

Chapter 1

Architectural Drawing

Chapter 1 provides an overview of the role of drawing in architectural design and various methods that are utilized for creating design drawings through analog and digital techniques. This begins with how we (humans) experience the world; including the perception of our surrounding environment and our ability to form mental images. Architectural drawing is based on our ability to see and imagine physical forms and objects, and to translate three-dimensional geometry into two-dimensional representations through descriptive geometry and projection techniques. This process plays a critical role in architectural design and the construction of buildings.

Various drawing methods provide architects and designers with the ability to visualize, represent, and communicate information through hand sketches, technical drawings, three-dimensional projections, simulations, and visualizations, to name a few. These various historical and contemporary analog and digital techniques can be applied throughout various stages of the architectural design process, expanding the tools that are available to architects and designers. This presents a new paradigm in architectural representation and the education of architectural drawing, which ranges from the development of visual acuity and dexterity that is required for hand sketching and drawing, to the development of coding skills for generating computational simulations and visualizations. In this chapter, the role of architectural drawing is presented as an increasingly expansive field that ranges from analog representations based on visual observation to computational simulations based on input parameters and data.

1.1 Drawing and Perception

“A line is a dot that went for a walk.”

—Paul Klee

This well-known definition of a line by the German artist Paul Klee seems simultaneously to express the simplicity and the complexity of the subject and the act of drawing. The analogy comparing a line to a dot going for a walk is fairly straightforward. The tip of a pencil can be placed on a piece of paper to create a dot (point), and moved along a trajectory to create a line. This is something that most children can do instinctively when handed a piece of paper and a pencil. However, we might find

ourselves confronted with other questions when drawing a line, such as: What do I want to draw? Where on the page should I start my drawing? Do I want to draw something that I am observing, or something that I am imagining? What am I trying to represent or communicate? When these questions arise, a connection between drawing and thought is established.

The act of drawing has been used throughout human history to express thoughts and communicate information. From prehistoric markings found on the walls of caves to contemporary data visualizations generated by computational processes, humans have utilized various types of tools to make marks—points, lines, curves, shapes, and forms—to create drawings as a method for visualizing a thought or idea, representing an object or place, storytelling, communicating information to others, and for many other reasons and applications.

Klee's drawing titled *In Engelshut (In Angel's Care)* at first glance appears to be a very simple, almost childlike illustration of a few closed shapes, depicting various elements of overlapping figures. (See Figure 1.1.) However, the overlapping shapes result in the generation of other figures and blur the reading of any one specific figure. This simultaneity of forms creates a dynamic, multi-dimensional quality in his work.¹ The resulting nonhierarchical juxtaposition of shapes eliminates any singular reading

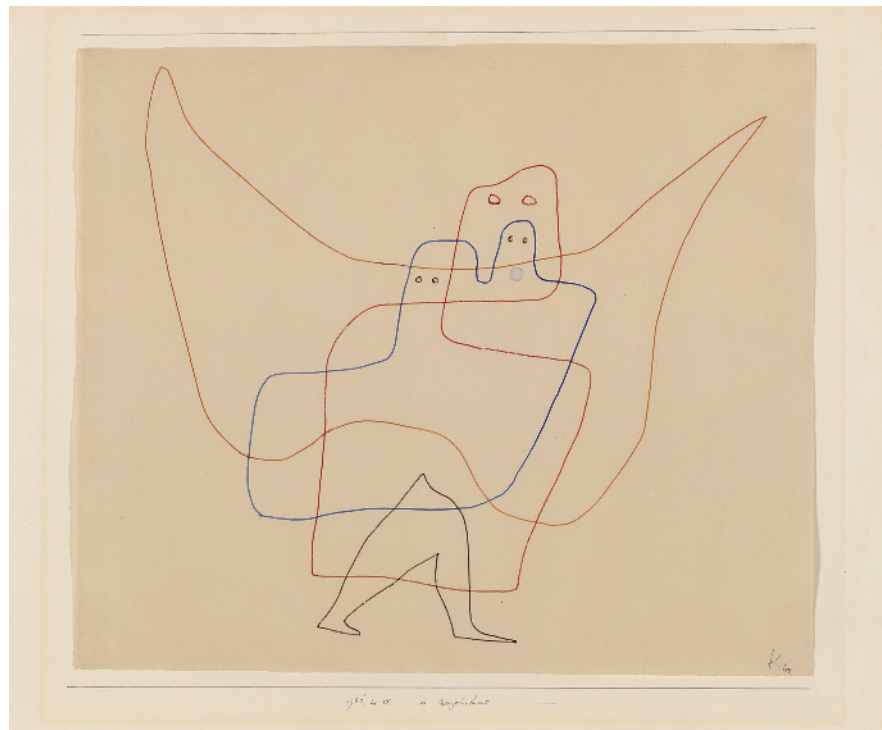


Figure 1.1. Paul Klee, *In Engelshut (In Angel's Care)*, 1931.

of a recognizable form, and creates a visual ambiguity in the drawing, which shifts depending on how the viewer combines the various shapes in their mind. This is due to the human sense of vision and our ability to recognize shapes and edges as a way of mentally processing the objects and forms that we see in the world. Through the elimination of a recognizable pattern this drawing sparks an awareness of this phenomenon, which leaves the work open for interpretation by the viewer. The simultaneous reading of various figural elements and shape combinations creates a visual complexity through the use of a few relatively simple lines and shapes.

Patterns and Light

The human senses of seeing, hearing, smelling, tasting, and touching allow individuals to experience and understand their surroundings. Of the five primary senses, the most effective one for understanding our situational environment is the human sense of sight, which uses light energy to detect formal and spatial information such as shapes, textures, depth, and color. This information varies based on the amount of light that is diffracted as it passes through a medium, or absorbed and reflected by a surface. Eyes receive light of varying intensity and wavelength as an image in the retina, which the brain processes as a spatially related pattern.² The human mind and eye process images through pattern matching, comparing a pattern to an image that has been previously stored in the brain.³ Patterns can be recognized through the visual perception of *edges* and *contours*. For example, in the *Kanizsa Triangle*, the illusion of a triangle is created by the juxtaposition of line segments and major circular sectors, which allow the mind and eye to form visual connections between the geometry. This results in the perception of a solid white triangle, as well as the appearance of depth, with the illusion of the white triangle appearing in the foreground. (See Figure 1.2.)

This method, in which the human mind and eye recognize patterns, allows for our ability to recognize three-dimensional forms through two-dimensional representations of their edges. For example, a collection of twelve lines on a two-dimensional, flat surface can be perceived and understood as a three-dimensional form, a box.⁴ (See Figure 1.3.) However, the particular arrangement of lines in this example allows for a double visual reading of the box: facing in the upward direction, or facing in the downward direction. A single reading can be achieved by creating hierarchy within the linkwork, such as through the introduction of dashed lines, or by rendering the box to suggest the location of a light source through the use of tone.

In addition to the detection of contours, the visual reading of shapes, surfaces, and forms can be accentuated through the use of *tone*. *Tone* is the change in the perception of a color based on the amount of light that strikes a surface. If a light source is located at one end of a surface, the intensity of light that strikes the surfaces varies from one end to the other, lighter on one end and darker on the other. Tonal variations provide the perception of lightness or darkness on a surface to describe the

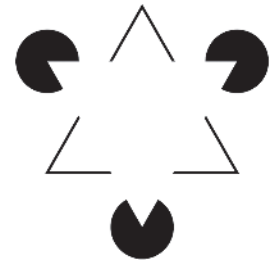


Figure 1.2. Gaetano Kanizsa, *Kanizsa Triangle*, 1955. Example of illusory contours. Courtesy of the author.

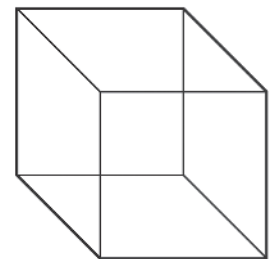


Figure 1.3. A representation of a block form created by a collection of lines. Courtesy of the author.

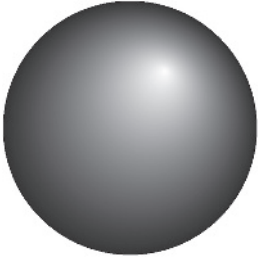


Figure 1.4. A representation of a sphere created through the use of tonal values. *Courtesy of the author.*

effect of light on a form. For example, a variation in tone that is rendered within a circle changes the perception of a flat, two-dimensional circle into the perception of a round, three-dimensional sphere, and provides an understanding of the light source and the interaction of light with the form. (See Figure 1.4.)

1.2 Drawing from Observation and Imagination

Hand-drawing processes involve the act of creating images of shapes and forms, with linework and tone, using tools such as pencils and pens in mediums such as graphite and ink. This differs from other methods of representation, such as collage, painting, and photography, which utilize other tools and mediums for creating imagery. However, in more recent history, with the invention of the computer and advancements in digital technology, the meanings of the term *drawing* and terms associated with drawing have expanded and can be understood through both analog and digital methods of representations. A *sketch*, for example, which is a quick, rough drawing made by hand, has also been used to describe little computer programs (code), for creating digital two- and three-dimensional graphics.⁵ Although the topic of drawing is vast, two common and fundamental methods for hand drawing are drawing from observation and drawing from the imagination. These two methods of drawing, which are referred to in Francis Ching's seminal book on architectural drawing, *Design Drawing*, continue to be fundamental methods for creating visual acuity, improving dexterity, and creative innovation.

Drawing from Observation

Drawing from observation requires an ability to perceive and draw *contours* and *tones*, and the dexterity to control the hand and tool (pencil), to draw the shapes and forms that are being observed. Drawing *contours* allows for the suppression of symbolic abstractions, and instead relies on paying careful attention to experience a subject through the sense of sight.⁶ Contours include the edges of a form, where there is a break in the direction of a surface, or where surfaces meet, as well as edges that are created from abrupt changes in the reflection of light on a form or surface, such as the edges of highlights and shadows. Adding tones to the drawing enhances the perception of the form by providing an understanding of its relationship to light. Drawing from observation with contours and tone is a method for enhancing the ability to perceive and understand shapes, surfaces, forms, and light; therefore, it is a technique for expanding our ability to "see." This is a useful skill that provides architects and designers with an acuity for recognizing visual patterns within the surrounding and built environment, representing formal and spatial information, and applying these principles when designing and drawing from the imagination. (See Figure 1.5.)



Figure 1.5. Álvaro Siza, Architect, *Sketch of Machu Pichu*. Courtesy of Álvaro Siza, Architect.

Drawing from the Imagination

Architectural design involves creativity and the use of the imagination to invent, problem-solve, and speculate, among many other things, on possible formal and spatial designs. Architecture consists of the design and construction of inhabitable structures. The process of designing architecture involves imagining possible spatial organizations, geometrical relationships, tectonic assemblies, and other complex issues related to designing and fabricating a building. The ability to sketch and draw from the imagination is a useful method for “thinking through an idea,” inventing, and solving problems related to these topics.

Architecture is also influenced by many factors outside of design and construction, such as political, social, and economic issues. These factors play a vital role in the design of our built environment. Drawing from the imagination can be a powerful method for expressing architectural ideas that respond to geometry, form, aesthetic, social, economic, political, and other factors, to create visionary images that speculate on possible future architectures, landscapes, urban spaces, and worlds. There are many examples of visionary architectural drawings; some of the most influential are the works of the Italian artist Giovanni Battista Piranesi. In the etchings from his series titled *Carceri d'Invenzione (Imaginary Prisons)*, c. 1750, massive forms, structures, cables, and stairways create a dark, ominous, and mysterious atmosphere, conveying a sense of confinement and immensity.⁷ (See Figure 1.6.) Some techniques that art critics and historians have described to achieve these effects in the imagery of the prints include a range of tonal contrast, spatial fragmentation, and the experience of observing the spaces in perspective from below.⁸ Piranesi's works have influenced the work of many artists, architects, writers, and film makers for centuries.



Figure 1.6. Giovanni Battista Piranesi, *Carceri d'Invenzione (Imaginary Prisons)*, Plate XI, The Arch with a Shell Ornament, c. 1750.

The architect Daniel Libeskind has produced a body of work that includes drawings, installations, buildings, and musical performances. His *Micromegas* series of architectural drawings compounds an inventive energy with drawing.⁹ (See Figure 1.7.) For Libeskind, architectural drawing is as much a prospective unfolding of future possibilities as it is a recovery of a particular history.¹⁰ The drawings

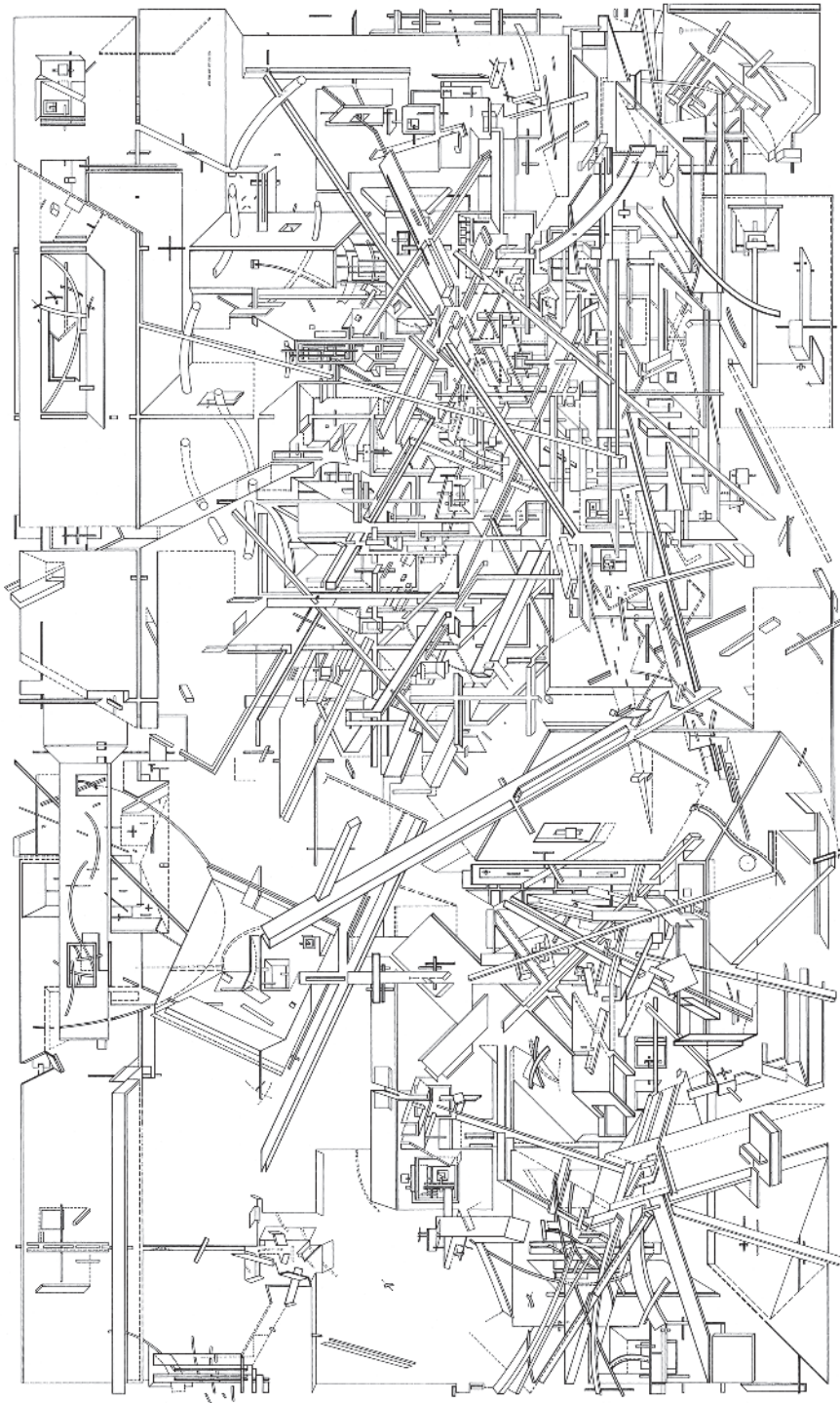


Figure 1.7. Daniel Libeskind, *Leakage, Micromegas series drawing*, 1979. Courtesy of Studio Libeskind.

of Lebbeus Woods often illustrate dystopian architectural conditions as imagery that reflects the political nature of architecture and its ability to influence society.¹¹ In his drawing *Photon Kite*, from his series *Centricity*, a curvilinear mechanical architecture hovers in the air, defying gravitational forces while maintaining a single connection to its surrounding environment through a tube. (See Figure 1.8.) These drawings and many other examples demonstrate the capacity for architectural drawing to influence, reveal, discover, and invent new scenarios and possibilities for architecture.

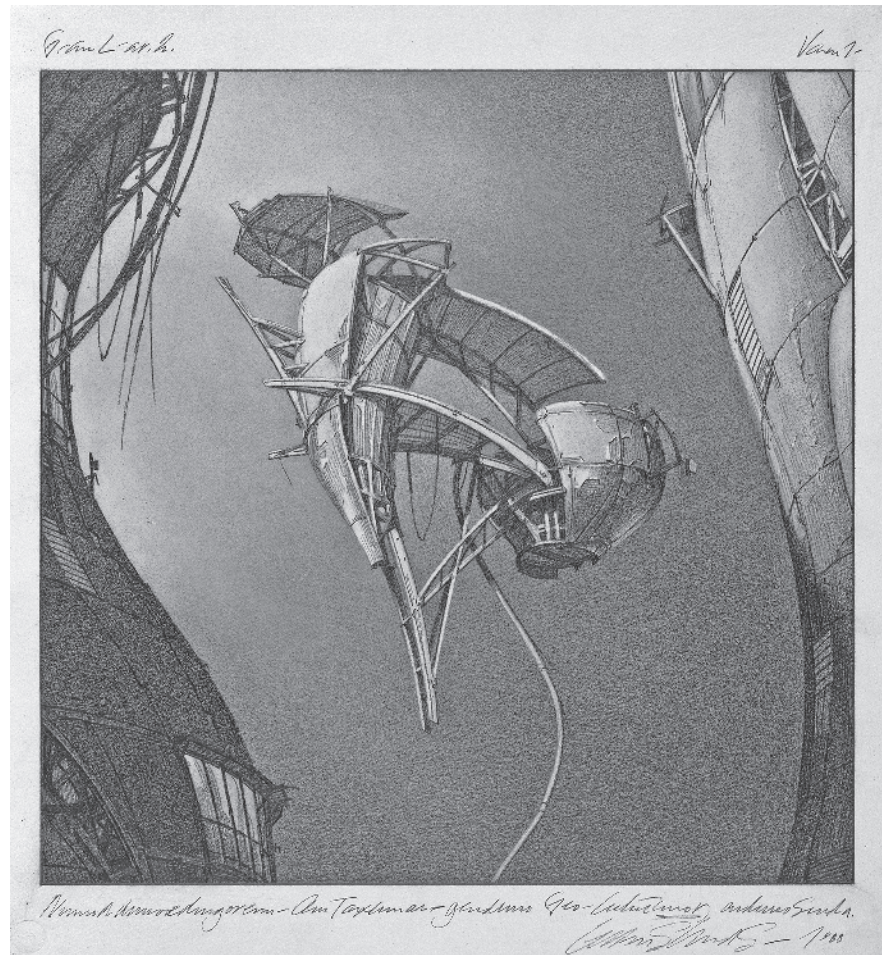


Figure 1.8. Lebbeus Woods, *Photon Kite*, from the series *Centricity*, 1988. Architectural drawing, graphite on paper. Collection SFMOMA. © Estate of Lebbeus Woods.

1.3 Drawing and Projection

There are many forms of drawing in architectural design, such as sketches, design drawings, technical drawings, renderings, and other forms of visual imagery. Although architectural drawing plays a critical role in the design and construction of buildings, drawing as a primary method for design and construction did not occur until the Italian Renaissance. Prior to this period, architects communicated information to builders, craftsmen, artisans, and others who labored on site through the use of physical models. The shift to drawing as the primary mode of creating architecture occurred around the mid-fifteenth century when the Florentine polymath Leon Battista Alberti claimed that architecture is an idea, conveyed by the author, notated in drawings, and built by manual workers.¹² During the Renaissance, which started in Italy and spread throughout Western Europe, architectural drawing was advanced through discoveries in descriptive geometry and projection techniques. The role of drawing in architecture took on two functions: the use of drawings as *visualizations* to explore and develop the idea of the building, and the use of drawings as *notational tools* provided to the builders for construction purposes.¹³ Alberti also noted the necessity for architecture to convey principles of perfect geometric forms that, as described by Vitruvius, relate to the human body.¹⁴ This inspired artists and architects to seek beauty in the truth of ideal geometric forms through a human-centric vision of the universe, as depicted in Leonardo da Vinci's drawing *The Proportions of the Human Body According to Vitruvius*. (See Figure 1.9.)

Descriptive Geometry

Architectural forms are often depicted and visualized through methods of *descriptive geometry*, the representation of three-dimensional objects on a two-dimensional plane. Descriptive geometry includes *parallel projections* and *perspective projections*. In *parallel projections*, points from a three-dimensional object in space are projected onto a two-dimensional plane, resulting in projection lines that remain parallel to one another. *Points* are geometric figures that have zero dimension. In descriptive geometry, points are projected onto a plane and can be connected with line segments to form a two-dimensional image of a three-dimensional object. As the complexity of the form increases, the number of points needed to create an accurate depiction of the form also increases. Piero della Francesca, the Italian painter of the early Renaissance, produced works that were known for accurately depicting the human figure through descriptive geometry and perspectival techniques. His interest in mathematics and perspectival theories led to the development of texts, including the treatise *De Prospectiva pingendi* (*On Perspective in Painting*), in which he

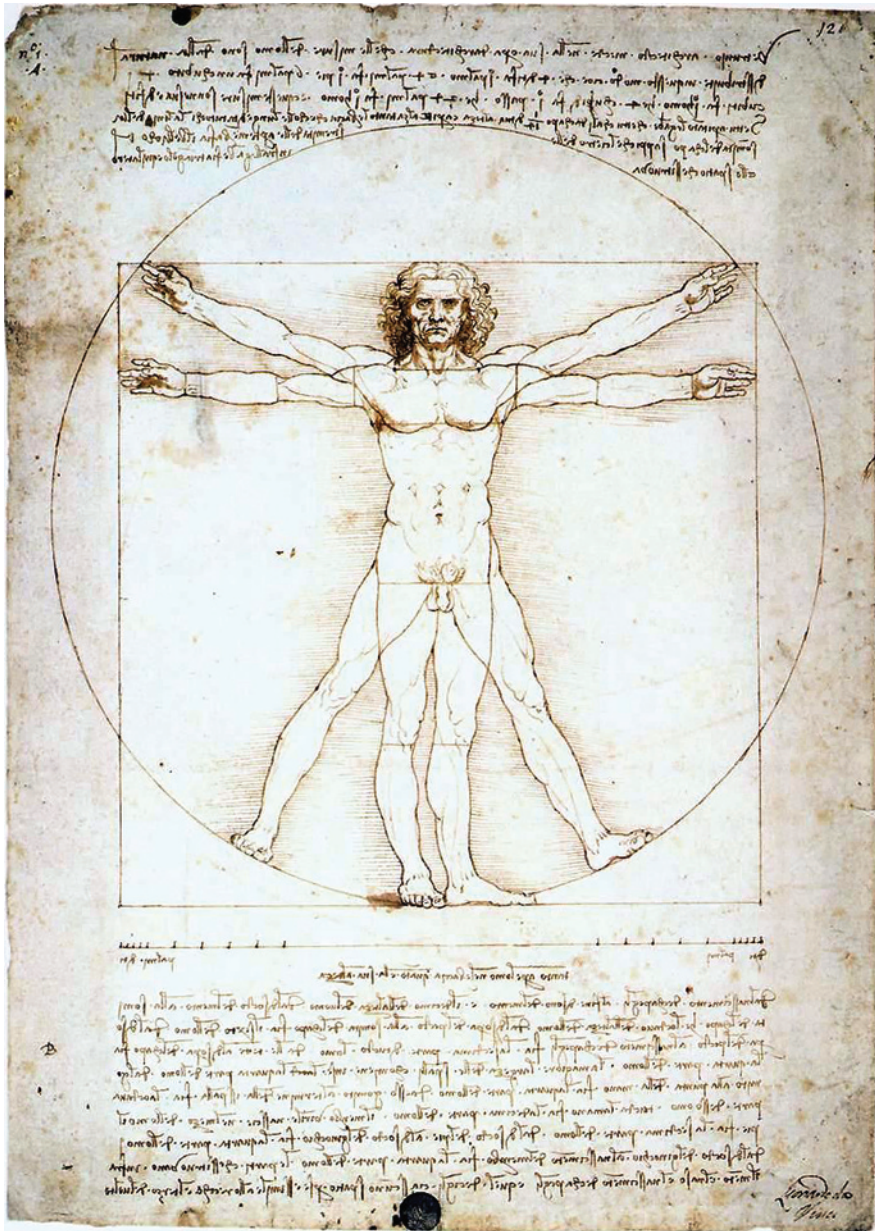


Figure 1.9. Leonardo Da Vinci, *The Proportions of the Human Body According to Vitruvius*, c.1490.

describes methods for designing, positioning, and coloring figures in space. The text focuses on perspective and describes the projection of complex surfaces and volumes that form the human body. In one of his drawings, a series of points are positioned to create various orthographic projections of a human head. (See Figure 1.10.)

Orthographic projections are a type of parallel projection in which the projection lines remain perpendicular to the projection plane. Orthographic projections are abstract representations and provide accurate scale and metric information of forms and spaces. Conventional architectural orthographic projections include plans, sections, elevations, and axonometric drawings.

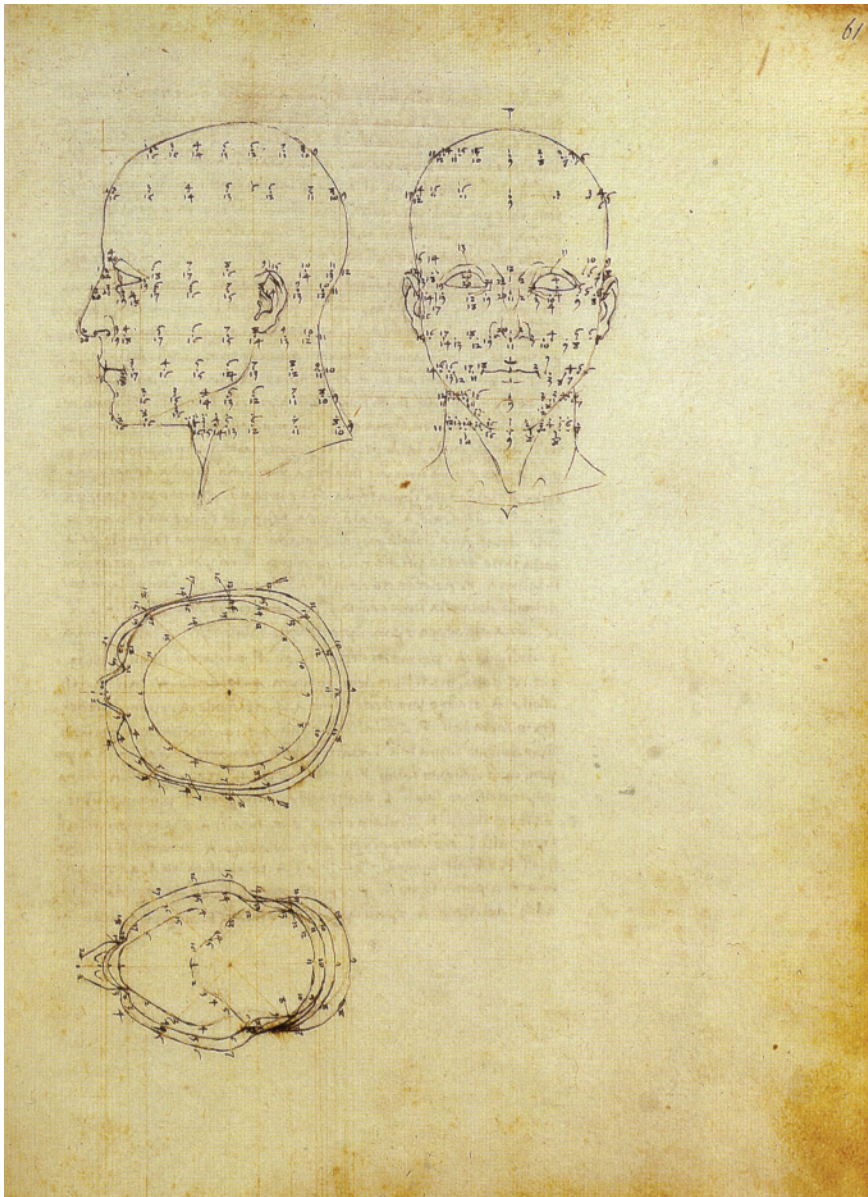


Figure 1.10. Piero della Francesca, *Projection of a Human Head*, from *De Prospectiva Pingendi*, c. 1474–1482.

In *perspective projections*, three-dimensional objects are represented by projection lines that converge at a vanishing point. Perspective projections convey forms and spaces as experienced through human vision. The Italian architect Filippo Brunelleschi is credited with discovering methods for creating accurate perspective drawings, and Alberti codified the methods for creating perspective drawing in his text *De Pictura* (*On Painting*), in 1435. This very influential text provided artists and architects with techniques for accurately depicting shapes, forms, and spaces as experienced through the sense of sight. Albrecht Dürer, a painter and theorist of the German Renaissance, depicted perspective projection techniques by illustrating methods for projecting points of an object onto a plane. In the engraving *Man Drawing a Lute*, a string (representing a visual ray) connected from a point on an object to a hook on the wall (representing the eye) traverses a plane with a swinging panel. Points are recorded where the string intersects the plane to form an identical image as perceived by the eye.¹⁵ (See Figure 1.11.)

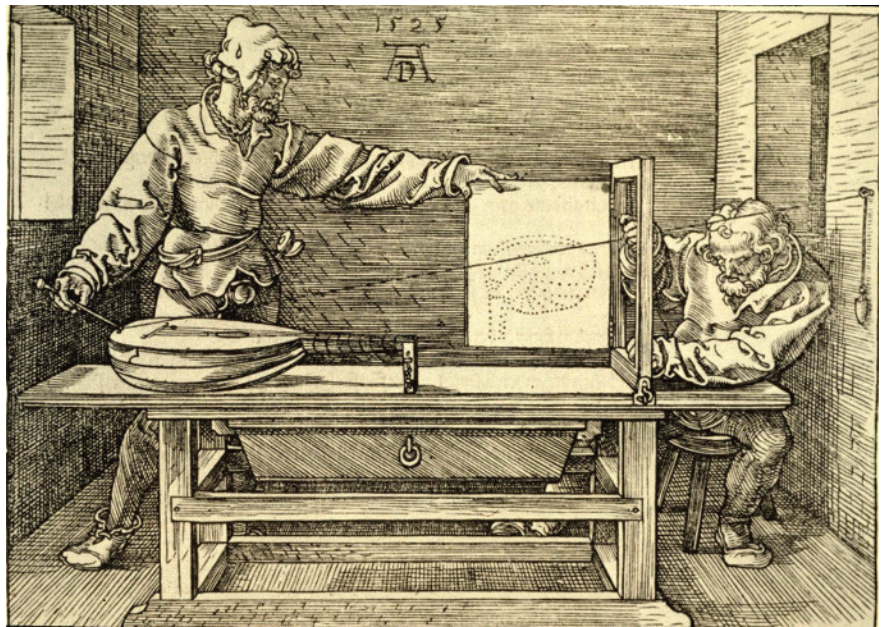


Figure 1.11. Albrecht Dürer, *Man Drawing a Lute*, 1525.

The use of both parallel and perspective projections provided methods for designing and conveying architectural designs through drawing. (See Figure 1.12.) Within digital 3D modeling software, the location of points in space and the projection of points onto a plane are the basis for viewing three-dimensional representations within viewports and on flat screens and monitors, and creating two-dimensional drawings from three-dimensional models.

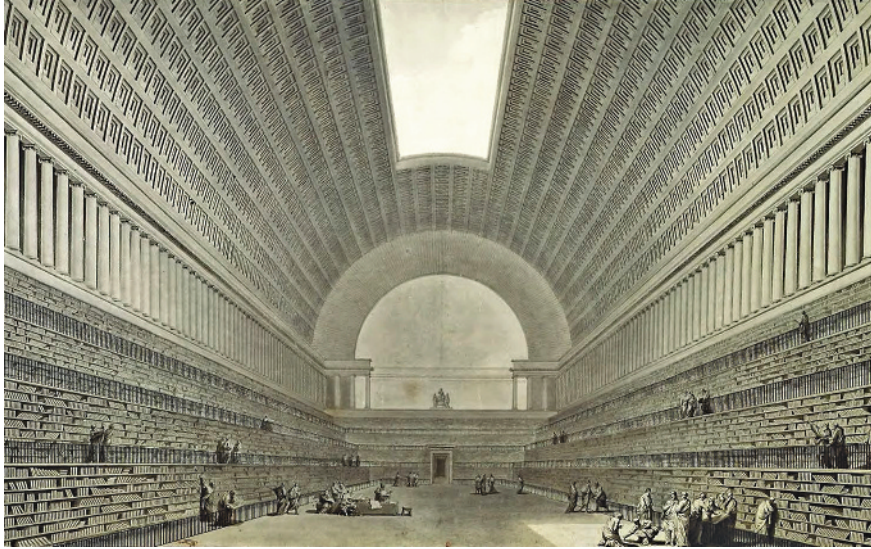


Figure 1.12. Étienne-Louis Boullée, *Restauration de la Bibliothèque Nationale (Restoration of the National Library)*, 1785–1788.

1.4 Drawing Methods

Architects use many different methods for designing and communicating designs. There are various types of drawings that are often implemented throughout the architectural design process. Some of the most significant architectural drawing types that are used to problem solve, visualize, and communicate information include sketches, design drawings, technical drawings, and simulations.

Sketch Drawings

Sketches are typically drawings that are produced quickly to visually understand or communicate an idea. Sketching, whether by hand or through the use of digital technologies, provides a method for quickly creating visual information to think through an idea and/or communicate an idea to others. The sketch of the Cube I Office Tower in Guadalajara, Mexico, by the Spanish architect Carme Pinós illustrates the formal and spatial arrangement of the tower's floor plan, and visually conveys a conceptual idea of three triangular shapes that overlap to form a central core. The sketch also illustrates the linear inner edges of the triangular shapes, which are merged together through a series of curves that create continuity in the envelope. (See Figure 1.13.)

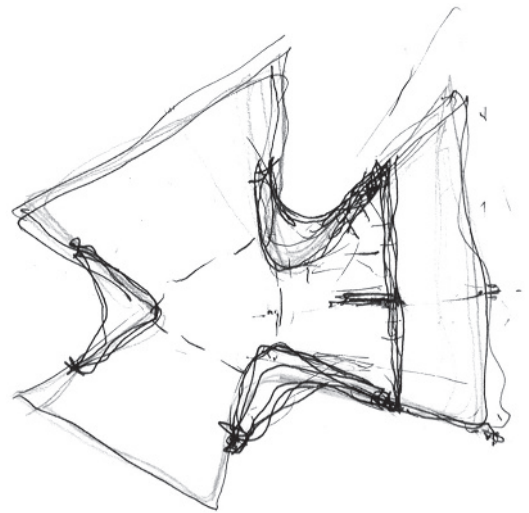


Figure 1.13. Carme Pinós, *Cube I Office Tower*, Guadalajara, Mexico, 2002–2005. Sketch drawing. Courtesy of Estudio Carme Pinós.

The sketches of the Guggenheim Museum Bilbao by the architect Frank O. Gehry indicate the sinuous nature of the building and communicate a sense of hierarchy and organization, through an overlapping and layering of linework that is slightly off center and diminishes in intensity to either side. The sketches also distinguish between various intensities of curved geometries, which represent a range of sinuous forms and surfaces (See Figure 1.14.)

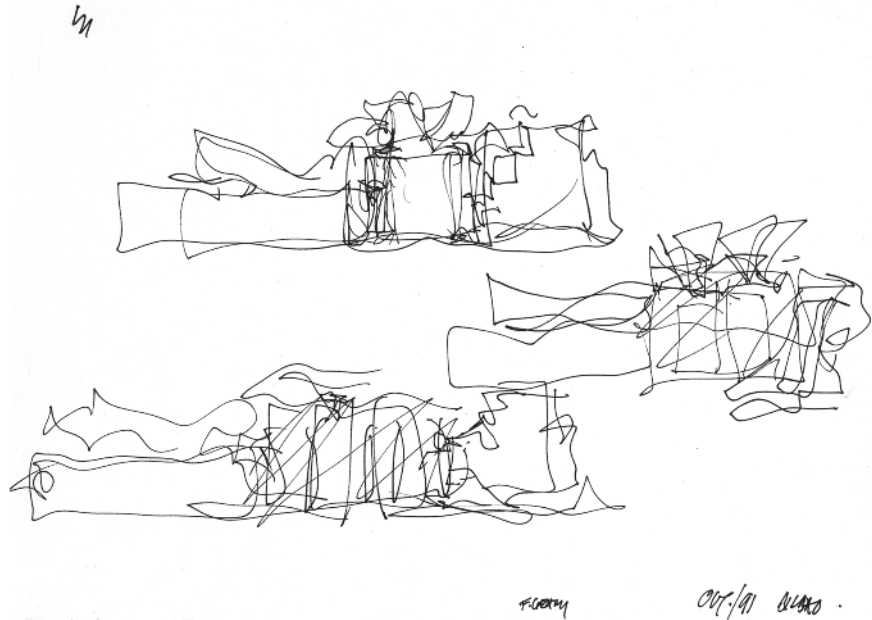


Figure 1.14. Frank O. Gehry, Guggenheim Museum Bilbao. Hand sketch. Courtesy of Gehry Partners, LLP, Los Angeles.

Hand-Drafted Drawings

Architectural drawings can be used to represent technical information that is necessary for the construction of a building. Drawings that communicate information related to the design and construction of physical objects, buildings, and environments are known as *technical drawings*. A set of technical drawings and other information, such as schedules, that are used in the design and construction of a building are called *construction documents*. Technical drawings are scaled, and proportionally accurate to the physical reality of the object, architecture, landscape, or urban design project that they represent. Technical drawing requires precision and accuracy that historically had been achieved by *hand drafting*, which is drawing with tools, such as straight edges, triangles, and compasses, that allow for control in drawing geometry and linework that can be measured. Additional tools, such as *French curves*, were developed to aid in drafting curve geometry. These hand-drafting tools provide a means of accurately drawing smooth continuous curves. In the historical process of wooden ship building, ribs and

keels, the elements that form the transverse and longitudinal structural framework of boats, were fabricated by drawing long, smooth curves onto timber, which were then cut to shape. In order to draw the curve geometry, a template consisting of long flexible strips of wood or steel, called *splines*, were defined and held into position by weights.¹⁶ (See Figure 1.15.) These tools and techniques served as a method for drawing the curve on large sheets of timber at a scale of 1:1, and eventually on paper. Although most contemporary boat design processes utilize digital methods for the production of technical drawings, the artform of hand-drafting *splines* is a practice that can still be found in use today. Computer-aided design (CAD) systems also use the term *spline*, which is derived from the traditional term, and is the basis of creating curve geometries in digital drafting and modeling environments.

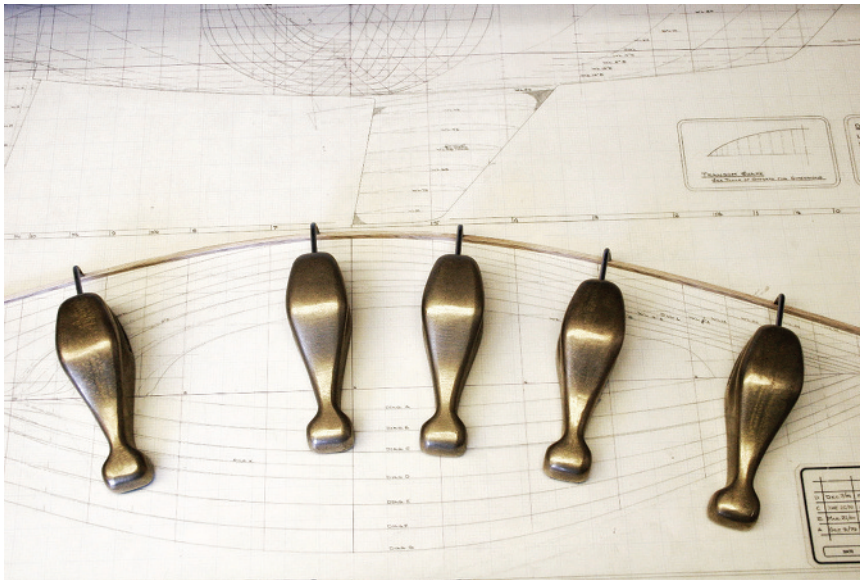


Figure 1.15. Bronze spline weights, Edson International, New Bedford, MA. *Courtesy of Edson International.*

The form of the Trans World Airlines (TWA) Terminal Building is an example of a modern work of architecture that consists of complex curved geometry. Located at John F. Kennedy Airport in New York, it was designed by the Finnish American architect Eero Saarinen and completed in 1962. This concrete and glass building, which has been interpreted as a metaphor for a bird or an airplane in flight, consists of sinuous forms that exhibit compound curvature. The curved Y-shaped concrete columns that blend into the concrete roof were constructed as a cast-in-place concrete structure that required extensive amounts of formwork to be built on site that reflected the curved geometries of the design. (See Figure 1.16.) The construction documents reflect the complexity of the curve geometries that were hand-drafted to accurately depict the sinuous forms and provide the information necessary for constructing the

formwork. The hand-drafted technical drawing of the front column illustrates a series of horizontal contours cut at equally spaced intervals. These curves were generated by taking measurements from horizontal datums that intersected with the physical model, and transcribing the measurements of these intersections into a two-dimensional drawing, to draw the curves that describe the sinuous surface. (See Figure 1.17.)

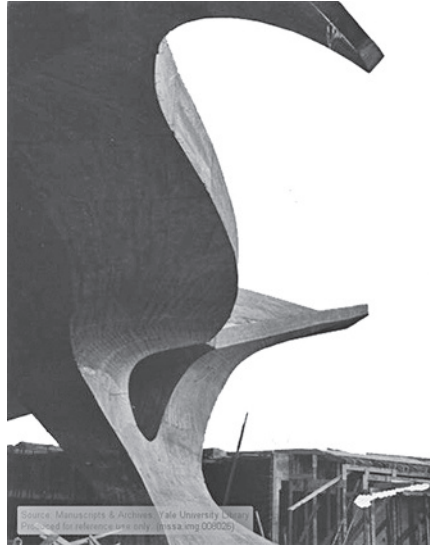


Figure 1.16. Eero Saarinen and Associates, Trans World Airlines Terminal Building, New York, NY. c.1956. Photograph of the curved column and roof. Eero Saarinen collection, 1880–2004 (inclusive), 1938–1962 (bulk). Manuscripts & Archives, Yale University Library. Photo: Richard Knight.

During this same time period that the TWA Terminal Building was completed, the Spanish and Mexican architect and engineer Félix Candela was completing his project Los Manantiales Restaurant in Xochimilco, Mexico City. This project is a thin-shell, cast-in-place concrete structure, consisting of doubly curved, ruled surfaces. Many of the hand-drafted technical drawings that were produced for the construction of Candela's projects illustrate descriptive geometry and projection techniques that describe *ruled* surface geometries, which are surfaces that can be described with straight lines. Candela's projects reflect his interest in using ruled surfaces in design as a means of constructing complex curved formwork using straight planks of wood. His designs reflect modernist ideals, such as the use of minimal forms, absence of ornament, and reinforced concrete, to create formally expressive, structurally efficient designs that use minimal amounts of material. Using descriptive geometry and projection techniques, the various views of curved *hyperbolic paraboloid* surfaces could be accurately represented. (See Figure 1.18.) This drawing method was used to create the technical drawings for Los Manantiales Restaurant, where plan, section, and elevation views illustrate the rule lines and surface curvature of the architecture. (See Figure 1.19.)

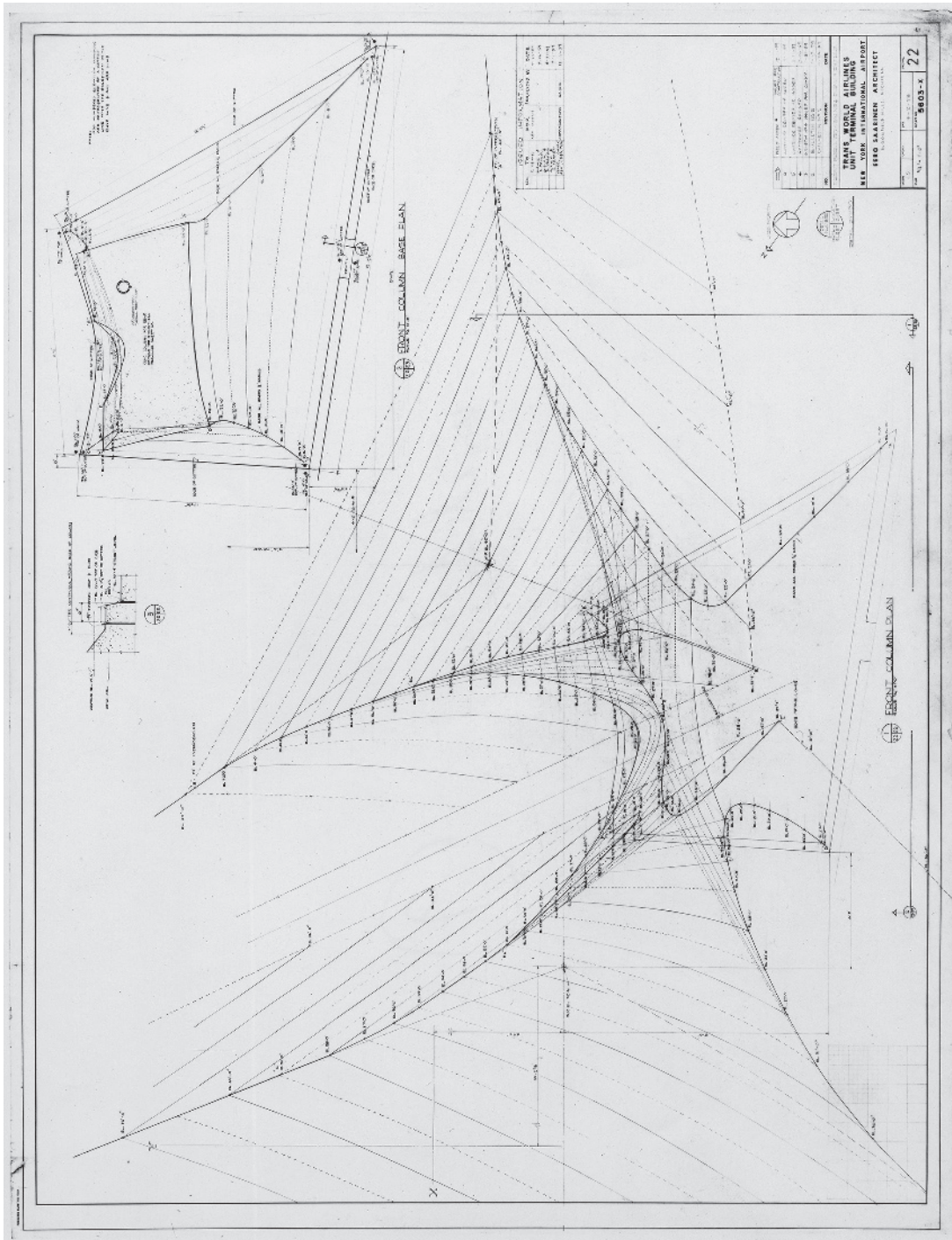


Figure 1.17. Eero Saarinen and Associates, Trans World Airlines Building Terminal, New York, NY, c.1956. As-built; plan for the curved front column. Eero Saarinen collection, 1880–2004 (inclusive), 1938–1962 (bulk). Manuscripts & Archives, Yale University Library.

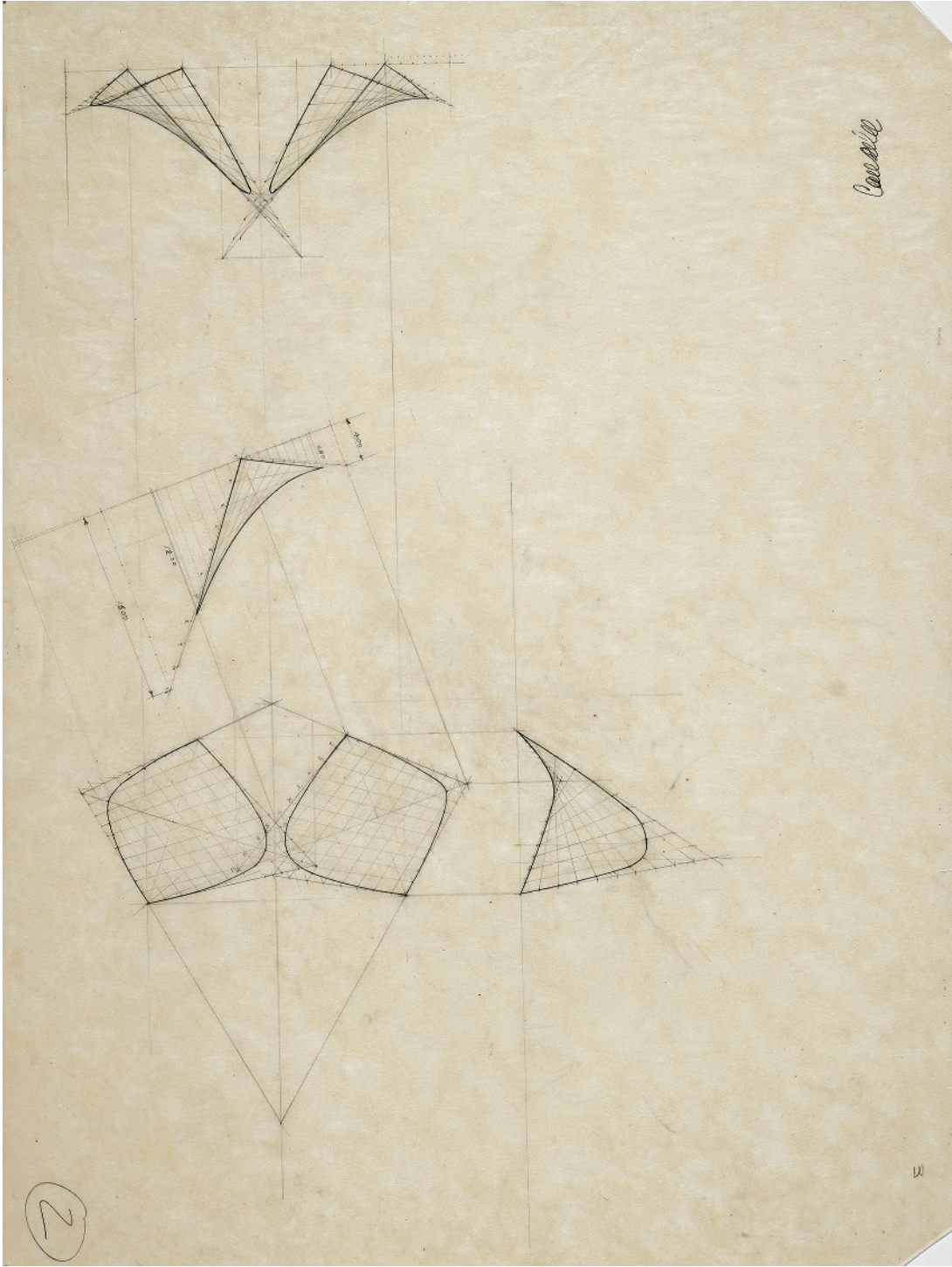


Figure 1.18. Félix Candela, Plan and elevation projection drawings of hyperbolic paraboloid surfaces. © Avery Architectural & Fine Arts Library, Columbia University.

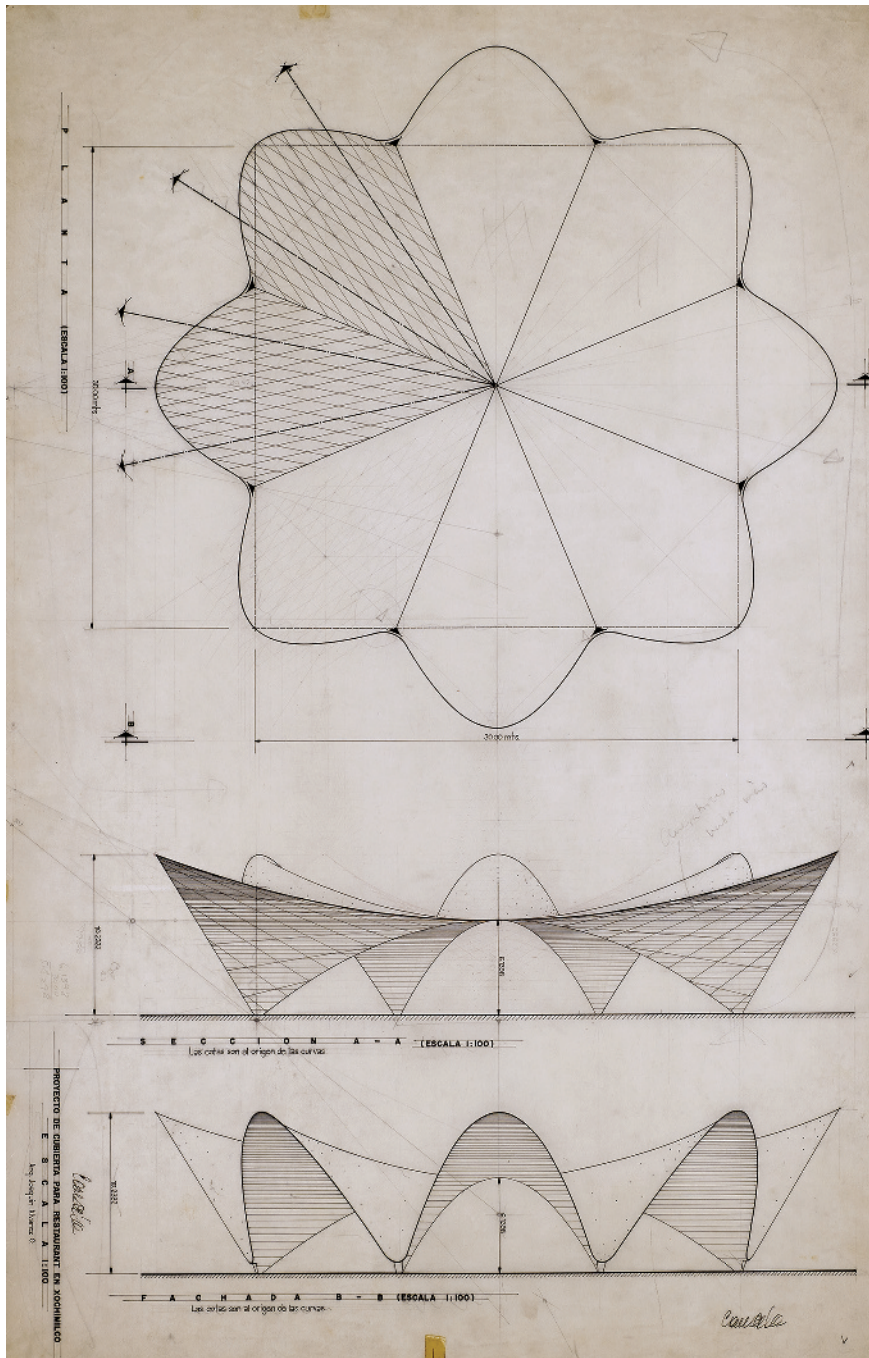


Figure 1.19. Félix Candela, Los Manantiales Restaurant, Xochimilco, Mexico City, Mexico, 1958. Drawing of the roof geometry. © Avery Architectural & Fine Arts Library, Columbia University.

Computer-Aided Design (CAD) Drawings

In the 1960s and 1970s, the invention and early advances of computer-aided design (CAD) systems demonstrated the use of digital platforms that could facilitate the process of creating technical drawings. The use of CAD systems eventually led to the replacement of hand drafting with computer-aided drafting. The majority of architectural practices today rely on CAD tools to create design drawings and technical drawings because, among other reasons, CAD tools can generate technical drawings faster, more accurately, and with fewer errors. By the late 1970s and 1980s, CAD systems had advanced and were being used to create geometry and forms through 3D modeling. During the 1990s, advances in CAD led to the ability to create 3D models that were based in topology, offered parametric capabilities, and could generate complex geometry, forms, and surfaces. Coupled with advances in computer-aided manufacturing (CAM) tools, capable of fabricating complex forms, with data that was output directly from the digital model, this opened up new possibilities for the design and construction of architecture. These technological advances led to some of the first built works of architecture that were designed primarily within 3D models. For example, the Yokohama International Passenger Terminal by Farshid Moussavi and Alejandro Zaera-Polo of Foreign Office Architects, designed in the mid-1990s and completed in 2001, was primarily conceived in section, as a series of digitally modeled surfaces that curved and folded to create an architectural topography.¹⁷ The continuous changes in the undulation and folds of the surface topology are visualized in an oblique drawing in which all of the transverse sections are represented. (See Figure 1.20.) This digital drawing demonstrates the ability of 3D models to influence new explorations of architectural representation through conventional projection techniques. Additionally, the ability to create section cuts in the 3D model provided a means for exporting the geometry from the digital model, which could be developed as technical section drawings. (See Figure 1.21.)

CAD drawings also include technical drawings that are produced through building information modeling (BIM) tools. BIM technologies utilize parametric modeling capabilities that link three-dimensional geometries with two-dimensional drawings. This parametric *associativity* between 2D and 3D representations allows for changes made in the 3D model to automatically update the associated 2D technical drawings, and vice versa. The Marqués de Riscal Winery in Elciego, Spain, designed by Gehry Partners, LLP utilizes Gehry Technologies' Digital Project BIM software to create 3D models that are associated with 2D projections. In addition to embedding data, or information, in the 3D model, BIM software is designed to allow for greater consistency and reduced errors between the 3D models and 2D technical drawings. This has become a very useful digital workflow for managing the design and construction of large-scale architectural projects that are complex. (See Figure 1.22.)

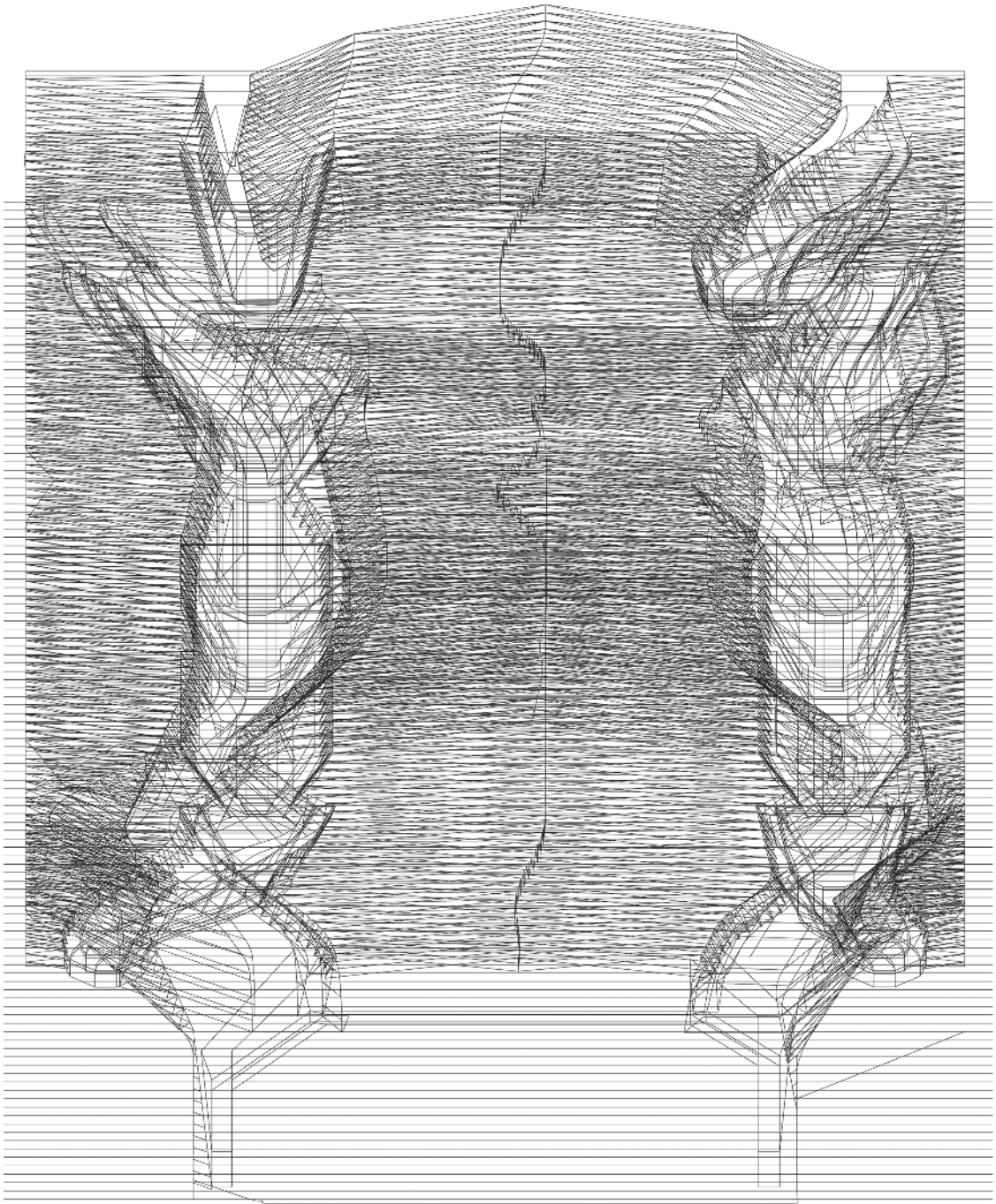


Figure 1.20. Farshid Moussavi and Alejandro Zaera-Polo, Foreign Office Architects, Yokohama International Port Terminal, Yokohama, Japan, 1995–2002. Oblique drawing of the transverse sections. *Courtesy of Farshid Moussavi Architecture.*

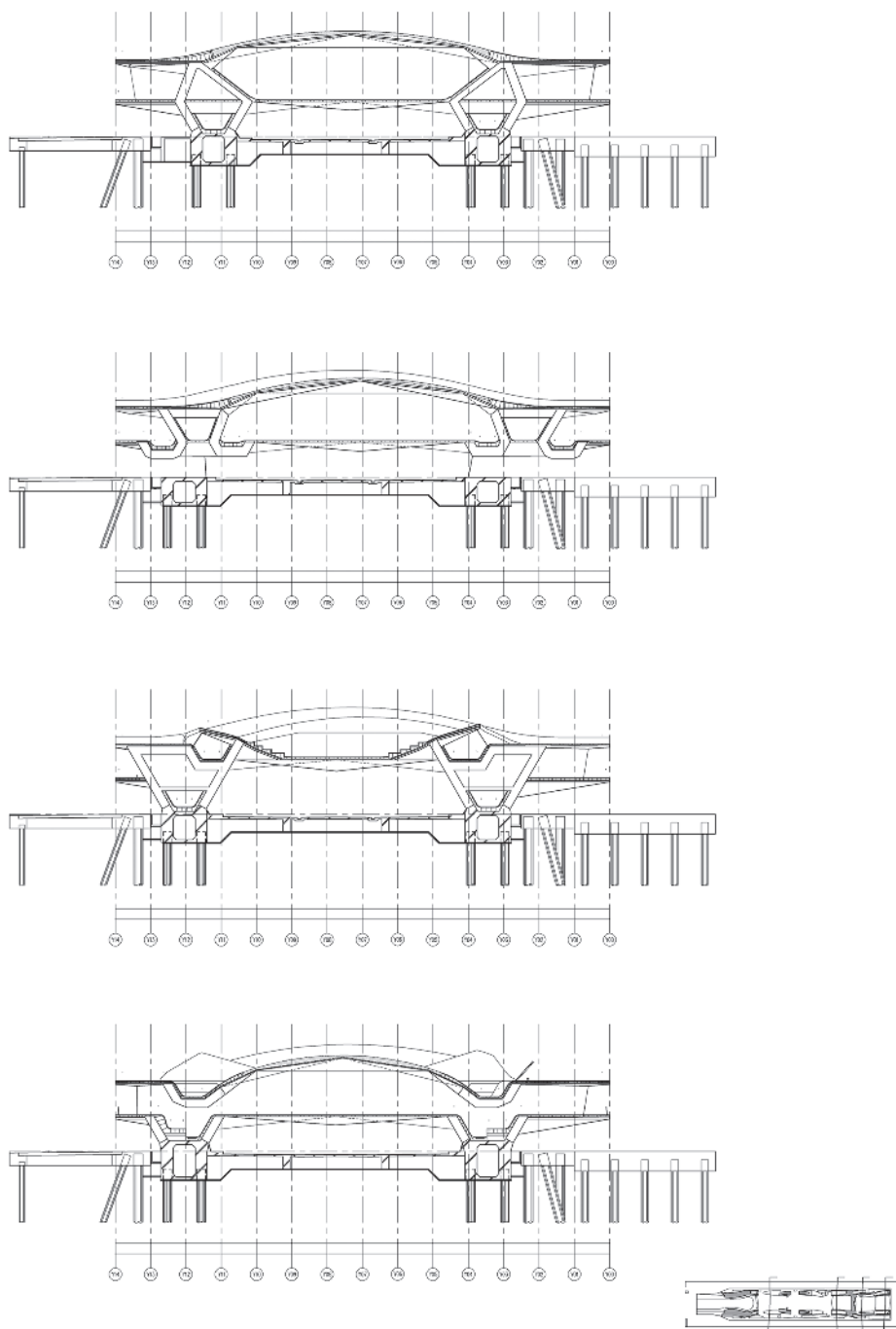


Figure 1.21. Farshid Moussavi and Alejandro Zaera-Polo, Foreign Office Architects, Yokohama International Port Terminal, Yokohama, Japan, 1995–2002. Technical drawings of the transverse sections. *Courtesy of Farshid Moussavi Architecture.*

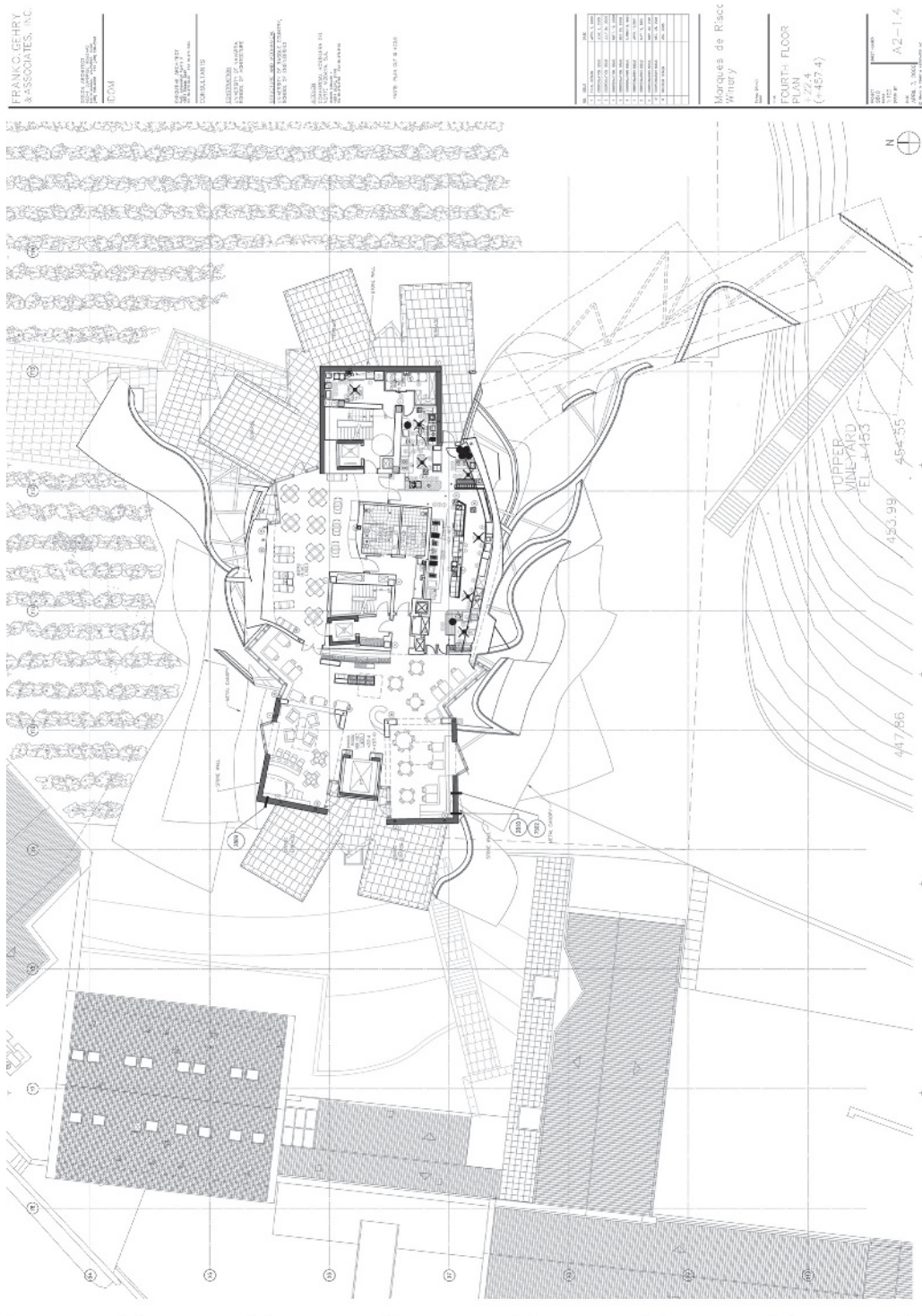


Figure 1.22. Gehry Partners, LLP, Marqués de Riscal Winery, Elciego, Spain, 2003–2006. Floor plan drawing. Courtesy of Gehry Partners, LLP, Los Angeles.

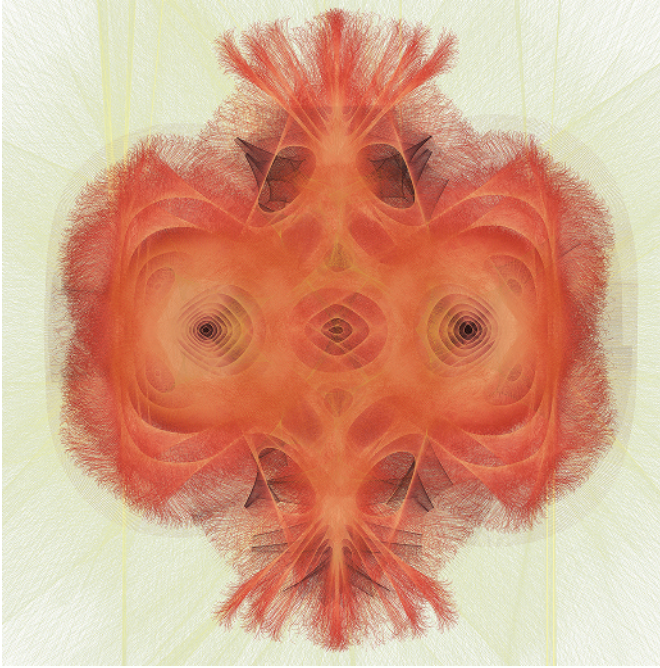


Figure 1.23. Young & Ayata, *Symmetry Series*, 2013. Computational drawing.
 Courtesy of Young & Ayata, New York.

Computational Drawings

The ubiquitous use and influence of computational tools and algorithms are evident and appear in many facets of contemporary culture. During the 1990s and 2000s, architects explored digital models, parametric design, algorithmic procedures, and simulation methods as tools for generating new architectural forms, modes of fabrication, and performance optimization. In terms of drawing, algorithms—which are essentially a set of instructions—can be utilized to create visual expressions built on rule-based operations. This opens up new possibilities for drawing, because algorithms and computational procedures are capable of generating visualizations of complex information and of processing large amounts of data, which is difficult if not impossible for the human mind to do. The drawings in the *Symmetry Series*, produced by the New York-based architecture firm Young & Ayata, are the result of

questioning the role of architectural drawings that are produced through the use of digital computations. The drawings express a discourse that confronts the topics of what is real and what is abstract in representation, and challenges the usefulness of the antiquated categorization of mediums such as drawing, painting, and photography.¹⁸ (See Figure 1.23.)

Computational simulations provide opportunities to simulate various types of forces and behaviors within digital modeling environments. These simulations are often used to evaluate and test geometric forms as a means of optimizing their performance. For example, simulating the effects of wind loads on a building within a digital model provides a means for structural engineers to test and improve the structural design and performance of a building. However, simulations have also been used as generative design tools for exploring emergent geometries and forms that are based on input parameters. These computational processes provide a means for discovery and the visualization of complex forces and behaviors through drawing and modeling. An example of the use of computational simulations as a generative design tool can be seen in the plan drawing for the design of the Kartel-Pendik Masterplan in Istanbul, Turkey, in 2006, by Zaha Hadid Architects. In this project, inputs of circulation within the urban fabric, and computational simulations of bundling curve networks, influenced by Frei Otto's bundling wool-thread models, were used to generate the network of curves for the masterplan.¹⁹ (See Figures 1.24 and 1.25.)



Figure 1.24. Zaha Hadid Architects, Kartal-Pendik Masterplan, Istanbul, Turkey, 2006. Simulation of a wool-thread model used to design the path network. *Courtesy of Zaha Hadid Architects.*



Figure 1.25. Zaha Hadid Architects, Kartal-Pendik Masterplan, Istanbul, Turkey, 2006. Site plan of the street layout and urban fabric. *Courtesy of Zaha Hadid Architects.*

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