Part V

Thermodynamic Practice
How Representation’s Tools Have Changed the Architectural Form
From Alberti’ Perspective to Computational Fluid Dynamics

In the 1980s, a historic revolution took place in architectural offices, which transformed radically the work of architects and then its objects. For hundreds of years, the modes of conception and representation of architecture, i.e., the real tools with which the architect works—pencil, T-square, set square, rule, compass, and paper, had remained virtually unchanged. It is a strong specificity of the architect, as of the musician, not to work directly with the material which ultimately materializes his work, unlike the painter or the sculptor, but upstream, with other tools, without any in relation to the construction, by drawing it, describing it, according to graphic and written codes. A building being ultimately in three dimensions, the architect, to simplify the task, to communicate his intentions and measures to the workers who will later be in charge of building, decomposed the volumes in two dimensions representable on paper with a pencil, according to horizontal and vertical planes called plan, section, and elevation. The dimensions and description of the materials can be measured or read on these. The forms of architecture which the general public calls “square”, that is to say, the most common architectural form, made of straight lines and junction of walls at right angles, were evidently the predominant shapes of the architect because of the use of the T-square, facilitating the drawing of straight lines and the square, the 90° angle, and the simplicity of its use. The tools to draw curves or to obtain other shapes were more complicated to make—plastic helped during the twentieth century to create templates, French curves or flexible ruler—and more complicated to use: One had to be very focused to follow the curve with the pencil, with a 50% chance to miss. These complex forms then implied greater efforts on the part of the workers to carry them out. On the construction site, the lead line for placing the vertical lines and a tight wire to locate the horizontal lines remained the most practical and cost-effective means of building, resulting in the profusion of a “square”, ordinary and simple architecture.

At the beginning of the nineteenth century, the philosopher Georg Wilhelm Friedrich Hegel criticized architecture, perhaps for that reason, that of producing forms that ultimately depended only on the obviousness and constraints of its wooden tools of representation, and the surrender of the construction to the natural forces, that of gravity, which causes a wall to be straight, since it would fall if it was leaning, the shape of the sloping roof, since the rainwater would stagnate and infiltrate inside if it was flat, the bottom walls of the building being thicker than the top walls since they have to bear more weight, the window which should not be too large because otherwise the weight of the wall above the void of the window will cause the lintel to collapse, etc. Hegel thus described architecture as the poorest, most imperfect art, because human imagination is most strongly constrained by the difficulty of representing volumes or of measuring a curve, by the force of gravity which makes all the walls and columns to be vertical, by the wind that makes the wall exist as a shelter, by the sun and snow that induce the roof, by the length of the tree trunks that determines the length of the rooms, because the length of the wooden beam will ultimately determine the position of the walls and therefore the size of the room, without finally being able to do much in the face of these physical constraints of nature, if not to bring some order.
It is nevertheless through the invention of new techniques of representation and construction that architectural forms have changed during the course of history, such as those who took place during the 1980s with the introduction of computer science. One notable precedent is that of the invention of perspective in the early fifteenth century, which revolutionized the mode of representation of architecture until then confined to plan, section, and elevation. It is important to note that this revolution does not originally take place in the final field of architecture, its object and its end, which would be built construction, but in the field of its means, its tools, those of the design and representation on paper, upstream of construction by workers. And because the architect actually uses the means of the painter and the draftsman to work, that is to say drawing, that for this reason artists were often at the same time painter and architect, a revolution in painting caused a major shift in architecture. History tells us that Filippo Brunelleschi demonstrated in 1425 on the baptistery of St. John in Florence, Italy, a new mode of representation in drawing on a glass panel, perfectly superimposed with reality. He used a hole to look with one eye through a drawing of the baptistery that is reflected on a mirror placed in front of the real baptistery, allowing to perfectly superimpose reality and representation. He thus validated a mode of geometrical representation in drawing that of perspective with a center point, which is today called a vanishing point on which all the lines parallel to the direction of the gaze converge. In fact, what Brunelleschi is putting into practice is a popular saying, “Well-targeted for a one-eyed man”, who says that when one shoots far from the target, relying on the fact that by closing one eye, we see the world no longer in three dimensions, but in two dimensions, as on a plane, as a table, which finally makes that, as the universal dictionary of 1690 writes: “one sees better, farther and straighter with one eye than when the two are used together.” This will result in the picturesque image of the painter, his palette of colors in the left hand, closing an eye, and holding out the brush before him to measure the angles and dimensions of the objects placed in front of him. The invention of perspective is thus first of all the idea of closing one eye to deprive oneself of the stereoscopic binocular vision in three dimensions in order to flatten all that are seen, having all depths on the same plane, the same two-dimensional surface, and thus being able to measure all the lengths, all the angles, and all the shapes in a single plane. This mode of reception of reality in two dimensions, by closing one eye, was immediately transformed into a pictorial production mode with the first paintings in perspective of the Italian painter Masaccio for Chapel Brancacci in Florence finished in 1427. Before that, painting represented little or only in a succession of planes, without perspective, in the manner of a superposition of architectural elevations placed one behind the other. And architecture proceeded with the same difficulty to represent the volume.

By introducing perspective into painting, as a new means of representation, the consequence was a major change in the art of painting, which has persisted for many centuries. But this also led to an upheaval in architecture and town planning that used the same tools of representation as those of painters. The art of architecture is transformed at the same time that the art of painting is changed by the invention of perspective. Thus, the painter and architect Leon Battista Alberti, 10 years before writing his treatise of architecture De re aedificatoria in 1449, establishes in his book of
theory of painting De picture (1435) the geometric principles of drawing in perspective, prescribing the graphic principles to represent the world in perspective. A new type of architecture document appeared that of perspective henceforth associated with the general presentation of an architectural project, alongside plans, sections and elevations, still valid today. But this new mode of drawing was not merely a mode of representation. It also became a mode of conception, embodied in the three urban paintings of the Città ideale of the end of the fifteenth century, where we see the profound modification of the way of conceiving the plan of a city and to draw architecture that was generated by the invention of perspective. It thus marks the origin of urbanism as a discipline, for one can plan the city according to depths, points of view, and vanishing points. The invention of perspective has first upset the mode of representation of the architect and then the real world. In designing the plan of a city or a building according to perspective, the architect begins to organize the arrangement of the volumes in depth, to arrange them according to the central point, generating new compositions, perspectives, symmetries, axes, ordered according to a point of view that begins to modify urbanism from the Renaissance, first with the village of Pienza by Rosselino or the Piazza Ducale of Vigevano built in 1492, then all European cities during the following centuries. The invention of perspective as a means of representing reality thus transformed the fabrication of reality afterward, with a never-ending success in the design of new town plans, squares and streets, and buildings until today. One of the first compositions based on the perspective that of the Capitol of Rome by Michelangelo in 1537 with a composition where the center point is an ancient equestrian statue will become the reference of the French squares of the seventeenth and eighteenth centuries, for example, the Place des Victoire or the Place Vendôme in Paris. The three urban paintings of the Città ideale at the end of the fifteenth century offer the three models of urban compositions based on perspective: one where the center point is occupied and blocked by an object (which will be used, e.g., in the compositions of the urban area of Rome in the Piazza del Popolo by placing an obelisk at the end of the horizon), one where the center point meets a never-ending horizon (which will be taken over for the Park of Versailles or the Salt Institute of Louis Kahn), and one which combines the first two models, leaving through the object that occupies the center a hole allowing the gaze to continue further (following the example of the triumphal arches on the Champs Elysees).

As a result of the invention of perspective, the architecture is also transformed, with the church of Santa Maria dei Miracoli or the Scuola Grande di San Marco by Pietro Lombardo of 1489, whose openings or stairs play with effects of perspective, unimaginable before the development of the technique by Alberti. And posterity shall be continued onto this day.

What is thus observed is that one of the most important changes in urban and architectural forms and composition that of the Renaissance was not played out in reality, at the final level of its constructed objects, but in the representation, in a transformation of the tools and means of the architect, on paper, with a ruler and a pencil. In the world of ideas, it has also not played out transcendent or philosophical
concepts that would have been upstream, as it is sometimes understood, but thanks to the empirical discovery, on paper, of geometric and mathematical rules, making it possible to reproduce reality. The discovery of a new way of representing the world in two dimensions, the one-eyed world, if you like, put on paper, eventually coincided with urban models. The great urban perspectives, the magnificence of the breakthroughs and squares of the Renaissance, the Baroque and the Neoclassicism, ultimately have less to do with a symbolic program that would have been imagined upstream than with a geometric technique of representation on paper, implying the centrality of perspective, the effects of symmetry, and the repetition of elements in the manner of colonnades, which made it possible to take a good measure of the effect of depth. The resulting order and magnitude is the consequence of perspective and not its cause. And it is to this same type of revolution in the means that we are witnessing from the 1980s.

The arrival of computers with Computer-Aided Design (CAD) software in architectural offices during the 1980s was first used to save working time by freeing the architect from the tedious load of technical drawings by hand, first in pencil, then in ink, and in its corrections involving the use of ink on the layer. Tracing paper itself, used at the beginning of the twentieth century by architects instead of paper, had already made things easier. By scratching bad lines with a razor blade, it was possible to correct a part of the drawing without having to redraw everything, as it was the case with paper. In the first instance, computer science had only this practical role of CAD (computer-aided drawing), allowing to draw faster, to be able to correct and modify the plans without difficulty and without limit, the sections and the elevations, graphic documents still relevant in the presentation of an architectural project. It was certainly because of the perspective that we began to wonder about the use of CAD. Indeed, it is necessary to build the building completely in 3D to be then able to walk inside or outside and to choose a point of view that will be found advantageous for the project. But it is also by walking in 3D in the building modeled on the computer that we begin to perceive things that we had not planned, qualities or defects that we can attenuate or accentuate by modifying the plan and section. But going a step further, some architects wondered whether the computer simply did not offer the possibility of conceiving the architecture directly in perspective, in three dimensions, without having to go first by the plan and the section, i.e., reversing the usual process of designing the project that begins with the plan, followed by the section and finished by the perspective. This is what the American architect Greg Lynn and the other teachers of the Paperless studio created in 1993 at the University of Columbia in New York at the initiative of its director Bernard Tschumi. In this new revolution of means of representation of architecture, new forms have emerged as a result of immediate work in 3D. In a lecture, the architect Alejandro Zaera-Polo recalls that working directly in three dimensions, in the space without the gravity of the computer screen, made him realize that in 3D, the plane and the section did not exist, because it allowed surface continuity between horizontality and verticality, and even the latter had no reason to exist that the planes could be biased, bent, freely deformed in the space of the screen that a floor could become a wall, without any link to the flatness in two dimensions of the sheet of paper. The plane and section suddenly appeared as an archaic means of representation of the
volumes, a codified simplification of the two-dimensional architecture separating the horizontal planes of the vertical sections without any reason on different layers or sheets of paper. No opportunities to work and properly represent space and volume were easily accessible. Alejandro Zaera-Polo thus naturally explained the appearance of these continuous surfaces which deform from the horizontal to the vertical through bias, because it was no longer limited to a representation split in plan on one side and in section of the other. Greg Lynn and the Paperless Studio questioned the T-square, set square, and the “square” shapes that these instruments induced, the resulting straight lines and planes. Computer software for 3D modeling, with functions such as NURMS (non-uniform rational mesh smooth), made it possible to work freely on curved surfaces, distort plans and create what Greg Lynn called “Fold”. Endless deformations of the surfaces, as well as “Blobs”, deformed volumes with soft and organic shapes, with no net breakage, no straight angle or line. A few years ago, architect Frank Gehry was the first to use 3D modeling software from aeronautics, but without inventing new shapes, to build the complex and curved shapes of a fish sculpture for Barcelona. Later, in an opposite approach to the Paperless studio in New York, he began to scan his models of crumpled paper with completely random shapes, so that he could then transcribe the otherwise inconceivable forms according to coordinates and geometric lines constructions that could be constructed later, following the example of the Guggenheim of Bilbao.

After the form, computing was applied to the calculations of the structures supporting the buildings, calculating and simulating geometrically the descent of loads in a wall or a volume, allowing to remove material in places where no or few loads are transmitted, as in the example of the Tod’s Omotesando building in Tokyo by Toyo Ito with engineer Mutsuro Sasaki.

The latest computer revolution is the use of multiphysics software, also known as computational fluid dynamics (CFD), initially designed for mechanics, electricity to study flow, friction, velocities, fluid turbulence, allowing to design and draw urban plans and buildings according to the behavior of the air, its velocity, its temperature, according to principles of convection, conduction, pressure. The mass plan of our project for the Jade Eco Park is based on three urban simulations of winds flowing into a new neighborhood of the city of Taichung in Taiwan built on the site of an old airport. By simulating the passage of fresh wind from the north into the new neighborhood, we were able to identify areas where it will naturally be cooler in the park, corresponding to the areas where the wind is strongest and therefore the most refreshing, acting as a natural fan. This first simulation carried out by the German Transsolar office allowed us to draw a first mass plan that was superimposed on two other simulations: the wet wind from the southwest and the air pollution fluxes from the neighboring roads. These three models, heat, humidity, and air pollution, have thus directly generated the mass plan, its forms and then its uses, in a linguistic reversal of urban and architectural composition where “The form and The function follow the climate”.

To illustrate the application of CFD software in architectural design, we present two urban-scale projects for the Jade Eco Park in Taichung and at the architectural level for the convective apartment project in Hamburg.
Urban Design
The ambition of the Jade Eco Park in Taichung, Taiwan, is to give back the outdoors to the inhabitants and visitors by proposing to create exterior spaces where the excesses of the subtropical warm and humid climate of Taichung are lessened. The exterior climate of the park is thus modulated so to propose spaces less hot (more cold, in the shade), less humid (by lowering humid air, sheltered from the rain and flood), and less polluted (by adding filtered air from gases and particle matters pollution, less noisy, less mosquitoes presence). The design composition principle of the «Taichung Jade Eco Park» is based on climatic variations that we have mapped by computational fluid dynamics simulation (CFD): Some areas of the park are naturally warmer, more humid, and more polluted, while some of them are naturally colder (because they are in the route of cold winds coming from the north), dryer (because protected from the southwest wind providing humidity of the see in the air) and cleaner (faraway from the roads). In theses last naturally cooler, less humid, and less polluted microclimates, we increase the coolness, the dryness, and the clean for creating more comfortable spaces for the visitors. Beginning with the existing climatic conditions as a point of departure, we have defined three gradation climatic maps following the results of three computational fluid dynamics simulations. Each map specifically corresponds to a particular atmospheric parameter and its variation of intensity thought out the park. The first one corresponds to variation on the heat on the site, the second one describes the variations in humidity in the air, and the third one the intensity of the atmospheric pollution. Each map shows how the intensity or strength of the respective atmospheric parameter is modulated through the park. By doing so, the maps keep areas within the park from reaching excessive natural conditions while making the experience of changes in climate much more comfortable in the areas where we will reinforce the coolness, the dryness, the clean. The three maps intersect and overlap randomly in order to create a diversity of microclimates and a multitude of different sensual experiences in different areas of the park that we could freely occupy depending the hour of the days or the month in the year. At a certain place, for example, the air will be less humid and less polluted but it will still be warm, while elsewhere in the park, the air will be cooler and dryer, but will remain polluted. The three climatic maps vary within a gradation, which ranges from a maximum degree of uncomfortable atmospheric levels that usually exist in the city (maximum rate of pollution, maximum rate of humidity, maximum rate of heat) to areas that are more comfortable where the heat, the humidity, and the pollution are lessened. Climatic Lands.

According to the computational fluid dynamics simulation (CFD), we have identified the coldest, driest, cleanest areas of the park where these existing climatic qualities are increased by densifying the number of climatic devices and trees with specific climatic properties to cool, to dry, to clean the air. These eleven most comfortable areas are designated as the Climatic Lands and are denominated Coolia, Dryia, and Clearia according to their specific climatic specification. The Coolia are the most colder areas in the Park. The Dryia are the dryest ares, and the Clearia are the areas with the less polluted air. The eleven Climatic Lands contain all the activities and programs. The three Climatic Paths link all the same types of Climatic Lands together.
**Coolia**

The Cool Lands (Coolia) are the most cooler areas of the park. They are defined by a high density of cooling trees and cooling devices. There are four Cooling Lands named as Northern Coolia, Western Coolia, Middle Coolia, and Southern Coolia. Inside these four Coolia (Cooling Lands), visitors can find all the equipments for Leisure.

**Dryia**

The Dry Lands (Dryia) are the most dryer areas of the park. They are defined by a high density of drying trees and drying devices. There are three Dry Lands named as Northern Dryia, Eastern Dryia, and Middle Dryia. Inside these three Dryia (Drying Lands), visitors can find all the equipments for Sports.

**Clearia**

The Clean Lands (Clearia) are the areas of the park with the less polluted air. They are defined by a high density of depolluting trees and depolluting devices. There are four Clean Lands named as Northern Clearia, Eastern Clearia, Middle Clearia, and Southern Clearia. Inside these four Clearia (Clean Lands), visitors can find all the equipments for Family Activities.

- Jade Eco Park, Taichung, Taiwan
- Philippe Rahm Architectes, Mosbach Paysagistes, Ricky Liu & Partners
- Client: IBA Hamburg, Germany/Partners: Transsolar, Böllinger & Grohmann, fabric.ch
Architecture
The design of the IBA Hamburg condominium building is based on the natural law of Archimedes that makes warm air rise and cold air drop. Very often in an apartment, a real difference of temperature can be measured between the floor and the ceiling, a difference that could sometimes even be 10 °C. Depending on our physical activities and the thickness of our clothes, the temperature doesn’t have to be the same in every room of the apartment. If we are protected by a blanket in bed, the temperature of the bedroom could be reduced to 16 °C. In the kitchen, if we are dressed and physically active, we could have a temperature of 18 °C. The living room is often 20 °C because we are dressed without moving, motionless on the sofa. The bathroom is the warmest space of the apartment because here we are naked. Keeping these precise temperatures in these specific areas could economize a lot of energy by reducing the temperature to our exact needs. Related to these physical and behavioral thermal figures, we propose to shape the apartment into different depths and heights: The space where we sleep will be lower, while the bathroom will be higher. The apartment would become a thermal landscape with different temperatures, where the inhabitant could wander around like in a natural landscape, looking for specific thermal qualities related to the season or the moment of the day. By deforming the horizontal slabs of the floors, different heights of the spaces are created with different temperatures. The deformation of the slabs also gives the building its outward appearance.

In thermodynamics, energy transfer by heat can occur between objects by radiation, conduction, and convection. Convection is usually the dominant form of heat transfer in gases. This term characterizes the combined effects of conduction and fluid flow. In
Convection, enthalpy transfer occurs by the movement of hot or cold portions of the fluid together with heat transfer by conduction. Commonly an increase in temperature produces a reduction in density. Hence, when air is heated, hot air rises, displacing the colder denser air, which falls. In this free convection, gravity and buoyancy forces drive the fluid movement.

Convective apartments, Hamburg, Germany
Philippe Rahm Architects
Client: IBA Hamburg, Germany/Partners: Fabric | Ch, Arup/Epfl/Werner Sobek/Weinmann Energies

Philippe Rahm