of truth."[15]

After all, architectural drawing is a minor branch of modern image-making, yet it looms surprisingly large in visual culture. The truth it conveys is socially mediated, a thruway for the development of what Theodore M. Porter has called "trust in numbers."[16] According to Porter, quantification triumphed in the modern sciences to compensate for a perceived loss of any trustworthy community. Architectural rendering, as we will see, contributed to the rise of this compensatory social trust, as a tool both to produce new buildings and to record existing ones.

TABLETOP SCIENCES, CA. 1780

Despite the emphasis that has been placed on the Renaissance origins of architectural delineation, "the line" as a combined graphic tool for architecture's design,

Figure 1.3. Shadows used as part of naturalist artifice in the elevation of the Arch of Titus at Rome. Antoine Desgodetz, *Les Edifices antiques de Rome: Dessinés et mesurés tres exactement* (Paris: Coignard, 1682).

execution, and presentation did not coalesce until the late eighteenth century. Until then, drawing shadows had been one way among others to denote precision in the plates of architectural treatises. For example, in the mid-sixteenth century Andrea Palladio invented one convention: draw the proportions of the classical orders as outlines if they are taken from written texts, or give them shadows if they are measured from buildings.[17] After Palladio, wherever there was a line, there was a measurement; if there was a shadow (and additional reality effects such as plants overgrowing a ruin), there was a building (Figure 1.3).[18]

Once geometry became "descriptive" in the eighteenth century, what had been a surveying tool became an instrument for design, and a systematic realignment of drawings and their objects took place. The line became the most authoritative descriptor of reality. "Geometric learning" was called upon to replace "what would otherwise be acquired by induction, through lengthy copying."[19] This does not mean that shadows disappeared; on the contrary, any line could now generate a shadow. Treatises on shadow casting proliferated, especially after descriptive geometry became a required field of training in France's new engineering schools.[20] According to one 1754 textbook (Figure 1.4), shadows demonstrated that the same geometric operation—drawing a line—could be used to cut stone, train the engineer, and represent volumes in space, "rendering objects as perfect(ly) as they could be to the understanding of others."[21] The word *render* expressed a kind of cognitive productivity.

Barely half a century after being introduced in engineering schools, descriptive geometry and its associated "science of shadows" were made a compulsory part of architectural training in France. Again, shadows survived, but in a radically different way from the naturalist artifice that had characterized the plates of

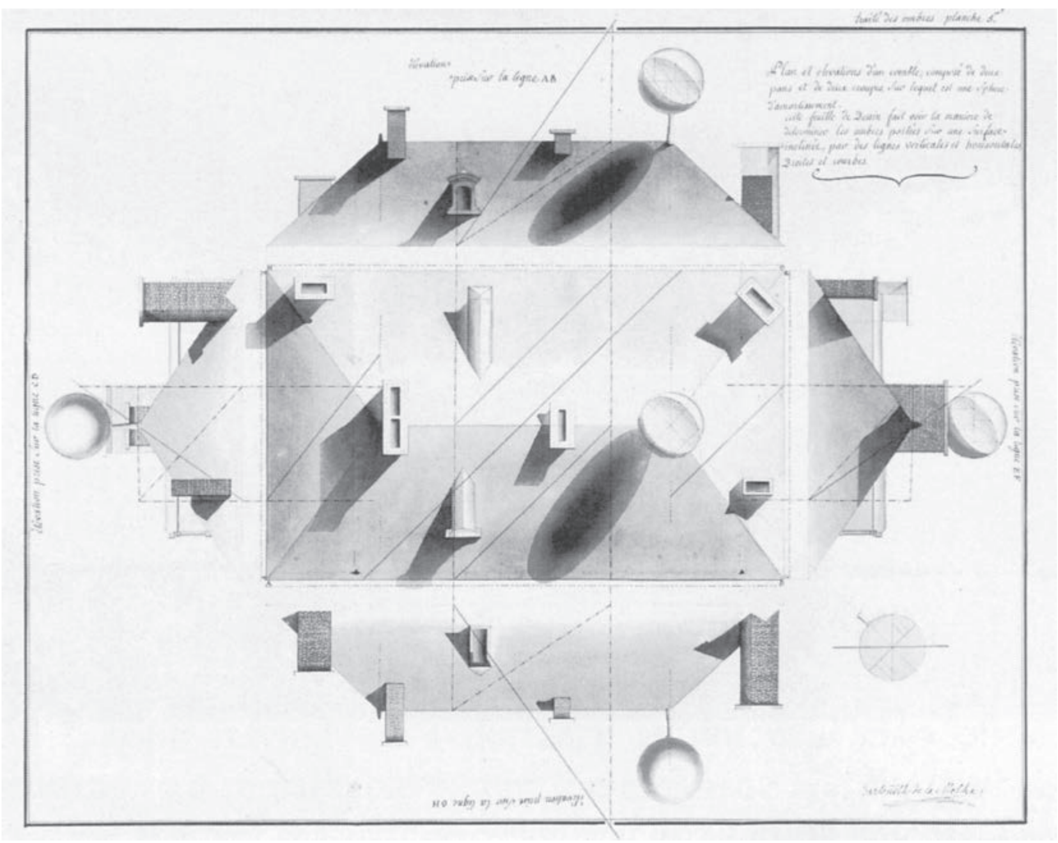

Figure 1.4. Roof plan showing off the new science of shadows. N.-F.-A. de Chastillon, *Traité des ombres dans le dessin géometral* (1754).

Vitruvian architectural treatises. Stanislas L'Éveillé, who wrote the first shadow-casting manual for architects in 1812, vaunted that he had literally "cast a new light" on the architectural canon, and depicted the paper on which his figures were drawn.[22] For architects, the burden was now to represent in three dimensions the space in which each line existed. The growing material reality that architects sought to encompass under a single graphic umbrella challenged what had seemed, to engineers, to be the metaproperties of the line. Stone and wood were soon joined by other media, including paper itself.

Such "cascading" of graphic media, as Bruno Latour has called it, is symptomatic of the rise of the experimental sciences in the late eighteenth century, with their distinct laboratory apparatuses, methods, and terminology.[23] As Raymond Williams has pointed out, this was also the period when *experience* and *experiment,* two words once meaning the same thing, underwent a split. *Experience* began to be seen as conservative, whereas *experiment* was forward-looking, linked to revolution. If experiments were events that took place in laboratories, experience became conceived as "against innovation," as "an appeal to the whole of consciousness, the whole being, as against reliance on a more specialized or more limited states or faculties."[24] Of course, artisanal experience continually crept into the world of experimental truth-making.[25] Painting, drawing, modeling—and handiwork from the makerly to the gestural—were pervasive in scientific laboratories, helping co-mingle experience and experiment into hybrid modes of knowing.[26] Rendering was one such practice. Certainly chemistry's experimentalists visualized their apparatus with shades and shadows rather than in outline. Robert Boyle's famous air pump was rendered as a three-dimensional volume when it was published—an additional cost that was expended so his groundbreaking "experiment" could be "experienced" by the reading public. Simon Schaeffer and Steven Shapin have called this phenomenon "virtual witnessing," and John Bender has even found *actual* witnesses in the plates of treatises in this period, drawn in three dimensions and out of scale, among rendered instruments and tabulated results.[27]

Rendered drawings also performed this virtual witnessing function in the architectural sciences, especially in the emerging field of structural engineering.[28] In 1787 the French engineer Jean-Baptiste Rondelet introduced his newest invention, a "machine for crushing stones," by publishing a rendered view of his workshop where an elaborate system of levers and pulleys, and solid blocks that lay waiting to be crushed, were dramatically lit from the side (Figure 1.5).[29] The machine itself was reinstalled at the École Polytechnique as an exhibition piece. As for the blocks, they were samples of the stone that Rondelet's mentor, the architect Jacques-Germain Soufflot, had used to build the church of Sainte-Geneviève.

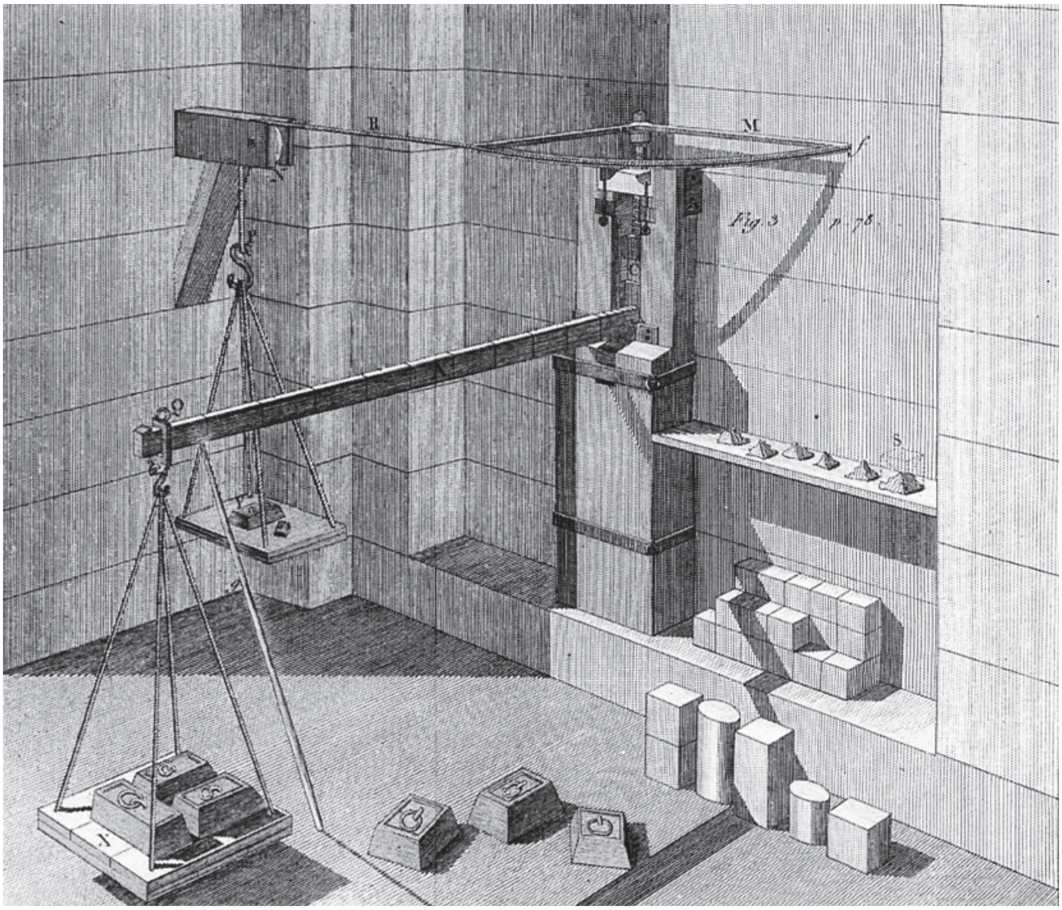

Figure 1.5. Engraving of a "Machine for Crushing Stones." Jean-Baptiste Rondelet, *Traité théorique et pratique de l'art de bâtir* (Paris: n.p., 1787).

When the stones had been tested for structural failure, the results had been drawn in section, with no shadows at all, only cracks and fissures hatched in. Renderings, in other words, had been made for the public, while hatching had been kept for the specialists.

One of the most telling instances when architectural rendering helped *both* expand a science's experiential appeal with the public *and* perfect its experimental apparatus for the specialist came not from engineering but from city planning, or rather its precursor, urban topography. In 1792 Edme Verniquet published the first complete urban survey of Paris, a plan of such unprecedented accuracy that it served as the base map for a century's worth of visionary urban reforms, including Georges-Eugène Haussmann's.[30] Verniquet produced his plan by measuring the distances between Paris's architectural landmarks, triangulating these measures to get a basic layout of the city, and then filling in the rest with street-by-street measurements of the city's fabric.[31] The most famous spread of Verniquet's oversized book is a "demonstrations sheet" that combines all his triangulations into a blanked-out plan of the city walls, traversed by nothing but the outline of the Seine, as in a portolan nautical chart showing coastlines amid a network of rhumb lines. The sheet seems to represent the virtual conquest of urban space by pure linear geometry, and indeed it served as internal "proof" of the accuracy of Verniquet's calculations.[32] Verniquet was even asked to reenact his trigonometric operations in a session at the Jardin du Luxembourg, where two scientists from the French Academy of Sciences observed him redraw all his measurements on a new sheet and arrive at identical results (Figure 1.6).[33] Verniquet was no experimentalist, but he was a keen participant in the culture of "science and spectacle" that pervaded late eighteenth-century Paris.[34] His own workshop, a space rented out in the Convent des Cordeliers from 1783 to 1787, became a must-see stop for notables visiting the city.[35] Here is what these visitors saw: a massive horizontal surface—a table 16.5 feet long by 13 feet wide—where two hundred

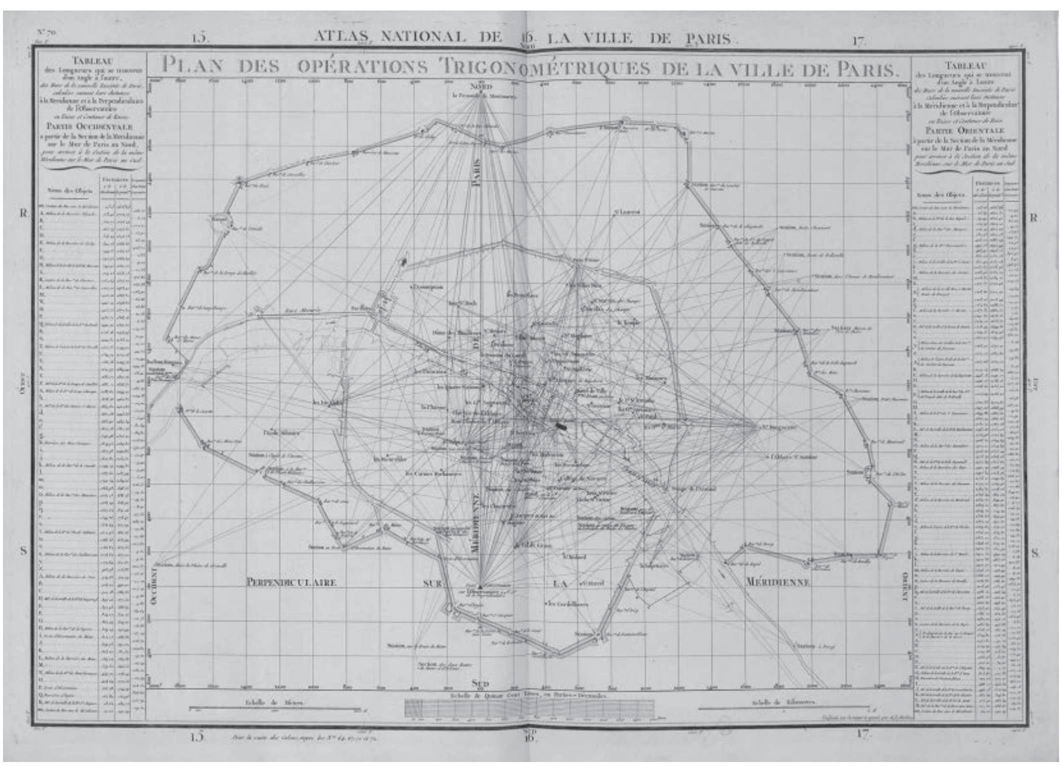

Figure 1.6. Plan of trigonometric operations. Edme Verniquet, *Plan de la Ville de Paris* (Paris: Verniquet, 1792). Courtesy of Bibliothèque nationale de France.

draftsmen assembled the information collected by more than sixty surveyors, returning from nightly excursions measuring streets by torchlight, or climbing to the tops of buildings by day. This tabletop was the representational space from which a new measurable Paris originated.

Once Verniquet published his map as an atlas, however, he complemented this geometric aesthetics with another type of drawing where shadows were added to convey truthfulness to an expanded readership. Here, Verniquet rendered each monument as a colossal and façade-less platonic volume, casting dramatic shadows on the page and also intersected by three lines—experiential monuments amid a mathematicized world. The baroque church of Saint-Sulpice, for instance, was represented by a plan of the cylindrical drum of its northern tower, extracted from the rest of the building, and casting a shadow leftward at forty-five degrees, according to the architectural convention set by Julien Le Roy in 1749 and still followed by contemporaneous visionary architects such as Etienne-Louis Boullée (Figure 1.7).[36] Alone or in groups of three, these volumes turned Parisian landmarks into "virtual witnesses" of Verniquet's procedure. [37]

So even without any descriptive geometry to teach, and without any Vitruvian theory to transmit, Verniquet's laborious effort to commit the buildings of Paris to paper amounted to a demonstration that architecture could supply a reliable source of data and comprehensive field of empirical reality to feed the new scientific mentality. His procedure was not called "rendering," but it corresponds to the old Roman word *redere,* to "give back," as in "render unto Caesar."[38] Mapping this much architecture necessarily implied a recipient with administrative authority and vast storage capacity. And although Verniquet began his measurements under the ancient regime, his project survived the French Revolution, his results and their public utility passing into the hands of the new nation-state.[39]

THE BEAUX-ARTS RENDERING AS WORKING DRAWING

The rendering only became a noun, *le rendu,* when architectural education was codified by the postrevolutionary French state throughout the nineteenth century. This transformation of rendering from process to thing closely followed the desire to quantify the mechanical productivity of the world. The term connoted quantification in several ways. In economics, the noun *rendement* meant the productive "yield" either of an agricultural enterprise or of a machine.[40] As an adjective, *rendu* was first associated with accounting, after finance minister Jacques Necker produced his Rendered Account (Compte Rendu) of the state's finances in 1781. At the École des Beaux-Arts, these two productive qualities combined with a third medium-specific one: *rendu* was something that happened to paper,

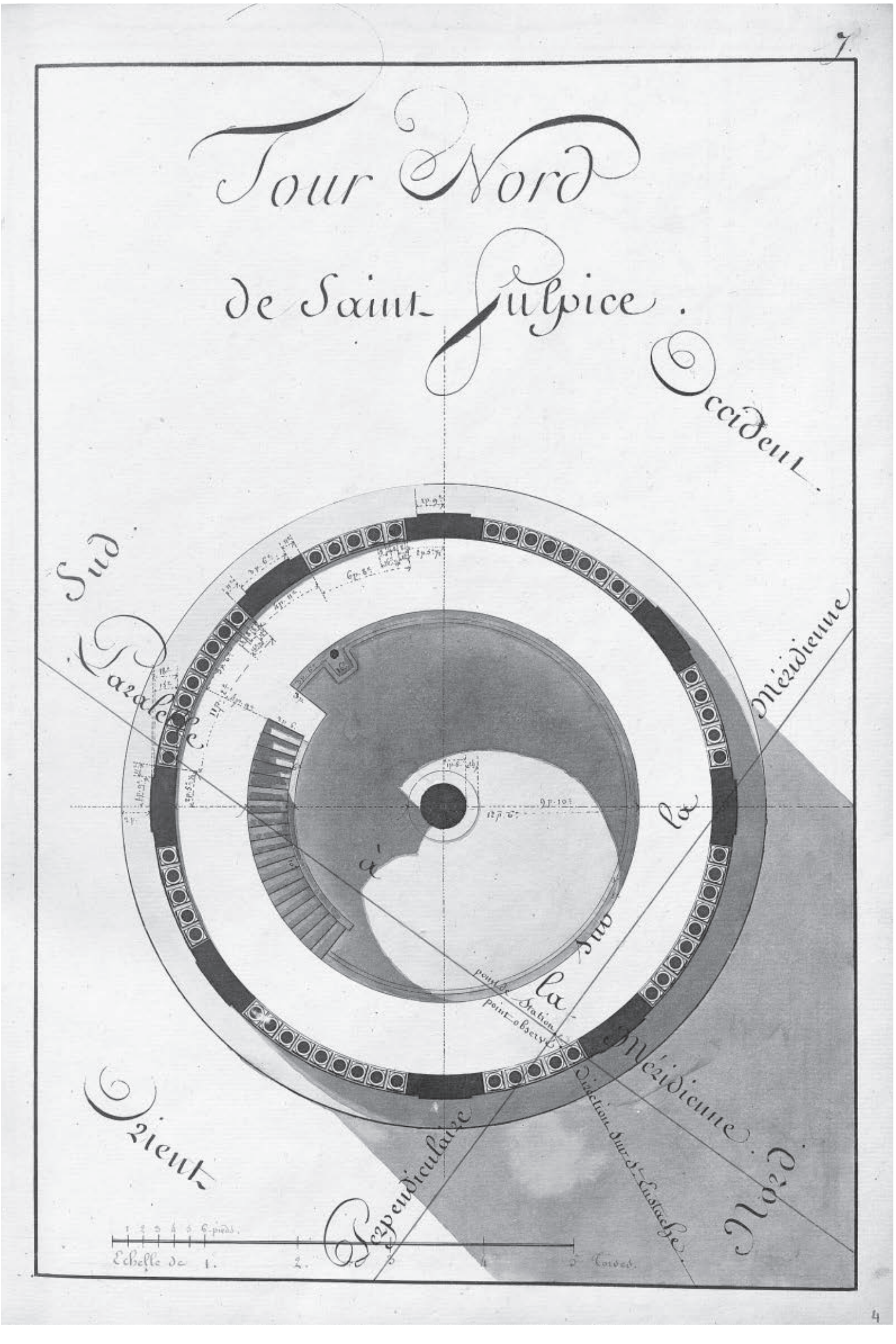

Figure 1.7. Northern tower of the church of Saint-Suplice rendered as a shadow-casting volume traversed by measuring lines. Edme Verniquet, *Plan de la Ville de Paris* (Paris: Verniquet, 1792).

specifically, "heavy stock such as Wattman paper," when it was worked over with "pencil and pen, and a bubble of China ink or sepia, and watercolor." [41] Within the arts, it was in architecture that *rendu* acquired its ultimate triple meaning as quality, thing, and procedure: "the coloring of a project; also, the finished project; also, the delivery of the project."[42]

When designing a project at the École des Beaux-Arts, to render meant to make complete. As the school's chief pedagogue, Antoine-Chrysostôme Quatremère de Quincy, put it in 1832, "rendered" was as a "synonym for *finished, done, completed*." Indeed, no drawing at the École was considered complete until it had been granted the "highest level of execution to even the smallest details and effects."[43] In the elevation drawings for any prize-winning competition entry, not a single line was left without volumetric or atmospheric enhancement—not a façade without a shadow, not a niche left empty of sculpture, not a sculpture left unshaded; every triptych and metope raised off the cornice and off the page, and every marble vein drawn in.

At the competing École Polytechnique, Jacques-Nicolas-Louis Durand complained that such "rendered drawings offer nothing geometrical to our eyes."[44] Charged with the architectural curriculum for the training of a quasi-military corps of engineers, Durand decided to adapt the Beaux-Arts system by removing the rendering phase of the project altogether. Anyone who obsessed over the surface of his drawings in this manner, he argued, could only get "confused" and produce an architecture of superficial façadism.[45] After all, it was at the Polytechnique that descriptive geometry flourished as pedagogical tool, providing a visual complement to the mathematics that were taught for mental rigor.[46] Durand thought architecture could contribute to training the engineering mind through graphic efficiency. "Reducing drawing to a simple trace," "gathering as many architectural objects as possible on one page" so that "shared lines coursed through them," and using watercolor washes *only* as a means of "distinguishing solid from void"—these economies of representation would yield visual, constructive, and professional clarity.[47] And this collapse of paper and wall was also stylistically fortuitous: drawing this way, it was possible to strip geometry bare (of patterns), much as a contemporary neo-Palladian taste demanded that walls be "denuded" of decoration.[48]

But visualization skills at the École des Beaux-Arts were also motivated by a professional economy. To begin with, the labor of rendering at the École was used to align a building and its representation not vertically through elevations but horizontally, in plan.[49] The plan was the privileged drawing at the École and, despite being taken from an impossible viewpoint (a horizontal cut taken a meter above the ground), it was extensively rendered. One vignette of an architectural student at work shows him hunched over his drafting desk, almost horizontal himself (Figure 1.8).[50] As David Van Zanten has described, rendered plans synchronized the movement of the hand of the architect with the bodies of the building's visitors, transforming the experience of composing a building into the experience of proceeding through it.

> Looking down into a fully rendered Beaux-Arts student plan, seeing the spaces assert themselves over the wall masses and push open a canyonized landscape of linked chambers, one's eye walks back and forth between the cliff-like walls, experiencing the composition the way [the architects] meant one to experience the composition of the buildings . . . itself.[51]

Rendering was a tool for thinking about architecture as made not of walls but of spaces. Second, then, composition of these spaces contained a certain collective ideal, driven as it was by the *marche* of a plan, a word that connoted both the fact that it "worked" (marcher) like a machine but also that it could be "marched through" as though by an army (Figure 1.9).[52] This operability embedded an entire system of bourgeois social values into academic architecture. Through drawing, hierarchy was engrained into architects and buildings alike, much more powerfully than rote repetition of the principles, such as propriety, decorum, and fit, that were supposed to regulate neoclassicism as a style.[53]

Rendering at the École des Beaux-Arts was also a way to systematize the production of architects, and to internalize the experiential basis of design in the person of the architect.[54] The ritualized culmination of any studio project was "the day of rendering" *(jour de rendu)*. Students gathered in the *salle Melponène* to stretch their drawings on canvases and register them with an attendant, who would then arrange to have them carried through Paris on a cart *(charrette)* so they could be "handed in" *(rendu)* to a jury of critics. At the end of the student's education, too, the architect was supposed to build up a cache of firsthand experiences (hopefully by winning the Grand Prix de Rome and traveling to Italy), process them, and deliver them via rendered drawings that were sent home once a year.[55] Henri Labrouste's 1828 reconstruction of the temple of Paestum was one such oversized envoi whose sheer material presence—overworked, difficult to store, cumbersome to display—was a testament to the immersive experience of the Rome Prize (Figure 1.10). Nineteenth-century Paris was flooded with architectural experiences, if we are to believe reports of the surplus of rendered paper in the city's market for drawings and complaints that such finished drawings appeared to proliferate in inverse proportion to the number of buildings actually built.[56]

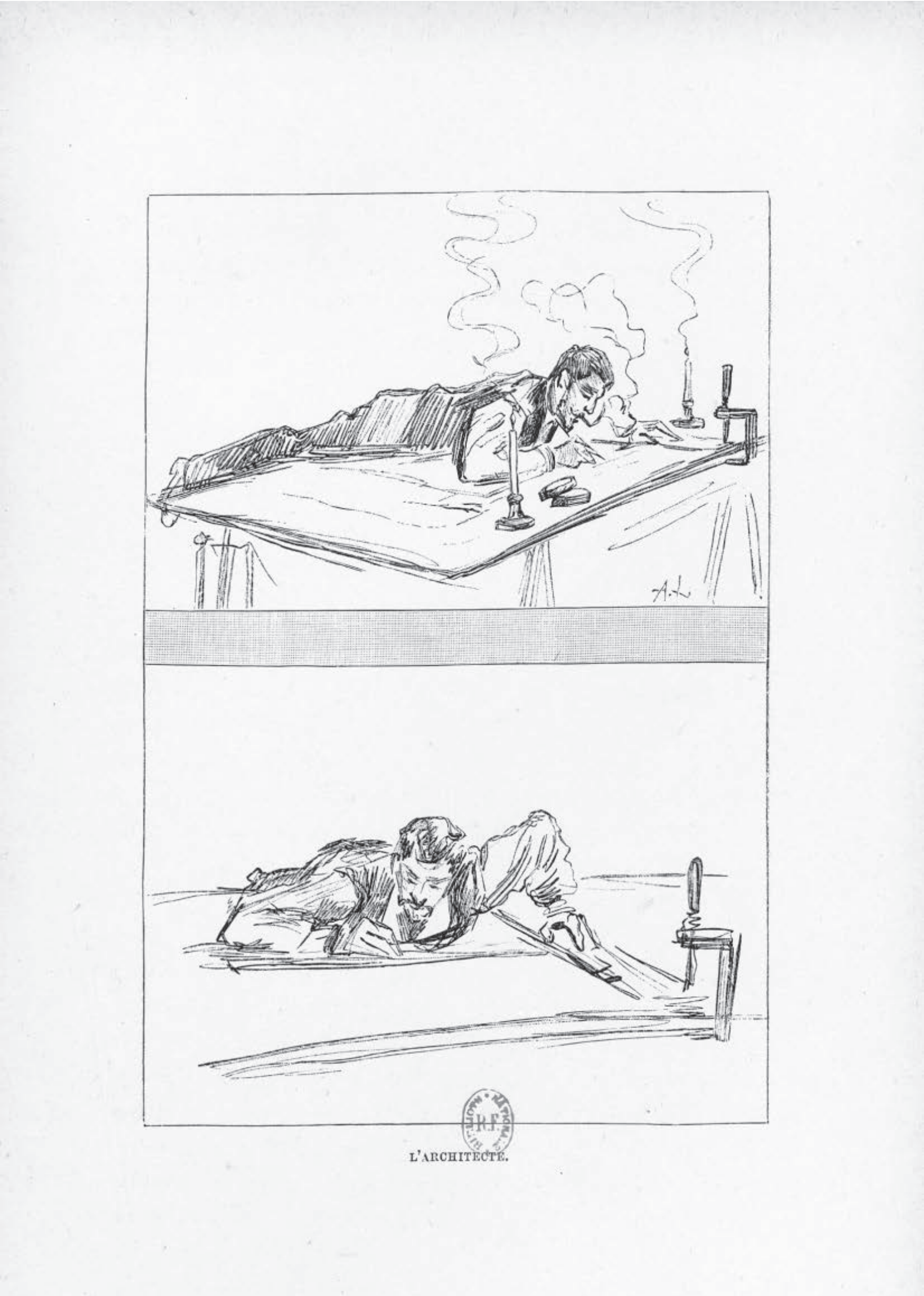

Figure 1.8. Vignette of the Beaux-Arts architect at work, almost horizontal himself. Alexis LeMaistre, *L'École des Beaux-arts, Dessinée et racontée par un élève* (Paris: Firmin-Didot, 1889).

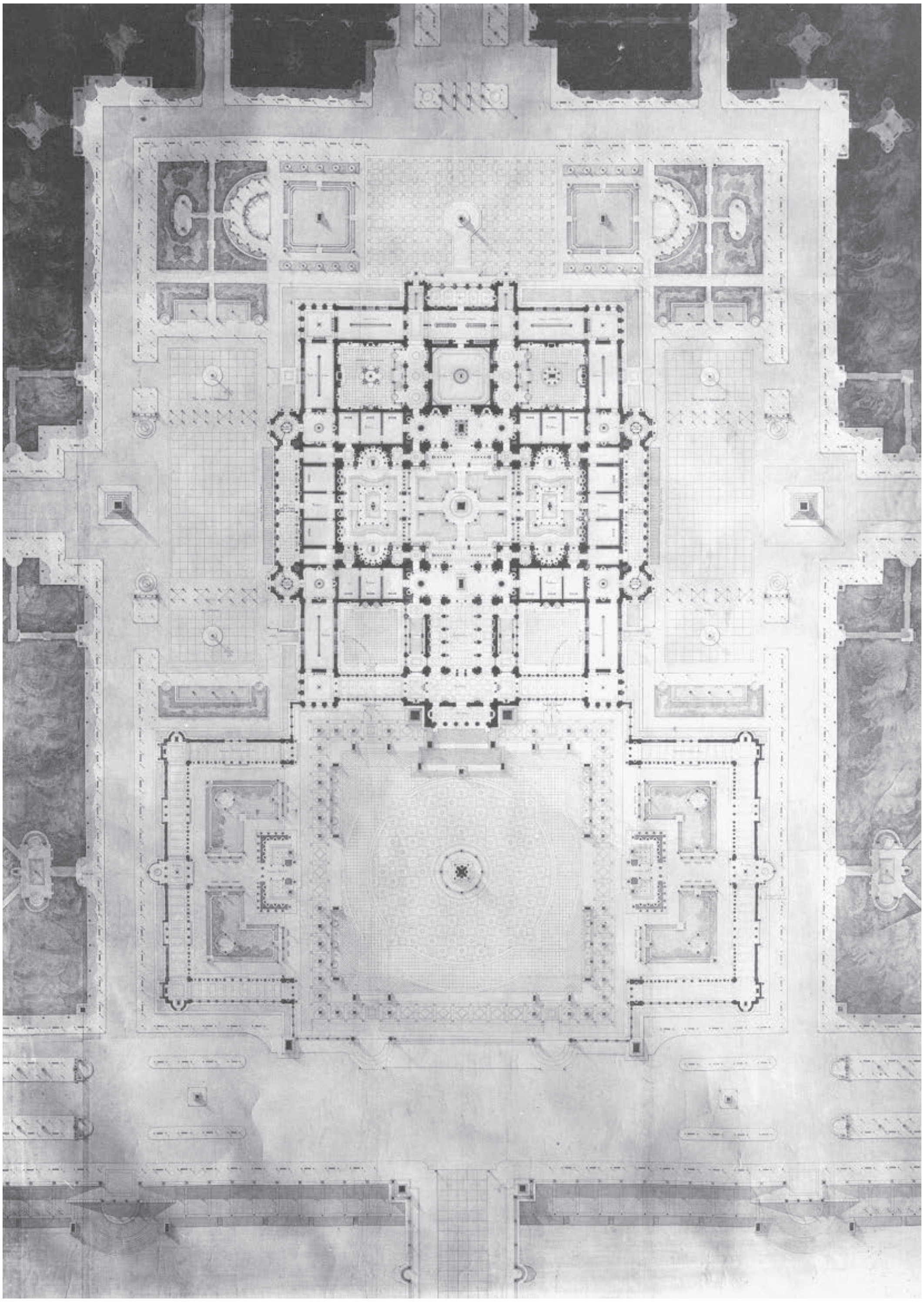

Figure 1.9. Émile Bénard, "A Palace for the Exhibition of Fine Arts," Winner of the Grand Prix de Rome, 1867. *Les grands prix de Rome d'architecture de 1850 á 1900: Avec les programmes des concours* (Paris: A. Guérinet, 1909), pl. 91.

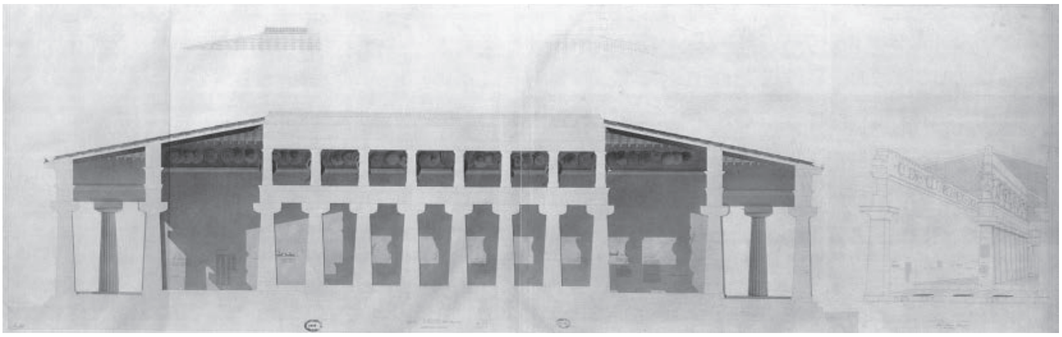

Figure 1.10. Henri Labrouste, longitudinal cross-section of the restoration of the Temple of Paestum, fourth-year submission from Rome, 1828–29. École nationale supérieure des beaux-arts, Paris.

But if the growth of the architectural drawing as a seductive commodity in the nineteenth century shows that architects increasingly took part in selling experiences, it also hints that what a rendering makes palpable is not always the building it depicts. Consider the flat pink profiles of columns in Labrouste's Paestum drawing, which give the section depth. In contrast to the shades of black ink Labrouste used to cast deep shadows into the cavernous interior, or the full spectrum of paints representing the ancient polychromy of the murals within, these pink profiles cut through stone and remain flatly on the surface of the page. Pink is essentially the color of rendered paper.[57] In that sense it is closer to the blue Labrouste used in his later drawings for the Bibliothèque Sainte-Geneviève, a medium-specific code indicating iron as construction material. These pink profiles materialized on paper the stereotomic-cum-analytical power that had been granted to the geometric line a century earlier. Given this new currency, the "cut" helped commodify the experience not only of Paestum but also of all the spaces where architects operated: the Parisian atelier, the salons of the city of Europe, the academies of Rome and Athens, and, increasingly, the industrial materials they specified.[58]

The apparent visual cohesion that emanated from the Beaux-Arts rendering, and the social distinction bestowed upon its author, actually relied on a strictly hierarchical division of graphic labor. Only a few students won the Rome Prize; most spent their time rendering in a piecemeal fashion and on behalf of someone else. The École's competition system was a pyramidal scheme where younger students who did not make it to the next round became helpers for those who did.[59] In the professional *ateliers,* every final drawing was rendered not by a single author but by an entire cohort of rendering hands, each working on separate portions of a single extensive surface (Figure 1.11). By the end of the nineteenth

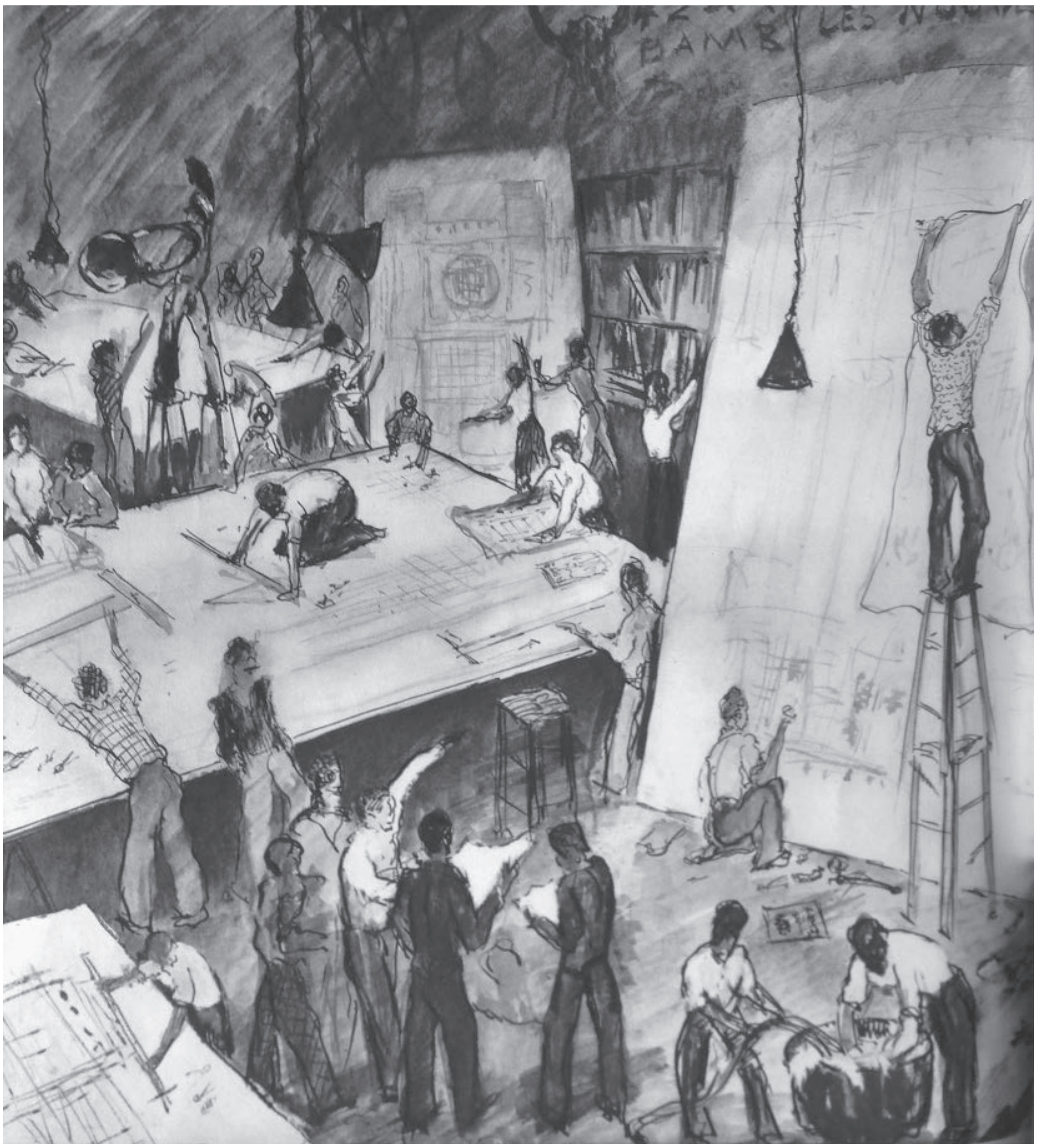

Figure 1.11. Claude Hertenberger, "L'Atelier," 1937. *École Nationale Supérieure des Beaux-Arts* (Paris: La Grande Masse, 1937). Copyright by La Grande Masse des Beaux-Arts.

century, rendering had become a tedious and repetitive task delegated to a specialized subclass of image workers who called themselves “nègres.” In a sure sign of the influence of industrial-era labor movements onto architectural culture, students started calling themselves the “great mass” in the early twentieth century, while the interns, still using the racist slur, tried to unionize.[60]

The Beaux-Arts system of distinction was only truly massified in the early twentieth century, however, when Beaux-Arts pedagogy was exported worldwide, and especially across architecture schools in the United States. American textbooks appeared to confirm the conflation of rendering with visual and professional finishing. John Harbeson published *The Study of Architectural Design* in 1927, for instance, to explain how the juried competition system worked, and to nationalize the standards for its associated medium, the rendered drawing.[61] The “time schedule” he published for a project broke down the system into incremental steps and even announced an automation of design.

Nov	31	Start inking final drawings
Dec	1	
	2	
	3	
	4	Cast shadows
	5 Sat.	Render
	6	”
	7 Mon.	Problem due 10 A.M.[62]

Unlike all the other steps, “render” became a repeatable loop, through a single typographic mark, ”. Harbeson also broke down the training of the eye visually. Devoting two chapters to rendering, he drew a full-page grid of “effects” that could be achieved with a single watercolor brush (Figure 1.12). The structure of this drawing (each cell in the grid cuts out a window through the page; each window is given its own depth effect) is strikingly similar to that of digital software tools; it looks like a hand-rendered version of the palette of options a Photoshop user can click on today.[63] But since there was no “clicking” possible, this menu offered no actions, only a sampler of architectural experiences and a serialized appeal to the senses.

As photography entered the design studio, the mechanization of vision also became useful to standardize rendered effects. Photographs pervade the manual I started with, Henry McGoodwin’s *Architectural Shades and Shadows,* and his terminology too, as when he recommends using washes “to ‘focus’ the drawing at the principal plane.”[64] Indeed McGoodwin directed his camera’s lens at an already

Figure 196. Graded Washes of Water Color.

Figure 1.12. "Graded Washes of Water Color." John F. Harbeson, *The Study of Architectural Design* (New York: Pencil Points Library, 1927).

dissected reality, by taking photographs of plaster casts of capitols, carefully disposed atop column stubs, and artificially lit in front of a neutral backdrop. Bringing the rendering-real of the analytical "cut" full circle, McGoodwin dissected an architectural order in plaster, only in order to render it complete again via drawing. Gone were the polychromous backgrounds of Labrouste's Paestum reconstruction. Instead, the backdrop for rendering was that most modernist of three-dimensional décors, the naked white wall (Figure 1.13).

PHOTOGRAMMETRY AS MECHANICAL RENDERING

It is a point of historical consensus that the architects of the modern movement eschewed hand-rendering and preferred to visualize their projects with mechanical media that conveyed the disjointed and fragmented nature of modern experience.[65] According to Manfredo Tafuri, the architectural avant-gardes used mixed media and photo collage to mimic the assembly method of industrial production, eventually allowing the bourgeois public to "absorb and transmit" the "experience of shock suffered in the city."[66] Still, insofar as they combined drawn outlines with photographic shadows, especially through collage, many modernist architects can be said to have operated within a rendering paradigm. In his Klee collage for the 1939 Resor House, Mies van der Rohe used planes of color and texture to flatten the page, and naked lines for perspectival illusion.[67] When Le Corbusier collaged his *Plan Voisin* onto an aerial photograph of Paris, rendered plan and horizontal photography offered two parallel illusions of planimetric depth, side by side.

This interpretation of modernist collage is only one side of the story of mechanized visualization in architecture, however. A perceptual modernization of the built environment also took place in the late nineteenth and early twentieth centuries through surveying by way of photogrammetry—a technology that derives mathematical information from photographs to produce line drawings.[68] The optical principles of photogrammetry were already known to Renaissance surveyors, who traced city views onto large vertical glass plates. In the nineteenth century, these plates were replaced with photographs, which could be traced over off-site.[69] By the time the German engineer Albrecht Meydenbauer coined the word *photogrammetry* in the early twentieth century, it was largely a way to process the data contained in the vast photographic archives of historic monuments amassed by nation-states, creating measured drawings for them.[70] With the addition of stereoscopy—a technology that produces the impression of three-dimensional depth by taking two photographs of the same object spaced almost imperceptibly apart—photogrammetry became the dominant architectural surveying system

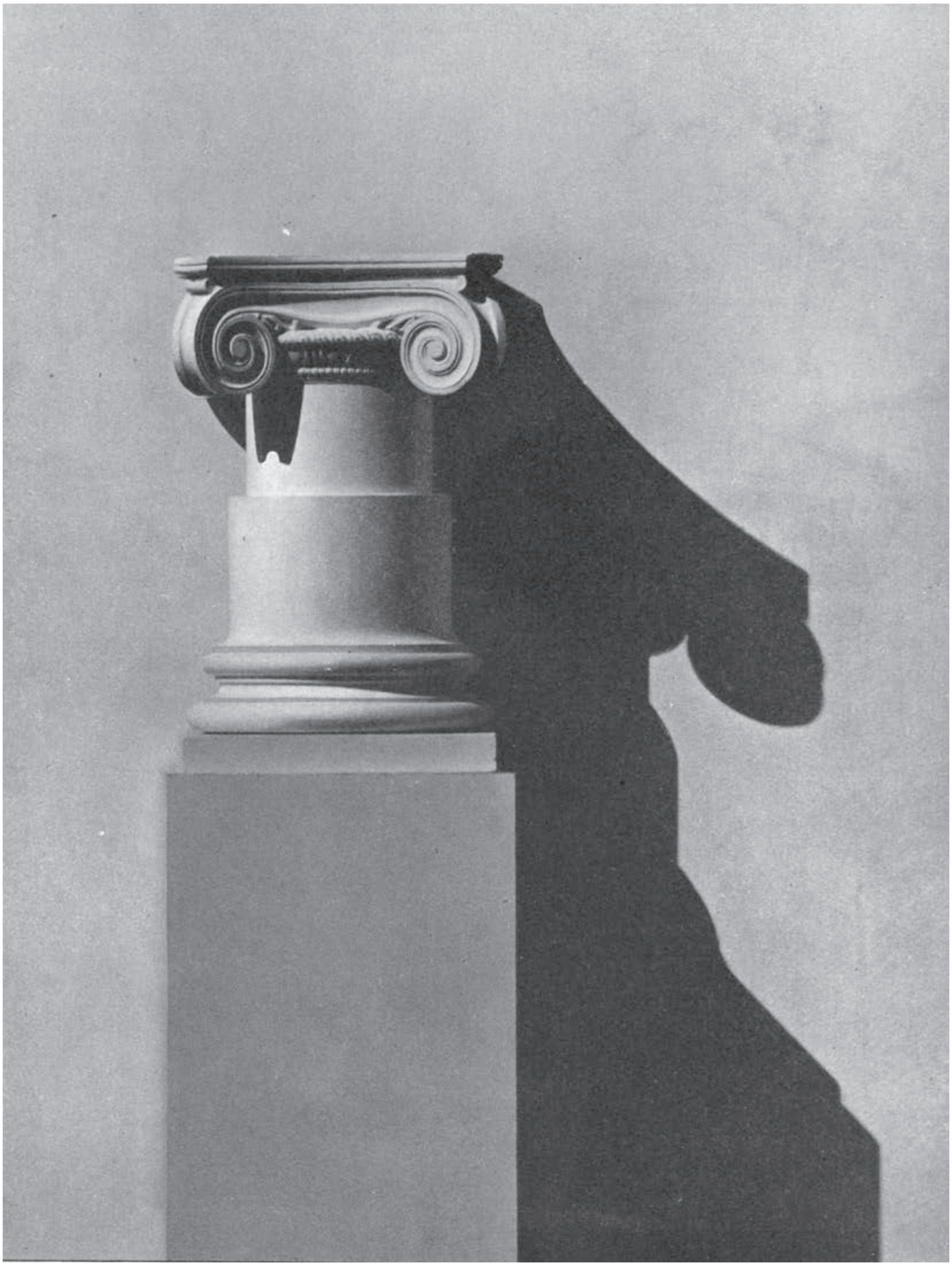

Figure 1.13. Photograph of a plaster cast used to practice drawing shadows. Henry McGoodwin, *Architectural Shades and Shadows* (Boston: Bates & Guild, 1904).

across Europe. Geometrically, the principle is the same as Verniquet's triangulation: from two views, one can derive a physical measure. But here one of the sides of the triangle is always composed by the very short distance between the viewer's two eyes.[71] The machine used to render the three-dimensional image—a "restitutor"—works by assigning each of these images to one eye of a human (Figure 1.14). This human is then asked to trace the position of a virtual "dot" that appears to "float" on the surface of a building as she sees it in three dimensions. Through a system of pulls and levers—right hand, left hand, and feet all operating a different prosthetic extension—her movements are transmitted mechanically to a drafting machine that produces a contour drawing. Every element of the classical rendering system is present but reenacted mechanically and by an upright body. English-language manuals use the term *rendering* to describe the product of these actions.[72] But photogrammetry more properly performs an act of unrendering: it presents a shadow to the eye and uses a machine to produce lines.

Stereophotography completely transformed the practice of surveying, turning what had been an architectural art requiring a point a view into a technical practice suitable for anyone with two eyes. Such was, at least, the caution sounded by many architects in the 1930s. Delegating depth perception to a prosthesis was too dangerous, they argued. Lengthy debates over whether to adopt these new and experimental stereographic technologies or whether to stick with the old method of single-point photography can be understood essentially as a debate between two kinds of experience.[73] At the 1934 International Congress of Photogrammetry, French architects in favor of traditional photogrammetry (where an

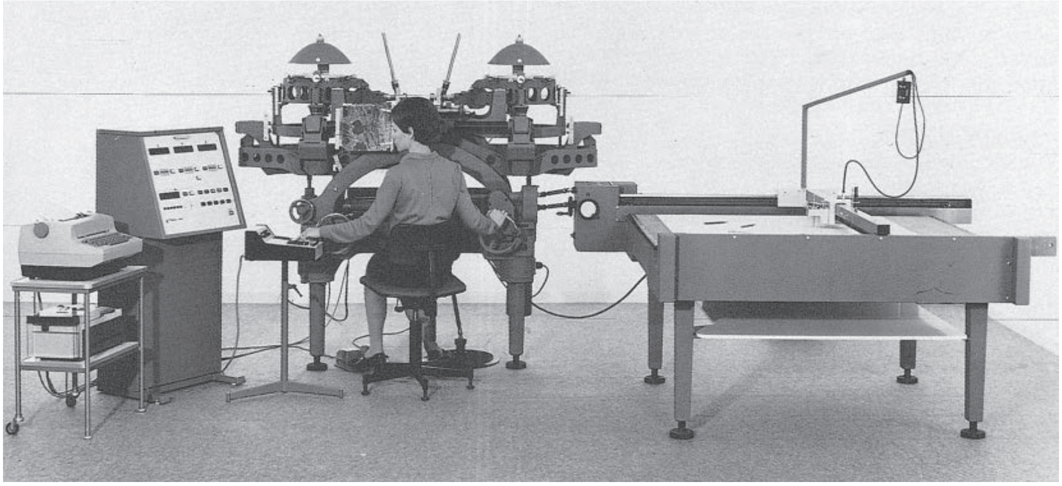

Figure 1.14. Wild A8 analog photogrammetry restitution machine, in use circa 1970. Jean-Paul Saint Aubin, *Le relevé et la représentation de l'architecture* (Paris: l'Inventaire, 1992).

architect traces over one photograph with ink) spoke of the convenience and mobility of their instruments and the continuing reliance on the traditional drawing skills of the architect. In contrast, the new stereoscopic "restitution machines" were large, expensive, and unwieldy. But the German delegation argued that they were more precise and reduced human error by requiring fewer measurements on site. The French side bet on the equation of human experience with mobility, predicting that stereo-photogrammetry would be adopted by architects only if smaller, more portable, and affordable photographic machines were made. But their German colleagues sought more accuracy by dividing up perception into minute, dispersed, and repeatable actions. They were proven right: oversized and expensive "restitutors" could be bought and maintained by state agencies and operated by a trained technician rather than an educated professional like the architect.[74] As control over the technologies was concentrated into state hands, so too was the architectural canon of buildings worthy of recognition and thus documentation. Photogrammetry brought a triple de-skilling of the architect: as a graphic artist, photographer, and cartographer.

Despite this de-skilling, claims that photogrammetric machines offered an experiential continuity were integral to their acceptance as truthful "restitutors" of reality. Although this system dramatically reduced the time that surveyors spent on building sites, it became known as a "tactile" technology, which could "cover the surface of the building in its actual state and with total continuity."[75] Maurice Carbonnel, one of the most famous architectural photogrammetrists of the twentieth century, vaunted he could "touch the image" and thus produce "threads of stone."[76] This cognitive metonymy is explained by the fact that de-skilling and re-skilling occurred at the scale of perception itself. Unlike collage, photogrammetry does not produce an image of disjunction. On the contrary, it offers the viewer an image of depth and wholeness but forbids him or her from experiencing it—from *receiving* it in the Husserlian sense. Instead, human operators follow a single "thread" between different media and their experience is discretized into separate channels. The fiction of wholeness persists only because of a continuous "line" in the instrumentation.

DIGITAL RENDERING: EXPERIENCE INTO EXPERIMENT

In our archaeology so far, we have already encountered several tools used by a digital renderer today: an iterative loop, a palette of shades, a menu of photo-realistic effects, a nearly subocular visual increment (Figure 1.15). These segments of imaging processes have survived as digital operations, but only by being extracted from their technoscientific birthplaces. Photogrammetry offers an apt

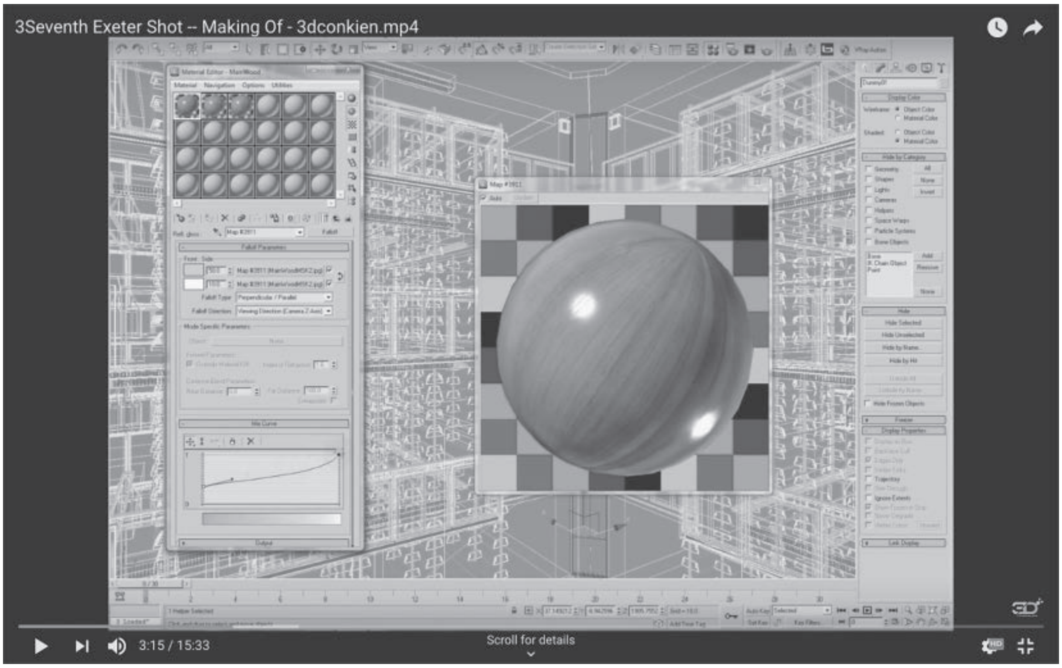

Figure 1.15. Screenshot of the interface to render Louis Kahn's Exeter Library. Alex Roman, "The Third & the Seventh," https://vimeo.com/7809605.

example. Its machine setup remained the same well into the 1980s—with a technician sitting at a viewing station, perceiving an illusion of depth, and producing architectural drawings using prosthetic drafting attachments. But after "restitution software" was introduced to replace the photo-mechanical viewing and plotting, it became unnecessary to measure the distance between the technician's eyes. All human input was reduced to viewing a single computer screen, sequentially clicking onto at least six points (three in one of two windows), then waiting for a progress bar to fill up to 100 percent.[77] That last step—the waiting—shows how the experiential basis of rendering's claim for a cognitive continuity has changed. Digital computing has all but removed the association of rendering with linear time, because software deals with time as a mathematical variable, to be computed and optimized.[78]

Architects today borrow their rendering tools from the computer graphics industry, where the tradeoffs about what deserves rendering time have already been made, often with the goal of maximizing spectacle.[79] The fly-through—borrowed from Hollywood film—has replaced the Beaux-Arts *marche* as the preferred way to walk through a building. For example, the most complete digital reconstruction of the site of Pompeii has been produced not by archaeologists but by the

CGI artists who made a three-minute sequence of the blockbuster film *Pompeii,* in which a camera flies over the city's streetscape as it is destroyed, first by massive balls of lava and then by an invading tsunami wave.[80] But to say architecture is submitted to spectacle is not saying much, given that the entire computer graphics industry has itself always been seen as a semiautonomous supplement to fundamental computing research. (This is the reason that graphics cards are bought separately, given a special "slot" in any computer today.) Computer graphics, the branch of computer science where rendering research takes place, is propelled by a desire to keep visualization fast, so it can be integrated into other coding endeavors.

There is no natural light in computing space, and also no difference between a shadow and a line: both need to be computed and rendered with equations. So, rather than relying on machines that see, rendering software models the behavior of light mathematically and optimizes the time to completion. There are two methods for doing this, each reliant on one of the basic operations of calculus, integration and differentiation. "Ray-tracing" imitates optical geometry by generating rays of light that bounce from the screen and toward an object, following them as they are reflected or refracted and rendering every point they encounter—a method best suited for visualizing shiny, isolated objects. "Radiosity" is borrowed from thermal engineering and works by computing the ability of surfaces to absorb and refract light against one another; it is best for rendering surface-bound environments.[81] Most rendering software uses a combination of both approaches, and because both are potentially indefinite operations, a certain processing time is set, after which the rendering process is cut off. The economy that drives the development of software has embedded criteria of visual "completion" into the rendering engines themselves.[82] But the machine "learns" what looks "finished" to the public at any given moment in time, not by comparing with an external referent.[83] Thus trust in computation differs from trust in numbers because every experiment contributes to perfecting this presumably growing machine intelligence.

Computer rendering was detached from sensory experience early on and explicitly distinguished from drawing or painting. Sketchpad, the earliest graphical computer interface, was presented in 1963 as based on "the medium of line drawing" in part to "make computers accessible to new classes of users (artists and draughtsmen among others)." But Ivan Edward Sutherland, Sketchpad's inventor, also argued the software would liberate them from "a lifetime of drawing on paper."[84] In other words, he hoped to enlist artists to help perfect his tool, but the tool would also transform their craft, retraining them to operate in computing space.

"Render" started to be used to mean an action performed by a computer a few years later, when computer scientists began to elaborate an inward-looking definition of sight called "machine rendering." Phrases such as "quantitative invisibility" and "conceptual opacity" (which paired mathematics and sensation) made the analogy possible.[85] As this new vocabulary developed, all the debates about epistemic substitution that had pertained to lines and shadows since the Enlightenment were transferred. For example, in order to make a surface, the computer had to be taught either to *not draw* the edges of certain objects or to *hide* certain lines. When the term *rendered* became applicable to actual surfaces, the two most important shading algorithms were invented by computer scientists, Henri Gouraud and Bui Tuong Phong, who had begun their careers in engineering schools in Paris and moved on to the pioneering computer graphics department at the University of Utah.[86]

At Utah and elsewhere, computer scientists working on this inward definition of machine vision routinely invoked architecture as an example of a renderable object. Architects had been early adopters of drafting software, and therefore computer scientists imagined that buildings could be made available in already digitized form rather than needing to be drawn from life. For example, in 1972 Martin Newell explained he wanted to avoid at all costs the impression that computer graphics were only a "sophisticated paintbrush," and therefore hoped to use "the output of design programs" as input.[87] (That is, rendering algorithms needed to be fed data not from empirical reality but from the output of other algorithms.) One of the primary uses of his research, he claimed, was "the assessment of the aesthetics of a new piece of architecture."[88] Already in 1968 a new ray-casting algorithm had been tested at IBM's Watson Laboratory on a number of digital objects, among them "an assembly of planes which make up a cardboard model of a building."[89] The model was of a courtyard building with low-slung canopies, clearly designed to produce a variety of shadow-casting conditions (Figure 1.16).

But the computer programming community eventually came to rely on a restricted repertoire of "standard objects," such as Newell's Utah teapot, to feed and perfect its ray-tracing algorithms, and not a single one of these objects was a building.[90] Architecture did periodically appear in the Utah experiments. Crude neoclassical forms, combining pedimented temples and circular domes, gave away that the problem being worked on was how to make a rounded surface look smooth. One striking example shows a perfectly smooth airplane dislodging the faceted dome of the U.S. Capitol building (Figure 1.17). By the time the Utah teapot was presented as standard, the renderer's ability to depict classical orders had markedly improved, but architecture's own standing had not. The famous "six platonic solids" displayed at SIGGRAPH '87 rested on top of fluted classical

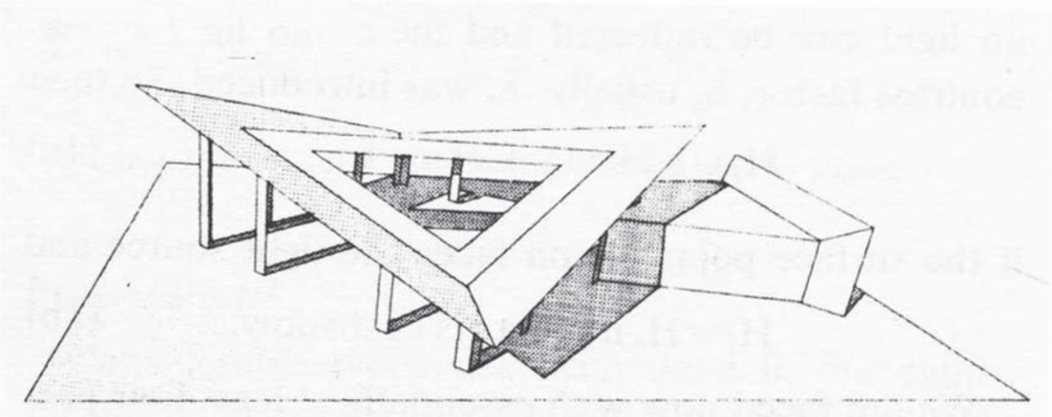

Figure 1.16. Cardboard model of a building. Arthur Appel, “Some Techniques for Shading Machine Renderings,” in *Sprint Joint Computer Conference* (New York: ACM, 1968).

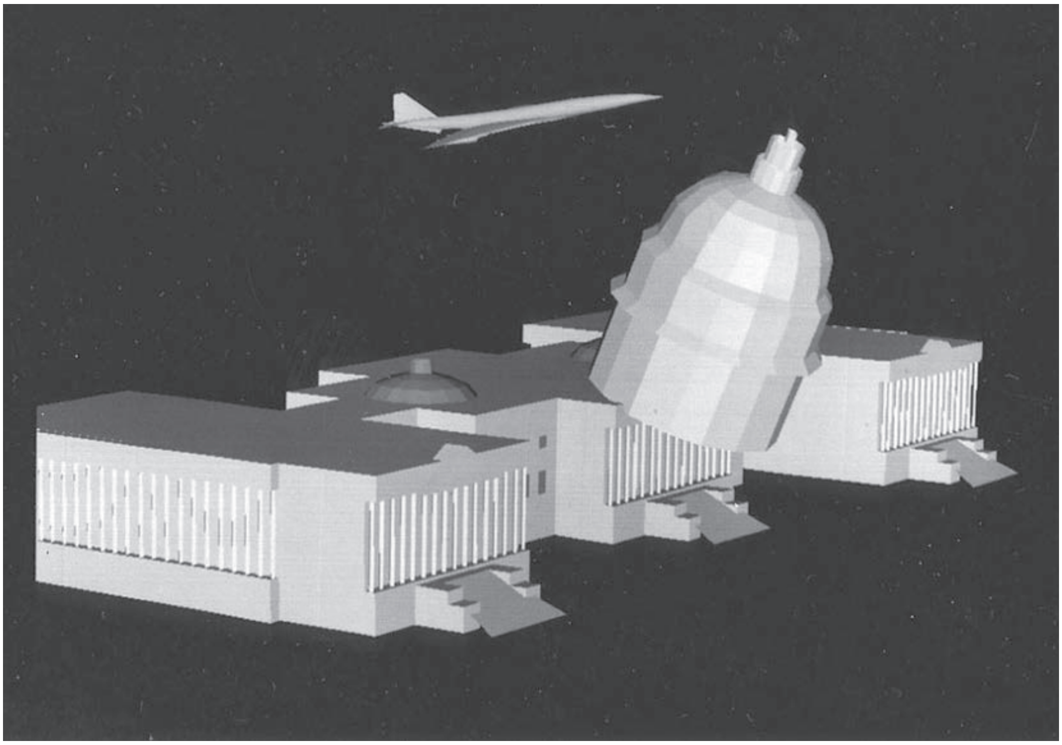

Figure 1.17. Polaroid from an early rendering experiment at the University of Utah. David C. Evans Photographic Collection, Special Collections, J. Willard Marriott Library, University of Utah.

pedestals, which look like highly stylized descendants of McGoodwin's academic plaster casts and column stubs (Figures 1.18, 1.13).[91]

This early history of computer graphics suggests that conventional architecture was consistently used to prop up engineering creativity. Even when the focus in rendering research turned from ray-tracing to radiosity in the 1980s (and digital objects were no longer rendered in isolation but were able to "bleed" their color onto wall surfaces in a scene), very little architectural specificity made it in.[92] Architectural planes in radiosity-rendered scenes were explicitly described as

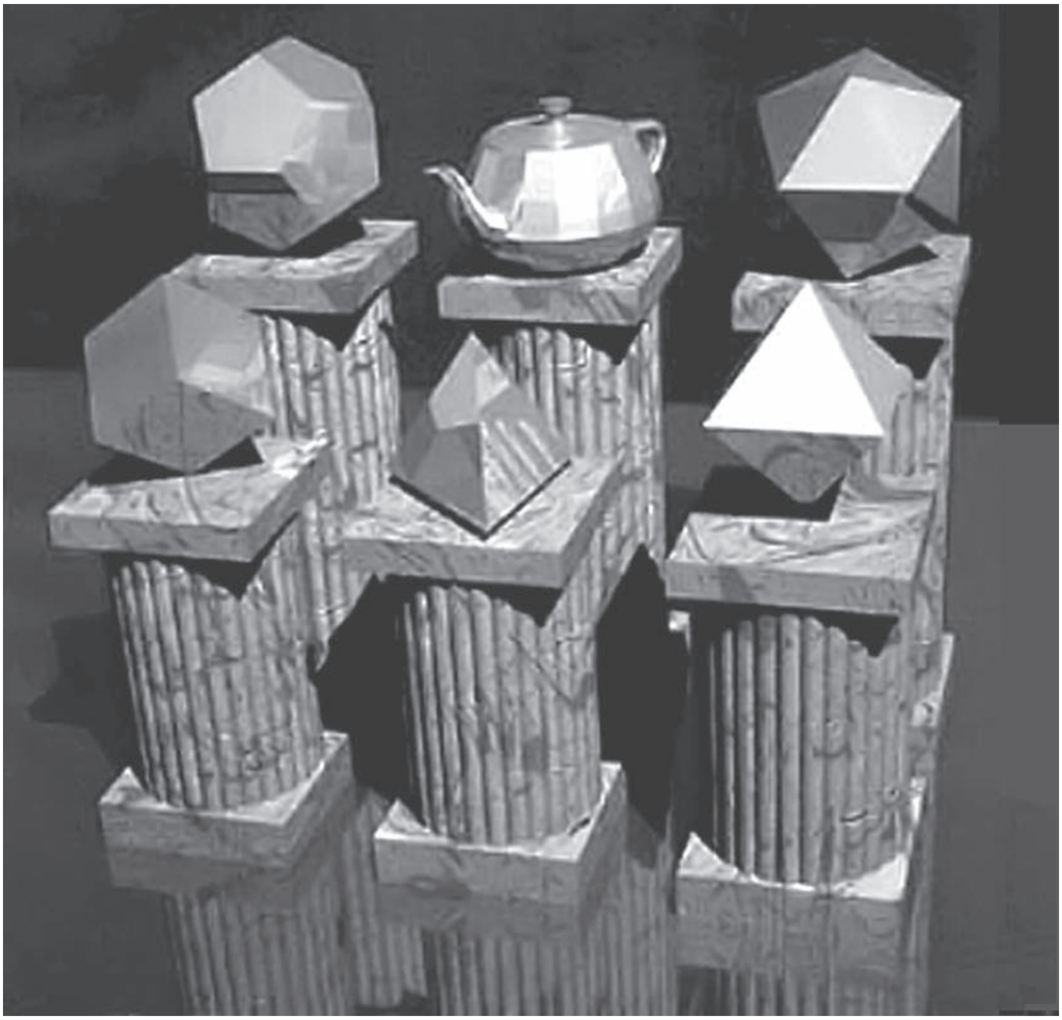

Figure 1.18. James Arvo and David Kirk, "Six Platonic Solids," including the Utah teapot, 1987. Copyright by Apollo Computer Inc., reproduced on the cover of SIGGRAPH '87, Anaheim, Calif., July 27–31, 1987.

technically "passive." This meant, among other things, that these surfaces could become supports for mapping raster images. Architecture also became useful in experiments for computer-aided spatial navigation precisely by being unremarkably vernacular. The Aspen Movie Map, precursor to Google Earth, relied on two different definitions of mapping—one based on input, the other designed for output—that is strikingly reminiscent of Verniquet's dual use of trigonometry and shadows. On the one hand, Aspen's street geometry was extensively "mapped" (horizontally, by a drive-through) by surveying the city with a gyroscopic stabilizer; on the other, the resulting wireframe model was made virtually navigable through laboriously "mapping" (a kind of digital gluing) photographs of Aspen's banal streetscape onto blank volumes.[93]

This expectation that architecture be used to make digital experiences "familiar" has only intensified in the so-called second digital age, defined by the internet rather than laboratory computing. To be sure, a blackbox mentality continues to drive the development of rendering tools through trial and error, feeding algorithms into algorithms and hoping for optimization. But a dispersed viewing public is also increasingly called upon to establish visual criteria of realism and protocols for virtual witnessing—and to help rendering algorithms learn.[94] The rendering studio has been transposed to the online forums frequented by software engineers. Here, rendering knowledge is advanced by a hacker's culture, where informal experiments are first circulated as nonstandard "tricks" or "hacks" and eventually adopted as industry standards.[95] Most rendering demonstrations are staged within a rendered environment and performed as if they were a first-person video game. One 2010 example, demonstrating how to render a brick wall, leads us into a postindustrial interior, lit by neon, where we circumvent a brick cube, watching it morph as mortar joints are given more or less depth. To modify Shapin and Schaeffer's terms only a little: the object of the game is to experience a first-person virtual witnessing of a rendering experiment.

THE AESTHETICS OF INCOMPLETION

To conclude, I would like to suggest that many in architecture have responded to this collapse of experience into experiment by bringing to their renderings a provisional theory of experience—a phenomenology, almost—that has manifested itself through an aesthetics of incompletion.

Consider the Experiential Technologies Laboratory, one of the first to produce digital reconstructions of monumental environments—for example, a fly-through of a computer model of the Egyptian site of Karnak—as sources of firsthand historical knowledge.[96] The laboratory promotes this new, "immersive" mode of architectural history in spite of the obvious deficiencies of its fly-throughs—the incompleteness of the buildings, their crude detailing, pastel coloring, absence of landscape features, flatness of the terrain, and the artificiality of the camera movements. These architectural historians are fully aware of the philosophical charge of the word *experience.* But they nevertheless claim the term because they compare their products not to experience as it is "given in reality," as Husserl would say, but rather to other typically choppy digital experiences—such as navigating Google Earth.[97] They bracket off photo-realism to achieve completion where it matters more—in an architectural sequence.

This bracketing strategy has been adopted by a remarkably diverse array of architectural producers. Consider the rendering software that the self-styled digital architectural avant-garde has experimented with since the 1990s to "shape" building forms. Greg Lynn has explained that he chose software originally designed for the entertainment industry, Maya, because it "produced the kind of smoothly rendered surfaces that he admires in the automotive and aeronautic industries."[98] Lynn uses an Arts and Crafts–inspired definition of rendering that applies to a building, whereby a "render" is a thin layer of cement applied by hand to waterproof external walls. But Lynn too is fully aware of Husserl's theory of reduction, and keeps these highly rendered objects scaleless and surreally elemental.[99] If the historians of the ETL perform a Husserlian bracketing to access Karnak as pure "phenomenon," in contrast, Lynn brackets off context to achieve completion in representing "elements" such as fire, water, and air in a way that recalls Gaston Bachelard.[100]

Other branches of architectural rendering could productively be related to other schools of phenomenological thought. A Merleau-Pontian branch, especially visual, could be identified in the work of millennial architects who embrace what Hito Steyerl has called "the poor image" and hope to derive innovative building forms from its lossy aesthetic.[101] Even corporate images that "drip a glossy resolution" can be classified as flirting with digital dissolution.[102] Luxigon describes its rendering of REX's proposal for the Calgary Central Library as showing "the drama of the experience" by "radiating a warm and welcoming civic face."[103] But the refracted light in the falling snow that sprinkles across the foreground also seems to puncture through the image to the artifice that lies beneath (Figure 1.1). Such acts are twenty-first-century updates to the technique of rendering the "cut," which revealed and aestheticized an analytical operation all at once. Most common perhaps are architectural renderings that promise experiential insight through the destruction, or taking apart, of immersive environments, and which we could call Heideggerian.[104] Scientific communities have perfected this art of the digital dissassembly. For example, a team of structural engineers and computer scientists at Purdue University rendered a sequence that shows two planes hitting the World Trade Center towers on September 11, 2001. Each act of this animated video repeats the destruction, each time "hiding" a different layer of the plane-building complex: the steel, the fuel, the glass, and so on. Although the goal is presumably scientific comprehensiveness, the effect is of a destruction whose causes are hauntingly remote—a building destroyed by a ghost (Figure 1.19).

To call architectural renderers phenomenologists is neither to elevate them into philosophers nor to vulgarize phenomenology. It is one way to illustrate how architectural renderings participate in working out standards for experiential completion and incompletion, now that "trust in numbers" is placed on thinking machines that need somehow to have a working theory of experience. Architectural visualization is ever-more relevant because of its long history of debates about epistemic substitutions: practice substituting for skill, geometry substituting for consensus, machines substituting for organs. After all, as Peter Gordon argued, phenomenology's philosophical authority has fundamentally shifted now that science no longer "enjoys a special access to a deworlded reality" but is "merely one world among others."[105] Architecture is one such world. Recent genealogies have emphasized its role in the emergence of an "interactivity" paradigm since the 1960s, but our longer archaeology of rendering cautions us not to believe that an age of unmediated spatio-temporal agency is upon us.

For most of the modern period, to render meant to recover experiences from an apparent loss or lack. In the eighteenth and nineteenth centuries, this loss was framed historically: renderings were a medium of the historical imagination, related to other acts of material recovery such as restitution, restoration, and reconstruction.[106] As rendering encountered mechanization, its tempo quickened (render, repeat). In the twentieth century, rendering became an operator in its own right, delegating productivity across the social order. In the twenty-first century, computer rendering instruments operate through a scattering of perceiving units across the globe, continuing this act of social ordering and delegation. On the one hand, architecture as a service industry allows instruments invented for knowledge production to be adapted to public use. On the other hand, the ubiquity of buildings makes their survey, through attention to the shadows they cast and colors they emit, especially useful for fine-tuning nonarchitectural technologies that rely on specialized access to the human senses. What this archaeology of rendering teaches us is to be attuned not to interactivity but rather *interpassivity*: our willingness to let others do the experiencing for us.[107]

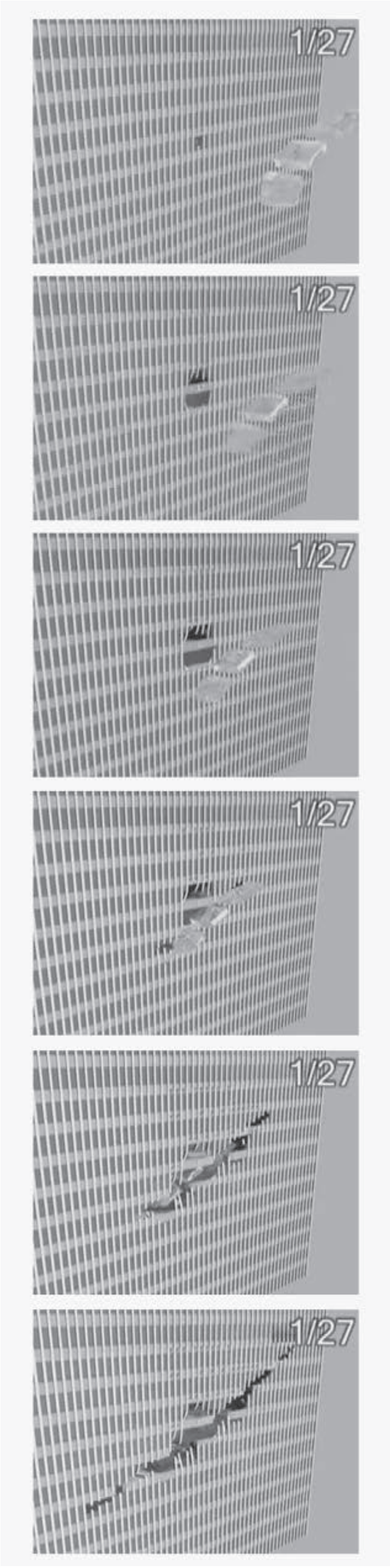

Figure 1.19. Paul Rosen, Voicu Popescu, Christopher Hoffmann, and Ayhan Irfanoglu, stills from “A High-Quality Physically-Accurate Visualization of the September 11 Attack on the World Trade Center,” 2007. Courtesy of Paul Rosen.

NOTES

I would like to thank the instruments group for many productive discussions, as well as John Tresch, Catherine Ingraham, Daniel Maslan, and the Media Seminar at Columbia University, for commenting on various versions of this essay. Thank you to Jacob Gaboury for a productive dialogue and for sharing archival material.

1. Adam Nathaniel Mayer, "Urban Fantasies in China: Architectural Visualization," *Clog: Rendering,* August 2012, 31–33.

2. Eric de Broche des Combes, in an interview with Lutz Robbers, "The Grey of the Sky," *Candide,* no. 9 (June 2015): 116.

3. Henry McGoodwin, *Architectural Shades and Shadows* (1904; repr., Washington, D.C.: AIA, 1989), 1, 2.

4. McGoodwin, 1.

5. Martin Jay offers an overview in his recent *Songs of Experience: Modern American and European Variations on a Universal Theme* (Berkeley: University of California Press, 2005). See also Mark Jarzombek, *The Psychologizing of Modernity* (New York: Cambridge University Press, 2000).

6. For an overview of the *Erfahrung/Erlebnis* distinction, see C. Jason Throop, "Articulating Experience," *Anthropological Theory* 3, no. 2 (2003): 231. Wilhelm Dilthey is usually credited for originally popularizing this distinction. See Wilhelm Dilthey, *Das Erlebnis und die Dichtung* (Leipzig: Teubner, 1905). On Dilthey, see Jay, *Songs of Experience,* 222–41.

7. Amelia Taylor-Hochberg, "AfterShock #1: Architectural Consumers in the Experience Economy," *Archinect,* September 11, 2013, https://archinect.com.

8. B. Joseph Pine II and James H. Gilmore, *The Experience Economy* (Boston: Harvard Business School Press, 1999).

9. For a history of "respect for the line and cult of dessin," see Richard A. Moore, "Academic 'Dessin' Theory in France after the Reorganization of 1863," *JSAH* 36, no. 3 (October 1977): 145–17. See also Marco Frascari, "Lines as Architectural Thinking," *Architectural Theory Review* 14, no. 3 (2009): 200–212.

10. "First we observed that the building is a form of body, which like any other consists of lineaments and matter, the one the product of thought, the other of Nature." Leon Battista Alberti, *De re aedificatoria* (ca. 1450), translated by Joseph Rykwert, Neil Leach, and Robert Tavernor as *On the Art of Building in Ten Books* (Cambridge, Mass.: MIT Press, 1988). Alberto Pérez-Gómez posits Euclidian geometry as "intuitively sensible," whereas non-Euclidian forms provoked a "recentering of the world." He sees the shadow being gradually subjected to the same kind of "abstraction" as architecture itself—for example, as buildings went from acting as physical shadow tracers to featuring elaborate false perspectives. Alberto Pérez-Gómez, "Architecture as Drawing," *Journal of Architectural Education* 36, no. 2 (Winter 1982): 2–7; Alberto Pérez-Gómez and Louise Pelletier, *Architectural Representation and the Perspective Hinge* (Cambridge, Mass.: MIT Press, 2000), 112–25. See also Alberto Pérez-Gómez, *Architecture and the Crisis of the Modern Sciences* (Cambridge, Mass.: MIT Press, 1984).

11. Friedrich Kittler, "Computer Graphics: A Semi-Technical Introduction," *Grey Room,* no. 2 (Winter 2001): 44. See also Friedrich Kittler, "Real Time Analysis: Time Axis

Manipulation," in *Draculas Vermächtnis: Technische Schriften* (Leipzig: Reclam, 1993), 182–207; and Friedrich Kittler, "Perspective and the Book," *Grey Room,* no. 5 (Fall 2001): 38–53.

12. Mario Carpo, *The Alphabet and the Algorithm* (Cambridge, Mass.: MIT Press, 2010), 45. Carpo argues that Alberti's invention was not a geometric nomenclature but a humanist ideal of reproduction (what he calls "identicality"). This ideal was already revived in the early twentieth century when modern architects hoped to standardize architecture's design and its production. But according to Carpo, it was not until the late twentieth century that identicality and difference were remarried to their full extent.

13. For a description of the 1970s movement, see Jorge Otero-Pailos, *Architecture's Historical Turn: Phenomenology and the Rise of the Postmodern* (Minneapolis: University of Minnesota Press, 2010); see esp. "Polygraph of Architectural Phenomenology," 14–17.

14. Edmund Husserl, *The Crisis of the European Sciences and Transcendental Phenomenology,* trans. David Carr (Evanston: Northwestern University Press, 1970), 48. Lines and shadows played a role in the history of science according to Husserl. For example, Galileo owed his scientific fame in no small part to his careful and repeated hand-rendering of the shadows cast by the Earth onto the surface of the moon. See Samuel Y. Edgerton, "Galileo, Florentine 'Disegno' and the 'Strange Spottednesse' of the Moon," *Art Journal* 44, no. 3 (Autumn 1984): 225–32. And Husserl cited "the practical art of surveying, which knew nothing of idealities," as a precursor to the Galilean mathematization of the world. Husserl, *Crisis,* 48–49.

15. Edmund Husserl, "The Origins of Geometry," in Jacques Derrida, *Introduction to the Origin of Geometry* (1962), trans. John P. Leavey Jr. (Lincoln: University of Nebraska Press, 1989), 172–73. Derrida and others have provocatively argued that because Husserl set aside, or "bracketed," the question of what constituted the real, he developed an understanding of science not as an empirical pursuit but rather as historical practice, a passing down of transcendental truths. Derrida, 59. Also useful is Georges Canguilhem: "The history of science is the explicit, theoretical recognition of the fact that the sciences are a critical, progressive discourse for determining what aspects of experience must be taken as real." Georges Canguilhem, *A Vital Rationalist,* trans. Arthur Goldhammer (New York: Zone Books, 2000), 28. For a history where "emotion and aesthetic experience were valued on a par with technical and rational mastery," see John Tresch, *The Romantic Machine* (Chicago: University of Chicago Press, 2012), 1.

16. Theodore M. Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and in Life* (Princeton, N.J.: Princeton University Press, 1995). For a sociotechnical history of "projecting" in the French architectural profession, see Jacques Guillerme, *L'Art du projet: Histoire, technique, architecture* (Paris: Mardaga, 2008).

17. Nicholas Savage, "Shadow, Shading and Outline in Architectural Engraving from Fréart to Letarouilly," in *Dealing with the Visual: Art History, Aesthetics and Visual Culture,* ed. Caroline van Eck and Edward Winters (London: Ashgate, 2005), 242–83.

18. When Antoine Desgodetz was commissioned to measure all the monuments in Rome in 1674, he returned to Paris with drawings whose outlines were drawn "very precisely" but also augmented with shadows that situated the ruins in three dimensions. Antoine Desgodetz, *Les Edifices antiques de Rome: Dessinés et mesurés tres exactement* (Paris:

Coignard, 1682). See also Wolfgang Herrmann, "Antoine Desgodetz and the Academie Royale d'Architecture," *Art Bulletin* 40 (1958): 23–53; and Henry Lemonnier, "Les dessins originaux de Desgodetz pour 'Les Édifices antiques de Rome' (1676–1677)," *Revue Archéologique* 6 (July–December 1917): 213–30.

19. Dupain l'Ainé, *La Science des ombres par rapport au dessein* (Paris, 1750), cited in Guillerme, *L'Art du projet,* 169.

20. On Gaspard Monge's transformation of geometry from a surveyor's tool into an architectural one, see Joel Sakorovitch, *Épures d'architecture* (Basel: Birkhäuser Verlag, 1998), 91.

21. N.-F.-A. de Chastillon, *Traité des ombres dans le dessin géométral* (1754), reprinted in Théodore Olivier, *Applications de la géométrie descriptive aux ombres à la perspective, à la gnomonique et aux engrenages* (Paris: Carilian-Goeury et V. Dalmont, 1847), 6. See also Joël Sakarovitch, "The Teaching of Stereotomy in Engineering Schools in France in the XVIIIth and XIXth Centuries," in *Entre méchanique et architecture,* ed. Patricia Radelet-de-Grave and Edoardo Benvenuto (Basel: Birkhäuser, 1995).

22. Stanislas L'Éveillé, *Etudes d'ombres, à l'usage des écoles d'architecture* (Paris: Truttel Wurtz, 1812), iii.

23. "The cascade of ever simplified inscriptions . . . allow harder facts to be produced at greater cost." Bruno Latour, "Visualisation and Cognition: Drawing Things Together," *Knowledge and Society: Studies in the Sociology of Culture Past and Present* 6 (1986): 16.

24. Raymond Williams, "Experience," in *Keywords: A Vocabulary of Culture and Society* (New York: Oxford University Press, 1985), 126–29. See also Peter Dear, *Discipline and Experience* (Chicago: University of Chicago Press, 1995).

25. Art historian Michael Baxandall has theorized the art of the Enlightenment along the lines of this bifurcation, detecting a "shadow epistemology" in drawings of Enlightenment artists. "Two modes of perceptive attentiveness" arose, he argues, with the line corresponding to the "local focus" required by scientific pursuit and the shadow providing "global awareness" of the kind "required by experience." Michael Baxandall, *Shadows and Enlightenment* (New Haven, Conn.: Yale University Press, 2007), 35, 48. See also Victor I. Stoichita, *A Short History of the Shadow* (London: Reaktion Books, 1997).

26. Pamela Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004); Matthew C. Hunter, *Wicked Intelligence: Visual Art and the Science of Experiment in Restoration London* (Chicago: University of Chicago Press, 2013); Zeynep Çelik Alexander, *Kinaesthetic Knowing* (Chicago: University of Chicago Press, 2017).

27. Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle and the Experimental Life* (Princeton, N.J.: Princeton University Press, 1985), 22–79; John Bender, "Matters of Fact: Virtual Witnessing and the Public in Hogarth's Narratives," in *Ends of Enlightenment* (Stanford: Stanford University Press, 2012), 57–78; John Bender and Michael Marrinan, *The Culture of the Diagram* (Stanford: Stanford University Press, 2010).

28. Antoine Picon argues that engineers operated "between sensation and calculation." Antoine Picon, *French Architects and Engineers in the Age of Enlightenment,* trans. Martin Thom (New York: Cambridge University Press, 1992), 148.

29. Jean-Baptiste Rondelet, *Traité théorique et pratique de l'art de bâtir* (Paris: n.p., 1802–17).

30. Verniquet's plan was the basis for the 1794 *Plan des artistes*; Antoine Picon calls it "the climax of the quest of accuracy" in the history of Parisian cartography. Antoine Picon, "Nineteenth-Century Cartography and the Urban Ideal," *Osiris* 18, 2nd ser. (2003): 135–49. See also Jean-Paul Robert and Antoine Picon, *Le dessus des cartes: Un atlas parisien* (Paris: Picard, 1999).

31. For an overview, see Jean-Marc Leri, "Edme Verniquet (1727–1804) cartographe du grand plan de Paris," in *Les architectes des lumières,* ed. Annie Jaxques and Jean-Pierre Mouilleseaux (Paris: ENSBA, 1989), 202–9. See also Jeanne Pronteau, *Edme Verniquet* (Paris: Commission des travaux historiques de la ville de Paris, 1986), 340; and Placide Mauclaire, *La vie et l'oeuvre de Verniquet, architecte, auteur du grand plan de Paris* (Paris: Picard, 1940).

32. See H. Monin, "Travaux d'Edme Verniquet, et en particulier sur le plan dit 'des artistes,'" *Bulletin de la bibliothèque et des travaux historiques* 1–4 (1898): xxiii.

33. Edme Verniquet, *Plan de la Ville de Paris* (Paris: Verniquet, 1792), 70–71. In Latour's words, the plan was an "immutable mobile." Latour, "Visualisation and Cognition," 21.

34. Liliane Pérez describes how "alongside monuments, museums and cabinets, engines and workshops were integrated into the range of economic curiosities." Liliane Pérez, "Technology, Curiosity and Utility in France and in England in the Eighteenth Century," in *Science and Spectacle in the European Enlightenment,* ed. Bernadette Bensaude-Vincent and Christine Blondel (London: Ashgate, 2008), 36.

35. Verniquet himself vaunted the "splendid testimony that all of the French and foreign scientists and artists who have visited the work have given as to its perfection." "Lettre de Verniquet, addressee a l'Assemblée Nationale en 1791," reprinted in Monin, "Travaux d'Edme Verniquet," xv.

36. See Basile Baudez, "L'Europe architecturale du second XVIIIe siècle: Analyse des dessins," *Livraisons de l'histoire de l'architecture* 30 (2015): 43–58.

37. The relational epistemology that arises from Verniquet's page can in no uncertain terms be related to the space of Verniquet's workshop, and to his own biography as a transitional figure in the French architectural profession of the late Enlightenment. As one historian has summarized, Verniquet was hired by the regime to make a complete survey of streets not because of his training but because he had become "the indispensable man [*l'homme indispensable*]," through his "experience and his works." Monin, "Travaux d'Edme Verniquet," xv.

38. *Oxford English Dictionary,* s.v. "render, v." III. "To return (something)," accessed October 30, 2014, https://www.oed.com. And specifically, 16a. "to restore, return, give back." See also "3b. To represent or reproduce, esp. artistically; to depict, portray."

39. His heirs spent a century attempting to secure retroactive payment for his work, as well as the "return" of the original plans, which, by the new republican standards, rightly belonged to him. The workshop's locus was a crucial datum in the debate. The inheritors argued that the plan that Verniquet had nailed to the table for his famous demonstration was one of three original drawings, now lost; the French National Assembly argued that it was an engraved reproduction of his atlas. Monin, "Travaux d'Edme Verniquet," xxi.

40. "Rendement," in *Dictionnaire de la langue française,* vol. 4, ed. M. P. Émile Littré (n.p.: n.p., 1873). On the use of "rendement" to refer to the efficiency of machines after accounting for friction and loss of energy, and eventually of bodies *(rendement de la machine humaine),* see Anson Rabinbach, *The Human Motor* (Berkeley: University of California Press, 1992), 185.

41. Ernest Bosc, "Rendre," in *Dictionnaire raisonné d'architecture,* vol. 4 (Paris: Firmi-Didot, 1883).

42. John F. Harbeson, "Rendu," in "A Vocabulary of French Words Used in the Atelier," appendix to *The Study of Architectural Design* (New York: Pencil Points, 1927).

43. Antoine-Chrysostôme Quatremère de Quincy, "Rendre" and "Rendu," in *Dictionnaire historique d'architecture,* vol. 2 (Paris: Le Clere, 1832), 370. On Quatremère de Quincy and drawing, see Sylvia Lavin, *Quatremère de Quincy and the Invention of a Modern Language of Architecture* (Cambridge, Mass.: MIT Press, 1992), 158–64.

44. "Consequently the rendering of geometrical drawings, far from adding to the effect or the intelligence of these drawings, can only make them cloudy and equivocal." Jacques-Nicolas-Louis Durand, *Précis of the Lectures on Architecture* (1802–5), trans. David Britt (Santa Monica, Calif.: Getty Research Institute, 2000), 34. See also Anthony Vidler, "Diagrams of Diagrams: Architectural Abstraction and Modern Representation," *Representations* 72 (Autumn 2000): 1–20.

45. Durand, "Les principes et le mécanisme de la composition," in *Précis of the Lectures on Architecture,* 20. See also Picon's introduction, "From 'Poetry of Art' to Method: The Theory of Jean-Nicolas-Louis Durand," in Durand, *Précis of the Lectures in Architecture,* 1–72.

46. Guy Lambert and Estelle Thibault, "L'importance du savoir graphique," in *L'atelier et l'amphithéâtre* (Paris: Mardaga, 2011), 136–40.

47. Durand, "Préface," in *Précis des leçons d'architecture données à L'École Polytechnique* (Paris: Bernard, 1805), vi. See also Antoine Picon's note that at the École des Ponts et Chaussées, around 1800 a "dryer, more abstract cartography, often executed in black and white, began to replace the heightened realism of the previous period." Picon, *French Architects and Engineers,* 247.

48. On Durand and neo-palladian taste for *"nu du mur,"* see Jean-Philippe Garric, "Durand ou Percier? Deux approches du projet d'architecture au début du XIXe siècle," in *Bibliothèques d'atelier: Édition et enseignement de l'architecture, Paris, 1785–1871* (Paris: INHA, 2014).

49. On the plan, see Jacques Lucan, *Composition, Non-composition* (Lausanne: Presses polytechniques et universitaires romandes, 2010), esp. 122–23, 187–89; and the critique of Paul Cret of the "plan as 'a pleasing image'" (227).

50. Alexis LeMaistre, *L'École des Beaux-arts, Dessinée et racontée par un élève* (Paris: Firmin-Didot, 1889).

51. David Van Zanten, "The Beaux-Arts System," in *AD Profile: The Beaux-Arts,* ed. Robin Middleton (London: AD Editions, 1977), 66–78.

52. Durand uses *marche* in *Précis of the Lectures on Architecture,* 20. The word *marche* evolved from a synonym for a territorial border, to a noun for the movement of marching

troops, to a step in a stair or ladder, also acquiring ceremonial connotations, musical ones, even the one of chess-playing strategy, only to finally acquire both its scientific meaning (the movement of celestial bodies) and its mechanical one (the clock-works) by 1837. *Dictionnaires d'autrefois,* s.v. "Marche," accessed April 8, 2015, https://artfl-project.uchicago.edu/content/dictionnaires-dautrefois.

53. Alan Colquhoun, "The Beaux-Arts Plan," in Middleton, *AD Profile,* 61–66.

54. Annie Jacques, *La carrière de l'architecte aux 19.e siècle* (Paris: Musée d'Orsay, 1986). See also Annie Jacques and Richi Mikayé, *Les dessins d'architecture de l'École des Beaux-Arts* (Paris: Arthaud, 1988); and Jean-Michel Léniaud, *Les bâtisseurs d'avenir* (Paris: Fayard, 1998), 72.

55. Pierre Pinon and Francois-Xavier Amprimoz, "La fortune des Envois," in *Les Envois de Rome: Architecture et archéologie* (Paris: Diff. de Boccard, 1988); *Les grands prix de Rome d'architecture de 1850 á 1900: Avec les programmes des concours* (Paris: A. Guérinet, 1909).

56. As one commentator noted, "If every building of Rome had occupied the same space that its drawings sent from Rome occupy every year, Rome and its monuments would have invaded all of Italy." Charles Blanc, *Les artistes de mon temps* (n.p.: Nabu, 2010), cited in Lucan, *Composition, Non-composition,* 123. See also Quatremère de Quincy, "Dessiner," in *Dictionaire historique d'architecture,* 520.

57. In 1826 a textbook advised that the tints could be blue, pink, or black, and that black of a cut could be "substituted for pink." Pink had been used as replacement for black *poché* in the sixteenth century to represent the massive brick ballasts of military architecture and were popularized by the sensationalist architects of the late eighteenth century to create an architecture of sublimity. Basile Baudez, "Inessential Colors: A History of Color in Architectural Drawings, 16th–19th Centuries" (Françoise and Georges Selz Lectures on Eighteenth- and Nineteenth-Century French Decorative Arts and Culture, October 3, 2017); Basile Baudez, "L'Europe architecturale du second XVIIIe siècle: Analyse des dessins," *Livraisons d'histoire de l'architecture* 30 (2015): 43–58. But, as Sylvia Lavin has noted, this seductive pink survived decades after the sublime mission was dropped. Sylvia Lavin, "What Color Is It Now?," *Perspecta* 35 (2004): 98–111.

58. Jacques and Mikayé, *Les dessins d'architecture de l'École des Beaux-Arts,* 138.

59. One English-language source on this labor hierarchy is William H. White, "A Brief Review of the Education and Position of Architects in France since the Year 1671," *The Transactions,* September 1884, 93–120, esp. 112–15 (remarks by R. Phené Spiers).

60. See André Dubreuil and Roger Hummel, "Rassemblement: Devoirs du nègre et devoirs du patron," *Grande Masse,* no. 7 (April 1929): 23–25.

61. On the Beaux-Arts in America, see Paul Cret, "The École des Beaux-Arts and Architectural Education," *JSAH* (April 1941): 3–15.

62. Harbeson, "Time Schedule for Analytique for which Five Weeks Are Allowed," in *The Study of Architectural Design,* 14.

63. Harbeson, 142.

64. McGoodwin, *Architectural Shades and Shadows,* 96. On photography of the Beaux-Arts, see Anne-Marie Garcia, *La photographie avec les Arts* (Paris: ENSBA, 2015).

65. As Anthony Vidler has put it, the "white crusade" of architectural modernism was directed against the "brown world" of the Beaux-Arts, where brown was the color both

of rendered paper and of "19th-century bourgeois kitsch." Anthony Vidler, "The Modernist Vision," in *Open Plan: Architecture in American Culture* (New York: Institute for Architecture and Urban Studies, 1977). Vidler adapted this opposition from none other than Theo van Doesburg, who had advocated a new "white world" in contradistinction to a "brown world" implied in the cardboard hues of cubism.

66. Manfredo Tafuri, *Architecture and Utopia: Design and Capitalist Development* (Cambridge, Mass.: MIT Press, 1977), 86. See also Benjamin's "Experience and Poverty" (1933), in *Selected Writings,* vol. 2, *1927–1934,* trans. Rodney Livingstone (Cambridge, Mass.: Belknap Press of Harvard University Press, 1992), 731–36.

67. On collage, see also Martino Stierli, "Photomontage in/as Spatial Representation," *Photoresearchers* 18 (2012): 32–43.

68. On photogrammetry, see Albrecht Grimm, "The Origin of the Term Photogrammetry" (ISPRS Congress, Hamburg, 1980); Joerg Albertz, "A Look Back: 140 Years of Photogrammetry," *Photogrammetric Engineering and Remote Sensing* 73, no. 5 (May 1987): 503–6; Maurice Carbonnell, "L'Histoire et situation presente des applications de la photogrammetrie à l'architecture" (International Council of Monuments and Sites, Paris, 1968); and R. Burkhardt, *Historical Development of Photogrammetric Methods and Instruments* (Falls Church, Va.: American Society of Photogrammetry and Remote Sensing, 1989).

69. The surveyor took photographs from two specifically marked positions, then traced perspective lines on top of them, "searching for the focal point." On Eugène-Emmanuel Viollet-le-Duc's use of this technique, see Aaron Vinegar, "Panoramic Photography as Imagination Technology: Viollet-le-Duc and the Restoration of the Château of Pierrefonds," in *Essays on Viollet-le-Duc,* ed. Werner Oechslin (Zürich: ETH / Geschichte und Theorie der Architektur Verlag, 2010), 92–109. See also Peter Collier, "The Impact on Topographic Mapping of Developments in Land and Air Survey: 1900–1939," *Cartography and Geographic Information Science* 29, no. 3 (2002): 155–74.

70. Albrecht Meydenbauer, *Handbuch der Meßbildkunst in Anwendung auf Baudenkmäler und Reiseaufnahmen* (Halle: Knapp Verlag, 1912). See Albrecht Grimm, "Zwei Meydenbauer'sche Instrumente für die Architektur-Photogrammetrie wiedergefunden," *Bildmessung und Luftbildwesen* 46, no. 2 (1978): 33–34; and R. Meyer, *Albrecht Meydenbauer—Baukunst in historischen Fotografien* (Leipzig: Fotokinoverlag, 1985). The loop from surveying to building was closed half a century later, as these archives were used to rebuild Europe's destroyed monuments after World War II.

71. A straightforward description of the apparatus is found in Jean-Paul Saint Aubin, *Le relevé et la représentation de l'architecture* (Paris: Éditions de l'Inventaire, 1992), 24–25.

72. See, for example, Otto von Gruber, "The Rendering of Details in Photographs," in *Photogrammetry: Collected Lectures and Essays,* ed. Otto von Gruber, trans. G. T. McGraw and F. A. Cazalet (Boston: American Photographic, 1932), 51–56.

73. M. Walther, "L'application de la photogrammétrie à l'architecture en allemagne," in *Quatrième Congrès International de Photogrammétrie: Procès Verbaux des Séances des Commissions* (Paris: Société Géographique de l'Armée Française, 1936), 305–22.

74. National bureaucracies used these machines first vertically, to record monuments, and then to map their territories horizontally, through aerial photography. On

photogrammetry as a precursor to "remote sensing," see John J. May, "Sensing: Preliminary Notes on the Emergence of Statistical-Mechanical Geographic Vision," *Perspecta* 40 (2008): 42–53.

75. Maurice Carbonnel, *Le fil des pierres: Photogrammétrie et conservation des monuments* (Paris: Institut Géographique National, 1978), 8.

76. "The operator perceives a mark, in the same visual space as the image in relief and, with the appropriate command tool, he can apparently 'touch' the image with this mark, and make it follow whatever lines one wishes to record." Carbonnel, 12.

77. ADAM Technology, "How Does Photogrammertry Work?," September 3, 2010, http://www.adamtech.com.au.

78. On temporality in cybernetics, see Orit Halpern, "Dreams of Our Perceptual Present," *Configurations* 13, no. 2 (Spring 2005): 283–319.

79. As Matthew Allen summarizes it, recent histories have tried to dispel the notion "that experimentation was driven by young practitioners playing around with fancy software and stumbling upon flashy effects." Matthew Allen, review of "Archaeology of the Digital," *Domus,* May 15, 2013, https://www.domusweb.it. See also Greg Lynn, ed., *The Archaeology of the Digital* (Montreal: Canadian Centre for Architecture; Berlin: Sternberg, 2013).

80. One recent reconstruction of the Forum in Pompeii is Gabriele Guidi, Fabio Remondino, Michele Russo, Fabio Menna, and Alessandro Rizzi, "3D Modeling of Large and Complex Site Using Multi-sensor Integration and Multi-resolution Data," in *VAST 2008: Proceedings of the 9th International Symposium on Virtual Reality, Archaeology and Cultural Heritage,* ed. M. Ashley, S. Hermon, A. Proenca, and K. Rodriguez-Echavarria (Aire-la-Ville: Eurographics Association, 2008). On the integration of digital models, including GIS, into the new plans for a "sustainable Pompeii," see Giovanni Longobardi, ed., *Pompei Sostenibile* (Rome: L'Erma di Bretschneider, 2002), 121–23. For the Hollywood film, see Ian Failes, "Stories from *Pompeii,*" March 3, 2014, http://www.fxguide.com.

81. In "Computer Graphics," Kittler summarizes that ray-tracing renders the world as a still life and radiosity reproduces the atmosphere of a genre painting. For an art historical perspective on the same distinction, see James Elkins, "Art History and the Criticism of Computer-Generated Images," *Leonardo* 27, no. 4 (1994): 335–42.

82. Kittler, "Computer Graphics," 44.

83. A computer, in information theory, is defined as an electronic machine in which the line between input and output includes feedback. Succinct and helpful descriptions of this feedback system are in Peter Galison, "Ontology of the Enemy," *Critical Inquiry* 21, no. 1 (Autumn 1994): 228–66; and John Harwood, *The Interface* (Minneapolis: University of Minnesota Press, 2010).

84. Ivan Edward Sutherland, "Sketchpad: A Man-Machine Graphical Communication System" (PhD diss., MIT, 1963), 17.

85. Arthur Appel, "The Notion of Quantitative Invisibility and the Machine Rendering of Solids," *Proceedings of ACM National Meeting* (1967): 387–93. On "conceptual opacity," see Sutherland, "Sketchpad," 1.

86. Henri Gouraud, "Computer Display of Curved Surfaces" (PhD diss., University of Utah, 1971); Bui Tuong Phong, "Illumination of Computer-Generated Images" (technical report, Department of Computer Science, University of Utah, UTEC-CSs-73-129, July 1973). For an example of the literature that builds on their work, see A. Glasner, "Situation Normal," *IEEE Computer Graphics and Applications* 17, no. 2 (March/April 1997): 87–92; Isabelle Bellin, "Images de Synthèse: Palme de la longévité pour l'ombrage de Gouraud," *Interstices,* September 15, 2008, https://interstices.info.

87. The "production of shaded pictures" had evolved "using the results of design programs as input." M. E. Newell, R. G. Newell, and T. L. Sancha, "A Solution to the Hidden Surface Problem," *Proceedings of the ACM National Meeting* (1972): 448.

88. Newell, Newell, and Sancha, 448.

89. Arthur Appel, "The Visibility Problem and Machine Rendering of Solids" (IBM Research Report RC 1611, May 20, 1966). See also Arthur Appel, "Some Techniques for Shading Machine Renderings of Solids," in *Sprint Joint Computer Conference* (New York: Association for Computing Machinery Press, 1968), 37–45.

90. Jacob Gaboury, "Image Objects: An Archaeology of 3D Computer Graphics, 1965–1979" (PhD diss., New York University, 2014), 133–75.

91. "Platonic Solids," published by James Arvo and David Kirk in "Fast Ray Tracing by Ray Classification," *Computer Graphics* 21, no. 4 (July 1987): 55–64.

92. See Alan Watt and Mark Watt, *Advanced Animation and Rendering Techniques* (New York: Association for Computing Machinery Press, 1991) 294.

93. For a description of how the Aspen movie map was made, see Molly Wright Steenson, *Architectural Intelligence* (Cambridge, Mass.: MIT Press, 2017), 202–8; for the way it produced a cognitive "familiarity" with the town of Aspen, see Felicity Scott, *Outlaw Territories* (New York: Zone Books, 2018), 413.

94. See Wendy Hui Kyong Chun, *Control and Freedom* (Cambridge, Mass.: MIT Press, 2005); and Wendy Hui Kyong Chun, "On Software, or the Persistence of Visual Knowledge," *Grey Room,* no. 18 (Winter 2005): 26–51.

95. Isaac Kerlow, "Selected Rendering Hacks," in *The Art of 3d Computer Animation and Effects,* 4th ed. (New York: Wiley & Sons, 2008), 285. This is how the global illumination (GI) problem was solved. One textbook recounts that "the mathematical foundations of GI were essentially complete by the middle of the 1980s but the cost of computing indirect lighting to a visually acceptable accuracy was a major obstacle to its practical use." Nokiro Kurachi, *The Magic of Computer Graphics,* ed. Michael Stark (New York: Taylor and Francis, 2011), 23. This problem of cost and practicality led developers to design various hacks, one of which, called "ambient occlusion," relies on the creation of a "virtual sky" in order to "recreate the effect of a luminous but overcast day." Kerlow, 253.

96. Diane Favro, "*Se non e vero, e ben trovato*: Digital Immersive Reconstructions of Historical Environments," *JSAH* 71, no. 3 (September 2012): 273–77. Favro explicitly describes these experiments as "phenomenological." Diane Favro and Christopher Johanson, "Death in Motion: Funeral Processions in the Roman Forum," *JSAH* 69, no. 1 (March 2010): 12–37.

97. For a review of Google Earth as "the experience of a map in motion," see Laura Kurgan, "Google Earth 5.0," *JSAH* 68, no. 4 (December 2009): 588–90.

98. Lawrence Bird and Guillaume LaBelle, "Re-Animating Greg Lynn's Embryological House: A Case Study in Digital Design Preservation," *Leonardo* 43, no. 3 (2010): 242–49; Howard Shubert, "Embryological House," Canadian Centre for Architecture, April 6, 2009, http://www.cca.qc.ca. See also Randall Newton, "Using Rendering Technology to Revolutionize Yacht Design," *GraphicSpeak,* October 11, 2013. This reference is to the use of modeling software for ballistics and aeronautic design, a well-covered aspect of computer engineering history. For an architectural history of computation that incorporates this history, albeit briefly, see Mario Carpo, *Design in the Second Digital Age* (Cambridge, Mass.: MIT Press, 2017).

99. For Lynn's reading of Husserlian "reduction," see Greg Lynn, "New Variations on the Rowe Complex," in *Folds, Bodies & Blobs: Collected Essays* (Paris: La Lettre Volée, 1998), 209. For the claim that computers allow designers to "draw and sketch using calculus," see Greg Lynn, *Animate Form* (New York: Princeton Architectural Press, 1999), 17.

100. Two helpful excerpts that highlight the difference in two philosophies are as follows: "The transcendental Ego emerged out of my parenthesizing of the entire Objective World and all other (including all ideal) Objectivities." Edmund Husserl, "Fifth Meditation," in *Cartesian Meditations: An Introduction to Phenomenology,* trans. Dorian Cairns (Amsterdam: Kluwer, 1960), 99. "Everyone must learn to escape from the rigidity of the mental habits formed by contact with familiar experiences. . . . To the imagination, fire is not a separable datum of experience: it is already linked by analogy and identity to a dozen other aspects of experience." Gaston Bachelard, *The Psychoanalysis of Fire,* trans. Alan Ross (London: Routledge, 1963), 1, vi

101. Hito Steyerl, "In Defense of the Poor Image," *e-flux,* no. 10 (November 2009). Sam Jacob makes a related argument about a new generation rejecting the high resolution in "Rendering: The Cave of the Digital," *e-flux,* February 2, 2018, https://www.e-flux.com.

102. Francesca Hughes, *The Architecture of Error* (Cambridge, Mass.: MIT Press, 2015), 218.

103. REX, "Calgary New Central Library," caption for image 20 of 24, accessed June 1, 2019, https://rex-ny.com.

104. Martin Heidegger, "Time and Being" (1962), in *On Time and Being,* trans. Joan Stambaugh (Chicago: University of Chicago Press, 2002). On *Abbau* and *Destruktion* as a phenomenological method, which Heidegger substituted for Husserl's *Reduktion,* see Brian Elliot, *Phenomenology and Imagination in Husserl and Heidegger* (New York: Routledge, 2005), 70.

105. Peter Eli Gordon, "Realism, Science, and the Deworlding of the World," in *A Companion to Phenomenology and Existentialism,* ed. Hubert L. Dreyfus and Mark A. Wrathall (London: Wiley-Blackwell, 2009), 425–44.

106. For a "media archaeology of the historical imagination," see Wolfgang Ernst, "Let There Be Irony: Cultural History and Media Archaeology in Parallel Lines," *Art History* 28, no. 5 (November 2005): 582–603.

107. Slavoj Žižek, "The Interpassive Subject: Lacan Turns a Prayer Wheel," in *How to Read Lacan* (New York: W. W. Norton, 2006), 23–39.