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An Architecture of Perfection

ANDREW TALLON
Vassar College

The Widening Refinement

William Henry Goodyear (1846–1923; Figure 1), son of the inventor of the vulcanization process for India rubber and the first curator of fine arts at the Brooklyn Museum, was widely respected as an authority on art and architecture.¹ The recipient of honorary memberships in the American Institute of Architecture, the Architects' Society of Rome, the Society of Architects of London, and the Royal Academy of Fine Arts of Venice, among other distinctions, he was praised in 1923 by the *New York Times* as “a type of American genius,” few of whom have “made more important contributions to the history of architecture or done more to stimulate original thought among the architects of the present day.”² Goodyear had published a number of books on a wide range of art-related topics; his research passion, however, was in the area of refinements—the subtle, default-correcting impositions of curvature on plan and elevation made by ancient Greek architects.³

Early in his career Goodyear turned his attention from the relatively well-known refinements of Hellenic temples

to those he believed also to exist in the medieval architecture of Italy.⁴ He was inspired by a passage in John Ruskin's *Seven Lamps of Architecture*, which affirmed that the apparent lack of rectilinearity and precision in plan and elevation at the cathedral in Pisa were, when they were not accidental, deliberately applied in order to breathe life into the building.⁵ Published in *Scribner's Monthly* in 1874, Goodyear's essay on the subject, “The Lost Art,” was hailed by Harvard University professor Charles Eliot Norton as “the most important contribution to the topic since Mr. Ruskin wrote *The Seven Lamps*.”⁶ Perhaps for lack of time—his responsibilities at the Brooklyn Museum were all-consuming—and a lack of funding for new research, Goodyear put his quest on hold until 1895, when the museum began official sponsorship of the mission.⁷ That same year Goodyear produced a prospectus for a book titled *Optical Refinements, Perspective Illusions and Symmetrophobia in Medieval Architecture*—a work intended to reveal “the hitherto unpublished and mainly unannounced personal discoveries and measurements of the author in this otherwise wholly unexplored field of research.”⁸ It was followed by a number of well-received publications devoted to medieval Italian churches.⁹ Goodyear, it seemed, had discovered the “secret of medieval beauty,” as the *New York Herald* called it in 1910, in a craft tradition of architectural refinements, passed down in unbroken succession from the classical past but lost when the Renaissance overtook the Middle Ages.¹⁰

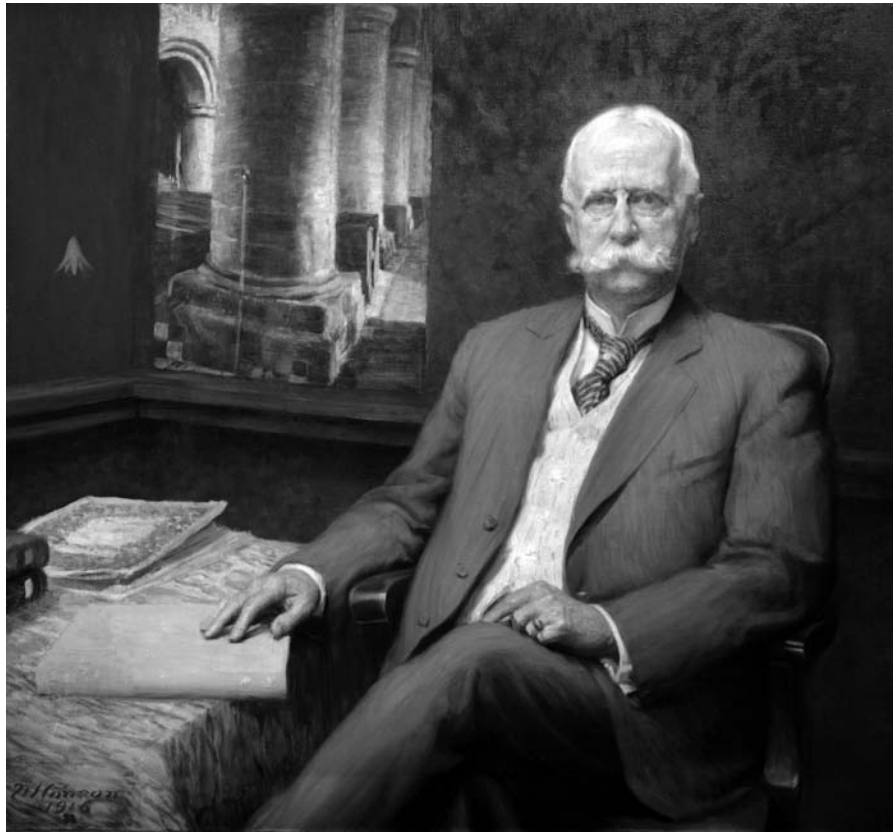


Figure 1 Wilford S. Conrow, *Professor William H. Goodyear*, 1916. Note the surveying rod against the pier of the building at rear (oil on canvas, 42 $\frac{7}{8}$ x 45 $\frac{1}{8}$ inches; Brooklyn Museum, New York, gift of Professor Arthur Kingsley Porter, 25.182; Brooklyn Museum, all rights reserved)

Soon Goodyear expanded his repertory to include the well-known Gothic churches of France, because he wished his primary audience in America to be able to see for itself what he had observed in the Italian churches, which he considered too far off the beaten track.¹¹ Buildings such as the Cathedral of Notre-Dame of Paris presented a characteristic in which Goodyear became increasingly interested: their walls appeared to move increasingly out of plumb as they rose (Figure 2). To document the phenomenon he suspended a series of lines from various points in the upper reaches of the buildings and used a large-format camera to make a high-resolution, calibrated photograph from which measurements could be taken (Figure 3).¹² Goodyear was unsatisfied with the results, however; hanging his plumb line required considerable time and effort, and the question of visibility was never fully resolved. He soon devised an ingenious technique.¹³ A plummet was suspended with slender fishing line on a frame placed directly in front of the camera lens, and by using an extremely small aperture, both the line and the out-of-plumb architectural member in the distance could be captured in focus. Though the exposures were long (often over an hour), he no longer had to hire a crew of people to drop lines, and had great freedom in terms of camera placement.¹⁴ A further innovation took place in 1910: Goodyear began to

use a camera with an internal plumb line, built specially by Yale University physics professor and optics specialist Charles S. Hastings. The plummet remained perfectly positioned and was impervious to the effects of wind.¹⁵

Goodyear accounted for the presence of these diverging uprights in medieval buildings—what he called the “widening refinement”—in Ruskinian terms: “Inconspicuous variations of architectural lines from the position or direction in which the eye naturally expects to find them tend to produce an illusive optical vibration or mystification which is conducive to an effect of ‘life.’”¹⁶ He supposed, in particular, that medieval builders, in “defiance [of] the ordinary laws of physics,” had meant to correct a problem of perspective.¹⁷ “In the lofty naves of medieval churches,” he explained, “the convergence of lines and walls, due to perspective, tends to an appearance of contraction and narrowness overhead which would be corrected by a slight outward divergence of piers and clerestory walls. These would consequently appear perpendicular, when they really lean outward, and so the correction is naturally overlooked.”¹⁸ A camera with photographic lens tilted above the horizontal (Figure 4) appears to validate the effect.

Yet the human eye does not operate as a camera lens does: the convergence of vertical lines is automatically



Figure 2 Saint-Quentin, collegiate church of Saint-Quentin. Main vessel looking west (author's photo)

rectified by the visual cortex based on experiential and gravitational information—hence the impossibility of evaluating questions of widening with the naked eye.¹⁹ Goodyear readily acknowledged that the widening refinement was optically complex and, as a result, somewhat abstruse.²⁰ In any case, from his point of view, there was sufficient proof elsewhere: the structural evidence presented by the buildings suggested to him that the effect could only have been intentional. “Masonry,” he wrote, “is neither putty nor India-rubber”: it simply could not be displaced to produce such impressive vertical divergence once the building was assembled, at least not without obvious cracking.²¹ Herein lay Goodyear’s

fundamental error—one that the members of the architectural establishment in Europe were quick to point out.

In 1905 Henry Heathcote Statham, the editor of the London journal the *Builder*, published an energetic criticism titled “The Glamour of Crooked Building.”²² Goodyear’s research, wrote Statham, had “always appeared to us to be, in the main, a laborious and fanciful twisting of fact to fit a theory which is itself improbable.”²³ Greek refinements, Statham pointed out, were regular:

But what is there consistent or intelligible in the medley of distortions of all kinds [in medieval buildings] which Mr. Goodyear



Figure 3 William H. Goodyear, *Paris, cathedral of Notre-Dame*, September 1903. North nave tribunes looking across north transept to the east. The inscription on the reverse reads: "One plumb line. Shows leaning piers and column built to parallel with outward lean of piers at crossing" (William H. Goodyear Collection, New York: Brooklyn Museum Archives 6.1.003 no. 167)

brings before us and asks us to accept as architectural refinements? There is no principle whatever in them ... it seems that any deviation from the straight line anywhere, whether inward or outward, is to be taken as evidence of artistic purpose; any bad setting-out of plan, or and freak of irregularity in a plan, possibly due to some local difficulty in the site, is to be regarded as an instance of the adjustment of lines for an architectural effect.²⁴

Statham continued:

Mr. Goodyear lays much stress, in several instances, on the fact that where pilasters or piers are found leaning outwards the arch between them has not parted, as he says it ought to have done if the movement had been due to settlement. ... With a very slow and gradual settlement it is quite possible than an arch may accommodate itself to the movement to an extent which would, on first consideration, hardly be expected.²⁵

In a subsequent editorial, published two months later, Statham concluded: "[Goodyear] has been carried away by a vision of architectural refinements pervading every twist and distortion in ancient buildings: he has spent in the measurement of them an unremitting diligence, and in their attempted interpretation an almost pathetic ingenuity; but he has forgotten to take with him one sober companion who neither architect nor architectural critic can afford to dispense with, viz.: Common Sense."²⁶

The same year, in the pages of the *Bulletin monumental*, soon-to-be president of the Société Française d'Archéologie, Eugène Lefèvre-Pontalis, called Goodyear's reasoning "bizarre" and his conclusions "erroneous." Goodyear, he wrote, wished "to attribute to medieval architects principles for which they would have had no use whatsoever in terms of both perspective and equilibrium," and Lefèvre-Pontalis pointed to evidence that builders had in fact actively struggled to keep their buildings from deforming.²⁷



Figure 4 Bourges, Cathedral of Saint-Étienne. South inner aisle looking west (author's photo)

The most serious censure was yet to come, however. In 1906, British architect and architectural historian John Bilson published in the *Journal of the Royal Institute of British Architects* a “Criticism” in response to Goodyear’s recent work (a series of four articles that had appeared in *Architectural Record* between 1904 and 1905); in the process, Bilson thrust the widening refinement to center stage of the European archaeological world.²⁸ In occasionally sardonic prose, he concluded simply that the deviations “which Mr. Goodyear believes to be intentionally constructed ‘refinements’ are nothing of the kind; they are merely the accidental results of movements which have taken place in the structure, [of which] conclusive proof is afforded both by the recorded history and by the present condition of the building.”²⁹ Art historian Louis Demaison, in a 1907 review of Goodyear’s study of Reims Cathedral, echoed Bilson’s surprise that Goodyear had not taken into account “the effect of the thrust of the vaults, the differential settlement that often

takes place in buildings, and the deformation which is the consequence.”³⁰

Even engineer and historian Auguste Choisy, who had himself written briefly on architectural refinements, and who had responded encouragingly (though with characteristic reserve) to Goodyear’s efforts, took care to point out the problems with Goodyear’s widening refinement.³¹ To suggest that an intentional outward displacement of the vertical members at the Cathedral of Notre-Dame of Amiens “was employed for purely aesthetic reasons,” wrote Choisy, is “rather problematic: by thus exaggerating the vault span, the thrust of the vaults would have increased considerably. It is strange that the architect would have tolerated this increase only to attempt to attenuate it by resorting to use of the *tas-de-charge*.”³²

Yet Goodyear—as far as can be determined from the documentary record—never lost faith in the existence of the widening refinement. Whether for reasons of conviction or

pride, he stuck to his word with tenacity and, when provoked, with an outrage that leaps from the page.³³ His friend and advocate Harvard University professor Arthur Kingsley Porter had hope that things would change. As he wrote to Goodyear, “I think the French archeologists are slowly becoming reconciled to the idea [of the widening refinement] and will not much longer refuse to see the truth. My advice would be simply to leave them alone. You can hardly expect from them a confession of error. I imagine the next generation will simply adopt your views without saying anything about it.”³⁴ Yet it was not to be: as art historian Robert de Lasteyrie wrote in 1917, “rare is the archaeologist or

architect familiar with medieval monuments who allows himself to be seduced by the theories of Mr. Goodyear.”³⁵

The regrettable consequence of this widespread rejection was the neglect and eventual disappearance of a resource of the greatest utility, the thousands of calibrated large-scale prints of Gothic buildings produced by Goodyear over the years—what Choisy rightly called a “precious collection” worthy of preservation in a museum.³⁶ At Notre-Dame of Paris, for example, Goodyear’s photographs supplied the most precise evidence ever proposed for the successive campaigns of bracing and construction in the western nave (Figure 5).³⁷ Yet the images were

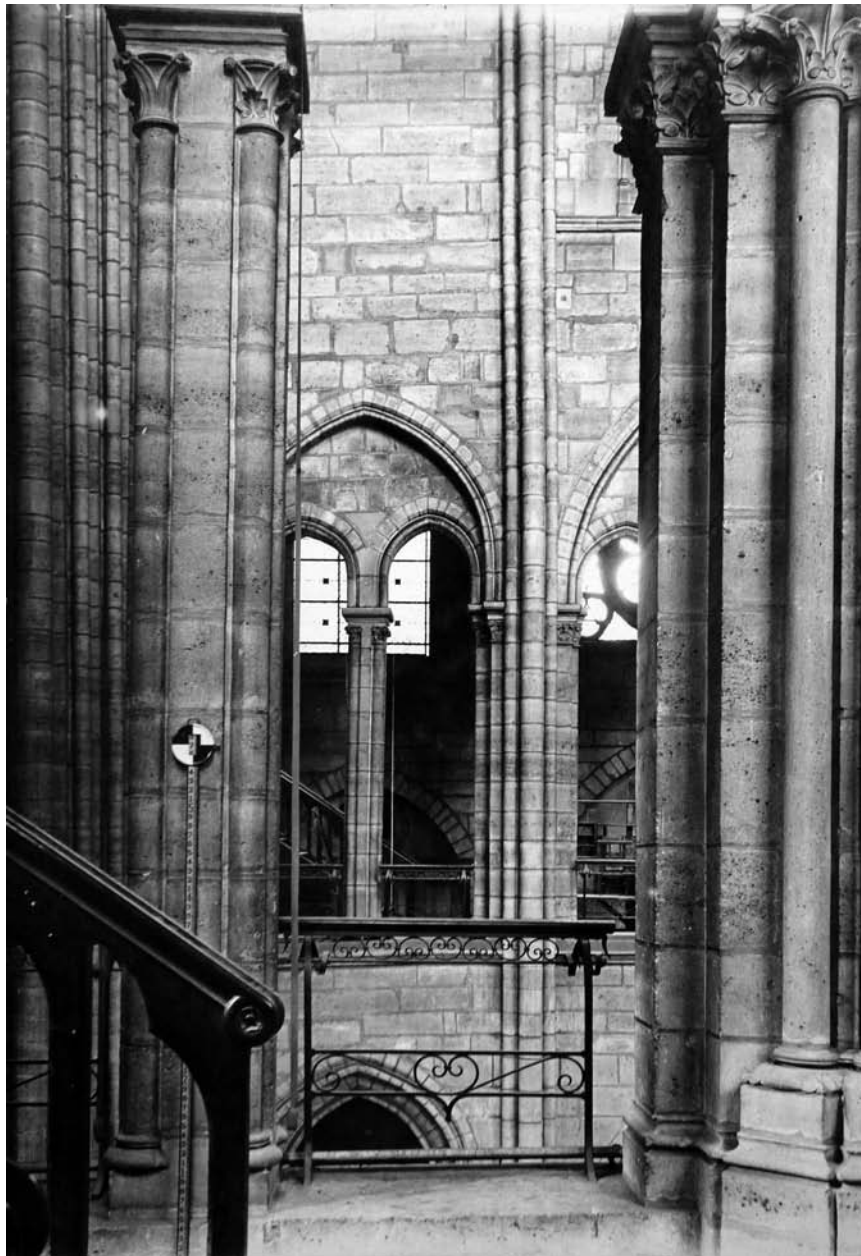


Figure 5 William H. Goodyear, *Paris, cathedral of Notre-Dame*, September 1903. Westernmost bay of the nave looking north. Note the plumb bob suspended in both tribune openings and the surveying rod (William H. Goodyear Collection, New York, Brooklyn Museum Archives 6.1.003 no. 186)

apparently indissociable from the theory they were meant to document; moreover, they had been seen by too few of those who actually repaired and wrote about the buildings.³⁸ In the end, Goodyear's greatest contribution to the study of medieval architecture was simply his resolve: by adhering without fail to his theory of widening refinement, he obliged the great students of French medieval architecture to respond in kind—to master and to articulate the vagaries of Gothic structure.³⁹

Perfection in the Measure of Man and of Heaven⁴⁰

Gothic buildings were (and to some extent still are) in a perpetual state of movement (or *elasticity*, to use the problematic term of Viollet-le-Duc) and, to put it simply, had trouble standing up straight.⁴¹ Driven by a desire to create a new kind of space—luminous, diaphanous, dematerialized—by means of an intangible constructional material, colored light, Gothic builders reduced to a bare minimum the dimensions of the architectural members charged with structural support. The aesthetic—and spiritual—potential was as dazzling as the structural consequences were impossible to calculate. The moment of truth came at the removal of the centering: the various nonaxial thrusts from vaults and arches demanded a response, and the building either stood fast as designed or, more often than not, adapted itself by deforming. The abbey churches of Saint-Pierre-de-Montmartre and Saint-Martin-des-Champs, the cathedrals of Reims, Amiens, and Beauvais, and perhaps most spectacularly, the collegiate church of Saint-Quentin (see Figure 2)—to name only a few—testify to the prevalence of the problem. It was the inherent plasticity of mortar, which could take months to harden, that enabled this dynamic response to vault thrust that so intrigued the *amateurs* of Gothic architecture in the late eighteenth and early nineteenth centuries.⁴²

Insofar as the architecture suffered from the malady of bowed uprights, the perfection of the architectural ensemble was compromised. This may seem a gratuitous observation, since we must assume that both patrons and builders desired structurally sound edifices. Yet the concept of perfection extends beyond mere questions of stability. When the church building is examined in the light of biblical texts as well as those of twelfth- and thirteenth-century exegetes, it becomes clear that keeping the walls in plumb was an imperative of theological order. The term *refinement* might now be recast: not as the creation of curvature but its very prevention, driven by a theologically grounded rectilinear perfectionism.

Two passages from the New Testament, among the many that employ architectural images, were central to the understanding of the church building in the Middle Ages:

Come to him, a living stone, rejected by human beings but chosen and precious in the sight of God, and, like living stones, let yourselves be built into a spiritual house to be a holy priesthood to offer spiritual sacrifices acceptable to God through Jesus Christ. (1 Peter 2:4–5)

So then you are no longer strangers and sojourners, but you are fellow citizens with the holy ones and members of the household of God, built upon the foundation of the apostles and prophets, with Christ Jesus himself as the cornerstone. Through him the whole structure is held together and grows into a temple sacred in the Lord; in him you also are being built together into a dwelling place of God in the Spirit. (Ephesians 2:19–22)

For Saint Augustine (354–430), the “living stones” in the epistle of Peter were unambiguously “the faithful of God”; the church building (*ecclesia basilica*) was no more than a structure in which the Church (*Ecclesia*) could be convened.⁴³ By the late eleventh century, however, a sea change had taken place: as much theologically as architecturally, the church building had undergone a radical transformation.⁴⁴ It was now possible to speak metonymically of church for Church; the material edifice, “built with stones,” wrote Bishop Bruno of Segni (ca. 1047–1123), “designates the Church, built of living stones.”⁴⁵

Once this primary equation was made, a path was cleared toward an ever-expanding lexicon of architectural metaphor. The great allegorists, such as Honorius of Autun (ca. 1080–ca. 1150), Hugh of Saint Victor (ca. 1096–1141), John Beleth (d. 1182), Sicardus of Cremona (ca. 1155–1215), and especially William Durand (ca. 1230–1296), attempted to render, with encyclopedic diversity, the fullness of the invisible reality that is the “dwelling place of God in the Spirit.”⁴⁶ In their hands, the image of living stones, erected in vertical courses, was a versatile and far-reaching tool for the representation of complex theological, sociological, or scriptural ideas.⁴⁷ The mural metaphor underwent numerous iterations; of particular interest here is the establishment of an allegory of constructional perfection. “The bigger stones,” wrote William Durand in the *Rationale divinorum officiorum*, “and the polished or square ones that are placed on the outside wall—in the middle of which lie the smaller ones—are the more perfected men whose merits and prayers sustain the weaker men in the holy Church.”⁴⁸ Moral and mural rectitude are here explicitly linked. They are further associated in scripture and its medieval exegesis in a more

surprising way: both could be assessed with the same instrument, the plumb line. The plummet was the standard means for assuring and, afterward, assessing the planar perfection of a mural surface.⁴⁹ Plumb bobs regularly appear in illuminated and stained glass representations of building scenes such as the erection of the Tower of Babel, or in depictions of contemporary construction as in the Lazarus window in the Cathedral of Saint-Étienne of Bourges (Figure 6).⁵⁰ Textual references are more difficult to find, probably because the tool was so common.⁵¹ One of the rare examples is found in Hugh of Saint Victor's *Didascalicon*, an unusually precise description of the process by which the perfection of a wall is assured using a plummet in the context of a constructional allegory for the Bible: "Divine Scripture is like a building, in which, after the foundation has first been laid, the structure itself is raised up; it is altogether like a building, for it too has its structure. ... Take a look at what the mason does. When the foundation has been laid, he stretches out his string in a straight line, he drops his plumb bob, and then, one by one, he lays the diligently polished stones in a row. Then he asks for other stones, and still others, and if by chance he finds some that do not fit with the fixed course he has laid, he takes his file, smooths off the protruding parts, files down the rough spots, and the places that do not fit, reduces to form, and so at last joins them to the rest of the stones set into the row."⁵²

The plummet metaphor is here used literally; some of Hugh's contemporaries would transpose it into the



Figure 6 Bourges, Cathedral of Saint-Étienne. Lazarus window: construction scene in which a plummet is used (author's photo)

tropological realm. Both Sigibert of Gembloux (ca. 1030–1112) and Rupert of Deutz (ca. 1075–1129), for example, in their respective commentaries on Ecclesiastes 7:16, use the image of a plummet (*perpendicularum*) as a moral yardstick. "Be not more just than is necessary," wrote Sigibert, "nor must you wish to be wise, lest you grow foolish through your [desire for] wisdom; just as the plumb line measures out the work to be done, in like manner the virtue of justice is the plummet of the other virtues and the straight line of morals."⁵³ Rupert adopted Sigibert's formulation verbatim and added: "The [plumb] line of justice makes straight those virtues which stand in the midst of vices, bringing them back from either side, so that nothing is lacking to them, and nothing is superfluous."⁵⁴

Such commentaries were directly inspired by allegorical passages written primarily by the Old Testament prophets in which the plummet, often accompanied by (or conflated with) the measuring line, figures as an instrument God used to assess the state of moral perfection (or iniquity) of the Israelites, the city of Jerusalem (Zion), or the kingdoms of Edom, Babylon, or Judah. Its use as moral measure occurs first in the second book of Kings: "Therefore, thus says the Lord, the God of Israel: I am about to bring such evil on Jerusalem and Judah that, when any hear of it, their ears shall ring: I will measure Jerusalem with the same cord [*funiculum*] as I did Samaria, and with the plummet [*pondus*] I used for the house of Ahab. I will wipe Jerusalem clean as one wipes a dish, wiping it inside and out."⁵⁵

Isaiah employs a similar image in contrasting the moral attributes of the kingdom of Judah, plunged in sin, and righteous Zion. "Therefore, thus says the Lord God: 'See, I am laying a stone in Zion, a stone that has been tested, a precious cornerstone as a sure foundation; whoever puts faith in it will not waver. I will make judgment a measuring line [*mensura*] and justice a plummet [*pondus*]. Hail shall sweep away the refuge of lies, and waters shall flood the hiding place.'⁵⁶ Isaiah issues a stern warning to adhere to the moral high ground; for those who do not, "This iniquity of yours shall be like a descending rift, bulging out in a high wall whose crash comes suddenly, in an instant."⁵⁷ Here the prophet supplies a clear sense of constructional danger in a non-rectilinear wall—out of plumb is clearly out of (moral) order. In the book of Lamentations, the destruction of Jerusalem at the hands of the Chaldeans, foretold by Isaiah, was likewise rendered as a chastisement in mural form for moral iniquity. "The Lord was bent on destroying the wall of daughter Zion: He stretched out the measuring line [*funiculus*] and did not withhold his hand from destroying; he brought grief on rampart and wall till both succumbed."⁵⁸

In a subsequent passage from the book of Isaiah, the plummet assumes an active role as the instrument by which

justice is meted out: “The Lord will stretch over [Edom] the measuring line [*mensura*] of nothingness, the plumb line [*perpendicularum*] of desolation.”⁵⁹ The sense is made clear in a commentary written by Hervé de Bourg-Dieu (ca. 1080–1150): “A measuring line will be extended over the blazing earth, so that it is reduced to nothing, because there sinners will forever be in distress in accordance with the measuring line, by which God will decree their punishments with a just verdict. ‘And a plummet to wreak desolation’: that is, a place of destruction, because there the damned will be scattered, and tormented with tortures in accordance with the decision of the justice of the supreme creator. For the word plummet is given to the tool whereby masons ensure that a wall is upright.”⁶⁰

But the measuring line could also be used in a positive sense as a tool for reconstruction, as recounted by Jeremiah in the wake of the destruction of Jerusalem: “See, days are coming—oracle of the Lord—when the city shall be rebuilt as the Lord’s, from the Tower of Hananel to the Corner Gate. A measuring line [*norma mensurae*] shall be stretched from there straight to the hill Gareb and then turn to Goah. The whole valley of corpses and ashes, all the terraced slopes toward the Wadi Kidron, as far as the corner of the Horse Gate at the east, shall be holy to the Lord. Never again shall the city be uprooted or demolished.”⁶¹ This is the measuring line of Job 38:5, used in the creation of the earth; it is the measuring line in the vision of the reconstruction of the Temple recorded by Ezekiel 40–42. Both are instruments of physical and moral quantification.⁶²

A final image of rebuilding, key to the Christian vision of the reconstructed Temple, comes from Zechariah: “I am consumed with anger toward the complacent nations; When I was only a little angry, they compounded the disaster. Therefore, thus says the Lord: I return to Jerusalem in mercy; my house will be rebuilt there—oracle of the Lord of hosts—and a plumb line [*perpendicularum*] will be extended over Jerusalem.”⁶³ Zechariah here links God’s program of moral reconstruction, recorded at the outset of his prophecy, with the physical reconstruction of the Temple, initiated by Joshua and Zerubbabel during the reign of Cyrus and in progress during the prophet’s lifetime under King Darius I. The Temple rebuilding (especially as recounted in the book of Ezra, chapters 1–6) was a frequent subject of high medieval manuscript illuminations; it is also the biblical scene in which plumb lines most often appear. Found primarily in thirteenth-century French bibles, such illuminations show Cyrus (or, less frequently, Darius) heralding a man who suspends a plummet against one of the walls in the fictive architecture that surrounds him (Figure 7).⁶⁴ The man is no mere builder; it is Zerubbabel himself, as Zechariah



Figure 7 Sweetheart Abbey Bible, French 1260–70. King Cyrus heralding the plummet-wielding Zerubbabel (Princeton University Library, MS Garrett 27, vol. 2, fol. 325v)

recounts: “The hands of Zerubbabel have laid the foundations of this house, and his hands will finish it. Thus you shall know that the Lord of hosts has sent me to you. For whoever has scorned such a day of small things will rejoice to see the plummet [*lapidem stagnum*] in the hand of Zerubbabel.”⁶⁵

Zerubbabel’s initiation of the rebuilding of the Temple was thought by Christian exegetes such as Haimo of Auxerre (d. ca. 855) to prefigure Christ’s creation of the new Temple—the Church—whose members, as we have seen, are assigned a specifically architectural role by Saint Paul.⁶⁶ In a commentary on the passage from Zechariah just cited, Haimo wrote: “[God] promises to his Church peace and mercy, and that a plummet or rope is to be extended over it; that is, he assigns measures and rankings to each member of the Church, in their own places and in their own times, in accordance with the nature of their merits.”⁶⁷ These illuminations, like the passage from Haimo, explicitly link mural and moral: Zerubbabel is plumbing not only the physical stones of the new Temple, but the living stones of the Church, to ensure, like Christ—indeed, like God himself, the wise master builder (1 Corinthians 3:10)—that the structure is built according to the perfection of God’s plan.

Abbot Suger (ca. 1081–1151), in a singular passage describing the new chevet of the abbey church of Saint-Denis, in which he subtly reframed the epistle of Paul cited above, transposed this theological precept into the realm of the material. For Suger, to build according to God’s plan meant to spare no expense—to seek nothing less than perfection in the execution of the work.⁶⁸

The midst of the edifice, however, was suddenly raised aloft by twelve columns representing the number of the Twelve Apostles and, secondarily, by as many columns in the side aisles signifying the number of the [minor] Prophets, according to the Apostle [Paul] who builds spiritually. *So then you are no longer strangers and sojourners, says he, but you are fellow citizens with the holy ones and members of the household of God, built upon the foundation of the apostles and prophets, with Christ Jesus himself as the capstone which joins one wall to the other. Through him the whole structure—whether spiritual or material—is held together and grows into a temple sacred in the Lord.* In him, we too apply ourselves as much to build materially, ever higher and ever more suitable, as we are instructed on our own to be built together, spiritually, [to become] *a dwelling place of God in the Spirit.*⁶⁹

By interposing the phrase “whether spiritual or material,” Suger forged a link between mural and moral; the bar was set high as much for the building as for the faithful, for the

church as much as for the Church. It is in this primary sense—perfection of workmanship in stones both literal and figurative—and less as a specific emulation of the characteristics presented in Ezekiel 40–42 and Revelation 21:9–21, that the Gothic building can be understood as an image of Heaven.⁷⁰

A further index of the importance accorded to mural perfection is supplied by the high medieval rite of church reconsecration. Consecration was understood as a type of baptism that, in the words of Bishop Bonizo of Sutri (ca. 1045–ca. 1090), “transforms insensible building stones into another nature”; in the process, the “house made of human hands [becomes] the dwelling of the Trinity and the angels.”⁷¹ The reconsecration of a church, then, is required, in William Durand’s words, “first, if all of its walls have been badly burned, or if the greater part of the walls has been stripped by the fire, [and] second, if the whole church, or the greater part of it collapses all at once, and it is repaired from all or some of the stones that fell, mixed with other stones; for the consecration of a church consists, above all, in the anointing of the exterior, and in the joining and placement of the stones.”⁷² If the wall is rendered imperfect through damage or deformation, the consecration is invalidated since, as Durand wrote, “*the form of something constitutes its being.*”⁷³ A church must be resanctified—rebaptized—because it preserves the essence of this sanctification in the “joining and placement of the stones.”

The same aspiration to mural perfection lay behind the medieval use of badigeon, or whitewash, on the interior and exterior walls of churches (Figure 8).⁷⁴ Walls were not so much *covered* to hide stonework considered imperfect as *clothed*, to use the expression of Raoul Glaber (ca. 990–ca. 1050), in a radiant mantle of white, on which stone courses were precisely redrawn.⁷⁵ These were in no sense, as the expression in French goes, “false joints”; quite to the contrary, these measured lines demarcated the *real and perfect* joints of the living stones of the Church, the very locus of sanctity of the church building, made apparent to all.⁷⁶ This, then, was an architecture of perfection—an architecture, in the words of the twelfth-century author of the so-called Pilgrim’s guide, “of ineffable workmanship” in which “no fissure or fault is found.”⁷⁷

An Architecture of Perfection: The Gothic Church Building

The evidence of a desire for rectilinear perfection exists in the construction of the buildings themselves, and can be directly observed using the technique of high-definition laser scanning.⁷⁸ A laser beam is projected spherically from the



Figure 8 Chartres, Cathedral of Notre-Dame. Choir clerestory wall with recently restored badigeon (author's photo)

scanner by means of a rotating mirror; the scanner calculates the distance between itself and every surface the beam encounters, at a rate of many thousands of times per second, by determining the time elapsed between emission and reflection. Each measurement in the resultant “cloud” is accurate to within several millimeters. The scanner must be placed in multiple locations to map complex spaces; these data clouds are fixed in space using geo-referenced targets, then assembled into a master cloud. The result is an extremely accurate three-dimensional spatial map of the surfaces of the building (Figures 9 and 10). Sections, plans, and other views can be easily created by limiting visible data points. Measurements can be made from any point to another, or from individual points to a reference plane—the equivalent of a virtual plumb line. The building, in short, can be “seen” as never before. Laser surveying is a direct revival of the close observation of deformation innovated by Goodyear—a discipline that essentially disappeared from the practice of medieval architectural history.⁷⁹ Indeed, laser deformation analysis is a revival, using state-of-the-art means,

of that which medieval builders did habitually when erecting their buildings (see Figure 6), or when confronted with a situation of structural distress: they verified plumb.⁸⁰

The cathedrals of Chartres and Bourges—an irresistible binary—are associated here not as a traditional means to map the range of architectural potential in early thirteenth-century France but rather to propose that their builders, despite widely differing aesthetic and structural agendas, had each found a successful solution to a problem that had pre-occupied Gothic builders, driven to adhere to a theological ideal, from the very start. How to build a perfectly straight building?

The structural system of the Cathedral of Notre-Dame of Chartres is sometimes qualified as overbuilt—with the implication that the builders had not mastered the fundamental (i.e., structurally rational) parameters of Gothic building (Figure 11).⁸¹ It may seem as much, at first sight, when Chartres is compared with one of its more lithe contemporaries, such as the Cathedral of Saint-Gervais and Saint-Protais of Soissons. Yet a more compelling



Figure 9 Chartres, Cathedral of Notre-Dame. Laser scan data (image by author)

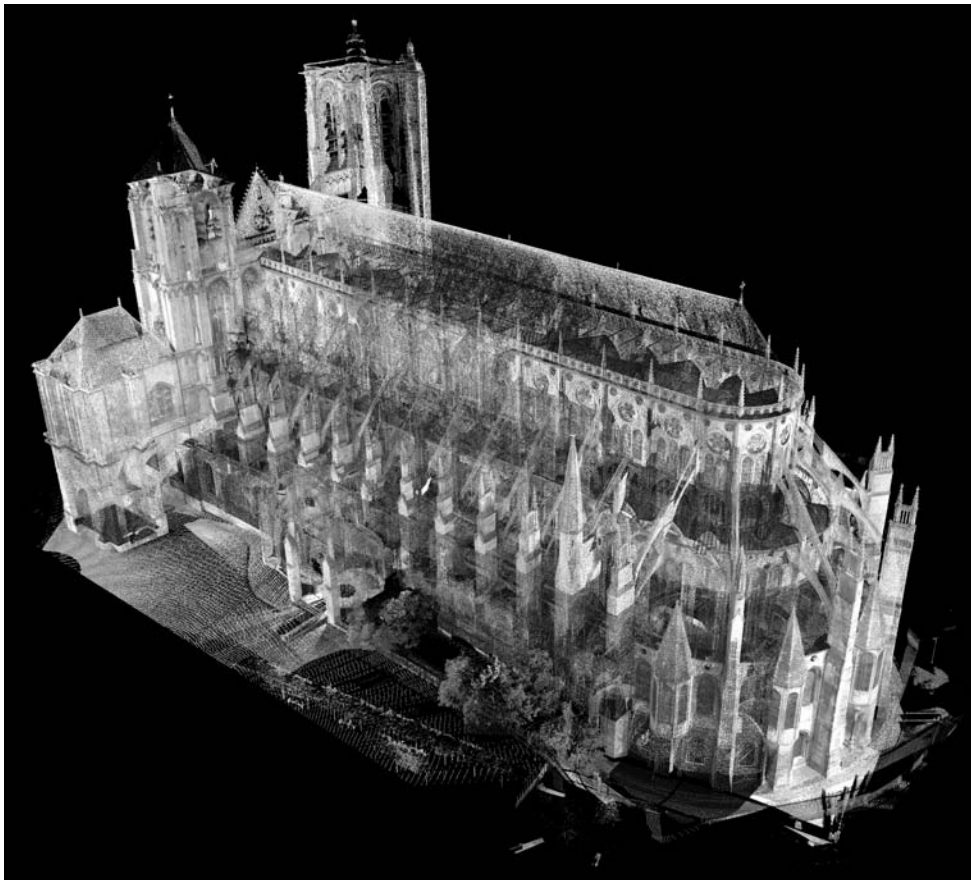


Figure 10 Bourges, Cathedral of Saint-Étienne. Laser scan data (image by author)

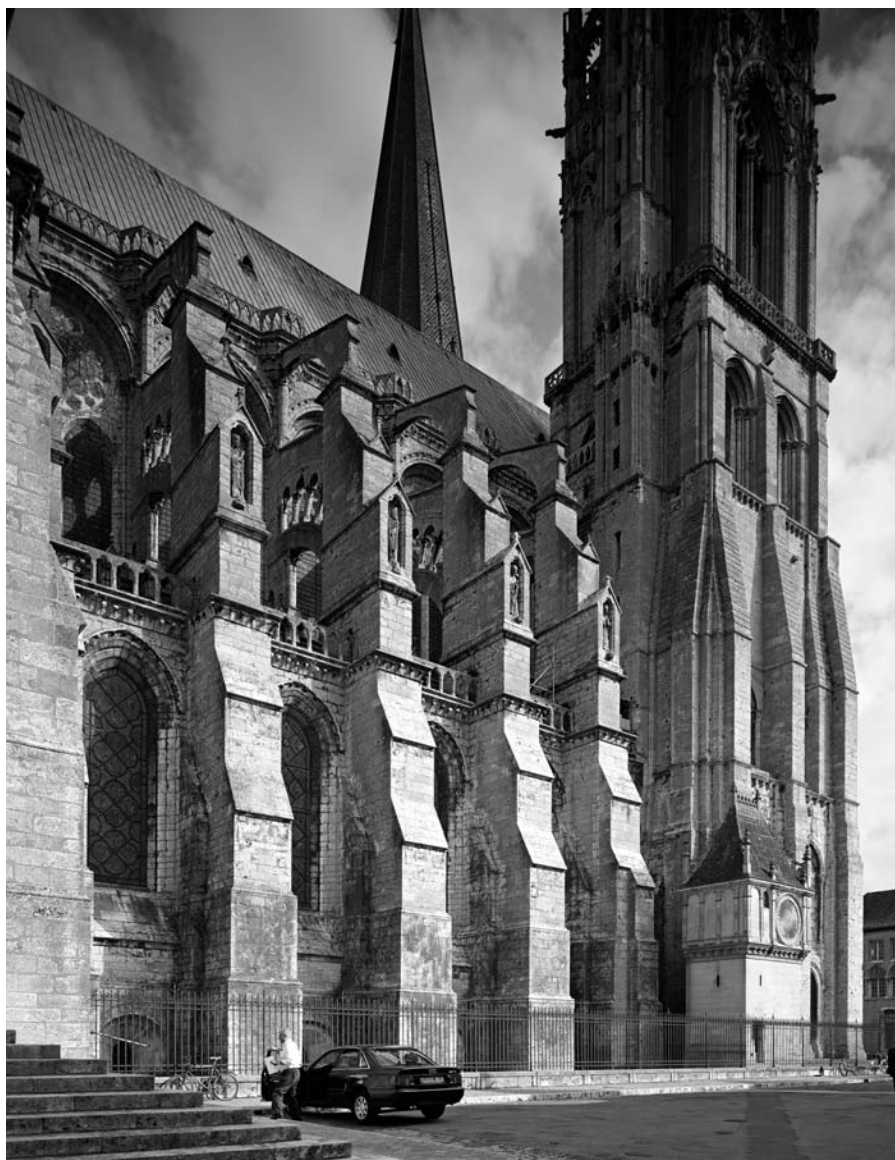


Figure 11 Chartres, Cathedral of Notre-Dame. North flank of the nave (author's photo)

characterization of this structural vigor might be offered. First, the impressive size must be understood not as the result of an unmastered fear of failure but as a desire to overwhelm, to reach for the sublime through colossal scale.⁸² Second, it is this ample structural muscle that enables the world of the interior—a space of empyrean order whose rectilinear perfection is put perpetually at risk by the reality of gravity and wind.

The results of a high-definition laser survey of the cathedral undertaken in 2011 are surprising.⁸³ As we have seen, Gothic buildings move, and can move quite a bit, despite the best intentions of their builders; had this not been the case, Goodyear would have had little to say. But the Cathedral of Chartres has hardly budged: the outward

deflections at clerestory level are on the order of only several centimeters, a deformation so small as to be perfectly invisible. The transverse section of Figure 12 can stand for all others, so little has the building been displaced.

It was not only the lithic mass that achieved this goal. A series of iron ties was placed above the surcharge of the aisle vault transverse arches; the purpose of the ties was to prevent the piers below from being thrust outward into the space of the main vessel by the aisle vaults. Had the builders concerned themselves only with questions of structural failure, or even mere stability, these straps, given the size of the buttressing system and the weight of the superstructure above them (which acts against such overturning forces), would have been redundant. Rather, they are a clear



Figure 12 Chartres, Cathedral of Notre-Dame. Section through laser scan data of the nave (image by author)

sign—along with the ubiquity of badigeon—that mural perfection was given the highest priority.

The Cathedral of Bourges is also graced with an unusual rectilinearity, revealed by a laser scan undertaken in 2008 (Figure 13), though it is not on the same order of that of Chartres.⁸⁴ The state of plumb of piers and walls is compromised in the westernmost bays of the nave by unstable foundations, which were ultimately responsible for the construction, on the south side of the facade, of a massive, chapel-containing buttress, the so-called *Pilier butant*, and on the north, for the collapse of the *Tour de beurre* in 1506.⁸⁵

As at Chartres, iron ties were placed over the transverse arches of the inner aisle vaults (Figure 14). Unlike Chartres, however, they were not part of the original design. They were installed only after the inner aisle vault centering of the chevet had been removed—after the builders had had a

chance to observe the behavior of the piers.⁸⁶ The laser scan reveals that these tall and slender pylons had begun to bend slightly, by several centimeters, into the main vessel, thrust outward by the inner aisle vaults. Once the ties were installed the deformation was arrested; the inclination out of plumb was then rectified as construction continued vertically. As at Chartres, the iron ties were not intended to prevent catastrophic failure; the building preserves no evidence of having risked such a danger. They are witnesses, rather, to a deliberate and precise combat waged against the free-ranging lateral forces that gave Gothic buildings their habitual curves.

The interior of the Cathedral of Bourges appears as if suspended from the heavens: an immense triangular tent, held aloft by its peak, with only a series of frail cords of masonry descending through space to tie it down.⁸⁷ It is an



Figure 13 Bourges, Cathedral of Saint-Étienne. Section through laser scan data of the nave (image by author)



Figure 14 Bourges, Cathedral of Saint-Étienne. Iron tie over the inner aisle vaults with position indicated in the inset (photograph and laser image by author)

effect created by the dramatic extension in height of the arcade piers and consequent staging of the elevation—or, stated in another way, due to the absence of the tribunes with which the primary spatial prototype for Bourges, the Cathedral of Paris, was equipped. It is possible that the vaults necessary to support tribunes were eschewed not only in service of an anagogical triangularity but also, as Francis Salet has argued, from a desire to preserve the vertical lines of piers and colonnettes in their pristine and parallel state, untrammelled by the capricious thrusts of vaults.⁸⁸

One is left at Bourges with the impression of perfect verticality (Figure 15).⁸⁹ The wall is resolutely dematerialized through the deployment of a fine web of linear elements; as a result, what few deformations exist are rendered imperceptible. There is no evidence that the walls were covered with badigeon.⁹⁰ The master of the Cathedral of Bourges seems not to have needed it: he chose to render the unknowable Ideal by using space itself as a medium, to clothe his building not in a mantle of white but in light, with perfected joints rendered in a filigree of stone.



Figure 15 Bourges, Cathedral of Saint-Étienne. Main vessel from the outer aisle triforium, looking west (author's photo)

Coda

Toward the end of his life William Goodyear renewed his interest in the French Gothic churches that had been the cause of so much personal distress. Some of the most important among them had been damaged in the First World War and, from his point of view, risked having their widening refinements inadvertently erased by architects anxious to rectify pressing structural problems.⁹¹ Paradoxically, these war-torn structures supplied the clearest evidence yet presented against Goodyear's reading of French Gothic architecture—though the evidence seems to have gone unnoticed by him or by his antagonists. In the devastated cathedrals of Reims and Soissons, among others, walls suddenly shorn of their flying buttresses behaved, under the

apprehensive watch of the public down below, just as countless Gothic vessels had, long ago, at the decentering of their vaults: they deformed outward under the action of vault thrust.⁹²

Goodyear's widening refinement proved to be without future among scholars of medieval architecture. Yet it survives in another form—of monumental order—on the opposite side of the Atlantic. The Swedenborgian Church of the New Jerusalem in Bryn Athyn, Pennsylvania, was built from the outset with Goodyear-inspired widening refinements at the request of patron Raymond Pitcairn, and despite resistance from architect Ralph Adams Cram (Figure 16).⁹³ "It was a memorable occasion for me," wrote Goodyear of the dedication ceremony on 5 October 1919, "considering the ridicule and even malice to which I have been subjected, and

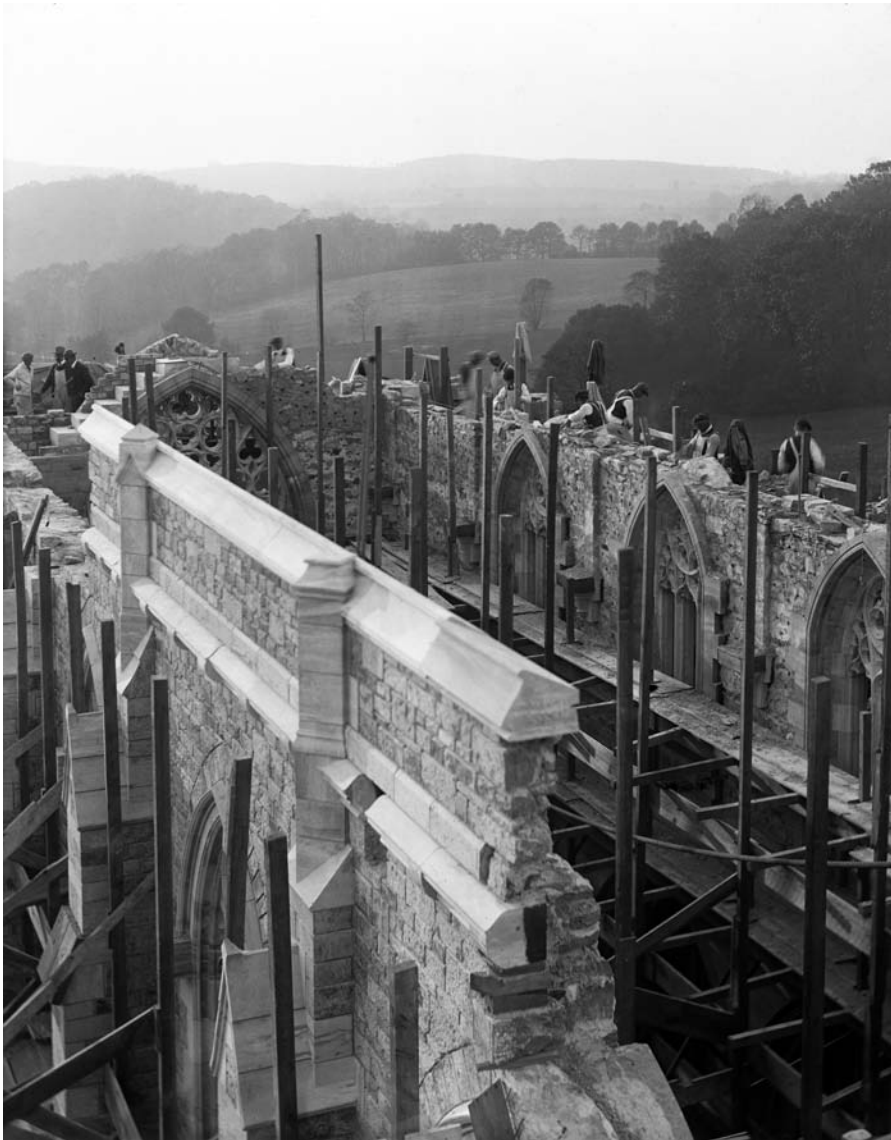


Figure 16 Bryn Athyn, Pennsylvania. Stonemasons at work on the Bryn Athyn Cathedral nave, ca. 1914 (Raymond and Mildred Pitcairn Archives, Bryn Athyn, Pa., no. 206 [Glencairn Museum Archives, Bryn Athyn, Pa., all rights reserved])

the widespread influential denials still current in England and in France that the Middle Ages ever purposely constructed churches of the kind which is now seen at Bryn Athyn. On the whole, I am inclined to think that my presence at the dedication was the greatest event in my life.”⁹⁴

An even greater vote of confidence was to follow. In November of the same year, architect Donald Robb contacted Goodyear for help with a project recently awarded him and Philip Hubert Frohman—the completion of Washington National Cathedral (Figure 17).⁹⁵ With the possible exception of the church of Saint John the Divine in New York City, this was the most prominent neo-Gothic church project in the country.⁹⁶ Goodyear was ecstatic and threw himself into the project with characteristic energy.⁹⁷ Three weeks later, Frohman made a strong (and ultimately successful) plea to the dean of the cathedral, the Very Reverend George C. F. Bratenahl, in favor of incorporating Goodyearian refinements:

The majority of our best churches ... are still altogether too hard, mechanical and rigid in effect. They look too machine-made, and lack that grace and charm possessed by the average

medieval church. Beauty of proportion and refinement of detail will do much to soften and mitigate this mechanical quality, but the way to eliminate it is to give up our modern devotion to mechanical duplication and make use of those refinements which the cathedral builders valued so highly. These refinements made the old Cathedrals beautiful when they were new. It was not necessary for them to be mellowed by the hand of time, for their builders had followed their love of the grace which is attained by those subtle curves and variations which are felt and appreciated even though they are not sufficiently obvious to be detected by the eye or, perhaps, I should say, by the mind or reason. I believe the time will come when these refinements will be recognized by all students of Christian art as being one of the many factors which contribute toward the emotional appeal of the Gothic cathedrals. As such, they have a distinct practical value.⁹⁸

It is an understandable desire, in the age of steel-trussed skyscrapers, to wish to give buildings whose language is appropriated from the distant past the worn patina of their prototypes—a romantic longing for an architecture of irregularity, of “mystery and spirit,” as L. Ingleby Wood wrote in 1905, which must be inscribed in the context of a widespread



Figure 17 Washington, D.C., Washington National Cathedral. Main vessel looking east (photograph copyright András Frenyo, all rights reserved)

reaction to the perceived sterility of modernism.⁹⁹ But to credit Gothic builders with the same desire is to misunderstand them fundamentally. The piers of Washington National Cathedral and the church of Bryn Athyn stand today subtly out of plumb: a celebration of Gothic structural malfunction and a paradoxical marriage between a medieval architecture of radical innovation, whose creators strove for perfect rectilinearity, and a profoundly antimodern longing for imperfection.

Notes

1. I am grateful to Nicholas Adams and Stephen Murray, who read early drafts; to Jean-Paul Deremble; to the editor and anonymous reviewers for their comments; and to Angela Park and her staff at the Brooklyn Museum Archives. Some of the following material is adapted from my book in progress, *The Structure of Gothic*.
2. "William H. Goodyear" [Obituary], *New York Times*, 24 Feb. 1923. See also "Prof. W. H. Goodyear Dies; Curator of Brooklyn Institute of Arts and Sciences a Victim of Pneumonia at 77," *New York Times*, 20 Feb. 1923, 17; "William H. Goodyear" [Obituary], *Art News*, 24 Feb. 1923, 6; "William H. Goodyear," *The National Cyclopaedia of American Biography* (New York: James T. White and Company, 1926), 455–56, in which Goodyear is called "America's first art historian"; and "William H. Goodyear," *Dictionary of American Biography*, ed. Allen Johnson and Dumas Malone (New York: Charles Scribner's Sons, 1931), 416–17. A testament to Goodyear's reputation is the strong bid he made in 1904 for the directorship of the Metropolitan Museum of Art: William H. Goodyear, "Scrapbook of Items Related to the Directorship of the Metropolitan Museum of New York," Papers of Arthur Kingsley Porter, Cambridge, Mass.: Harvard University Archives HUG 1706.104.5, box 2, folder 3, 1904.
3. Goodyear would later produce a book on the subject: *Greek Refinements: Studies in Temperamental Architecture* (New Haven, Conn.: Yale University Press, 1912). His two most popular works were *Roman and Medieval Art* (Meadville, Pa.: Flood and Vincent, 1893), published by Macmillan with new editions in 1897, 1899, 1905, 1909, and 1910; and *Renaissance and Modern Art* (Meadville, Pa.: Flood and Vincent, 1894), published by Macmillan with new editions in 1900, 1901, 1904, and 1913.
4. To my knowledge, only one work in the years since Goodyear's death has been devoted to his quest to document medieval refinements: a ten-page self-published article by Mary Dean, "Optical Refinements in Medieval Architecture: An American Theory and the English Reaction" (Hammer-smith, UK, 1990), originally intended for inclusion in *Medieval Architecture and Its Intellectual Context: Studies in Honour of Peter Kidson*, ed. Eric Fernie and Paul Crossley (London: Hambledon, 1990). A copy of Dean's article is held in the library of the Brooklyn Museum. Goodyear's work on Gothic refinements is briefly discussed in P. A. Michelin, "Refinements in Architecture," *Journal of Aesthetics and Art Criticism* 14, no. 1 (1955), 37, and, in the context of his relationship with Auguste Choisy, in a conference paper by Javier Girón Sierra, "L'utilisation de nouvelles techniques par W. Goodyear au début du XX^e siècle et leur apport à l'histoire de l'architecture selon A. Choisy," in *Le relevé en architecture ou l'éternelle quête du vrai: Journées internationales d'études*, 5 et 6 novembre 2007, ed. François de Mazières and Mireille Grubert (Lyon, 2011), 180–90.
5. John Ruskin, *The Seven Lamps of Architecture* (New York: John Wiley and Sons, 1885), chap. 5, "The Book of Life," especially § 9.

6. William H. Goodyear, "A Lost Art," *Scribner's Monthly* 8, no. 4 (1874), 432–40; Charles Eliot Norton, *Historical Studies of Church-Building in the Middle Ages: Venice, Siena, Florence* (New York: Harper & Brothers, 1902), 321.
7. See William H. Goodyear, *Illustrated Catalogue of Photographs & Surveys of Architectural Refinements in Medieval Buildings* (Edinburgh: Morrison and Gibb, 1905), ix–x.
8. William H. Goodyear, "Optical Refinements, Perspective Illusions and Symmetrophobia in Medieval Architecture," William H. Goodyear Collection, New York, Brooklyn Museum Archives 2.1.009 (Research and Writings), ca. 1895. The book was only partially completed.
9. The most important were William H. Goodyear, "Perspective Illusions in Medieval Italian Churches," *Architectural Record* 6 (1896), 163–83; "Construction Asymmetry in Medieval Italian Churches," *Architectural Record* 6 (1897), 376–405; "A Discovery of Horizontal Curves in Medieval Italian Architecture," *Architectural Record* 6 (1897), 481–508; and "Architectural Refinements in Italian Churches," *American Journal of Archaeology* 6, no. 2 (1902), 166–96.
10. "American Art Expert Reveals Secret of Mediaeval Beauty," *New York Herald*, 21 Aug. 1910. See also William H. Goodyear, *Rediscovered Secrets of Medieval Art* (Dublin: Classical Association of Ireland, 1914), 3–4.
11. "As Paris is nearer than Pisa to the sphere of frequent visits on the part of American experts, the observation on Notre Dame may draw their attention in a larger degree to the remarkably convincing measurements made at Pisa." William H. Goodyear, "The Leaning Façade of Notre Dame as Compared with That of Pisa," *American Journal of Archaeology* 5, no. 1 (1901), 13.
12. See William H. Goodyear, "The Museum Architectural Research of 1907," *Brooklyn Institute of Arts and Sciences: The Museum News* 3, no. 2 (1909), 22–27; and Charles S. Hastings, "Architectural Refinements in Mediaeval Churches Computed," *Architectural Record* 26 (1909), 132–39.
13. "Prof. Goodyear," wrote the *New York Times* on 4 July 1909, is "entitled to the honor of being the first investigator to devise adequate methods of ascertaining photographically the deflections of vertical lines in cathedral architecture." "Series of Architectural Photographs of Great Interest on Exhibition at the Brooklyn Art Museum. They Clearly Indicate the Ideas of Prof. Goodyear as to the Builders of Medieval Times," *New York Times*, 4 July 1909, 5. This was not exactly the case: architectural *photogrammetry*, a term coined by Albrecht Meydenbauer in 1867 for the precise measurement of buildings using calibrated photography, was a well-established practice at this point. See Jörg Albrecht, "Albrecht Meydenbauer: Pioneer of Photogrammetric Documentation of the Cultural Heritage," in *Proceedings of the XVIII. International Symposium of CIPA 2001, Potsdam*, ed. Jörg Albrecht (Stuttgart: E. Schweizerbart, 2002), 19–25, and, for the work of a French contemporary, Aimé Laussedat, *La métrophotographie* (Paris: Gauthiers-Villars, 1899). Goodyear, however, was certainly the first to have undertaken the photographic documentation of Gothic buildings in such a single-minded (and well-publicized) way.
14. See the handwritten notes on the reverse of proof photographs in the collections of the Brooklyn Museum: Field Survey Photographs, William H. Goodyear Collection, New York, Brooklyn Museum Archives 6.1.003–007, 1903, 1905, 1906, 1907, and 1909.
15. Goodyear, "Biographical memoranda beginning with the year 1905 and continuing an earlier series," Papers of Arthur Kingsley Porter, Cambridge, Mass., Harvard University Archives HUG 1706.104, folder 1, 1911, p. 9; letter to Arthur Kingsley Porter, 8 Nov. 1909, Papers of Arthur Kingsley Porter, Cambridge, Mass., Harvard University Archives HUG 1706.104, folder 3, 1909, 2; and Charles S. Hastings, Correspondence with William H. Goodyear, Charles Sheldon Hastings Papers, 1869–1930, New Haven,

Conn., Yale University Library Manuscripts and Archives MS 997, box 1, folders 2–3, 1909.

16. William H. Goodyear, "Architectural Refinements in French Cathedrals. Fourth Paper. Notre-Dame," *Architectural Record* 17 (1905), 31. The term "optical mystification" is first employed in reference to Greek architecture in William H. Goodyear, *Roman and Medieval Art* (Meadville, Pa.: Flood and Vincent, 1893), 49.

17. William H. Goodyear, "An Echo from Evelyn's Diary," *Architectural Record* 7 (1897), 183.

18. *Ibid.*, 184.

19. See Stephen E. Palmer, *Vision Science: Photons to Phenomenology* (Cambridge, Mass.: MIT Press, 1999), 333–37; James J. Gibson and O. H. Mowrer, "Determinants of the Perceived Vertical and Horizontal," *Psychological Review* 45, no. 4 (1938), 300–23; and S. E. Asch and H. A. Witkin, "Studies in Space Orientation: I. Perception of the Upright with Displaced Visual Field," *Journal of Experimental Psychology* 38 (1948), 325–37. On the idiosyncrasies of the perception of curved lines, see James J. Gibson, "Adaptation, After-effect, and Contrast in the Perception of Curved Lines," *Journal of Experimental Psychology* 16, no. 1 (1933), 1–31.

20. Goodyear, "Echo from Evelyn's Diary," 183; William H. Goodyear to Arthur Kingsley Porter, 20 Sept. 1913, Papers of Arthur Kingsley Porter, Cambridge, Mass., Harvard University Archives HUG 1706.104, folder 4, 1913.

21. William H. Goodyear, "Architectural Refinements in French Cathedrals. Third Paper. Notre-Dame," *Architectural Record* 16 (1904), 581.

22. Henry Heathcote Statham, "The Glamour of Crooked Building," *Builder* 89, no. 23 (1905), 311–13. The article was reprinted the following month in the United States: Henry Heathcote Statham, "The Glamour of Crooked Building," *American Architect*, no. 7 (1905), 117–19. Statham had briefly reviewed Goodyear's work the previous year in equally incendiary terms: "Magazines and Reviews," *Builder* 87, no. 13 (1904), 177.

23. Statham, "The Glamour of Crooked Building," 311.

24. *Ibid.*, 312.

25. *Ibid.*, 313.

26. Henry Heathcote Statham, "Some More about Crooked Buildings," *Builder* 89, no. 9 (1905), 605.

27. Eugène Lefèvre-Pontalis, "Review of 'Vertical Curves and Other Architectural Refinements in the Gothic Cathedrals and Churches of Northern France' by William Goodyear," *Bulletin monumental* 69 (1905), 374–75. Translations are by the author unless otherwise indicated.

28. William H. Goodyear, "Architectural Refinements in Early Byzantine Churches and French Cathedrals," *Architectural Record* 15 (1904), 116–40; William H. Goodyear, "Architectural Refinements in French Cathedrals. Second Paper. The Cathedrals of Paris and Amiens," *Architectural Record* 16 (1904), 439–63; Goodyear, "Architectural Refinements in French Cathedrals. Third Paper," 569–90; William H. Goodyear, "Architectural Refinements in French Cathedrals. Fourth Paper"; John Bilson, "Amiens Cathedral and Mr. Goodyear's 'Refinements': A Criticism," *Journal of the Royal Institute of British Architects*, 3rd ser., 13, no. 16 (1906), 397–417.

29. Bilson, "Amiens Cathedral and Mr. Goodyear's 'Refinements,'" 416–17. This was only the opening salvo; the extended (though essentially deadlocked) exchange between Goodyear and Bilson took place in the following sequence: William H. Goodyear, "Architectural Refinements: A Reply to Mr. Bilson," *Journal of the Royal Institute of British Architects* 15, no. 9 (Nov. 1907), 17–51; John Bilson, "Amiens Cathedral and Mr. Goodyear's 'Refinements': A Rejoinder," *Journal of the Royal Institute of British Architects* 15 (1908), 84–90; William H. Goodyear, "Amiens Cathedral and Mr. Bilson's Rejoinder," *Journal of the Royal Institute of British Architects* 16, no. 25 (Sept. 1909), 715–40—to which Bilson, who had an advance proof,

submitted a short reply (printed on page 740). Goodyear, not to be outdone, managed to convince the editors of the *JRIBA* to print a final reply on a single page inserted into the journal. To better reach the audience in France, Lefèvre-Pontalis had Bilson's "Amiens Cathedral and Mr. Goodyear's 'Refinements'" translated: John Bilson, "La cathédrale d'Amiens et les 'raffinements' de M. Goodyear," *Bulletin monumental* 71 (1907), 32–76. Goodyear prepared a new article in French in response and submitted it to the *Bulletin monumental*, but Lefèvre-Pontalis rejected it as too lengthy; Goodyear, despite Auguste Choisy's gracious urgings, refused to shorten it. See William H. Goodyear to Herbert Batsford, 30 June 1909, William H. Goodyear Collection, New York, Brooklyn Museum Archives 1.1.003 (General Correspondence: Batsford, Herbert), 1909, and William H. Goodyear to Arthur Kingsley Porter, 3 April 1919, William H. Goodyear Collection, New York, Brooklyn Museum Archives 1.1.072 (General Correspondence: Porter, Arthur Kingsley), 1919. The sixty-three-page typescript article is preserved in the archives of the Brooklyn Museum: William H. Goodyear, "L'évasement de la cathédrale d'Amiens," William H. Goodyear Collection, New York, Brooklyn Museum Archives 2.1.003 (Research and Writings), ca. 1909.

30. Louis Demaison, review of "The Widening Refinement in Rheims Cathedral by William H. Goodyear," *Bulletin monumental* 71 (1907), 612.

31. Auguste Choisy, *Histoire de l'architecture*, 2 vols. (Paris: Gauthier-Villars, 1899), 2:410–12. Goodyear appears to have learned of Choisy's work from French archaeologist Camille Enlart in 1904 and soon began corresponding with the eminent authority. Camille Enlart to William H. Goodyear, 15 Aug. 1904, William H. Goodyear Collection, New York, Brooklyn Museum Archives 4.1.002 (Scrapbooks), 1904.

32. The *tas-de-charge* is a constructional technique in which the haunches of the main vaults were loaded with masonry to check the tendency of the vault to hinge and deform. Auguste Choisy to William H. Goodyear, 20 Jan. 1905, William H. Goodyear Collection, New York, Brooklyn Museum Archives 4.1.003 (Scrapbooks), 1905. Choisy made a presentation about Goodyear's work in 1907 to the Académie des Inscriptions et Belles-Lettres, published the same year: "Allure des lignes ascendantes dans les édifices gothiques," *Comptes rendus de l'Académie des Inscriptions et Belles-Lettres*, 23 (Aug. 1907), 492–93. Choisy was enthusiastic but noncommittal; he noted, in particular, that at the Cathedral of Reims, "there are bays in which the outward spread of the vaults over the piers that carry them is nearly 50 cm. If this spread is attributed exclusively to thrust [as opposed to an optical refinement], it supplies an indication of the sort of deformation that a vault can sustain without rupture and grave disorder." Choisy died in 1909, and his passing was a blow to Goodyear. See William H. Goodyear to Herbert Batsford, 7 Oct. 1909, William H. Goodyear Collection, New York, Brooklyn Museum Archives 1.1.003 (General Correspondence: Batsford, Herbert), 1909.

33. The first eight pages of his initial answer to Bilson, for example, were devoted not to the buildings but to the fact that Bilson had had the temerity to place the word *refinements* in quotation marks. Goodyear, "Architectural Refinements: A Reply to Mr. Bilson," 17–25. Statham, whom Goodyear considered "a malignant enemy" (William H. Goodyear to William Crocker, 9 Apr. 1912, Papers of Arthur Kingsley Porter, Cambridge, Mass.: Harvard University Archives HUG 1706.104, folder 2, 1912) and against whom he considered a libel suit, received a similar response, framed in sententious and surprisingly personal terms. See Goodyear, "The Glamour of Crooked Building," *American Architect*, no. 23 (Dec. 1905), 203–7; and Goodyear, "Architectural Refinements in French Cathedrals. Third Paper," 585–86. Statham's brief reply is printed here: Henry Heathcote Statham, "The Wrath of Professor Goodyear," *Builder* 90, no. 20 (1906), 61. Goodyear attempted to reinforce his position by citing the testimony of those

who had been, in his words, “converted to belief in the widening refinement”; see, in particular, William H. Goodyear, “The Controversial Aspects of the Architectural Exhibition at the Brooklyn Museum,” *American Architect* 97, no. 26 (1910), 45–56. The witnesses were of uneven quality. Choisy was the best among them—though his letters to Goodyear appeared in print with their fundamental objections excised. See, for example, William H. Goodyear, “The Controversial Aspects of the Architectural Exhibition at the Brooklyn Museum,” *American Architect* 97, no. 26 (1910), 45–56.

34. Arthur Kingsley Porter to William H. Goodyear, 10 July 1919, William H. Goodyear Collection, New York, Brooklyn Museum Archives 1.1.072 (General Correspondence: Porter, Arthur Kingsley), 1919.

35. Robert de Lasteyrie, “La cathédrale de Reims par Louis Bréhier,” *Journal des Savants*, March 1917, 99.

36. Choisy, “Allure des lignes ascendantes dans les édifices gothiques,” 493. Some hope that the documentary effort begun by Goodyear would be continued in a more systematic way was suggested by a notice in the *Building News and Engineering Journal* of 2 October 1908. “The Royal Commissioners of Historical Monuments of Belgium have undertaken the official examination of widening refinements in Mediaeval cathedrals. ... [Goodyear] has established a case which demands that further investigation should be made, and it is right that this should be done by important public bodies with ample funds at their disposal, in order that many buildings may be examined thoroughly, and the results compared.” “Our Office Table,” *Building News and Engineering Journal*, no. 2804 (1908), 494. Professor Louis Cloquet was charged with the task. Yet he studied only a few buildings and not, it seems, using Goodyear’s photographic technique. See Louis Cloquet, “Les raffinements architectoniques,” *Bulletin des commissions royales d’art et d’archéologie* 47 (1908), 270–90. Cloquet’s presentation at the annual meeting of the Royal Commission was immediately followed by one given by Canon René Maere, “‘Raffinements’ de l’architecture du Moyen Âge,” *Bulletin des commissions royales d’art et d’archéologie* 47 (1908), 294–335. Maere’s use of quotation marks around the word *raffinements* indicates his bent. The survey seems to have been abandoned, surely in part because of Maere’s strongly worded testimony.

37. See, in particular, Goodyear, “Architectural Refinements. Third Paper,” 569–90. For an analysis of these deformations, see Dany Sandron and Andrew Tallon, *Notre-Dame de Paris* (Paris: Parigramme, 2013), 90–93.

38. Goodyear lamented that his published photographs had been too small to permit proper study. “I must say quite frankly that the French are hardly to blame” for their rejection of the widening refinement, wrote Goodyear to Arthur Kingsley Porter on 3 April 1919. “They have never had any opportunity to become acquainted with its matter or its proofs.” The photographic techniques and the large-scale photographs were presented primarily in two great exhibitions, the first at the Scottish National Portrait Gallery in Edinburgh in 1905 and the second at the Brooklyn Museum in 1909. Goodyear to Porter, 3 Apr. 1919; see also William H. Goodyear, “Illustrations of the Widening Refinement in the Architectural Exhibition at the Brooklyn Museum,” *American Architect* 97, no. 16 (1910), 113–24.

39. See, for example, John Bilson, Harold Brakspear, and Charles Peers, “A Report to the Society of Antiquaries on Certain Repairs Now Being Undertaken at Durham Cathedral,” *Proceedings of the Society of Antiquaries of London*, 2nd ser., 28 (1916), 49–53, whose precise and perceptive analysis of the out-of-plumb deformation of the walls of Durham Cathedral was stimulated by Bilson’s recent experience with Goodyear; and André Masson, “Le bouclement des piliers de la croisée de Saint-Ouen de Rouen en 1441,” *Bulletin monumental* 85 (1926), 307–16.

40. Revelation 21:17, “mensura hominis quae est angeli.” Biblical translations are taken from the New American Bible, rev. ed. (Oxford: Oxford University Press, 2011).

41. Viollet-le-Duc, and Choisy after him, had used the term *élastique* to indicate that Gothic buildings were inherently flexible as they underwent a constant process of cracking and load redistribution while their foundations settled or as their walls were displaced by vault thrusts and wind, or damaged by rainwater. See, in particular, Eugène-Emmanuel Viollet-le-Duc, “De la construction des édifices religieux en France, depuis le commencement du christianisme jusqu’au XVI^e siècle (part 2b),” *Annales archéologiques* 2 (1845), 443–50; Eugène-Emmanuel Viollet-le-Duc, “Construction,” *Dictionnaire raisonné de l’architecture française du XI^e au XVI^e siècle*, 10 vols., vol. 4 (Paris: B. Bance, 1858); and Choisy, *Histoire*, 2:259–60. The concept of elasticity—a better term would have been *plasticity*—was the source of considerable misunderstanding. “When an expert like Choisy said that,” wrote Paul Frankl, “it is no wonder that whole generations of architects and art scholars calmly continued to live and theorize under Viollet-le-Duc’s influence, although they must have known that Gothic transverse arches, ribs, and vaults were not made of rubber.” Paul Frankl, *The Gothic: Literary Sources and Interpretations through Eight Centuries* (Princeton, N.J.: Princeton University Press, 1960), 577. See the response by Jacques Heyman, “On the Rubber Vaults of the Middle Ages and Other Matters,” *Gazette des Beaux-Arts*, 6th ser., 71 (1968), 182–83.

42. See Martin Bressani, “Resurrecting Gothic: Some Sources to Viollet-le-Duc’s Ideas,” in *Bautechnik des Historismus: Von den Theorien über gotische Konstruktionen bis zu den Baustellen des 19. Jahrhunderts*, ed. Uta Hassler, Christoph Rauhut, and Santiago Huerta (Munich: Hirmer, 2012), 118–29.

43. “Lapides vivi qui sunt, nisi fideles Dei?” Augustine of Hippo, *Enarrationes in psalmos* 44, Jacques-Paul Migne, Patrologia Latina Database, 36: 512. See Günther Binding, *Der früh- und hochmittelalterliche Bauberr als sapiens architectus* (Darmstadt: Wissenschaftliche Buchgesellschaft, 1998), 339–48; Dominique Iogna-Prat, *La Maison Dieu: Une histoire monumentale de l’Église au Moyen Âge (v. 800–v. 1200)* (Paris: Éditions du Seuil, 2006), 51; and Yves Congar, *L’église de saint Augustin à l’époque moderne* (Paris: Cerf, 1996), 18–24.

44. Iogna-Prat, *La Maison Dieu*, traces this evolution. See also Didier Méhu, “*Historiae et imagines*: De la consécration de l’église au Moyen Âge,” in *Mises en scène et mémoires de la consécration de l’église dans l’Occident médiéval*, ed. Didier Méhu (Turnhout: Brepols, 2008), 15–48; and Michel Lauwers, “‘Des pierres vivantes’: Construction d’églises et construction sociale dans l’Occident médiéval,” in *Matérialités et immatérialité dans l’église au Moyen Âge: Actes du colloque tenu à Bucarest les 22 et 23 octobre 2010*, ed. Stéphanie Diane Daussey et al. (Bucarest: University of Bucarest, 2012), 359–78.

45. “Ipsa vero ecclesia eam utique Ecclesiam designat, quae in ea continetur, id est multitudinem: unde etiam ecclesia vocatur, eo quod Ecclesiam contineat”; “haec ecclesia ex lignis, lapidibusque constructa, eam Ecclesiam designat, quae ex vivis lapidibus aedificatur.” Bruno von Segni, “Quid significet ecclesia,” *Tractatus de sacramentis ecclesiae*, Migne, Patrologia Latina Database 165: 1092A–B. Cited by Binding, *Der früh- und hochmittelalterliche Bauberr als sapiens architectus*, 389; see also Iogna-Prat, *La Maison Dieu*, 314 and 461–62.

46. Ephesians 2:22. On medieval architectural allegory in general see Edgar de Bruyne, *Études d’esthétique médiévale*, 2 vols. (Paris: Albin Michel, 1998), 1:672–740; Bruno Reudenbach, “Säule und Apostel: Überlegungen zum Verhältnis von Architektur und architekturexgetischer Literatur im Mittelalter,” *Frühmittelalterliche Studien* 14 (1980), 310–51; Binding, *Der früh- und hochmittelalterliche Bauberr als sapiens architectus*, 7–34 and 381–406; and Christiania Whitehead, *Castles of the Mind: A Study of Medieval Architectural Allegory*, Religion and Culture in the Middle Ages (Cardiff: University of Wales Press, 2003), particularly 49–60.

47. This prolific allegorical exploration was undertaken primarily in a series of Latin liturgical handbooks, written during the twelfth and thirteenth

centuries, which were designed to educate the clergy on the operations and interpretation of the sacraments and the divine office. See Whitehead, *Castles of the Mind*, 50–53.

48. “Grossiores vero lapides et politi seu quadrati, qui ponuntur alitrinsecus foris in quorum medio minores lapides iacent, sunt viri perfectiores qui suis meritis et orationibus continent infirmiores in sancta Ecclesia.” *Library of Latin Texts—Series A*, Brepols, http://clt.brepols.net/Itla_Corpus_Christianorum, *Continuatio Mediaevalis* 140: book I, chap. 1, para. 9, line 129. Durand takes his cue in particular from John Belet’s work of the same name (Migne, *Patrologia Latina* Database, 202: 13A–166C) and Hugh of Saint Victor’s *De sacramentis*, book 2, part V, sec. 1 (ibid., 176: 439B–C). For an English translation of the latter, see Hugues of Saint Victor, *Hugh of Saint Victor on the Sacraments of the Christian Faith (De Sacramentis)*, trans. Roy J. Deferrari (Cambridge, Mass.: Medieval Academy of America, 1951), 279.

49. On the constructional use of plumb lines in the Middle Ages, see Lon R. Shelby, “Medieval Masons’ Tools: The Level and the Plumb Rule,” *Technology and Culture* 2 (1961), 127–30, and Roland Bechmann, *Villard de Honnecourt: La pensée technique au XIII^e siècle et sa communication* (Paris: Picard, 1991), 65–66.

50. See, for example, the illumination of the Tower of Babel in the early thirteenth-century commentary on the Psalms in the Morgan Library, New York (MS 338, fol. 168v).

51. For example, the plumb bob is simply listed among the tools required by the mason in Richard of Saint Victor’s *Speculum doctrinale* and the *Dictionarius* of Jean of Garlande. Victor Mortet and Paul Deschamps, *Recueil de textes relatifs à l’histoire de l’architecture et à la condition des architectes en France, au Moyen Âge: XI^e–XIII^e siècles* (Paris: A. Picard, 1995), 2:22n3 and 277.

52. Hugh of Saint Victor, *The Didascalicon of Hugh of Saint Victor*, trans. Jerome Taylor (New York: Columbia University Press, 1991), 140. “Divinam Scripturam aedificio similem dixisse, ut primum fundamento posito structura in altum levetur, plane aedificio similem; nam et ipsa structuram habet. . . . Respice opus caementarii. Collocato fundamento lineam extendit in directum, perpendicularum demittit, ac deinde lapides diligenter politos in ordinem ponit; alios atque alios deinde quaerit: et si forte aliquos primae dispositioni non respondentes invenerit, accipit limam, praeeminentia praecidit, aspera planat, et informia ad formam reducit; sicque demum reliquis in ordinem dispositis adiungit.” Hugh of Saint-Victor, “De allegoria,” *Eruditionis didascalicae libri septem*, book 6, cap. 4. Migne, *Patrologia Latina* Database, 176: 802B–C.

53. “Tu ne sis iustus multum plus quam que necesse est, ne sapiuisse velis ne plus sapiendo stupescas; ut perpendicularum metitur opus faciendum, virtus iustitiae sic virtutum reliquarum est perpendicularum directa que linea morum.” Sigibert of Gembloux, *Commentarium in Ecclesiasten (fragmenta)*. *Library of Latin Texts—Series A*, fragment 3, p. 219, verse 219.

54. “Iustitiae linea virtutes illas dirigit stantes in medio vitiorum reduces utrinque, ut nihil illis desit, nihil inde supersit.” Rupert of Deutz, *In librum ecclesiastes commentarius*, chap. 3. Migne, *Patrologia Latina* Database, 168: 1263C.

55. 2 Kings 21:12–13. Verse 13: “Et extendam super Hierusalem funiculum Samariae et pondus domus Ahab et delebo Hierusalem sicut deleri solent tabulae delens vertam et ducam crebrius stilum super faciem eius.”

56. Isaiah 28:16–17. Verse 17: “Et ponam iudicium in pondere et iustitiam in mensura et subvertet grando spem mendacii et protectionem aquae inundabunt.” For an analysis of this passage, see J. J. M. Roberts, “Yahweh’s Foundation in Zion (Isa 28:16),” *Journal of Biblical Literature* 106, no. 1 (1987), 27–45, especially 43–44.

57. Isaiah 30:13. “Propterea erit vobis iniquitas haec sicut interruptio cadens et requisita in muro excelso quoniam subito dum non speratur venit contritio eius.”

58. Lamentations 2:8. “HETH cogitavit Dominus dissipare murum filiae Sion tetendit funiculum suum et non avertit manum suam a perditione luxitque antemurale et murus pariter dissipatus est.” The prophet Amos uses the term as follows: “Your land shall be parceled out by measuring line [*funiculus*], and you yourself shall die in an unclean land; and Israel shall be exiled from its land” (7:17).

59. Isaiah 34:11. “Et extendetur super eam mensura ut redigatur ad nihilum et perpendicularum in desolationem.”

60. “Super terram ardentem extendetur mensura, ut redigatur ad nihilum, quia peccatores aeternaliter ibi deficient secundum mensuram, qua Deus eorum poenas justo disponet iudicio. ‘Et perpendicularum in desolationem,’ id est in demolitionem, quia damnati ibi dissipabuntur, et discerpentur suppliciiis iuxta arbitrium iustitiae summi opificis. Perpendicularum enim vocatur, quo coementarii maceriam ad rectitudinem deducunt.” Hervé de Bourg-Dieu, *Commentariorum in Isaiam libri octo*, book 5. Migne, *Patrologia Latina* Database, 181: 327B–C.

61. Jeremiah 31:38–39. Verse 39: “Ecce dies veniunt dicit Dominus et aedificabitur civitas Domino a turre Ananehel usque ad portam Anguli et exhibit ultra norma mensurae in conspectu eius super collem Gareb et circuibit Goatha.”

62. As Walter Cahn writes in reference to Ezekiel 40:3, “The ‘line of flax’ in [the vision] is the implement of a stonemason. It assures a level coursing of the ‘living stones’ that make up the holy edifice—the Prophets, the Apostles, and their successors—and it symbolizes rectitude.” Walter Cahn, “Architecture and Exegesis: Richard of St.-Victor’s Ezekiel Commentary and Its Illustrations,” *Art Bulletin* 76, no. 1 (1994), 56.

63. Zechariah 1:15–16. Verse 16: “Propterea haec dicit Dominus revertar ad Hierusalem in misericordiis domus mea aedificabitur in ea ait Dominus exercituum et perpendicularum extendetur super Hierusalem.”

64. For example: Paris, Bibliothèque Sainte-Geneviève MS 1185, fol. 127v, and MS 15, fol. 185r; Paris, Bibliothèque Mazarine MS 9, fol. 166r; Bourges, Bibliothèque Municipale MS 6, fol. 241v; Reims, Bibliothèque Municipale MS 40, fol. 163v; Amiens, Bibliothèque Municipale MS 21, fol. 167v (Darius); New York, New York Public Library MS 7, fol. 209v; or Princeton, Princeton University Library MS Garrett 27, fol. 327v.

65. Zechariah 4:9–10. “Manus Zorobabel fundaverunt domum istam et manus eius perficient eam et scietis quia Dominus exercituum misit me ad vos quis enim despexit dies parvos et laetabuntur et videbunt lapidem stagnum in manu Zorobabel septem isti oculi Domini qui discurrunt in universa terra.”

66. “Spiritualiter Hierusalem est Ecclesia.” Haimo of Auxerre, *Ennaration in duodecim prophetas minores*. Migne, *Patrologia Latina* Database, 117: 225B. See Iogna-Prat, *La Maison Dieu*, 545–46.

67. “Ecclesiae autem suae pacem et misericordiam repromittit, et perpendicularum sive funiculum dicit extendendum in ea, id est mensuras et ordines singulorum qui sunt in Ecclesia, suis locis et temporibus pro meritorum qualitatibus distribuit.” Haimo of Auxerre, *Ennaration in duodecim prophetas minores*. Migne, *Patrologia Latina* Database, 117: 225C.

68. See Lauwers, “‘Des pierres vivantes,’” 368, and Abbot Suger, *Oeuvres: Écrit sur la consécration de Saint-Denis; L’oeuvre administrative; Histoire de Louis VI*, trans. Françoise Gasparri, 2 vols. (Paris: Les Belles Lettres, 2008), 1:190n69. For a critical examination of the theological underpinnings of Suger’s building, see Christoph Marksches, *Gibt es eine Theologie der gotischen Kathedrale? Nochmals: Suger von Saint-Denis und Sankt Dionys vom Areopag* (Heidelberg: Universitätsverlag Winter, 1995). On the human emulation of God in the act of creation, see de Bruyne, *Études d’esthétique médiévale*, 1:638; Binding, *Der früh- und hochmittelalterliche Bauberr als sapiens architectus*, 453–64; and Olivier Boulnois, *Au-delà de l’image: Une archéologie du visuel au Moyen Âge (V^e–XVI^e siècle)* (Paris: Éditions du Seuil, 2008), 336–62.

69. "Medium quippe duodecim apostolorum exponentes numerum, secundario vero totidem alarum columnae prophetarum numerum significantes, altum repente subrigebant aedificium juxta apostolum spiritualiter aedificantem. Jam non estis, inquit, hospites et advenae, sed estis cives sanctorum et domestici Dei, superaedificati super fundamentum apostolorum et prophetarum, ipso summo angulari lapide Christo Jesu, qui utrumque conjungit parietem, in quo omnis aedificatio sive spiritualis, sive materialis crescit in templum sanctum in Domino. In quo et nos quanto altius, quanto aptius materialiter aedificare instamus, tanto per nos ipsos spiritualiter coaedificari in habitaculum Dei in Spiritu sancto edocemur." Migne, *Patrologia Latina Database*, 186: 1247D–1248A. Translated by Erwin Panofsky in Abbot Suger, *Abbot Suger: On the Abbey Church of St.-Denis and Its Art Treasures*, ed. Erwin Panofsky and Gerda Panofsky-Soergel, 2nd ed. (Princeton, N.J.: Princeton University Press, 1979), 105, with modifications following Suger, *Oeuvres*, 33. Italics indicate the portions of Suger's text taken directly from Ephesians 2:19–22. For a discussion of this passage see Günther Binding, "Beiträge zum Gotik-Verständnis bei Abt Suger von Saint-Denis," in *Beiträge zum Gotik-Verständnis*, ed. Günther Binding, 2nd ed. vol. 53, *Veröffentlichungen der Abteilung Architekturgeschichte des Kunsthistorischen Instituts der Universität zu Köln* (Cologne: Abt. Architekturgeschichte, 1995), 109–11.

70. For further discussion of this idea see Laurence Hull Stookey, "The Gothic Cathedral as the Heavenly Jerusalem: Liturgical and Theological Sources," *Gesta* 8, no. 1 (1969), 35–41; Robert Suckale, "La théorie de l'architecture au temps des cathédrales," in *Les bâtisseurs des cathédrales gothiques*, ed. Roland Recht (Strasbourg: Les Musées de la Ville de Strasbourg, 1990), 41–50; Peter Kurmann, "La cathédrale gothique est-elle l'image de la Jérusalem Céleste?," in *Le monde des cathédrales: Cycle de conférences organisé par le Musée du Louvre du 6 janvier au 24 février 2000*, ed. Roland Recht (Paris: Documentation française, 2003), 41–56; and Christoph Marksches, "Neue Forschungen zur 'Theologie der gotischen Kathedrale,'" in *Theologie und Kosmologie*, ed. Jürgen Hübner, Ion-Olimpiu Stamatescu, and Dieter Weber, Religion und Aufklärung (Tübingen: Mohr Siebeck, 2004), 184–208.

71. "Ipsos lapides insensibiles in aliam transformant naturam, dum domum manufactam per consecrationem habitaculum facium trinitatis et angelorum." Bonizo of Sutri, *Liber de vita christiana*, cited by Iogna-Prat, *La Maison Dieu*, 415–16. Bishop Ivo of Chartres (ca. 1040–1115) wrote of the church building that "once erected and once become as one stone through the binding of the mortar, so that it might merit the name and attendant honor of the Temple of God, and so that the sacrament of baptism required to create a new people might be accomplished therein, is first baptized for its own sake in order to consecrate [it] to the holiness of multiple sacraments." Ivo of Chartres, "Sermo IV: De sacramentis dedicationis," *Sermones de ecclesiasticis sacramentis et officiis*. Migne, *Patrologia Latina Database*, 162: 528D–529A. Cited by Iogna-Prat, *La Maison Dieu*, 472–73.

72. Timothy M. Thibodeau, *The Rationale Divinorum Officiorum of William Durand of Mende: A New Translation of the Prologue and Book One* (New York: Columbia University Press, 2010), 70. "... quod contigit primo si fuerit combusta ita quod parietes omnes, uel eorum maior pars, fuerint decrustati [et] secundo, si tota ecclesia aut eius maior pars simul funditus corruerit et ex toto siue ex eisdem siue ex aliis fuerit lapidibus reparata; consecratio etenim ecclesie maxime in exteriori unctione et in lapidum coniunctione et dispositione consistit." *Library of Latin Texts—Series A, Corpus Christianorum, Continuatio Mediaevalis* 140: book 1, chap. 6, para. 31, lines 362 and 370. For the equivalent as recorded in the Roman Pontifical, see Michel Andrieu, *Le Pontifical romain au Moyen-Âge. Tome I: Le Pontifical romain du XII^e siècle*, 4 vols., Studi e testi (Vatican City: Biblioteca Apostolica Vaticana, 1938), 1:195–97, and Michel Andrieu, *Le Pontifical romain au Moyen-Âge.*

Tome II: Le Pontifical de la Curie romaine au XIII^e siècle, 4 vols., Studi e testi (Vatican City: Biblioteca Apostolica Vaticana, 1940), 2:443–45.

73. Thibodeau, *Rationale Divinorum Officiorum*, 71. Italics mine. "... quoniam forma est esse rei." *Library of Latin Texts—Series A, Corpus Christianorum, Continuatio Mediaevalis* 140: book I, chap. 6, para. 34, line 414.

74. Long neglected by restoration architects and scholars, the practice has begun to be placed in its proper context. See Jürgen Michler, "La cathédrale Notre-Dame de Chartres: Reconstitution de la polychromie de l'intérieur," *Bulletin monumental* 147 (1989), 117–31, especially 124–28; Géraldine Victoir, "La polychromie et l'apport de son étude à la connaissance de l'architecture gothique," in *Architecture et sculpture gothiques: Renouveau des méthodes et des regards*, ed. Arnaud Timbert and Stéphanie Diane Daussey, Art et Société (Rennes: Presses Universitaires de Rennes, 2012), 121–35; and most recently, Arnaud Timbert, "Recevoir et produire la lumière: La polychromie d'architecture (XII^e–XVI^e s.)," in *De verres et de pierres: La lumière dans l'architecture du Moyen Âge*, ed. Nicolas Reveyron (forthcoming); and Jean-Paul Deremble, "Nouvelles perceptions de la Lumière dans la cathédrale de Chartres restaurée," in *Chartres: construire et restaurer la cathédrale (XI^e–XXI^e s.)*, ed. Arnaud Timbert, Art et Société (Lille: Presses Universitaires de Septentrion, forthcoming).

75. "... passim candidam ecclesiarum vestem indueret." Mortet and Deschamps, *Recueil*, 4. See Deremble, "Nouvelles perceptions de la Lumière."

76. Deremble, "Nouvelles perceptions de la Lumière"; see also Jérôme Baschet, *L'iconographie médiévale* (Paris: Folio, 2008), 81.

77. "In eadem vero ecclesia nulla scissura, vel corruptio invenitur; mirabiliter operatur, magna, spaciosa, clara, magnitudine condencenti latitudine longitudine et altitudine congruenti, miro et ineffabili opere habetur." Alison Stones, Paula Gerson, and Jeanne Krochalis, eds., *The Pilgrim's Guide: A Critical Edition*, 2 vols. (London: Harvey Miller Publishers, 1998), 2:68–71.

78. See Andrew Tallon, "Rethinking Medieval Structure," in *New Approaches to Medieval Architecture*, ed. Robert Bork, William Clark, and Abby McGehee (Farnham, UK: Ashgate, 2011), 209–17.

79. Although discussions would regularly surface in the unpublished reports of restoration architects, the concept of reading Gothic deformation only rarely surfaces in print. See, for example, Léon Biet, "Eglise Notre-Dame de Laon: Rapport du 20 juin 1846," in *Exposition Universelle de Vienne en 1873: Section française; Les Monuments historiques de la France à l'exposition universelle de Vienne*, ed. Edmond du Sommerard (Paris: Imprimerie Nationale, 1876), 116–35; Bilson, Brakspear, and Peers, "A Report to the Society of Antiquaries," 49–53; Masson, "Le bouclement des piliers"; Pol Abraham, "Viollet-le-Duc et le rationalisme médiéval," *Bulletin monumental* 93 (1934), 69–88, especially 83; Jean-Pierre Paquet, "Structures des monuments anciens et leur consolidation," *Monuments Historiques de la France*, no. 1 (1957), 169; in a more popular vein, François Loyer, "Notre-Dame lavée," *L'oeil* 208 (1972), 12–23 and 50; and Norbert Bongartz, *Die frühen Bauteile der Kathedrale in Troyes: Architekturgeschichtliche Monographie* (Stuttgart: Hochschul-Verlag, 1979), 110–21. Photogrammetric surveys were undertaken for a number of French Gothic buildings in the 1970s and 1980s (see Jean-Paul Saint-Aubin, ed., *Répertoire des photographies d'architecture de l'Inventaire* [Paris: Ministère de la culture, Direction du patrimoine, 1984]) but were little used outside of geometrical studies such as Dominic Boulérice, "Géométrie et construction des voûtes d'ogives au XII^e siècle: Les voûtes de l'abbé Suger à Saint-Denis (Seine-Saint-Denis)," in *Carriers et bâtisseurs de la période préindustrielle*, ed. Jean-Pierre Gély and Jacqueline Lorenz (Paris: Éditions du Comité des travaux historiques et scientifiques, 2011), 73–84. Recent deformation analysis of Gothic buildings has been almost exclusively confined to questions of conservation, independent of historical considerations; see, for example, Julia Armesto

et al., "Monitoring and Assessing Structural Damage in Historic Buildings," *Photogrammetric Record* 23 (2008), 36–50, and Pere Roca et al., "Monitoring of Long-Term Damage in Gothic Cathedrals," in *Structural Studies, Repairs and Maintenance of Heritage Architecture VIII (STREMAH) 2003*, ed. C. A. Brebbia (Southampton, UK: WIT Press, 2003), 109–19.

80. On 8 April 1572, for example, Parisian master masons Gilles de Harlay and Nicolas Tiersault made use of plummets to document the alarming deformations in the crossing piers of the cathedral of Beauvais, which were buckling under the weight of the tower being erected above. They had reason to be concerned: the tower collapsed the following year (Stephen Murray, *Beauvais Cathedral, Architecture of Transcendence* [Princeton, N.J.: Princeton University Press, 1989], 146). It might be tempting to credit English scholar Alexander Neckham (1157–1217) with a similar documentation of the spreading supports of a Gothic building. "One must understand," wrote Neckham in chapter 172 of *De naturis rerum*, "that no walls, even those built of wooden beams, are parallel. . . . For it is inevitable that the farther the walls rise from the earth, the greater will the distance between them be found to be." Neckham, however, speaks not of deformation due to the thrust of Gothic vaults but rather the Aristotelian notion that gravity acted toward the center of a curved earth, which implied that two objects placed with plumb bobs perpendicularly to the earth's surface could not be in parallel. The effect is in fact entirely negligible. See Victor Mortet, "Hugue de Fouilloi, Pierre le Chantre, Alexandre Neckam et les critiques dirigées aux XII^e siècle contre le luxe des constructions," in *Mélanges d'histoire offerts à M. Charles Bémont par ses amis et ses élèves à l'occasion de la XXV^e année de son enseignement à l'École Pratique des Hautes Études* (Paris: Librairie Félix Alcan, 1913), 130–34. Translation by Margaret Taylor, in Teresa G. Frisch, *Gothic Art, 1140–ca. 1450: Sources and Documents* (Toronto: University of Toronto Press in association with the Medieval Academy of America, 1987), 31.

81. For example, Robert Mark and William Clark, "Gothic Structural Experimentation," *Scientific American* 251, no. 5 (1984), 176–85. For further discussion of the structure of the cathedral see Andrew Tallon, "La structure de la cathédrale de Chartres," in *Chartres: Construire et restaurer la cathédrale (XI^e–XXI^e s.)*, ed. Arnaud Timbert (Lille: Presses Universitaires de Septentrion, 2013).

82. See Robert Branner, *Chartres Cathedral*, Norton Critical Studies in Art History (New York: W. W. Norton, 1969), 84–85.

83. The laser survey was funded by the Andrew W. Mellon Foundation in the context of the Mapping Gothic France project (mappinggothic.org), undertaken by the author in collaboration with Stephen Murray of Columbia University. I would like to thank the following people for their assistance: Nicole Griggs and Antoine Billault; Gilles Fresson and Dominique Baudry; Benjamin Outrey of Leica Geosystems; Joshua Sakolsky; and Patrice Calvel, Jean-Pierre Blin, Pascal Chauveau, and Xavier Clarke de Dromantin.

84. The laser survey, undertaken by the author, was funded by the Samuel Kress Foundation. I am grateful to the following people for their assistance: Columbia University professor Peter Allen and his then students Paul Blaer, Matei Ciocarlie, and Chase Hensel; Patrick Ponsot; and Jean-Pierre Blin and Pascal Chauveau.

85. For further discussion of the structure of the cathedral of Bourges, see Andrew Tallon, "La perpendicularité: Vers une perfection architecturale," in *La cathédrale Saint-Étienne de Bourges: Actes du colloque du 12 octobre 2012*, ed. Sylvie Marchant and Irène Jourd'heuil (forthcoming).

86. Ibid. and Maxime l'Héritier, Adrien Arles, and Bernard Gratuze, "Étude archéologique et archéométallurgique des chaînages de fer de la cathédrale Saint-Étienne de Bourges," in Marchant and Jourd'heuil, *La cathédrale Saint-Étienne de Bourges*.

87. See Hans Sedlmayr, *Die Entstehung der Kathedrale* (Graz, Austria: Akademische Druck u. Verlagsanstalt, 1976), 59–61. Branner called it a "total space" (Robert Branner, "Encore Bourges," *Journal of the Society of Architectural Historians* 25, no. 4 [1966], 299–300), and a "vast and airy universe" (Robert Branner, *The Cathedral of Bourges and Its Place in Gothic Architecture*, ed. Shirley Prager Branner [Cambridge, Mass.: MIT Press, 1989], 103).

88. Francis Salet, "Notre-Dame de Paris, état présent de la recherche," *La sauvegarde de l'art français* 2 (1982), 102. On the sectional triangularity of Bourges see Peter Kidson, "Bourges after Branner," *Gesta* 39, no. 2 (2000), 156, and Andrew Tallon, "Divining Proportions in the Information Age," in *Proportional Systems in the History of Architecture*, ed. Matthew Cohen (forthcoming).

89. Jürgen Michler described the elevation at Bourges in the terms of a modern steel-frame building of overpowering verticality where the wall is reduced to a mere "filler" in a chassis of *durchdringende Pfeiler*—columns that penetrate without interruption to the vaults, surrounded by colonnette "force lines." Jürgen Michler, "Zur Stellung von Bourges in der gotischen Baukunst," *Wallraf-Richartz Jahrbuch* 41 (1980), 30–31 and 40. See also Roland Recht, *Le croire et le voir: L'art des cathédrales (XII^e–XV^e siècle)* (Paris: Gallimard, 1999), 208.

90. See Branner, *The Cathedral of Bourges*, 101 and 229n41.

91. William H. Goodyear, *Exhibition of Enlarged Photographs of French Cathedrals and Churches in the War Zone, with Explanatory Notes Relating to Their Refinements of Construction* (Brooklyn: Brooklyn Museum, 1918); and William H. Goodyear, "Architectural Refinements in Medieval French Cathedrals as Related to the Question of Repairs or Restoration in the War Zone," *American Journal of Archaeology* 23, no. 1 (1919), 71–72. When Goodyear, in a decidedly Ruskinian mode (see John Ruskin, *The Seven Lamps of Architecture*, "The Lamp of Memory," § XVIII–XX, 180–83), began to advise architects to abandon their attempts to repair buildings despite signs that indicated real problems, the stakes were no longer just intellectual. After a photographic survey of the Hagia Sophia in 1914, for example, Goodyear declared that the building's notorious nonrectilinearity was in fact the result of a series of refinements, and concluded that the building, despite signs to the contrary, should be considered structurally sound because it was intended to look this way. See Henry Browne, "A Practical Aspect of Refinement in Medieval Architecture," *Studies: An Irish Quarterly Review* 13, no. 1 (1914), 132–33. Today's architectural engineers—the successors of those who, in Browne's view, were "so far from understanding the secrets of its beauty that they mis[took] them for faults of construction, or at least the decay of the long ages" (133)—continue to struggle to understand the building's state of equilibrium, compromised precisely because of extremely rapid construction and subsequent deformation, in the face of potential seismic activity. See, for example, Robert Mark and Ahmet S. Çakmak, eds., *Hagia Sophia from the Age of Justinian to the Present* (Cambridge: Cambridge University Press, 1992) and Rowland Mainstone, *Hagia Sophia: Architecture, Structure and Liturgy of Justinian's Great Church* (London: Thames and Hudson, 1997). Yet even if based on a fundamental misunderstanding of the building, the red flag raised by Goodyear was of critical importance: it delayed what might well have been a disastrous restoration until more advanced and appropriate means were in place for the proper care of the building. This paradox is perhaps best illustrated by the example of the church of San Marco in Venice, whose story can be followed in the pages of one of Goodyear's scrapbooks: William H. Goodyear, "Exhibits Relating to Architectural Refinements III (scrapbook)," William H. Goodyear Collection, New York, Brooklyn Museum Archives 4.1.003 (Scrapbooks), 1904–5. A clipping from the 16 December 1904 *New York Herald* announced: "Official Aid for St. Mark's: Arches and Cupola Found to Be in a Particularly Bad State Owing

to Subsidence. Chains and Girdles Wanted. Walls in Lamentable Condition and Foundations in Need of Immediate Strengthening." The next day: "To Repair St. Mark's at Once. Italian Government Orders Work to Be Begun for Preservation of Cathedral of Venice." And the following day: "St. Mark's, Venice, to Be Preserved. Damage Prevented from Becoming Worse and Restoration Will Give It New Lease on Life." But on 29 December the story changed dramatically: "St. Mark's Not in Danger. Architect Grateful for Letter of Mr. William H. Goodyear in Favor of Venice Basilica." A clipping from the *Brooklyn Daily Eagle* of 9 January 1905 supplies the details: "An antiquarian memoir published by the Brooklyn Museum has saved the Italian Government the expenditure of a very considerable sum of money, and that it has preserved St. Mark's, at Venice, from an unnecessary reconstruction, which would have involved the destruction of the hitherto unrecognized source of the building's greatest charm and beauty"—that is, the "inclinations of the vertical members." "Professor Goodyear Talks on the Safety of St. Mark's," *Brooklyn Daily Eagle*, 9 Jan. 1905, 136–38. See also William H. Goodyear, *The Architectural Refinements of St. Mark's at Venice, with Remarks on Other Churches Showing a Similar System of Leaning Verticals* (New York: Macmillan, 1902).

92. See Roger Gilman, "The Theory of Gothic Architecture and the Effect of Shellfire at Rheims and Soissons," *American Journal of Archaeology* 24, no. 1 (1920), 37–72. For a similar example after the Second World War, see Albert Chauvel, "La cathédrale de Rouen: Les destructions, le sauvetage," *Monuments Historiques de la France*, n.s., 2, no. 2 (1956), 55–92.

93. See E. Bruce Glenn, *Bryn Athyn Cathedral: The Building of a Church* (Bryn Athyn, Pa.: Bryn Athyn Church of the New Jerusalem, 1971), 59–72; and Raymond Pitcairn to William H. Goodyear, 7 Nov. 1917, Papers of Arthur Kingsley Porter, Cambridge, Mass.: Harvard University Archives HUG 1706.104, folder 7, 1917.

94. William H. Goodyear to William Crocker, 8 Oct. 1919, William H. Goodyear Collection, New York: Brooklyn Museum Archives 1.1.017 (General Correspondence: Crocker, William), 1919.

95. Robb, who had just seen the church at Bryn Athyn, wrote that he was "thoroughly convinced that no small amount of its charm [was] due to the horizontal and vertical curvatures." Donald Robb to William H. Goodyear, 7 Nov. 1919, William H. Goodyear Collection, New York, Brooklyn

Museum Archives 1.1.027 (General Correspondence: Frohman & Robb), 1919.

96. Architects George Heins and Christopher Grant LaFarge also incorporated refinements—subtle variations in the size of the arcades—in the choir of the Cathedral of Saint John the Divine in New York City, inspired by Goodyear's early work. See William H. Goodyear, "Temperamental Architecture in the New York Cathedral Church of St. John the Divine," *Architect & Contract Reporter*, no. 19 (1911), 314–16, and "Temperamental Architecture in the Cathedral Church of St. John the Divine, New York," *New York Architect* 5, no. 4 (1911), 41–53.

97. Goodyear responded to Robb immediately (his seven-page letter is dated only three days later); included was a series of his articles in bound volumes. Subsequent communications between the two reveal that plans were being made to have an exposition of Goodyear's photographs in Washington; that Arthur Kingsley Porter had returned from a year's stay in France and reported that "the widening refinement [is] practically universal in the French Gothic churches"; and that Robb, on 12 June 1920, wondered about the lack of any discernible pattern in the irregularity of the tribune intercolumniation at the cathedral of Paris, which Goodyear had considered intentional. In this climate of acceptance and even celebration of his work, Goodyear acknowledged for the first time, if somewhat elliptically, that in fact not all "spatial variations" such as those at Notre-Dame were aesthetic in origin—the nearest thing to an admission of error that has surfaced in the documents. See the William H. Goodyear Collection, New York, Brooklyn Museum Archives 1.1.027 (General Correspondence: Frohman & Robb).

98. Philip Hubert Frohman to George C. F. Bratenahl, 29 Nov. 1919, William H. Goodyear Collection, New York, Brooklyn Museum Archives 1.1.027 (General Correspondence: Frohman & Robb), 1919. On the Goodyear-inspired modifications made to the cathedral, see Christopher Dean Hamilton Row, "World without End: Philip Hubert Frohman and the Washington National Cathedral" (PhD thesis, Harvard University, 1999), 138–49 and 188–99.

99. L. Ingleby Wood, "Medieval Architectural Refinements," *Burlington Magazine*, Dec. 1905, 184. See in particular T. J. Jackson Lears, *No Place of Grace: Antimodernism and the Transformation of American Culture, 1880–1920* (Chicago: University of Chicago Press, 1994).