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From a Geometry of Vision to a Geometry of Light in Early-Modern Perspective

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How to cite: Fowler, C. O. 'From a Geometry of Vision to a Geometry of Light in Early-Modern Perspective.' *Architecture_MPS*, 2017, 11(*1*): 1. DOI: https://doi.org/10.14324/111.444.amps.2017v11i1.001.

Published: 01 January 2017

Peer Review:

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Architecture_media_politics_society. vol. 11, no. 1.

January 2017

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Abstract

Must the architect or artist understand how the world is perceived on the convex surface of the eye to simulate the three-dimensional world on a two-dimensional plane? For many early-modern artists, optics – defined as the science of vision – was fundamental. Yet, for architects, the integration of optical theories into two-dimensional representations of buildings remained more tenuous. Architectural drawing depended on orthographic projection and the representation of built form through plan, section and elevation, which did not seek to mimic the process of vision. If anything, architectural drawing separated itself from the illusion of vision in its attempt to account for the discrepancies between the represented and the built form. Nevertheless, the shifting science of optics would come to influence the two-dimensional representation of the built world for both architects and painters.

This essay covers a broad survey of perspectival treatises from the fifteenth to the eighteenth century in order to consider how changes in the science of optics shifted the means by which artists and architects theorized the representation of space and the simulated illusion of perspective. As will be seen, the seemingly innocuously obvious geometric parts for the creation of perspectival space – the Euclidean point and line – became obsolete in the eighteenth century due to fundamental shifts in the science of optics. Whereas once optics was a study of vision through points and lines, in the seventeenth century with the works of Johannes Kepler (1571–1630) and René Descartes (1596–1650), among many others, optics transformed into a study of light. As light rather than

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vision became the focus of optics and its geometrical laws, the connection between a geometry of vision and a geometry of spatial representation became challenged. When light – not vision – became subject to the laws of geometry, the eye became one instrument among many (lenses, camera obscuras, microscopes and telescopes) capable of deception and fault. In turn, geometry lost its intellectual and metaphysical resonances and became a practical tool of application. The influence of the visioning technology of geometry on perspectival drawing for both the built and the figurative world lost its theoretical foundation. No longer a technology of vision, the art of geometry became reduced to non-theoretical rudimentary forms for beginning draftsmen.

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Introduction

Must the architect or artist understand how the world is perceived on the convex surface of the eye to simulate the three-dimensional world on a two-dimensional plane? For many early-modern artists, optics – defined as the science of vision – was fundamental. Yet, for architects, the integration of optical theories into two-dimensional representations of buildings remained more tenuous. Architectural drawing depended on orthographic projection and the representation of built form through plan, section and elevation, which did not seek to mimic the process of vision. If anything, architectural drawing separated itself from the illusion of vision in its attempt to account for the discrepancies between the represented and the built form. Nevertheless, the shifting science of optics would come to influence the two-dimensional representation of the built world for both architects and painters.

This essay covers a broad survey of perspectival treatises from the fifteenth to the eighteenth century in order to consider how changes in the science of optics shifted the means by which artists and architects theorized the representation of space and the simulated illusion of perspective.[1] As will be seen, the seemingly innocuously obvious geometric parts for the creation of perspectival space – the Euclidean point and line – become obsolete in the eighteenth century due to fundamental shifts in the science of optics. Whereas once optics was a study of vision through points and lines, in the seventeenth century, with the works of Johannes Kepler (1571–1630) and René Descartes (1596–1650), among many others, optics transformed into a study of light. As light rather than vision became the focus of optics and its geometrical laws, the connection between a geometry of vision and a geometry of spatial representation became challenged. When light – not vision – became subject to the laws of geometry, the eye became one instrument among many (lenses, camera obscuras, microscopes and telescopes) capable of deception and fault. In turn, geometry lost its intellectual and metaphysical resonances and became a practical tool of application. The influence of the visioning technology of geometry on perspectival drawing for both the built and the figurative world lost its theoretical foundation. No longer a technology of vision, the art of geometry became reduced to non-theoretical rudimentary forms for beginning draftsmen.

Alberti and Rays of Vision

To stimulate the eye to conceive of an extended world on a flat panel, the artist must know, or think he comprehends, how the eye works. The first artists who attempted to master and teach this art of "seeing through" relied upon an optics based in Euclidean geometry and late-medieval optical treatises. According to this optical tradition, vision occurred as species traveled in "rays of vision" between the object and the eye. Central to these medieval geometrical optical theories of vision was the concept of species, the minute bodies that traveled between the object and the senses. The species at once guaranteed an exact image, while making it impossible to "know the thing itself" as the endlessly replicating species mediated between the perceiver and the world.[2] Equipped with ideas of species and rays of vision, artists constructed perspectival processes that acted out the process of vision in the material world.

Beginning with Alberti's treatise on painting, *De pittura* (1435), most major works on perspective until the middle of the seventeenth century introduce perspective and the simulation of spatial representation with the point and the line. Species moved along lines, which were considered rays of vision between object and eye. In turn, these linear rays of vision converged in the single point of the eye's surface. This foundation in Euclidean points and lines established perspective as an art that bridged the sensible and the suprasensible worlds. For in Euclidean geometry, points and lines can only exist as intellectual forms. Euclid defined the point as "that which has no parts" and the line as "length without breadth."[3] Once a point or a line takes shape with a little bit of ink on a page, the point becomes divisible and the line takes on breadth. No matter how minute the size of the point or how fine the breadth of the line, once points and lines materialize they lose their mathematical perfection. In short, points and lines not only visualized intellectual geometric forms but also the invisible traces of vision.

In *De pittura*, Alberti articulated this process of vision to elucidate his explanation of perspective, describing sight as visual rays that transmit images of the object to the eye. He materialized these invisible rays of sight as "extremely fine threads, connected as straight as they can [be] in a single extremity as in a bundle and accepted in the same place and at the same moment inside the eye, where the sense of sight resides."[4] Vision was "a pyramid of rays." The base of the pyramid was the visible surface. The visual rays formed the side of the pyramid. The apex of the pyramid met in the eye. This triangular process of vision mapped onto the painter's panel. The artisans' lines demarcating perspective became the materialization of the invisible visual rays along which species traveled between object and eye. In turn, this bundle of lines converged in the center of the eye, its point. As scholars argue, Alberti innovated in using medieval optical theory to describe perspective.[5] The ambiguity of Euclidean points and lines as intellectual constructs that lost their essential qualities once realized as visible constructs allowed for Alberti to balance two forms of knowledge and vision: one that remains in the intellect and the other that pertains to the visible world. While scholars have focused on Alberti's use of points and lines in painting, there has been less attention to his utilization of non-physical points and lines for the intellectual world of the architect.

In the opening to *De re aedificatoria* (1443–1452), Alberti likened a building to a "form of body," a corporeal structure made of "lineaments and matter."[6] As the body united flesh and soul, so the architectural structure interwove the material and the immaterial. For Alberti, these lineaments that composed the structure were immaterial products of thought intrinsic to the building's composition. Lines (the geometrical parts that compose angles) and matter created a structural edifice. Alberti's lines and lineaments guided a structure composed of stone, wood and mortar. Lineaments were "nothing material" but "of such sort that we perceive that there are the same lineaments in many buildings when we perceive the same form in them, i.e. that individual parts, as well as the placement and order of individual parts, correspond mutually in all angles and lines."[7] Architectural lineaments were lines that could be "conceived in the rational soul and perfected by the rational soul and the learned *ingenium*."[8] Like the Euclidean line, the lineament was an intellectual construct. Lineaments were both the structural lines of buildings and the immaterial supporting structure of design.[9] These lineaments were the intellectual abstractions materially realized in orthogonal projections and the built form itself. In *De re aedificatoria*, Alberti warned architects to use only linear drawings (plans and elevations) in orthogonal projection with no shading, and to avoid the use of painter's one-point perspective which could distort the accuracy of measurements necessary for the architect.[10]

In his two separate treatises on painting and architecture, Alberti outlined two different ways to represent the extended world on a two-dimensional plane. Both forms of representation relied upon Euclidean points and lines. Yet the painter's perspective simulated vision. By contrast, Alberti used the Euclidean line as the basis for his *lineamenta* and the intellectual form in the mind of the architect. Here, points and lines do not mirror the process of vision but the act of intellectual abstraction, as the architect conceives of the built form mentally with the *lineamenta*. Alberti's separation, however, between these two means of representation through points and lines becomes obscured in later perspectival treatises. The art of perspective takes on a formative role in architectural treatises as architects increasingly rely on one-point perspective for their architectural representations and the role of light and shadow in architectural drawings gains importance. Moreover, shading and an embrace of vision's deceptive qualities become intrinsic to two-dimensional representations of the built environment as vision is increasingly understood in relation to light as opposed to Euclidean points and lines.

Geometries of Vision

The role of points and lines as technologies of vision continues throughout Italian Renaissance perspectival treatises. Alberti's intellectual engagement with making sensible forms that only exist in the intellect – Euclidean points and lines – continued to influence writings on perspective. This ambiguous role of the line as both a material and an immaterial entity continued in *Le due regole della prospettiva pratica* first written by the Italian painter–architect Vignola (1507–1573) and later extensively edited by the Dominican Egnatio Danti (1536–1586). In his definition of perspective, Vignola reduced perspective to a study of lines: "Here perspective stands for all the things that are represented by lines in paintings or drawings."[11] Danti took Vignola's definition of the line and expanded on it, considering the ambiguous qualities of the line as both the intellectual and material tool for the artist.[12] As Danti wrote: "Perspective considers the line that is a thing both natural and sensible, that which has the quality of width. This line comes from the imagination of the geometric line."[13] Here Danti acknowledged that the lines of perspective are sensible lines born from the "geometric line," which was invisible and could only exist in the imagination. While the first definition of perspective defined it as a science of the line, the proceeding definitions demonstrate the integral interplay among points, lines and eyes. In the second definition, Danti described the point as the "smallest greatness that cannot be divided."[14] For the third definition, Danti elucidated the line, which unfolds from the point. This intellectual line existed as "length with so little breadth that is cannot sensibly be divided."[15] These lines that represent all things first exist in the imagination as intellectual and immaterial geometrical entities that cannot be divided. It is only when they take on sensible qualities in the art of perspective that they may be divided. The fourth definition then expanded on these points and lines to consider them, not only as mathematical entities, but also as integral to the process of vision. Danti described in the fourth definition the center of the eye (*centro dell'occhio*) and its crystalline humor.[16] In this center, the rays of vision culminate in the point, where perfect vision forms.[17] Perspective is "all things represented by lines" because vision itself is a linear process. Points and lines defined both the art of perspective and vision. In its use of points and lines, perspective materializes both the geometric entities that can only exist in the imagination and the invisible rays and points of vision. In this way, although orthogonal drawings may defer the perspectival illusionism of painting, they are nevertheless composed of the Euclidean points and lines that utilize the abstract quality of Euclidean forms to move between the intellect and the material world of representation.

This geometrization of vision and the tenuous relationship between things seen in the sensible world and things unseen in the mathematic realm continue to structure the writings on perspective and the representation of space in the treatises north of the Alps. In the treatise of the humanist and architectural theorist Walther Hermann Ryff (ca. 1500–1548), *Furnembsten, notwendigsten, der gantzen Arhictectur angehörigen mathematischen und mechanischen Kunst* (1547), Ryff commenced with the point and the line to structure space. Again, Ryff began with points and lines because these Euclidean forms defined both perspective and optics, an understanding based on a geometrization of vision. Influenced by Alberti's writings, Ryff's ideas resonate with Alberti's attempt to materialize intellectual geometry in the production of perspective. Like Alberti, Ryff distinguished between the invisible and intellectual world of the mathematician and the visible domain of the painter–architect: "Whereas the learned (*kunstreich*) mathematician is only mentally involved in the construction of the various classes and forms of things, ignoring their material reality, we shall present the subjects we treat thereof as visible and perceptible."[18] He engaged the reader in this ambiguous territory with his opening definitions of the point and the line: "Following after the mathematicians, there is a point that is the smallest, most pure, subtle mark that man can with his senses understand or realize."[19] Ryff discussed the fundamental role of the point in the construction of perspective: "And first one should note what a point is, namely a sign that is invisible that painters and similar artists need for perspective. The ground of this art takes its beginning from making what is invisible visible."[20] Geometric points and lines both mirror the process of vision with its rays of vision hitting the central point of the eye's crystalline humor and they also embody the ability of the artisan to bridge the intellectual world of forms and their visible materialization.

Tracing the Endpoint of a Geometry of Vision

While citations of treatises that begin with points and lines may seem repetitive, almost every treatise that describes perspective for architects, painters and sculptors begins with the definitions of Euclidean points and lines until the mid-seventeenth century. In the writings of the Nuremberg goldsmith Wenzel Jamnitzer (1507/1508–1585) and his *Perspectiva Corporum Regularium* (1568), Jamnitzer defined perspective as "the art and nature of lines and currents from our face to other things that travel back and forth so that everything in the world is seen through human eyes."[21] Similarly, the importance of points and lines for the structuring of perspective and the representation of three-dimensional space on a two-dimensional plane may also be seen in the work of Jehan Cousin the Elder (1500–ca. 1593) and his *Livre de Perspective* (1560), in which Cousin wrote that "in order to understand the art of perspective, it is first necessary know points, lines, surfaces and bodies.[22]

This tradition of geometric points and lines in the construction of space and the simulation of extended objects on a two-dimensional plane culminated in the writings of Bosse, the teacher of perspective for the *Acadèmie de peinture et de sculpture*. In the opening of his treatise, *Traité des pratiques geometrales* *et perspectives* (1665), Bosse defined the point according to the Euclidean tradition as "that which has no parts."[23] This point is the foundation of geometry, which provided the basis by which to represent surfaces and the visible world of nature. Bosse described the perfection of perspective as the ability to "represent by imitation the surfaces of nature's objects and that which one can conceive by idea or imagination. This imitation or copy gives the eye that regards it the same sensation as the original."[24] For Bosse, there was the possibility that the painter can still properly imitate objects in nature and give the same sensation to the eye through the mastery of geometry, points and lines.[25]

Bosse's geometry is famous for its connection to the far-reaching work of Girard Desargues (1591–1661). Nevertheless, Bosse was removed as teacher of perspective at the *Acadèmie*, and Desargues's geometry had little influence on seventeenth-century artistic or architectural practice. While scholars have contextualized Bosse's complicated relationship with the *Acadèmie* in his tendentious interactions with Charles le Brun, it also may be considered that Bosse's pedagogy of perspective was becoming obsolete.[26] Optics was beginning to study light as opposed to vision. By contrast, vision and its instrument of the eye was becoming a material phenomenon limited by the capabilities of eye, a material instrument for sight like any other – lenses, microscopes, telescopes. Euclid's points and lines no longer acted as both tools of perspective and the means to understand vision. Vision began to be described as a process of light painting on the retina of the eye, as opposed to visual rays traveling between objects and eyes. The foundation of perspective in points and lines as embodiments of visual rays began to be superseded by discussions of light, matter, speed and force. Rays of light replaced rays of vision.

Geometry of Light

As Ofer Gal and Raz Chen-Morris demonstrate in *Baroque Science*, natural philosophers started to study the properties of light over vision in their optical treatises and so vision and the human observer became omitted from the science of optics. The eye became one instrument of many that could reflect the geometrical properties of light. Light, not vision, became geometrical. As optics became a science of light as opposed to vision, artists and theorists began to define the art of perspective in relationship to light as opposed to vision. This change is fundamental for grasping a shift that occurs in the pedagogy of perspective in the later seventeenth century. This obfuscation of vision from treatises on optics occurred because the eye came to be recognized as an instrument capable of material error. As Gal and Chen-Morris state, the eye "no longer furnishes the observer with genuine re-presentations of visible objects. It is merely a screen, on which rests a blurry array of light stains, the effect of a purely causal process, devoid of any epistemological signification."[27]

The beginning of optics as a science of light as opposed to visual rays began with Kepler and a famous passage in *Ad Vitellionem paralipomena* (1604), in which Kepler likened vision not to visual rays transporting species between object and eye but to light painting on the eye's retina. Kepler described vision as "colors illuminated by the Sun," that "fall on an opaque medium, where they paint their source: and vision is produced, when the opaque screen of the eye is painted this way."[28] With this epistemic shift, "images are mere causal effects; stains of light that happened to bounce off an object and fall on a screen; no forms or visual rays are involved."[29] Kepler's work on light and the process of vision made processes of perspective seem inherently false. As Gal and Chen-Morris summarize, the tool of "Alberti-style perspective ... is artificial in imposing ideal mathematical structure on visual reality which is inherently diffused; a series of partially overlapping stains of light."[30] In turn, geometry applied to light and not vision. As Kepler wrote in his *Optics*: "Light falls under geometrical laws … as a geometrical body."[31] Vision became a process of light falling on a surface.[32]

An important example of a shift towards describing the representation of spaces (both architectural and two-dimensional) may be seen in the Jesuit Andrea Pozzo's *Rules and Examples of Perspective Proper for Painters and Architects* (1693/1700). In his overview of a history of architectural drawing, Alberto Pérez-Gómez points towards this as a transitional treatise with little geometry and as perhaps the "first truly applicable manual on perspective."[33] The importance of points and lines remain in Pozzo's treatise when he defines "the Eye of the Beholder" as a point. Yet Pozzo also expressed a desire to present "the shortest way for designing in Perspective the several orders of Architecture," "free from the Incumbrances of occult Lines."[34] As Pérez-Gómez states, geometry—and occult Lines—play little practical part in Pozzo's treatise. Instead, Pozzo discussed the role of light in the role of architectural drawing. In his discussions of drawings for ephemeral stage constructions in Rome's Jesuit Church, he wrote, not about the mediations of points and lines, but the role of light striking the eye: "From the foregoing Preparations, is drawn the Perspective of this noble Piece of Architecture; which struck the Eye when seen by Day-light, but was more especially surprising by Candle-light."[35] The Jesuit attention to perspective as founded upon light as opposed to an intellectualized abstraction of points and lines continues in the work of the Jesuit mathematician Bernard Lamy (1640–1715), who discussed perspective as light's ability to paint images on the eye. He opened his treatise on perspective by remarking what a wonderful thing it is that a canvas, which is nothing but a point (*ce qui n'y est point*), can create the semblance of relief, depressions and distance when the work is flat and near. As he explained, this is not a mastery of geometry but light: "It is an effect and at the same time proof that the eye, according to the philosophers, does not see; but that it is the soul that forms the different images of objects according to their different impressions of light that is reflected on the eye."[36]

In 1715 the English mathematician Brook Taylor published *Linear Perspective: or, a New Method of Representing Justly all Manner of Objects*, a work that would be influential throughout the eighteenth century. In his opening sentences, Taylor wrote about affecting the "Eye of the Beholder": "To produce this Effect, it is plain the Light ought to come from the Picture to the Spectator's Eye." For Taylor, there are no longer "rays of vision" but "rays of light."[37] Building on Taylor's work, the eighteenth-century landscape painter John Joshua Kirby wrote *Dr. Brook Taylor's Method of Perspective Made Easy, both in Theory and Practice* (1755), dedicated to William Hogarth.[38] Kirby did not define perspective in connection to an immutable intellectual geometry but to the fallibility of the human eye: "The Definition I have given of the Word Perspective, is this; *viz*. To draw the Representations of Objects as they appear to the Eye, *&c.* and I have avoided the more general Definition, *viz*. of drawing the Representation of Objects by the Rules of Geometry."[39] Kirby expanded on his explanation of why it is better to understand perspective in relation to vision and its fallacies as opposed to the certainties of mathematical rigor:

> For since the Fallacies of Vision are so many and great, and since we form our common Judgment and Estimation of the Appearance of Objects from Custom and Experience, and not from mathematical Reasoning; therefore it seems reasonable not to comply with the strict Rules of Mathematical Perspective in some particular Cases … but to draw the Representation of Objects as they appear to the Eye.[40]

Kirby described vision, not in terms of rays, but "small particles of Matter," which are likened to "Sparks from a Coal." These sparks of coal "excite in our Minds the Idea of Light and as they differ in Magnitude, they produce in us the Ideas of different Colours."[41] Vision is now seen in relation to space and time as sparks of light hurtling between objects: "they are no more than about seven Minutes in passing over a Space equal to the Distance between the Sun and us, which is about eighty-one Millions of Miles, and is considerably more than a Million Times greater than the Velocity of a Canon Ball." Most importantly, Kirby – like Taylor – summarized by describing these fast-traveling particles of "coal," not in relation to vision, but to light: "A Stream of these Particules issuing from the Surface of a visible Body in one and the same Direction, is called a Ray of Light."[42]

Nevertheless, the uncertain relation between optics (now as a theory of light) and architectural drawing still echoed the concerns of Alberti three centuries earlier. In his treatise on perspective for architects, *The Perspective of Architecture: A work entirely new; deduced from the principles of Dr. Brook Taylor* (1761), Kirby does not discuss optics. While his previous work on perspective for painters was concerned with describing optics so that painters could mimic these effects on their canvases, Kirby does not find optics relevant to perspective in architectural representation. In this way, his work continues the tradition started by Alberti in a firm separation between two separate forms of spatial representation for architects and painters. Yet whereas Alberti utilized the Euclidean point and line to integrate the movement between the intellectual and material worlds of the architect into the *lineamenta*, in Kirby's work these points and lines have lost their ability to abstract, metamorphose and exist between mind and reality. In *The Perspective of Architecture*, Kirby stripped geometry of any intellectual or optical knowledge and made it a practical tool for architects devoid of any other resonances.[43] Geometry's earlier role in architectural representation as the intellectual abstraction of *lineamenta* grounded in Albertian conceptions of Euclidean geometry and optics has become obscured. Instead Kirby listed the geometric shapes necessary to know in order to draw architectural forms: the triangle, the square and the circle. The point and the line as separate intellectual and practical entities are irrelevant in his writings. Immutable forms like Euclidean points and lines no longer drive perception. Now qualities of speed, duration, force and mass define vision. For Alberti, perspective explored the interrelationship between immaterial and material knowledge, a process of ideas becoming visible. But then light not vision became defined by geometry while the eye became one material instrument among many. In turn, the invisible domain of Euclidean points and lines became a quantifiable universe of space and time.

When geometry lost its role as a mediating force for understanding the process of vision it also lost its metaphysical qualities in architectural drawing and perspectival treatises. As geometry became a technology of light instead of vision, architectural theorists began to focus more on the representational possibilities of light in drawing as opposed to the strict linear plans of lineaments imagined by Alberti. In turn, architects no longer discussed points and lines as the basic technology of architecture, but instead understood geometry as the basic shapes of circles, rectangles and triangles, forms for beginning draftsmen. The ability to measure light, movement, speed, force and duration through the technology of geometry became the increasingly specialized domain of the natural philosopher. In turn, architects began to turn towards the aesthetic pleasure of light in movement across the façade, an immeasurable transient passage judged by the eye.

Notes

1 The canonical secondary literature on perspective includes Erwin Panofsky, *Perspective as Symbolic Form*, trans. Christopher S. Wood (New York: Zone Books, 1991); Hubert Damisch, *L'origine de la perspective* (Paris: Flammarion, 1987); James Elkins, *The Poetics of Perspective* (Ithaca: Cornell University Press, 1994); Lyle Massey, *Picturing Space, Displacing Bodies: Anamorphosis in Early Modern Theories of Perspective* (University Park, PA: Pennsylvania State University Press, 2007); Lyle Massey, ed., *The Treatise on Perspective: Published and Unpublished* (Washington, DC: National Gallery of Art; New Haven: Yale University Press, 2003); Samuel Edgerton, *The Mirror, The Window, and the Telescope*: *How Renaissance Linear Perspective Changed Our Vision of the Universe*

(Ithaca: Cornell University Press, 2009); Kirsti Andersen, *The Geometry of an Art: The History of the Mathematical Theory of Perspective from Alberti to Monge* (New York and London: Springer, 2007).

2 For work on late-medieval vision, see Katherine H. Tachau, *Vision and Certitude in the Age of Ockham: Optics, Epistemology and the Foundation of Semantics, 1250–1345* (Leiden and New York: E.J. Brill, 1988); A. Mark Smith, "Getting the Big Picture in Perspectivist Optics," *Isis* 72.4 (1981): 568–89; David C. Lindberg, *Theories of Vision from al-Kindi to Kepler* (Chicago: University of Chicago Press, 1976).

3 In Western Europe, Adelard of Bath (1080–1152) and Campanus of Novarra (1220–1296) were the first translators of Euclid's *Elements* from Latin into Arabic. The Venetian publisher Erhard Ratdolt published the first printed edition of Euclid's *Elements* in 1482. On Euclid in the early-modern period, see Antoni Malet, "Euclid's Swan Song: Euclid's *Elements* in Early Modern Europe," *Greek Science in the Long Run: Essays on the Greek Scientific Tradition (4th c. BCE – 17th c. CE*), ed. Paula Olmos (Newcastle: Cambridge Scholars Publishing, 2012).

4 Translation from: Leon Battista Alberti, *On Painting: A New Translation and Critical Edition*, ed. and trans. Rocco Sinisgalli (New York: Cambridge University Press, 2011), 26. "E noi qui immaginiamo i razzi quasi essere fili sottilissimi, da uno capo quasi come una mappa molto strettissimi legati dentro all'occhio ove siede il sense che vede et quivi…" Leon Battista Alberti, *Della pittura,* ed. Luigi Malle (Firenze: G.C. Sansoni, 1950), 58.

5 Lyle Massey, "Configuring Spatial Ambiguity: Picturing the Distance Point from Alberti to Anamorphosis," *The Treatise on Perspective*, 162.

6 Leon Battista Alberti, *On the Art of Building in Ten Books*, trans. Joseph Rykwert, Neil Leach and Robert Tavernor (Cambridge, Mass.: MIT Press, 1989), 7. Leon Battista Alberti, *L'Architettura* [*De re aedificatoria*], ed. Giovanni Orlandi and Paolo Portoghesi (Milano: Edizioni Il Polifilo, 1966), 15. "Nam aedificium quidem corpus quoddum esse animadvertimus, quod lineamentis veluti alia corpora constaret et material, quorum alterum istic ab ingenio produceretur, alterum a natura susciperetur: huic mentem cogitationemque, huic alteri parationem selectionemque adhibendam." For the literature on the term, see Susan Lang, "*De lineamentis*: L.B. Alberti's use of a Technical Term," *Journal of the Warburg and Courtauld Institutes* 28 (1965): 331–35; Caroline van Eck, "The Structure of *De re aedificatoria* Reconsidered," *Journal of the Society of Architectural Historians* 57 (1998): 280–97; Richard Krautheimer, "Alberti and Vitruvius," *The Renaissance and Mannerism. Studies in Western Art: Acts of the Twentieth International Congress of the History of Art* vol. II (Princeton: Princeton University Press, 1963), 42–52; Branko Mitrović, *Serene Greed of the Eye: Leon Battista Alberti and the Philosophical Foundations of Renaissance Architectural Theory* (München: Deutscher Kunstverlag, 2005), 29–72.

7 Alberti, *On the Art of Building*, 19. Alberti, *De re aedificatoria*, 19: "Neque habet lineamentum in se, ut materiam sequatur, sed est huiusmodi, ut eadem plurimus in aedificiis esse lineamenta sentiamus, ubi una atque eadem in illis spectetur

forma, hoc est, ubi eorum partes et partium singularum situs atque ordines inter se conveniant totis angulis totisque lineis."

8 Alberti, *On the Art of Building*, 21. Alberti, *De re aedificatoria*, 21: "Haec cum ita sint, erit ergo lineamentum certa constansque perscriptio concepta animo, facta lineis et angulis perfectaque animo et ingenio erudito."

9 Mitrović, *Serene Greed of the Eye,* 31. Van Eck, "The Structure of *De re aedificatoria*," 284. Van Eck connects *lineamenta* to both intellectual *design* and the physical process of drawing.

10 As two scholars articulate, there is a tension in Alberti's treatise between "drawings that simulate vision (the painter's task, according to Alberti) and those that should provide accurate measurements for builders." Mario Carpo and Frédérique Lemerle, "Introduction," *Perspective, Projections, and Design: Technologies of Architectural Representation*, ed. Mario Carpo and Frédérique Lemerle (London and New York: Routledge, 2008), 2.

11 Danti-Vignola, *Le due regole della prospettiva pratica / di M. Iacomo Barozzi da Vignola; con i comentarij del R.P.M. Egnatio Danti* (Roma: Per Francesco Zannetti, 1583), 1: "Sotto questo vocabulo di Prospettiva s'intende communemente quell prospetto, che ci rappresenta in un'occhiata qual si voglia cosa. Ma in questo luogo da'Pittori & disegnatori sono intese tutte quelle cose, che in pittura, o in disegno per forza di linee ci sono rappresentate." On Vignola's education in both painting and architecture, see Bruno Adorni, "Vignola, A Serious Training: Painting, Perspective, Architecture," *The Notion of the Painter-Architect in Italy and the Southern Low Countries*, ed. Piet Lombaerde (Turnhout: Brepols, 2014), 59–72.

12 On Danti's editorial role in Vignola's text, see Francesca Fiorani, "Danti Edits Vignola: The Formation of a Modern Classic on Perspective," *The Treatise on Perspective*, 127–159.

13 Vignola-Danti, *Le due regole della prospettiva pratica*, 1–2. "Il Prospettivo considera la linea come cosa natural & sensibile, che habbia qualche larghezza, nella quale viene imaginata la linea Geometrica…"

14 Ibid., 2. "Il punto è una piccolissima grandezza, che non può dal senso essere attualmente divisa."

15 Ibid. "La line è una lunghezza con tanta poca larghezza, che non può sensamente essere divisa."

16 Ibid. "Centro dell'occhio è il centro dell'humore Cristallino."

17 Ibid., 2–3. "…dove si forma la perfetta visione, che è nel centro dell'humor Cristallino, lontano dal centro della sfera dell'occhio…"

18 Walther Hermann Ryff, *Furnembsten, notwendigsten, der gantzen Arhictectur angehörigen mathematischen und mechanischen Kunst* (Nürnberg: Iohan Petreius, 1547), 3. "Dann der kunstreich Mathematicus pflegt allein im sinn und verstand on alle materi mancherley species und formen der ding in rechte mas zubringen / dieweil wir aber die ding davon wir handeln / sichtbarlich und augenscheinlich darsetzen wöllen / ist von nöten das wir etwas grös[b]er und verstendlicher und nit als scharpff und spitzig dise ding handeln." Translation: Jeanne Peiffer,

"Constructing Perspective in Sixteenth-Century Nuremberg," *Perspective, Projections and Design*, location 2146.

19 Ryff, *Furnembsten, notwendigsten, der gantzen Arhictectur*, 3. ""Nach Mathmatischer abteilung ist ein punckt / oder puncklein / das aller kleinest / reinest unnd subtilest stüpfflein / oder gemerck / so man im sin verstehen oder mercken mag / und weiter nit … Eyn lini / ist ein strich oder riß / von eine punckt zum andern."

20 Ibid. "Und für das erst soll man mercken was der punckt sey / nemlichen ein zeichen wie auch droben gesagt / das seiner kleine halben weiter nit zertheilt oder zerren net werden mag dann unsichtbar ist / das mag dem Maler unnd allen der gleichen künstnern / so die Perspectiva brauchen / nit diesntlich sein / dann in der Perspectiva allein höchste kunst und fleiß angewendet wird / was am liecht und tag ist / durch dise kunst in das wreck zubringen / dann was unsichtbar / we wurd das selbing in ein PErspectiva bringen mögen. Darum von solchem stupfflin oder puncktlein so sichtbar ist / der grund diser kunst den anfang nimbt."

21 Wentzel Jamnitzer, *Perspectiva corporum regularium* (Nuremberg, 1568), Aiiiv. "… die Perspectiva zu nennen pflegen / Nemlich ein Kunst die da lehrt / von eigenschafft / art und natur / der Linien und Strom so von unserem gesicht auff andere ding hin und wider geworffen werden / dann alles das / so inn der gantzen welt durch unsere Menschliche augen angeschawet wirdt."

22 Jean Cousin, *Livre de perspective de Jehan Cousin* (Paris, 1560), Aiiijr. "Pour venir à l'intelligence de cest Art de Perspective, faut premierement avoir la cognoissance des Poincts, Lignes, Superficies & Corps…"

23 Abraham Bosse, *Traité des pratiques geometrale et perspectives: Enseignées dans l'Academie royale de la peinture et sculpture* (Paris: Chez l'auteur, 1665), 49. "Selon les Mathematiciens, *le Point*, *est ce qui n'a aucune partie*."

24 Ibid., 137. "Le but principal de celuy qui desire se perfectionner en al pratique de cet Art de Pourtraiture our Perspectice est, de se render capable de s'y bien representer par imitation sur toutes sortes de surfaces les objets de la nature, & ceuz que l'on peut concevoir par idée ou de l'imagination; que cette imitation ou copie, fasse à l'oeil du regardant la mesme sensation que son original, & suivant l'idée que l'on en peut avoir conceuë."

25 Bosse structures perspective around an understanding of how the eye sees, considering as fundamental to this process the geometry of points and lines. Ibid., 5. "Je parle aussi de la maniere de bien desseigner & peindre à veuë d'oeil d'apres le naturel, afin que l'on ne tombe pas dan l'erreur ordinaire de desseigner & peindre comme l'oeil voit; mais faire en forte que ce que l'on sera suivant les regles que je donne, fasse à l'oeil du Regardant la mesme vision que le naturel, veu d'une pareille distance & elevation d'oeil."

26 Carl Goldstein, "Studies in Seventeenth-Century French Art Theory and Ceiling Painting," *Art Bulletin* 47.2 (1965), 234. On Bosse and the *Académie*, see also Shella McTighe, "Abraham Bosse and the Language of Artisans: Genre and Perspective in the Académie royale de peinture et de sculpture, 1648–1670," *Oxford Art Journal* 21.1 (1998): 3–26; Martin Kemp, "'A Chaos of Intelligence': Leonardo's 'Traité' and the Perspective Wars in the Académie royale," in *'Il se rendit en Italie':*

Etudes offertes à André Chastel, eds Francesca Fiorani and Alessandro Nova (Paris: Flammarion, 1987), 415–26.

27 Gal and Chen-Morris, *Baroque Science*, 16.

28 "…et a coloribus Sole illustratis … donec in medium quacunque ratione opacum incidant, ibique suum fontem depingant: Fierique visionem …, cum opacus oculi paries hoc modo pingitur." Johannes Kepler, "Ad Vitellionem paralipomena, quibus astronimae pars optica traditur," *Gesammelte Werke 1571–1630*, eds. Walther von Dyck and Max Caspar, vol. II (Munich: C.H. Beck, 1937–), 41–42. Also cited in Gal and Chen-Morris, *Baroque Science*, 20.

29 Gal and Chen-Morris, *Baroque Science*, 24.

30 Ibid., 29.

31 Johannes Kepler, *Optics: Paralipomena to Witelo and the Optical Part of Astronomy*, trans. William H. Donahue (Santa Fe: Green Lion Press, 2000 [1604]). Gal and Chen-Morris, *Baroque Science*, 121.

32 The connection between the work of Kepler and shifts in paradigms of artistic production has already been suggested by Svetlana Alpers in *The Art of Describing: Dutch Painting in the Seventeenth Century*. An artist such as Johannes Vermeer, whose work is paradigmatic for Alpers' argument, may seem to mimic the qualities of light reflected on an opaque surface (as described by Kepler). Yet it is also known that he materialized the perspectival threads of vision in his representations of interior spaces, adhering to older workshop models. Whether or not Keplerian-vision provided a metaphor for how Vermeer conceived of painting, it is certain that by 1700 artists began to reframe the discussion of creating perspectival space through light rather than geometric rays of vision. Svetlana Alpers, *The Art of Describing: Dutch Art in the Seventeenth Century* (Chicago: University of Chicago Press, 1984). On Vermeer and perspectival threads, see Christopher Heuer, "Perspective as Process in Vermeer," *RES: Anthropology and Aesthetics* 38 (2000): 82–99.

33 Alberto Pérez-Gómez, "Questions of Representation: The Poetic Origins of Architecture," in *From Models To Drawings: Imagination and Representation in Architecture*, ed. Marco Frascari, Jonathan Hale and Bradley Starkey (London and New York: Routledge, 2007), 20.

34 Andrea Pozzo, *Rules and Examples of Perspective Proper for Painter and Architects, etc. In English and Latin: containing a most easie and expeditious method to delineate in perspective all designs relating to architecture, After a New Manner, Wholly free from the Confusion of Occult Lines* (London: printed by Benj. Motte, 1707), 14.

35 Ibid., 235.

36 Bernard Lamy, *Traité de Perspective où sont contenus les fondemens de la peinture* (Paris: Chez Anisson, 1701), 1: "C'est un effect & en meme temps une prevue de ce que l'oeil, à parler en Philosophe, ne voit pas; mais que c'est l'ame qui se forme differenetes images des objets, selon les differentes impressions que lumiere qui en est reflechie, fait sur les yeux."

37 Brook Taylor, *Linear Perspective: or, a new method of representing justly all manner of objects as they appear to the eye in all situations* (London: Printed for R. Knaplock at the Bishop's-Head in St. Paul's Church Yard, 1714), 1–2.

38 On the relationship between Taylor and Kirby's works, see Kirsti Andersen, *Brook Taylor's Work on Linear Perspective* (New York: Springer-Verlag, 1992), 55–6.
39 In providing this definition, Kirby directly contradicts the opening definition of Taylor's *Linear Perspective*, in which he writes: "Perspective is the Art of drawing on a Plane the Appearances of any Figures, by the Rules of Geometry."
40 John Joshua Kirby, *Dr. Brook Taylor's Method of Perspective made easy, both in theory and practice* (Ipswich: Printed by W. Craighton, 1755), 70–1.
41 Kirby, *Dr. Brook Taylor's Method of Perspective*, 8.
42 Ibid.
43 Joshua Kirby, *The Perspective of Architecture: A Work Entirely New Deduced from the Principles of Dr. Brook Taylor* (London: R. Francklin, 1761).

Bibliography

Adorni, Bruno. "Vignola, A Serious Training: Painting, Perspective, Architecture." In *The Notion of the Painter-Architect in Italy and the Southern Low Countries*, edited by Piet Lombaerde. Turnhout: Brepols, 2014.

Alberti, Leon Battista. *L'Architettura* [*De re aedificatoria*]. Edited by Giovanni Orlandi and Paolo Portoghesi. Milano: Edizioni Il Polifilo, 1966.

Alberti, Leon Battista. *On the Art of Building in Ten Books*. Translated by Joseph Rykwert, Neil Leach and Robert Tavernor. Cambridge, Mass: MIT Press, 1989.

Alberti, Leon Battista. *On Painting: A New Translation and Critical Edition*. Edited and translated by Rocco Sinisgalli. New York: Cambridge University Press, 2011.

Alberti, Leon Battista. *Della pittura*. Edited by Luigi Malle. Firenze: G.C. Sansoni, 1950.

Alpers, Svetalana. *The Art of Describing: Dutch Art in the Seventeenth Century*. Chicago: University of Chicago Press, 1984.

Andersen, Kirsti. *Brook Taylor's Work on Linear Perspective*. New York: Springer-Verlag, 1992.

Andersen, Kirsti. *The Geometry of an Art: The History of the Mathematical Theory of Perspective from Alberti to Monge*. New York and London: Springer, 2007.

Bosse, Abraham. *Traité des pratiques geometrale et perspectives: enseignées dans l'Academie royale de la peinture et sculpture.* Paris: Chez l'auteur, 1665.

Brown, Gary I. "The Evolution of the Term 'Mixed Mathematics.'" *Journal of the History of Ideas* 52.1 (1991): 81–102.

Carpo, Mario and Frédérique Lemerle, eds. *Perspective, Projections, and Design: Technologies of Architectural Representation*. London and New York: Routledge, 2008.

Cousin, Jean. *Livre de perspective de Jehan Cousin.* Paris, 1560.

Damisch, Hubert. *L'origine de la perspective*. Paris: Flammarion, 1987.

Danti, Egnatio and Giacomma Barozzi da Vignola, *Le due regole della prospettiva pratica / di M. Iacomo Barozzi da Vignola; con i comentarij del R.P.M. Egnatio Danti.* Roma: Per Francesco Zannetti, 1583.

Dürer, Albrecht. *Dürers schriftlicher nachlass auf grund der originalhandschriften und theilweise neu entdeckter alter abschriften*. Edited by K. Lange and F. Fuhse. Halle: Max Niemeyer, 1893.

Edgerton, Samuel. *The Mirror, The Window, and the Telescope: How Renaissance Linear Perspective Changed Our Vision of the Universe*. Ithaca: Cornell University Press, 2009.

Elkins, James. *The Poetics of Perspective*. Ithaca: Cornell University Press, 1994.

Gal, Ofer and Raz Chen-Morris. *Baroque Science*. Chicago and London: University of Chicago Press, 2013.

Goldstein, Carl. "Studies in Seventeenth Century French Art Theory and Ceiling Painting." *Art Bulletin* 47.2 (1965): 231–56.

Heuer, Christopher. "Perspective as Process in Vermeer." *RES: Anthropology and Aesthetics* 38 (2000): 82–99.

Jamnitzer, Wentzel. *Perspectiva corporum regularium*. Nuremberg, 1568.

Jeaurat, Edme-Sébastien. *Traité de perspective à l'usage des artistes*. Paris: Chez Charles-Antoin Jombert, 1750.

Kemp, Martin. "'A Chaos of Intelligence': Leonardo's 'Traité' and the Perspective Wars in the Académie royale." In *'Il se rendit en Italie': Etudes offertes à André Chastel*, edited by Francesca Fiorani and Alessandro Nova, 415–26. Paris: Flammarion, 1987.

Kepler, Johannes. *Optics: Paralipomena to Witelo and the Optical Part of Astronomy*. Translated by William H. Donahue. Santa Fe: Green Lion Press, 2000

———. "Ad Vitellionem paralipomena, quibus astronimae pars optica traditur," *Gesammelte Werke 1571–1630*. Edited by Walther von Dyck and Max Caspar. Munich: C.H. Beck, 1937.

Kirby, John Joshua. *Dr. Brook Taylor's Method of Perspective made easy, both in theory and practice.* Ipswich: Printed by W. Craighton, 1755.

Krautheimer, Richard. "Alberti and Vitruvius." In *The Renaissance and Mannerism. Studies in Western Art: Acts of the Twentieth International Congress of the History of Art* vol. II, 42–52. Princeton: Princeton University Press, 1963.

Lamy, Bernard. *Traité de Perspective où sont contenus les fondemens de la peinture*. Paris: Chez Anisson, 1701.

Lang, Susan. "*De lineamentis*: L.B. Alberti's Use of a Technical Term." *Journal of the Warburg and Courtauld Institutes* 28 (1965): 331–5.

Lindberg, David C. *Theories of Vision from al-Kindi to Kepler*. Chicago: University of Chicago Press, 1976.

Malet, Antoni. "Euclid's Swan Song: Euclid's *Elements* in Early Modern Europe." In *Greek Science in the Long Run: Essays on the Greek Scientific Tradition (4th c. BCE – 17th c. CE*), edited by Paula Olmos, 205–235.Newcastle: Cambridge Scholars Publishing, 2012.

Massey, Lyle. *Picturing Space, Displacing Bodies: Anamorphosis in Early Modern Theories of Perspective*. University Park, PA: Pennsylvania State University Press, 2007.

Massey, Lyle, ed. *The Treatise on Perspective: Published and Unpublished*. Washington, DC: National Gallery of Art; New Haven: Yale University Press, 2003.

McTighe, Shella. "Abraham Bosse and the Language of Artisans: Genre and Perspective in the Académie royale de peinture et de sculpture, 1648–1670." *Oxford Art Journal* 21.1 (1998): 3–26.

Mitrović, Branko. *Serene Greed of the Eye: Leon Battista Alberti and the Philosophical Foundations of Renaissance Architectural Theory*. München: Deutscher Kunstverlag, 2005.

Panofsky, Erwin. *Perspective as Symbolic Form*. Translated by Christopher S. Wood. New York: Zone Books, 1991.

Pérez-Gómez, Alberto. "Questions of Representation: The Poetic Origins of Architecture." In *From Models To Drawings: Imagination and Representation in Architecture*, edited by Marco Frascari, Jonathan Hale and Bradley Starkey, 11–22. London and New York: Routledge, 2007.

Ryff, Walther Hermann. *Furnembsten, notwendigsten, der gantzen Arhictectur angehörigen mathematischen und mechanischen Kunst.* Nürnberg: Iohan Petreius, 1547.

Smith, A. Mark. *From Sight to Light: The Passage from Ancient to Modern Optics*. Chicago and London: University of Chicago Press, 2014.

———. "Getting the Big Picture in Perspectivist Optics." *Isis* 72.4 (1981): 568–89.

Tachau, Katherine H. *Vision and Certitude in the Age of Ockham: Optics, Epistemology and the Foundation of Semantics, 1250–1345*. Leiden and New York: E.J. Brill, 1988.

Taylor, Brook. *Linear Perspective: or, a new method of representing justly all manner of objects as they appear to the eye in all* situations. London: Printed for R. Knaplock at the Bishop's-Head in St. Paul's Church Yard, 1714.

Van Eck, Caroline. "The Structure of *De re aedificatoria* Reconsidered." *Journal of the Society of Architectural Historians* 57 (1998): 280–297.