1 Doing More With Less. 
Towards An Architecture Of Optimization

With the airdrop of the atomic bomb over Hiroshima on Monday, August 6, 1945, a new era in human history began. Almost to the date six years earlier, Albert Einstein had warned the American president Franklin D. Roosevelt of the dramatic consequences the newly gained knowledge of nuclear fission might have. Regardless of all the pacifist efforts, the atomic bomb detonated and caused unprecedented devastation in Japan. On all frontiers, the Second World War had escalated into a war of scientists against scientists, which also raised questions of man’s relationship with nature, and more precisely, of whether the implementation of science through technology led to actual progress. Mankind, meditating upon its immense and destabilizing powers, gradually came to realize that it was carrying in its hands the seeds of its own welfare, but also its own destruction.

Kahn’s architecture of the pre- and early post-war era was strongly influenced by the scientific credo of optimization, in which the machine based on the lawfulness of nature acted as a model for an efficient architecture. Historically, it was Babylonian astronomy that introduced the concept of universal order in the cosmos. Yet, the human relation to natural phenomena still took on the form of mythopoeic accounts instead of sober analysis, so that every sun- or moonrise had additional spiritual significance. As a logical consequence, the sacred was understood in both the primitive ages and the first higher civilizations as being immanent in nature, and only the advent of the first monotheistic religions in the Near and Middle East would establish a transcendent order. As Ernst Cassirer pointed out, nature was, henceforth, no longer “the great and benign mother, the divine lap from which all life originates,” but rather “conceived as the sphere of law and lawfulness.”

At this point, the workings of the universe as an expression of the immanent reason or logos, as implemented either by a theological God or a Socratic Good, lay open to human decipherment. Unbiased by mythological speculation, man commenced to break through the imaginary boundaries of the celestial spheres and penetrate into the deeper rhythms of nature. The Western uomo universale found its antecedent in the figure of the hakeem, the polymath of the Islamic Renaissance, as both emphasized the cohesion of the sciences. With the crusades in the late 11th century, the wealth of Oriental knowledge came to the Occident through the intermediate agency of the monasteries, cathedral schools and universities. Scholasticism acted thereby as a vehicle and modifier of Christianity, yet, unlike the latter, which asked to silence the inner voice of analytical reason, it suggested God to reveal himself through nature; all to the point that mathematical knowledge became synonymous with faith.

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Doing More With Less. Towards An Architecture Of Optimization

The medieval era also witnessed the invention of the weight-driven mechanical clock; an instrument that Lewis Mumford regarded as “the key-machine of the modern industrial age.” His reasons were quite evident: compared with the sundial, which was apt to be disturbed by clouds, and the water-clock that could freeze, the measurement of time by an artificial agent strongly encouraged the belief in an independent order – the peculiarly abstract sphere of science: factual, precise and accurate. Besides, in agriculture the improvement of plows enhanced man’s power to conquer the earth. Technology, thus, served as a link between nature and man: it translated theoretical advancements into practical results and promoted a mental constitution of mastery over nature.

Based on the Renaissance’s development of perspective and its first attempts in descriptive geometry, the mathematization of space also set in. Transcending the two-dimensionality of Euclidean geometry, now space as a hierarchy of allegorical values was superseded by space as an infinite system of points with absolute coordinates. In direct relation with this abstract delineation of space stood the development of better lenses, which led around 1600 to the invention of the telescope and the consequent de-stabilizing realization that not the earth including man, but the sun stood at the center of the universe. The Age of Reason witnessed, too, the final disruption of the idea of the world being a perfectly functioning machine, and the simultaneous re-conceptualization of God as its mechanic. In the new cosmology the inert universe made up of dead matter acted selflessly like an automaton – the utter technological promise as exemplified by Jacques de Vaucanson’s Canard digérateur of 1739 (Figure 1). In short, mechanics became the new religion, and the machine emerged as its messiah.

Consequently, nature was defined as a sequence of deterministic events – an essentially trivial affair, completely predictable in its orderly behavior. The mathematical agencies of number and geometry resolved and substituted the apparent complexity of the world with general prototypes and the harmony of an underlying regime. Truth became transparent, but only in as much as it avoided the irregularities of lived experience, which were thought to be resolved in larger systems of regulation. Arguably, nature’s striving for optimization enabled the first scientists to derive the laws of its workings, while somewhat in a reverse process, the aspiration to produce similar forms of organization informed technological production, or the creation of a second nature through man’s dictate. In this vein, laying the corner stone of the mechanistic materialism characteristic of the 19th century, Francis Bacon wrote: “Nature to be commanded must be obeyed; and that which in contemplation is as the cause is in operation as the rule.” With his credo of “knowledge is power,” Bacon

regarded man as a living god, who through the comprehension of nature appropriated the skills to command the world. Shortly before his death, Bacon also wrote about gardening, a practice he believed to be the purest of human pleasures:

Where does the Wisdom and the Power Divine
In a more bright and sweet Reflection shine:
Where do we finer stroaks, and colours see
Of the Creators Real Poetry.8

As is evident in these last lines, early science was cast into a complex matrix of religious thought. Instead of defending a purely theological world hypothesis, in

which the actual, experienced world was regarded as a valueless shadow of the heavenly order – St Augustine’s “City of God” – the progressive accumulation of scientific knowledge conveyed the belief that it was not a fallen world, but rather that Divine value was immanent in the perceivable here and now. In Newton’s Natural Philosophy, according to Voltaire, “[i]f matter gravitates [...] it received its gravitation from God,”9 and yet, if the French philosopher had hoped this kind of metaphysics could arrest the burgeoning atheism characteristic of the impending industrial age, he erred. While rational thinking shifted its focus from questioning why things came about to asking how, “[t]his situation,” according to Alberto Pérez-Gómez, “advanced the transformation of applied mathematics into a powerful instrument for the technological domination of reality.”10 Based on cold reason, geometry and mathematics became “purely formal disciplines, devoid of meaning, value, or power except as instruments [...].”11

At the same time, the earlier water, wind and wood complex, was replaced by an advanced industry based upon iron and coal. Coal, mineable in advance and capable of being stored, released the new industrial complex from seasonal influences.12 Yet, inasmuch as the mechanization of nature was a technological success story, a general impoverishment of life with bad sanitary conditions characterized the new industrial towns. The workers in the factories – all conceptualized as large-scale machines through the breakdown of the production process into a series of specialized operations – were degraded to human robots following the steam engine’s pace. More woods and groves were cut down than ever before, the waters poisoned by the washing of ore, and the air darkened by the smoky dust of the furnaces’ exhalations. Where a sense of humility had still characterized 18th-century scientific research with its prerogative to reconcile with Divine nature, it was now debased to a mere resource of industrious exploitation.

1.1 From the Correlation of Parts to Medieval Space-Structures

In architectural terms, the new utilitarian creed of Positivism, which according to Pérez-Gómez “created the illusion of the infinite capacity of human reason to control, dominate, and put to work the forces of nature”13 was intuitively captured in the

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11 Ibid., p. 11.
12 Altogether the mine spurred technological advancement: in its milieu emerged the steam pump and by derivation the steam engine, in which through the boiling of water the expanding vapor set a rotary motion in action that could perform mechanical work and be later transformed into electrical power.
13 Pérez-Goméz, op.cit., p. 272.
tactile glass and iron structure of the Crystal Palace in London (1851; Figure 2). Its architect, the English landscape gardener Joseph Paxton, found inspiration in the platter-like foliage of a *Victoria regia* (Figure 3), a marvel of economy with regard to its web-like cantilevers stiffening the leaf’s membrane.\(^{14}\) Paxton made use of only a limited number of standardized and serially produced elements, whose subsequent montage replaced the former act of building on-site.\(^{15}\)

At the same time in France, more rigorous mathematical stress analysis was introduced at the beginning of the 19th century,\(^{16}\) initially necessitated by the erection of large domes like the Panthéon (Ste Geneviève) by Jacques-Germain Soufflot in Paris (1755-92) and the planning of cast-iron bridges, railway stations and exhibition halls. Trained at the École polytechnique (in operation since 1794 and derived from the École des ponts et chaussées, founded in 1756), the engineers’ new analytic methods were based upon differential calculus, projective geometry and the quantitative study of material properties in order to better determine the dimensions of a building’s structural elements in relation to the prevailing loads they needed to support. Altogether, the process of planning and construction became generalized through *theory*, whose primary objective was to make practice more economical and precise.\(^{17}\)

The professor of architecture of this new breed of engineers was Jacques-Nicolas-Louis Durand. Teaching his students a modular design approach based on abstract grids and the combination of simple formal elements, he made designing through the

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\(^{15}\) The testing ground for Paxton’s endeavors had been the Duke of Devonshire’s pleasure grounds at Chatsworth. Supplementing the picturesque landscape design by Lancelot Capability Brown, Paxton erected in Chatsworth a number of wooden greenhouses with sophisticated heating and ventilation systems. The father-in-law of the Fourth Duke of Chatsworth was Lord Burlington, whose Renaissance-inspired Chiswick Palace in the boroughs of London had, from 1723 onward, offered William Kent the first opportunity to introduce a less formal style of landscape design. While the formal garden practice – as manifested in the Islamic tradition, the medieval monasteries, the gardens of the Italian Renaissance and the parterres of the French Baroque palaces – relied on the biblical vision of the Garden of Eden to recreate abodes of heaven on earth, the informal tradition sought to acknowledge the apparent disorder in all its eerie beauty and take advantage of the natural disposition of the grounds. Thus, just as Newtonian physics had set its focus on the existing reality, so the picturesque landscape gardener felt at home in *this* world.

\(^{16}\) The founder of modern structural analysis was Claude-Louis Navier with his *Résumé des leçons données à l’École des ponts et chaussées sur l’application de la mécanique à l’établissement des constructions et des machines* (Paris: Firmin-Didot père et fils, 1826).

\(^{17}\) For instance, Jean-Baptiste Rondelet’s *Traité théorique et pratique de l’art de bâtir. Avec atlas de planches* (Paris: Firmin-Didot frères, 1817) was a first attempt in defining how building practice could be objectified in its process of realization.
Fig. 2: Joseph Paxton, Crystal Palace, London, England, 1851.
Fig. 3: *Victoria regia.*
“mécansime de la composition” similar to the resolution of an algebraic equation. Durand’s method was summarized in the *Précis des leçons d’architecture donnés à l’École polytechnique* (1802-5), which in a sort of building catalogue collected all sorts of building types on the same scale through plans, sections and elevations while eschewing any atmospheric perspectives. In his historical overview, *Parallel of Architecture*, which Kahn owned, masterpieces from all ages were presented on the basis of the aforementioned graphical parameters, leaving out any trace of the context.18 Notably, Durand was the most famous pupil of Étienne-Louis Boullée, who had been a teacher of architecture at the École des ponts et chaussées himself. The latter’s clear and austere stereo-metric forms which lacked embellishment and were ruled by a basic recognition of the lawfulness of the Newtonian finite world, could just as well be used as a model to exemplify the rationalist spirit in French theory at the time.

In parallel with the training of engineers, the ideal of a new *truthfulness* manifested itself in France’s architectural circles. Headed by Eugène-Emmanuel Viollet-le-Duc, a group of architects admiring the cathedrals’ structural honesty set out to translate their objectives into the theory of contemporary cast-iron architecture. Viollet-le-Duc’s drawings for a number of unrealized projects, such as a lecture hall with a web-vaulted, triangulated ceiling-structure supported on an independent iron framework (Figure 4), emphasized lightness and the appropriation of the new materials’ constructive possibilities. In the same vein, Auguste Choisy’s *Histoire de l’architecture* (1899), deeply influential for Kahn, assimilated the development of new architectural styles with the advancement of novel structural methods and materials. Following Choisy’s logic, the Tour Eiffel (1887-9) marked the dawn of a new age in iron construction, while Anatole de Baudot’s church of St Jean de Montmartre (1899-1905) in Paris gave birth to *ciment armé* construction, which, resisting compression and suspending tension, created undreamt-of possibilities of architectural expression.19

Viollet-le-Duc compiled his theoretical investigations in the *Dictionnaire raisonné de l’architecture française du XIe au XVe siècle* (1854–1868), of which Kahn also owned a copy. Notably, his analysis deriving from the restoration work on several medieval structures drew reference from the work of the French zoologist and paleontologist Georges Cuvier, who, around the turn of the 19th century, had begun to develop a theory of how to piece together the fossil remnants of extinct species. With his principle of the “correlation of the parts,” Cuvier argued that every organism formed a functional unity, and every part allowed conclusions concerning the entire ensemble and *vice*

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18 Kahn owned Durand’s *Recueil et parallèle des édifices de tout genre anciens et modernes* (Paris: Gillié fils, 1799-1801). If not indicated otherwise, all information concerning the books in Kahn’s library stems from the “Catalogue of Louis I. Kahn’s Personal Library,” compiled by Joseph A. Burton between 1978-80, LIKC.

Fig. 4: Eugène-Emmanuel Viollet-le-Duc, *Salle voutée*, 1864.
versa. In his opinion, the forms of animal skeletons were a precise counter-image of the functions that different animals performed. For instance, an animal that was to run would have a skeleton whose form was entirely conducive to the maximization of speed. What was true for the overall skeleton was likewise valid for all its individual parts, each of which was perfectly attuned to the particular role it had to fulfill in the organism’s overall function.

Fascinated by Cuvier’s doctrines, Viollet-le-Duc embedded his convictions of a similar organic architecture in the public discourse, and jeopardized the monopoly of the École des beaux-arts. Transgressing from a formal to a morphological understanding of architecture, he challenged the rigid application of historicist elements with his understanding of forms logically deduced from given causes. Equating a building with a living organism, Viollet-le-Duc argued:

There is nothing excessive or superfluous about them, any more than there are any features that serve no purpose. If you make a change in any part of such a delicate organism, the other parts are automatically changed as well.20

Tracing the development of Gothic architecture from the crudities of the Romanesque basilicas to the finesse of the grand cathedrals with their finely balanced thrusts and counterthrusts, Viollet-le-Duc observed a constant effort to acquire statically more optimized systems in order to reduce the amount of precious stone. Likewise, his English contemporary, John Ruskin noted in *The Seven Lamps of Architecture* (1849), another treatise Kahn possessed:

There are hardly any of the magnificent and serene methods of construction in the early Gothic, which have not, in the course of time, been gradually thinned and pared away into skeletons, which sometimes indeed, when their lines truly follow the structure of the original masses, have an interest like that of the fibrous framework of leaves [...].21

The Gothic builders’ most groundbreaking invention was the flying buttress that apparently caught Kahn’s attention, too: when sending a postcard from Paris in late 1950, he chose as motif the back of Notre-Dame Cathedral with its external supports (Figure 5). The slender, interior columns carrying the skeletal ribs were in fact only an illusion, as their diameter did not respond to the actually impinging forces. Appearing to transcend the structural requirements, the entire organism avoided collapse only through a careful correlation of parts. Even going further and anticipating the logic of space frames, the Master of Bristol developed in the eastern parts of its Cathedral

a series of extraordinary skeletal vaults with flying ribs. Kahn, who owned Francis Bond’s *Gothic Architecture in England* (1905), kept in his personal slide collection a collage of these experimental ceilings (Figure 6), which consisted of the vaults of the south aisle of the chancel (1298 – c. 1320, left), the vaults of the anteroom of the Berkeley Chapel (c. 1305-10, top right), and the ceiling structure of the outer north porch of St Mary Redcliffe Church in Bristol (14th century, bottom right). Regarding the chancel vault, Nikolaus Pevsner remarked that its weight, in a virtuoso manner, was conveyed to the outer aisle walls by “flying buttresses,” thrown across the aisles in the “form of bridges from arcade pier to outer wall.” Turning the aisles into naves, on top of the bridges tiptoed pointed arches that formed the skeletal framework of the ceiling’s contiguous cells to enclose the space.

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24 This attempt to make the outer buttresses obsolete climaxed in Antonio Gaudí’s Sagrada Familia in Barcelona (begun 1882), where inclined columns in torsion bifurcated into triangulated branches to carry the hyperbolic ceilings.
1.2 Machines for Living in Virgilian Settings

Looking out across the Atlantic, advances towards the formation of a more rational architecture were taking place in America as well; notably, Kahn’s hometown of Philadelphia, as rendered in one of his sketches of a factory complex (1930-5) (Figure 7), served as the United States’ industrial capital throughout the 19th century. When the Brooklyn Bridge in New York, designed by John A. Roebling and his son Washington, opened its pathways in 1883, it was the longest suspension bridge in the world. Combining neo-Gothic pointed-arch piers and technologically advanced steel cables, the structure became an emblem of the time’s striving to make things bigger, faster and higher. Also in New York, one of Kahn’s favorite buildings, the Pennsylvania Train Station (1910), designed by Charles McKim, William Mead and Stanford White, exemplified the new utilitarian creed. A Beaux-Arts inspired entrance hall with a barrel-vaulted and coffined ceiling – rendered in magnitude after the Roman Baths of Caracalla (212-16 AD), but in fact a travertine covered steel structure – contrasted with the open platforms that were reminiscent of Henri Labrouste’s airy Bibliothèque nationale in Paris (1862-8).

At around the same time, Chicago witnessed the development of the skyscraper: only through a fusion of the new technical and constructive capacities was the actual ascent of these high-rise buildings possible. In an instant the architecture of the past –

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Fig. 6: Bristol Cathedral (left: south aisle of the chancel, 1298 – c. 1320; top right: anteroom of the Berkeley Chapel, c. 1305-10) and St Mary Redcliffe Church, Bristol, England, 14th century (bottom right).
massive, solid and protective – encountered the architecture of the future – light, airy and open. However, the very height of these structures imposed difficulties, as the wind pressures increased significantly with greater altitude, making conventional ventilation through the opening of windows impossible. Besides, due to their enhanced slenderness, the outer curtain walls lost their favorable thermal qualities.
to insulate, store and retain heat. Consequently, to produce appropriate working conditions in all weathers, it became necessary to create an artificial climate. Soon, “man-made weather” would completely liberate buildings from the constraints of size and location: in 1902, the American engineer and inventor Willis Haviland Carrier succeeded in controlling the water content and temperature of air by drawing it, paradoxically, through a fine spray of water to create a sort of regulated fog.

As industrialization proceeded, the demand for large-scale industrial infrastructures increased. The cast-iron truss carried on slim pillars developed as an answer to the factories’ need for more openness and flexibility, while grain elevators in the American Midwest – for example, the Standard Elevator designed by the engineer Alfred E. Baxter in Buffalo in 1928 (Figure 8) – emerged as self-referential monuments to the culture’s esprit. These reinforced concrete constructions of colossal scale, aesthetically dominated by formal reductionism, seemed to be derived directly from the rational production process. The silos’ naked forms, with their inherent and abstract beauty, were closer to the objectivism of a machine than to any prior architectural canon. Neutral, without décor and formal pretense, they correlated directly with their practical cause.

These motives to assimilate the machine as an agent of cultivation also guided the French architect Tony Garnier in his utopian renderings of an industrialized city. The production of electricity, which emerged in the late 19th century as the backbone of a supposedly cleaner industrial society, no longer depended on coal, since other natural resources, such as water, wind or sunlight, could be employed as well. In addition, electricity was more convenient for human service, since once converted at a central power station it was transportable and could be re-converted into mechanical power at any local outlet. Garnier’s territorial layout of a utopian town, drafted between 1901 and 1904 and published as Une cité industrielle in 1907 (Figure 9), relentlessly visualized man’s ability to put nature to work, as an entire region merged into one unified machine. Simultaneously, the Italian Futurists realized that the contemporary scenario had to be accepted and taken full advantage of. In 1914, summarizing the group’s intentions, Antonio Sant’Elia wrote:

We must invent and rebuild ex novo our Modern city like an immense and tumultuous shipyard, active, mobile and everywhere dynamic, and the modern building like a gigantic machine.

25 In its pioneering days the development of air-conditioning was spurred by efforts to ameliorate the foul air quality in English factories. For this purpose several technological advancements were indispensable: firstly, electric lighting, which reduced the heat emission and eliminated the soot of the former gas lights; secondly, large blowing fans, which allowed the directing of artificially treated air into the desired locations; and lastly, air-conditioning, the control of the humidity and temperature of air.


Fig. 8: Alfred E. Baxtor, Standard Elevator, Buffalo, New York, 1928.

Fig. 9: Tony Garnier, *Une cité industrielle*, 1907.
While Garnier and the Futurists sought in their architectural utopias a more deeply rooted integration of architecture and technology, Auguste Perret set his focus on exploiting the new constructive possibilities. Searching for an authentic expression of his era with the help of nature, the “main nutrition of the imagination, true source of inspiration, of all prayers the most effective, mother tongue of every creator,” the French architect synthesized in his Concrete Gothicism the values of trabeated Greek architecture with the structural verve of Viollet-le-Duc. Both the utopian vistas of Garnier and the constructive rigor of Perret came together in the work of Le Corbusier, the great champion of Kahn. According to the Swiss-French architect, building should be an applied form of scientific inquiry and draw on the industrial ideals of

standardization, mass production, efficiency: three connected phenomena that rule contemporary activity pitilessly, that are neither cruel nor atrocious but, on the contrary, lead to order, to purity, to liberty.29

With the serial production of houses, Le Corbusier implied a transfer of industrial rigor to the domain of architecture, since his “machines for living in” should be manufactured just like cars. Trained as a watchmaker in La Chaux-de-Fonds, he recalled that in his youth,

nature was the setting where, with my friends, I spent my childhood. [...] I knew flowers inside out, the shapes and colors of birds, how a tree grows and how it keeps its balance even in the eye of a storm.

Overwhelmed by the miracles of nature, Le Corbusier realized “we could be no more than humble imitators of her forms and her wonderful materials.” From early on he collected “objets à reaction poétique” – stones, sea shells, fruits, bones, crystals, flowers, wasps’ nests, or leaves – to trigger his creative process, while his publications were filled with descriptions of the human body’s skeleton and blood circulation system, plants’ retroactivity to the dictum of the sun, and the earth’s inclined axis as enabler of the seasons. For him, the engineer – “l’homme moderne par excellence” – worked detached from cultural mannerisms in harmony with universal law. Le Corbusier also intended to “look at things from the point of view of architecture,” but

“in the state of mind of the inventor of airplanes.” Dedicating with *Aircraft* (1935) an entire volume to the subject, he was delighted that man had realized his age-long dream to fly and valued the new bird’s-eye visions in *aerial* scale. Shortening time and distance, together with the new forms of telecommunication, a truly *international* culture appeared on the horizon.

Le Corbusier’s interest in technology directly influenced the *environmental software* of his buildings, too. Facing thermal problems with the Cité de Refuge in Paris (1929-33), in an add-on process a *brise-soleil* and a *mur neutralisant* needed to be installed. This second device consisted of a double-layered wall with airspace of a few centimeters in between (Figure 10). Through this void, clean air either hot or cold depending on the building’s location and season, circulated to provide a constant interior temperature of 18° Celsius:

> Every nation builds its houses in response to its climate. At this time of general diffusion, of international scientific techniques, I propose: only one house for all countries, the house of exact breathing.

This airtight and autonomous building system – Le Corbusier believed at the time that windows were made for lighting and not for ventilation, just as no noise or dust should enter a truly hygienic building – relied on a bulky external factory, where the used air was regenerated and then blown back into the circulation system by fans.

Le Corbusier’s delineation of the general landscape, however, appeared in opposition to such mechanistic-architectural impositions. In the Ville verte (1930), cross-shaped high-rise buildings with a minimal footprint hovered above a symphony of greenery. Similarly sentimental in attempting to conserve the purity of the native landscape with its ravishing views were Le Corbusier’s proposals for the suburban planning of singular residences that took the Villa Savoye in Poissy of 1931 as a prototype. Grass should grow along the edge of the roads, while trees, flowers, and herds remained undisturbed: “The inhabitants, who came here because this countryside with its rural life was beautiful, will contemplate it,” he prophesized: “Their home life will be set in a Virgilian dream.” Describing the Villa Meyer in Paris (1925), Le Corbusier considered the surroundings: “Comme à Robinson, comme un peu sur les peintures de Carpaccio.” Both these references are informative: Robinson as the role model of the *noble savage*, who, unaided by technological help,

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34 Le Corbusier, *Precisions*, p. 64.
35 Ibid., p. 139.
Fig. 10: Le Corbusier, *Mur neutralisant*, 1930.
encountered the brute wilderness of his lonely exile; and Carpaccio, who exemplified with his mathematical clear-headedness the analytical, but also poetic examination of nature. This confrontation and ambivalence of forces would continue to be central in Le Corbusier’s work, yet also gain prevalence in Kahn’s architectural proceedings.

1.3 Biotechnics and the Illusionary Nature of the Glass House

In Germany, a stronghold of the Romanticist tradition, the French concept of comparing natural organisms with mechanisms had found considerable opposition, and the counter-doctrine of Vitalism asserted that an inner, metaphysical life force was present at all times. However, German natural philosophy acknowledged that vital development itself followed the logical tenets of science, and under the strict rules of necessity enunciated an organism’s form from the inside out. In this vein, the photographer Karl Blossfeldt, a representative of the Neue Sachlichkeit, for whom the plant was to be regarded as an “artistic-architectural constitution,” emphasized:

> Alongside an ornamental-rhythmic creating original force, which is apparent everywhere in nature, the plant builds only useful and functional forms.37

According to these objectives, Ludwig Mies van der Rohe conceived in the 1920s a series of visionary projects, which with clarity and sobriety in mind expressed the material characteristics and the functions they were to perform. In the Concrete and Brick Country Houses of 1923 and 1924, and the Barcelona Pavillon of 1929, for instance, the static symmetry of classical composition was transformed into an asymmetrical and vivid configuration that responded more closely to the inner functions. Building upon a primary structural skeleton, a fluent space solidified, which seamlessly defined spatial zones, while the freestanding walls projected into the wider landscape. A similar flow of space also characterized the living floor of the Villa Tugendhat in Brno (1928-30). Facing south and annexed to the west by a winter garden for the growth of tropical plants (Figure 11), its interior climate was artificially controlled, but any device indicating this fact was discretely hidden from sight.38 In summer, to counteract the southern exposure, textile screens blocked the sun’s rays, while two floor-to-ceiling high steel-frame windows could be retracted into the floor with the help of an electric motor, and, thus, open up half the façade.

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38 The air of the main living space was *à priori* prepared in the basement that included a depot for the storage of cold air, a regulated fine-spray humidifying chamber, a rainwater tank and a boiler-room. Controlled in warmth and coolness, but also cleaned, freshened and aromatized with sea salt since Mrs. Tugendhat suffered from asthma, the treated air was lastly blown into the living space.
Mies van der Rohe’s greenhouse was a utopian statement of how technological ingenuity could liberate modern man. Likewise aiming to master the consequences of mechanization by means of a synthesis of architecture and technology, the Swiss art historian and trained engineer Sigfried Giedion emphasized in Mechanization takes Command (1948): “What matters is to domesticate mechanization, rather than to let the mechanical core tyrannize the house.”

Mies van der Rohe’s architecture of “less is more,” abstracted and reduced to its essentials, found theoretical backing in the writings of Raoul H. Francé. According to the Austrian-Hungarian philosopher every natural process had a precisely corresponding form. Francé distinguished between seven constitutional letters of the organic alphabet, whereby each was constantly tested in its viability to obtain optimized forms. These insights could be transferred to cultural production as well, as he argued:

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40 Cf. Fritz Neumeyer, Mies van der Rohe: Das kunstlose Wort (Berlin: Siedler Verlag, 1986) pp. 137-42. According to Neumeyer, books by Raoul H. Francé like Die technischen Leistungen der Pflanzen (1919) or Die Pflanze als Erfinder (1920) were the most frequent in the architect’s library.
All technical forms can be deduced from forms in nature. The laws of least resistance and of economy of effort make it inevitable that similar activities shall always lead to similar forms.41

László Moholy-Nagy also relied on the resulting concept of “biotechnics” in his book *The New Vision* (1928), wherein he enforced that *organic* might be a more appropriate term than functional for describing the correlation between a building’s form and use.42

In 1938, Mies van der Rohe received the commission for the planning of the Illinois Institute of Technology. The ideals of the Bauhaus not only prospered in Chicago, however, where in addition to Mies van der Rohe’s activities Moholy-Nagy had installed the New Bauhaus in 1937; but by the early 1950s, practically all American architecture schools had substituted their former Beaux-Arts curriculum with an educational system based upon the German paragon. Walter Gropius became dean at Harvard’s Graduate School of Design, and as the first act of his tenure removed history from the curriculum to accentuate his own credo of the collaborative approach: the students should join the building industry and learn in large teams to compose buildings from prefabricated parts.43

Trained under the new authority, a younger generation of American architects rapidly assimilated the Modernist tenets. Among them, Philip Johnson designed a Glass House in New Canaan between 1945 and 1949, which paid tribute to Mies van der Rohe’s congruent development of the Farnsworth House in Plano, Illinois (1945-51), and his earlier studies for the Resor House in Jackson Hole, Wyoming (1937-8). In each case, unrestricted glass façades opened up unobstructed views of the surroundings. The buildings’ puritanical order framed the landscape, which took on a distinctly pictorial, almost stage-like presence. These houses epitomized the changed relationship between man and nature, which became most obvious during the winter months: only with the most up-to-date advancements in mechanical engineering were such architectural *absences* actually possible. Just as the Gothic cathedrals would collapse without the help of the outer buttresses, invisible technical equipment made the organisms of these edifices work. In fact, the reliance upon environmental management devices reduced the internal-external relation to visibility only.44

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42 Ibid.
43 “Gropius appraises Today’s Architect,” in *The Architectural Forum*, vol.96, no.5, 1952, pp. 111-4; 030.II.A.60.34, LIKC. Not surprisingly, Gropius was proud of the fact that it was difficult to differentiate the work of one his pupils from that of another. Cf. Joan Ockman, (ed.), *Architecture Culture 1943-68* (New York: Rizzoli, 1993) p. 138.
44 To solve the crux that the glass inside became a solid black mirror at night, Johnson’s, but also Kahn’s later lighting consultant Richard Kelly illuminated the exterior surroundings to create a “landscape wallpaper,” while during the day, dimmers adjusted the illumination level to counteract abrupt contrasts. Cf. Matthew Tanteri and Renee Cooley, (eds.), “Richard Kelly: Selected Works” (New York: IESNY: The Center for Architecture, 1993).
As far as Mies van der Rohe’s work in America is concerned, it is noteworthy that with his arrival in the United States a major shift occurred in his architecture. Obviously, the recent obsession with simple volumes and symmetrical orders contradicted his earlier subscription to a free and unbound spatial continuum. In other words, if Mies van der Rohe had broken free from the box in Europe, he would reconstitute it in the United States. Furthermore, while the column as part of the structural frame had earlier been a freestanding interior element, it was now externalized to become a part of the enclosing wall membrane. In this way, on the one hand, structure and space became an integral element, and on the other, a universal space resulted that was not fixed to one particular use, but interchangeable. The more classical stance in Mies van der Rohe’s work had its roots in the writings of his friend Romano Guardini:

Singular forces, especially steam, electricity and chemical energy, were released from their natural connectivity. Their rational laws were deciphered and based on that knowledge their potency was unleashed. And something in humanity, a certain attitude toward these unleashed natural energies, an ethos, a mentality, the very will to work mechanically and rationally uncoiled and allocated itself to this force.45

This quotation from 1927 should not be misread, since Guardini, a Catholic priest remained highly critical of the described rational mentality. In fact, in his Briefe vom Comer See he called for a new Humanism, which re-awakened a classical in-touchness with the natural elements.

In any case, with the impending Second World War, the United States were propelled into a position of global leadership and appeared as a beacon of opportunity. The country quickly became – at least in terms of quantity – the homeland of Modernism in the post-war years. As the visually unifying element, the curtain wall transformed the urban landscape: with glittering transparency a new vernacular culture of mechanization burst forth that ignored all climatic constraints.46 With the development of coated glass, the total rupture between the inner and outer climate was finally accomplished, since these all-glass buildings paradoxically relied on the permanent use of artificial lighting. Simultaneously, the suspended, multipurpose ceiling came into practice, which, integrating acoustic panels, air-conditioning elements and fluorescent tubes to homogenously illuminate the interiors, arrived

45 Romano Guardini, Briefe vom Comer See (Mainz: Matthias-Grünewald-Verlag, 1927) p. 64; transl. by the author. Mies van der Rohe referred to 1926 as the decisive year in which he realized that architecture should release itself from the rational one-sidedness of industrialization. Most explicitly, this new striving manifested itself in the tripartite design of Crown Hall on the IIT campus, erected between 1950 and 1956.

46 Two basic methods for the conditioning of air were applied: The first, a small, self-contained box called the Weathermaker, which had been available on the market since late 1928, needed only to be connected to an electrical outlet in order to cool, dehumidify and circulate air. The second, the Conduit Weathermaster System, developed in 1939 for large-scale projects, distributed filtered and moisture-controlled air from a central station to local air conditioning units. Cf. Ingels, Carrier, pp. 76-95.
in standardized panels. According to Reyner Banham, “[t]he tyranny of the tile format was to become almost absolute,” leading to the endless repetition of the same modules. A monotonous order of technologically optimized buildings spread throughout the country, creating a generic sameness that obliterated local and programmatic differences.

One might assume that the advent of atomic warfare and the revelation of genocide on a previously unfathomable scale could only engender a profound crisis in rationalist thought. In marked contrast, though, the trajectory of technological optimism continued. During the Atomic Age, natural forces would more than ever be made serviceable to mankind, and in a climate of exaltation critical voices remained scarce. In 1951, the Experimental Breeder Reactor I in Arco, Idaho became the world’s first electricity-generating nuclear power plant. Three years later, in Obninsk, Russia the nuclear power station Atom Mirny (“Peaceful Atom”) commenced its production, and, thus, the split of the atom also split its lines of utilization in halves: one being military, the other civil. While atomic energy had eliminated thousands of lives during the war, it was now supposed to provide energy for entire populations and transmute the molecular structure of synthetic materials. In regard to this “new philosopher’s stone,” the Architectural Forum announced proudly in 1954:

The sober facts indicate that science has at last achieved the ancient dream of transmuting a base material into a material as different as a Damascus blade from a tobacco push and vastly more valuable, though nothing is added – no alloy, no combination.

Nevertheless, in the fall of 1952 the small Pacific island of Elugelab had been vaporized by the test of the first American hydrogen bomb. Numerous additional explosions followed, each of the “awesome fireballs” – like the one on the cover of Life Magazine on April 19, 1954 (Figure 12) – being watched by the wider public. Calculations revealed that a hydrogen bomb multiplied the power of an atomic bomb about a thousand fold. With the belief that the Russians had achieved a similar scientific breakthrough, anxiety began to spread around the globe. The Indian president Jawaharlal Nehru called for an immediate halt to the tests, and Mumford underlined in an open letter to The New York Times that “submission to Communist totalitarianism would still be far wiser than the final destruction of civilization.”

47 Banham, Well-Tempered Environment, p. 216.
49 Lewis Mumford, “Policy on Bomb Examined,” in The New York Times, 28 March 1954, p. 10. Kahn was also affected by the politic turmoil of the post-war years. An ardent supporter of the ideas of the United Nations, in 1947 he asked Howard Myers, editor of The Architectural Forum, to introduce and recommend him to the UN Building’s chief executive architect, Wallace K. Harrison, for a possible collaboration; Myers’ letter of recommendation, 14 January 1947, 030.II.A.61.29, LIKC. Beginning in 1946, Kahn also attended meetings and collected bulletins of the “World Government” organization, which intended to replace each nation’s legislation with a single global institution. Cf. 030.II.A.63.19, LIKC.
Fig. 12: Explosion of a Hydrogen Bomb on the Cover of Life Magazine, 1954.
Between the 1930s and '50s, as part of his “Renewal of Life” series, Mumford had surveyed in an all-encompassing manner Western society in relation to technology. He remained thoroughly skeptical of the total change brought by the machine, and was especially concerned about its destructive effects upon nature. In his theories, strongly influenced by his mentor, the Scottish biologist, sociologist, and town planner Patrick Geddes, he followed the latter’s distinction between a Paleo- and Neotechnic phase of industrialization, but added an Eotechnique time of preparation. While the Paleotechnic epoch had dissipated energies inefficiently, the electricity-powered Neotechnic period should use technology as a key to improve life. Recognizing the connection between filth and disease, the general criterion for the performance of a building should be its contribution to the health of its occupants. Mumford recognized an emergent “biotechnic régime” that had the potential to better adapt technology. Targeting architecture, he maintained, “a good part of our mechanical substitutes are superfluous,” since their mechanical effects could be reproduced by the proper utilization of the “available knowledge of geography and climatology, of the strength of materials and the properties of insulations.”

1.4 First Steps in the Realm of Optimization

Kahn’s acknowledgement of the architecture of optimization had not really been a question of choice, but rather one of survival. After an almost yearlong journey around Europe in 1928 and 1929 to make a “study of Modern Architecture,” he returned to Philadelphia in the midst of a devastating economic crisis. Educated under Beaux-Arts guidelines at the University of Pennsylvania between 1920 and 1924, Kahn, after a short stint of employment in the office of his former teacher Paul Philippe Cret (April 1929 to September 1930), found himself unemployed during the Great Depression. He came to realize that a quintessential change in outlook was unavoidable. Beginning

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50 The “Renewal of Life” series comprised the four volumes Technics and Civilization (1934), The Culture of Cities (1938), The Condition of Man (1944), and The Conduct of Life (1951).
51 As a member of the Regional Planning Association of America, Mumford triggered the planning of suburban towns of limited size that were surrounded by green belts. Emphasizing self-sufficiency, open spaces, individual gardens and the closing of large blocks to vehicular traffic, the association’s ideals followed Ebenezer Howard’s tenets of the Garden City – a first reaction to the overcrowding, squalor and inadequate housing conditions caused by the Industrial Revolution in Great Britain.
53 Kahn traveled mostly alone, but also with Edward Durell Stone and Louis Skidmore. His travels took him to England, the Netherlands, Germany, Denmark, Sweden, Finland, Latvia, Estonia, Lithuania, Czechoslovakia, Austria, Hungary, Italy, Switzerland and France.
54 Cf. 330.I.B.5 “Louis I. Kahn: Draft Resume, c. 1930,” SAKC. Kahn, between his graduation and journey to Europe, had worked in the Philadelphian offices of John Molitor (1925 to 1926) and William H. Lee (1927 to 1928).
to study the rational doctrines on his own, he came to revere Gropius and “to live in a beautiful city called Le Corbusier.”

As mentioned before, while Kahn learned indirectly from both Gropius and Le Corbusier, his actual mentor had been Cret. Educated like Garnier and Perret under Julien Guadet at the École des beaux-arts in Paris, the French architect had been teaching in Philadelphia since 1903. While Cret continued to adore the forms of the past, he recognized that the needs and manner of contemporary life called for different expressions. In his essay “The Architect as Collaborator of the Engineer” (1927), Cret, directly following the constraints of Le Corbusier in *Vers une architecture* (1923), demanded a reunion of the architect and the engineer since their occupations were complementary to each other:

> The ‘new’ influence that has come from modern mechanics, from the creation around us of forms evolved by the effort to realize absolute utility and absolute economy, has simply aroused us to a fresh realization that ‘the laws of number are the laws of order and reason,’ and that beauty is as much the child of cold reason as of imagination.

Cret remained skeptical of a *total* optimization, however, as he admonished, “[w]e must guard against a tendency to make a fetish of the rigid forms that are produced by pure mechanics.” In 1931, with quite similar prospects, Kahn helped establish an ad hoc association “of unemployed architects, engineers and draughtsman to study new trends in planning and construction,” which was initially termed the “Society for the Advancement of Architecture” (S.A.A.), and later renamed to “Architectural Research Group” (A.R.G.). The group’s policies were founded on the principles of optimization:

> Architecture should be the visual resultant of the manifold co-operations of thought, social relations, biological activities, and cosmic backgrounds of a civilization. As such, the true architecture of today must therefore be logical as well as scientific and must encompass all the natural tendencies of our civilization in order to ensure the maximum of comfort, efficiency, and at the same time strive for the greatest possible economy.

By implication, the A.R.G. strove to promote the use of prefabricated modules, with the objective to correlate “the various materials and their uses based on aims

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toward standardization, unification, and economy.\textsuperscript{60} The architectural contribution
was intended to lead to a “good life,” which also required “the introduction of fine
mechanical equipment such as manufactured weather and illumination.”\textsuperscript{61} In
a lecture given to graduate students at the University of Pennsylvania in 1933, the
A.R.G.’s spokesperson, possibly Kahn, underlined that

a true, straight-forward solution is one that is stripped of all non-essentials, such as inappropri-
ate ornament, false breaks in walls, unnecessary columns, rooms put in only to balance a plan,
cornices, where they are not needed to shed water or keep off the sun, and so on. I believe this
sort of solution is prerequisite to beauty. It is the law the architect should never vary from.\textsuperscript{62}

Alongside his involvement with the A.R.G., Kahn was associated with \textit{The T-Square
Club Journal of Philadelphia}, which under its new editor George Howe embraced the
rational design directives as well. Together with his partner, the Swiss immigrant
William Lescaze,\textsuperscript{63} Howe also succeeded in his practical efforts to become instrumental
in the introduction of Modernism to America. Their design for the Philadelphia
Savings Fund Society from 1932 proved to be the first completed Modern skyscraper,\textsuperscript{64}
and according to Howe was “straightforwardly economic and not falsely mystical or
vainglorious.” Following the dictum of a building’s function,

the sculptural quality of architecture resides first and foremost in the moulding of its internal
volumes, which are the expression of the human problem, and only secondarily in the moulding
of the external shell, which in its essential form must follow the convolutions of the organism.\textsuperscript{65}

In addition, Norman N. Rice, a former classmate of Kahn’s and the first American
to work in the office of Le Corbusier, would occasionally write for \textit{T-Square}, too. For
Kahn these essays represented the clearest statements on the premises of Modern

\begin{itemize}
\item \textsuperscript{60} Ibid.
\item \textsuperscript{61} “Architecture and Modern Housing;” lecture held at the University of Pennsylvania, 9 January
1933, no author, 330.I.B.13 “Lecture 1933,” SAKC.
\item \textsuperscript{62} Ibid.
\item \textsuperscript{63} Lescaze had studied at ETH Zurich between 1915 and 1919. After spending a brief period working
for Henri Sauvage in Paris, he immigrated to the United States in 1920. His houses from the early 1930s
with glass-brick walls akin to Pierre Chareau and Bernard Bijvoet’s Maison de verre in Paris (1927-32)
are among the earliest Modernist buildings in Manhattan.
\item \textsuperscript{64} After the Milam Building in San Antonio, it was also the second fully air-conditioned high-
rise building. In order to achieve greater economy in the distribution of the necessary ductwork, a
distribution floor was installed midway up the tower. Influenced just as much by the planning of
the UN Headquarters in New York (1946-52; design by Le Corbusier and Oscar Niemeyer), Kahn
applied the slab typology in the Jefferson National Expansion Memorial in St. Louis (1947), the
Triangle Redevelopment Project in Philadelphia (1946-8) and the Plan for Midtown – City Center in
Philadelphia (1947-8; Kahn in collaboration with Oscar Stonorov).
\item \textsuperscript{65} George Howe, “A Design for a Saving and Bank Office Building,” in \textit{The T-Square Club Journal of
Philadelphia}, vol.1, no.4, 1931, p. 11.
\end{itemize}
architecture. Rice observed in “This New Architecture” (1931) that the controversy between the fundamentalists, who swore to the “Alma Mater of the historic styles,” and the other “relatively small group of radicals, the avowed disciples and the young neophytes,” who prayed in the name of the new religion, was becoming more intense. It was obvious for him that to follow form was not to follow tradition and that function should determine form as it had done in medieval times. Following the tenets of optimization, the task of the architect was “to visualize the building as an organism whose every part is necessary and obeys a necessity.” Only this could be a truthful architecture, because it advocated the inherent beauty of industrial production and redeemed the academic falsehood that “tries to fit function to arbitrary forms.”

In 1932 Le Corbusier published the essay “We Are Entering upon a New Era” in T-Square. With prophetic words he proclaimed that the contemporary changes were so tremendous “that we can only regard it as the beginning of a new cycle in the history of the human race.” In the following issue, focusing on the opening of the groundbreaking “International Style” exhibition in New York, the journal gathered the exhibition’s curators Henry-Russell Hitchcock and Johnson as guest-editors. The questions raised by Mumford at a related symposium and printed in the same issue –

Are you ready to abandon the outworn theories of individual design and ornament that were fastened on your architectural education: can you think and design in rational values?

– must have been especially relevant for Kahn. In 1935 he passed the State Board Examination for Architects, and in the following years began to work on a number of large-scale housing projects. Planning the Jersey Homesteads Development in Hightstown (1935-9), Kahn collaborated with the German Alfred Kastner, who had designed previously with Oscar Stonorov, another German immigrant, the Carl Mackley Houses in Philadelphia (1931-4) – the first Siedlung rendered after European prototypes in America.

Catherine Bauer, the author of Modern Housing (1934) and an associate of Mumford’s in the Regional Planning Association of America, was another important member of Philadelphia’s architectural community at the time. In 1940, she launched the United States Housing Authority in Washington D.C., which offered funds and

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66 Kahn’s letter recommending Rice to the jury of fellows of the American Institute of Architects, 29 December 1961, 030.II.A.58.20, LIK.
70 Cf. 330.I.B.17 “LIK, Documents for Architectural Registration,” SAKC.
71 Stonorov had earlier worked with the André Lurcat in Paris and was co-editor of Le Corbusier’s Œuvre complète; the first volume just being published at the time of his arrival in America in 1929.
gave guidelines to coordinate urban and suburban development, besides emphasizing the architectural and political significance of low-cost mass-housing. Initially this agency allowed Kahn to prepare an exhibition contribution, which resulted in the Rational City Plan (1939) shown at the Museum of Modern Art in New York. Clearly in analogy with Le Corbusier’s Ville contemporaine for three million inhabitants of 1922, in Kahn’s urban proposal of a city for two million people a series of cruciform towers levitated above wide, empty fields that were grid-segmented by the main traffic system. Besides, for a number of Kahn’s projects in the 1940s and ‘50s, Bauer’s Housing Authority acted as client, for instance the Carver Court Housing Development in Coatesville, Pennsylvania (1941-4, Kahn in collaboration with Howe and Stonorov). Working as landscape consultant on the project, as well as on several of Kahn’s other housing schemes, was Daniel Urban Kiley. He would be the first in a series of prolific landscape architects to collaborate with Kahn over time, and he definitely helped Kahn to appreciate the whole terrain as a single unit of three-dimensional design, in which some spaces were under cover and others simply were not.

Before his encounter with Kahn, after a four-year apprenticeship with Warren Manning, who himself had worked for Frederick Law Olmsted, Kiley had enrolled in the landscape program at Harvard’s Graduate School of Design in 1936. Among his classmates were Garrett Eckbo and James Rose, who shared his dislike for the conservative tone of the department. As Kiley recalled, neither Gropius nor Bremer Pond, the head of the landscape department, were “willing to accept the currency of a fluid spatial dialogue between building and land.” As a consequence of this rejection of Modernist ideals in the education of landscape architects, he left Harvard without a degree, but remained in close contact with Eckbo and Rose. Together, they co-authored three interrelated articles around the turn of 1940 that would become seminal for the further development of their profession.

Dividing the contemporary environment into three broad categories – the urban, mainly the result of industrial progress, the rural, largely influenced by agriculture, and the primeval, nature per se and only partially exploited – Kiley, Eckbo and Rose promoted to value the landscape in functional, rather than purely aesthetic terms. Seeking release from the classical principles of design, “[t]he approach has shifted, as in building, from the grand manner of axes and façades to specific needs and specific forms to express those needs.” Their ultimate goal was to produce landscapes of the utmost efficiency:

72 Kahn and Kiley worked together on the following housing developments: Pine Ford in Middletown, Pennsylvania (1941-2; Kahn in collaboration with Howe), Lily Ponds in Washington D.C. (1942-7; Kahn in collaboration with Stonorov), Mill Creek Project in Philadelphia (1950-4), and the Row House Studies for the City Planning Commission of Philadelphia (1951-3).
73 Dan Kiley and Jane Amidon, Dan Kiley: In his Own Words (London: Thames & Hudson, 1999) p. 11.
The irreducible requisite of any successful planning is that the forms developed will direct the flow of energy in the most economic and productive pattern.75

Kahn, while engaged with those large-scale housing developments, quite naturally also confronted questions of communal identity. While the totalitarian regimes in Europe had implemented a neo-classical monumentality, after the war the Modern movement was to provide the built counter-symbols of the regained freedom. In 1943, Giedion together with José Luis Sert and Fernand Léger published “Nine Points on Monumentality,” in which they called for new means of collective expression. A year later Giedion clarified his position in “The Need for a New Monumentality,” published in Paul Zucker’s anthology New Architecture and City Planning (1944). Therein, he stipulated the need for no more “pseudomonumentality,” no more “classical masks,” and no more following of routines from bygone ages that had lost their inner significance. Simultaneously, though, in order to avoid the “empty shells” produced by the International Style – a general failure that Mumford summarized in his witty remark, “if it is a monument, it cannot be modern, and if it is modern, it cannot be a monument”76 – the new communal architecture was in Giedion’s opinion “forced to seek the monumental expression [...] beyond functional fulfillment.”77

In the same collection, Kahn also contributed his first more widely distributed essay “Monumentality,” which argued for “living memorials” that indicated a striving for structural perfection. Significantly, for Kahn, form not only had to follow function, but also force. In his conception of a new monumental architecture, a vehement structural component took hold that sought to derive more graceful forms from a more precise analysis of the physical stresses involved. Accordingly he called for new methods of calculation, “based on the effect of continuity in structures,” as these would yield efficient shapes that eschewed improvident moment coefficients. His accompanying biomorphic illustrations of a pointed arch steel structure glorified the material’s inherent capacities of fluid construction (Figure 13).

Notably, alongside his gazelle-like rendering, Kahn included a sketch of Beauvais cathedral that was drawn after an illustration by Choisy. The reference to the French architectural historian, who had proclaimed that architecture in changing its structural means also changed its form, made obvious that Kahn’s search for a new monumentality was – not unlike Mies van der Rohe’s – directed towards the exploitation of the technical resources of his time: “Beauvais cathedral needed the steel we have. It needed the knowledge we have.”78 For Kahn, the engineering achievements attained during the war were paving the way towards a new art:

Standardization, prefabrication, controlled experiments and tests, and specialization are not monsters to be avoided by the delicate sensitiveness of the artist. They are merely the modern means of controlling vast potentialities of materials for living, by chemistry, physics, engineering, production, and assembly, which lead to the necessary knowledge the artist must have to expel fear in their use, broaden his creative instinct, give him new courage, and thereby lead him to the adventures of unexplored places.79

1.5 Following the Logics of Structural Continuity

The Parasol House of 1944 – designed in collaboration with Stonorov as an answer to the call by the furniture company Knoll to develop prototypical low-cost “Equipment for Living” – offered Kahn a further opportunity to extend his rational design specifications. In the unrealized design, the entire structure was subdivided into smaller segments of modular lightweight ceilings, while only one column carried each. Underneath these large canopies, non-load bearing walls constituted the individual apartments. Kahn’s use of a tree-like structure – a theme that both structurally and

79 Ibid., p. 587.
metaphorically would accompany him for the rest of his career – was inspired by the dendriform construction of Frank Lloyd Wright’s Johnson Wax Administrative Building in Racine (1936-9).\(^{80}\) With this building, Wright, whose work Kahn praised in his notebooks as “the most wonderfully true architecture Amerique,” had set a perfect example of reinforced concrete construction that followed the principles of \textit{structural continuity}.\(^{81}\) In the working space, numerous pillars, akin to tree trunks in a forest, merged in a fluent manner into cantilevered ceiling plates.

Kahn’s fascination with continuous structures, where shape, space, and structure interlocked, also became apparent in his schemes for the Jewish Agency for Palestine Emergency Housing from 1949. After Israel’s declaration of independence in 1948, and because of the expected mass immigration,\(^{82}\) an advisory board of American experts, including Kahn, was formed to study the expected housing shortage.\(^{83}\) Putting into practice his ideas from the essay “Monumentality,” Kahn proposed the establishment of several prefabrication centers, which would turn the country into a center of building fabrication in the Near East. After the evaluation of various material choices, Kahn arrived at the conclusion that “Israel’s material in building is concrete,” because also

in France, Belgium, Switzerland and South America where concrete has been used extensively for the modern design of buildings and bridges have developed grace and power arriving from necessity and economy.\(^{84}\)

To solve the crux of prefabrication and to enable the required rapid erection at various sites, with the assistance of the Philadelphian engineer Carl Billner, Kahn proposed the construction of a series of parabolic shell structures (Figures 14, 15).\(^{85}\) Concrete should be poured into a framework fitted with vacuum mats that would immediately absorb the water not required for the setting of the cement, and, hence, lead to a faster hardening and higher crushing strength of the material. The parabolic section, in which wall and roof became a continuous element, required a minimum of material for the required span. In appearance similar to a catenary curve – the section that

\(^{80}\) In German the words \textit{Bau} (“building”) and \textit{Baum} (“tree”) are intrinsically connected.

\(^{81}\) “Notebooks,” 288.III.15, RSWC. Cf. Wurman, \textit{What will be has always been}, reproduction of Kahn’s notebooks at the end.

\(^{82}\) Cf. Gershon Meron, “Israel’s Economic Program,” in \textit{Economic Forum}, 030.II.A.35.29, LICK.

\(^{83}\) The group visited Israel in 1949 for three and a half weeks, and on his return Kahn stopped in Paris for a brief visit to the Gothic cathedrals of Rouen and Chartres. Cf. Anne G. Tyng, “Louis I. Kahn: A Modern Architect’s Response to Egypt, Greece and Italy;” from a symposium in Evanston, 1 November 1980, 074.II.C.72, AGTC.

\(^{84}\) Kahn’s handwritten notes on Israel’s proposed building program without date, and the “Preliminary Report on Housing in Israel,” 7 June 1949, 030.II.A.35.33, LIKC.

\(^{85}\) Cf. Memorandum regarding the method and estimated cost of erecting a parabola shaped shell, 2 June 1949, 030.II.A.35.30, LIKC.
Fig. 14: Louis I. Kahn, Palestine Emergency Housing, Israel, 1949.
Fig. 15: Louis I. Kahn, Palestine Emergency Housing, Israel, 1949.
Following the Logics of Structural Continuity

a suspended chain assumes when supported only at its ends and, thus, resembling most closely the line of thrust – it allowed for extreme thinness. One can glean Kahn’s interest in this form also when seeing him look at the parabolic shell structure of one of his students working on the problem of a National Center for UNESCO in the spring of 1949 (Figure 16). The project relied on a brief from his unsuccessful competition submission for the Jefferson National Expansion Memorial in St. Louis (1947) – notably won by Eero Saarinen proposing a giant concrete arch with the profile of a catenary curve.86

Altogether, warps, waves, droops, shells and other non-rectangular forms became ever-increasingly the order of the day. Scientific studies of the air-resistance of birds

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86 Cf. Eeva-Liisa Pelkonen, “Toward Cognitive Architecture,” in Stanislaus von Moos and Jochen Eisenbrand, (eds.), Louis Kahn: The Power of Architecture (Weil am Rhein: Vitra Design Museum, 2012) p. 139. Between 1916 and 1924 the French engineer Eugène Freyssinet erected some enormous parabolic Concrete Hangars in Orly, comparable in size only to the obliquely shaped mud-brick barrel-vault hovering over the audience hall of the Palace of Ctesiphon (531-79 AD). In relation to Kahn’s smaller-scale parabolic vaults in Israel, one may also reference mud-brick vaults that without the need of scaffolding had been employed since ancient times by Nubian masons – a building technique revived by the Egyptian architect Hassan Fathy, for instance, in the planning and partial execution of New Gourna between 1945 and 1948.
and the water-resistance of fishes appropriated shape as a decisive factor in terms of efficiency, and set the general basis for a more streamlined society. One of the first to attack the cube-ism of both classicism and the International Style was the Austrian immigrant Frederick Kiesler, who later taught with Kahn at Yale. In his “Manifesto of Tensionism” (1925), Kiesler had demanded an organic architecture that transcended “the coffins with airholes” to more adequately accommodate the “elasticity of life.”87 The result of his deliberations was the unexecuted Endless House (first version in 1950), a self-bearing monocoque construction that, without beams and columns, enunciated a spatial continuum. Such a construction was in Kiesler’s opinion more natural, since nature’s method of building was continuous, and also in architecture the number of joints should be decreased in order to increase a building’s strength.88

Before Kiesler, at the turn of the century, a number of European Art Nouveau architects had figuratively employed a fluid set of organic forms. Among these, the Spanish architect-engineer Antonio Gaudí avidly observed nature’s architecture in the peaks of the Montserrat mountain range, while in a eucalyptus tree standing outside his atelier he discerned the geometrical model for his “Mediterranean Gothic:”

Everything is in equilibrium. And this is nothing other than a series of hyperbolic paraboloids. Then I saw that hyperbolic paraboloids are the mountains, the valleys, the waves of all nature.89

Working in an empirical way, Gaudí suspended catenoids of hanging cords in his Bauhütte, which were then distorted into funicular polygons by attaching weights at the points where the loads charged. Inverted photographs of these hanging structures revealed upright polygons that adhered most closely to the operative forces. Achieving unity between the structural and architectural expression, Gaudí’s inclined piers and vaults of double curvature absorbed the static resultants and made the use of supplementary buttresses irrelevant.90

Subsequent to Gaudí’s endeavors, the Swiss engineer Robert Maillart also broke away from the atavistic construction principle of bearing and loading. Exploiting

90 Gaudí’s “ruled-surfaces” of double-curvature consisted of conoids, paraboloids, and hyperboloids: mathematically difficult to project, they could be erected with ease using straight timber forms.
the potential of the parabolic shell in his Cement Pavilion for the Swiss National Exhibition in Zurich in 1939, in the factory buildings he designed mushroom-columns merged in a fluid manner into beamless slabs. No longer differentiating between the horizontal and vertical members, and thus no longer thinking of beams and columns as separate structural elements, Maillart treated the structure as a whole. This pursuit to construct ever more fluid structures carried well into the 1960s through the work of such engineers as Eduardo Torroja, Pier Luigi Nervi and Felix Candela. For Nervi structural correctness was identical with functional, technical and economic truthfulness; and thus, beauty expressed nothing less than structural fitness.91 In America, the North Carolina State School of Design in Raleigh emerged as the center of structural exploration. Led by Kahn’s friend Henry Kamphoefner, the school counted among its permanent and visiting faculty Matthew Nowicki, Eduardo Catalano, Richard Buckminster Fuller, Felix Samuely, Robert LeRicolais, as well as Torroja and Candela.92 Kahn visited several times as a lecturer,93 and in the introduction to the winter 1952 issue of the Student Publication of the School of Design North Carolina State College, Kamphoefner put forward the architect-engineer as “the coordinator of the structural dynamics in the over-all pattern of life.”94

Paradoxically, the structural engineers, who had been praised for their mathematical rigor, themselves demanded more empirical techniques of stress analysis. In line with Kahn’s claim to obtain better calculation methods, Candela stated, “any pretense of obtaining exact estimations mathematically is an absolute illusion.”95 His experimental concrete umbrella, erected in Vallejo in 1953 (Figure 17), on the one hand masterfully exemplified the objective to think the structure as a whole, and on the other underlined his argument that mathematics idealized incidents, which in reality never occurred in such an isotropic manner.96 Promoting the same idea, the translated preface of Felix Cardellach’s Filosofía de las estructuras (1910) was reprinted in the Student Publication of the School of Design North Carolina State College in 1956. Cardellach, a Barcelonan contemporary of Gaudí, had from early on attacked the “Parnassus of mathematics,” believing that its results were often imperfect due to the impossibility of knowing the entirety of

92 Nowitzky’s design for the multi-purpose Dorton Arena in Raleigh, the “Paraboleum,” (1948-53) in which a saddle-shaped roof supported by steel cables was held in place by two intersecting parabolic concrete arches, made widely visible the school’s focus upon structural issues.
Doing More With Less. Towards An Architecture Of Optimization

reality. Torroja, one of the pioneers in the structural study of reduced scale models, also confirmed that mathematics in its traditional forms of application was becoming ineffective.\footnote{Cf. Eduardo Torroja and Carlos Benito, “Experimental Testing of Thin Shells by Means of Reduced Scale Models,” in \textit{Student Publication of the School of Design North Carolina State College}, vol.9, no.2, 1960, pp. 3-15.}

Leaving this discussion aside, however, Kahn’s interest in the principle of continuity was mostly fueled by his study of D’Arcy Wentworth Thompson’s \textit{On Growth and Form} (1917).\footnote{According to Kahn it was the one book that people ought to choose if they were to read only a single book in their life. Cf. Joseph A. Burton, “Notes from Volume Zero: Louis Kahn and the Language of God,” in \textit{Perspecta}, no.20, 1983, p. 84.} In 1951, the Institute of Contemporary Arts (I.C.A.) in London devoted an exhibition called “Growth and Form” to its contents, and Kahn also treasured the related catalogue \textit{Aspects of Form – A Symposium on Form in Nature and Art} by Lancelot Law Whyte, a Scottish scientist, banker and natural philosopher.\footnote{Whyte was in Kahn’s opinion a unique man, who had “realized the meaning of Form in the universal sense;” letter to G. Holmes Perkins concerning the engagement of Whyte to lecture at the}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig17.jpg}
\caption{Felix Candela, Concrete Umbrella, Vallejo, Mexico, 1953.}
\end{figure}

...
Form, Thompson attempted in a pioneering effort to study biological phenomena in relation to mathematical and physical laws, “all the while regarding the fabric of the organism, ex hypothesi, as a material and mechanical configuration.” While zoological and morphological studies had hitherto been slow to accept numerical analysis, Thompson was reluctant to prove that efficient causation also concerned organic constitutions and their growth. Setting his focus upon a physical analysis of such processes and forms, Thompson saw no reason why these should not just as adequately be solved by reference to their antecedent phenomena in a material system of mechanical forces. He was quite aware that

...they have also, doubtless, their immanent teleological significance; but it is on another plane of thought from the physicist’s that we contemplate their intrinsic harmony and perfection, and ‘see that they are good’. Nor is it otherwise with the material forms of living things. Cell and tissue, shell and bone, leaf and flower, are so many portions of matter, and it is in obedience to the laws of physics that their particles have been moved, moulded and conformed.

While other agents might exist acting in a living body than in an inorganic substance, according to Thompson, these forces, as far as they caused mechanical actions, were of quite the same character. In other words, their effects were also ruled by necessity and always obeyed the same rules when being acted upon under similar conditions. Regarding the momentous natural condition as an optimized solution in a continuous process of transformation, elemental beauty resided in the efficient form, since it derived its material constitution by means of strict adherence to given imperatives. In biological terms, the slender leg of a gazelle and the sturdy leg of an elephant answered to the same set of physical preconditions: both were beautiful in relation to nature’s relentless dictate of optimization. However, while small creatures were governed in their corporeal morphogenesis by capillarity, gaseous pressures, surface tension, electric charge and the intermolecular force of cohesion, gravitation and climatic forces mainly targeted larger ones. Taking reference from Galileo Galilei’s “Principle of Similitude,” Thompson argued that everywhere nature worked true to scale, because

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University of Pennsylvania, 23 September 1965, 030.II.A.57.107, LIKC. In the same letter, Kahn mentions that Anne G. Tyng had met Whyte in London, although without indicating a date. In Tyng’s archive are several letters addressed to Whyte from the mid-1960s, 074.II.A.6, AGTC. Whyte was trained as an experimental physicist under Ernest Rutherford at Cambridge. In 1928, he received a Travelling Fellowship by the Rockefeller Foundation to continue his studies in Berlin, where he contacted Albert Einstein. His later writings found great response among architects, designers and visual artists in the United States. Cf. Lancelot L. Whyte, Focus and Diversions (New York: George Braziller, 1963).


101 As Thompson noted, “to treat the living body as a mechanism was repugnant, and seemed even ludicrous, to Pascal; and Goethe, lover of nature as he was, ruled mathematics out of place in natural history.” Ibid., p. 2.

102 Ibid., p. 10.
the thing will fall to pieces of its own weight unless we either change its relative proportions, which will at length cause it to become clumsy, monstrous and inefficient, or else we must find new material, harder and stronger than was used before.\textsuperscript{103}

In accordance with Kahn’s argument that the builders of Beauvais cathedral needed contemporary steel, Thompson stated that “[p]ractical applications, undreamed of by Galileo, meet us at every turn in this modern age of cement and steel.”\textsuperscript{104} Touching upon more architecture-related matters in the chapter “On Form and Mechanical Efficiency,” the British scientist, again noting that Galileo had first solved the problem, arrived at the conclusion that in order to save weight, the engineer, just like nature, should avoid the dead middle zone, and “giving a parabolic outline to our beam, we have its simple and comprehensive solution.”\textsuperscript{105} To further support his argument, Thompson shared a story about the Swiss engineer Karl Culmann, who in 1866 had entered by chance into an anatomist’s dissection room at ETH Zurich (Figure 18):

The engineer, who had been busy designing a new and powerful crane, saw in a moment that the arrangement of the bony trabeculae was nothing more nor less than a diagram of the lines of stress, or directions of tension and compression, in the loaded structure: in short, that Nature was strengthening the bone in precisely the manner and direction in which strength was required […].\textsuperscript{106}

\subsection*{1.6 Platonic Solids, Space Frames and the Tenets of Structural Addition}

However, Kahn did not solely pursue the direction of continuous structures, but in the late 1940s began to experiment with other modes of lightweight construction as well. Consequently, he became increasingly interested in optimized forms not shaped by force, but derived from the ideal mathematical \textit{division of space}. Kahn’s shift was critically informed by his employee Anne Griswold Tyng, who according to him knew of “the aesthetic implications of the geometry inherent in biological structures.”\textsuperscript{107} Tyng had been one of the first women to attain a master’s degree in architecture from Harvard in 1944, and beginning in 1945, she was employed in Kahn’s office. There she acted as “geometrical analyst” and drew his attention to phenomena such as atomic orders of spatial distribution. Through Tyng, Kahn was also introduced to the Platonic Solids (Figure 19), depicted here in an illustration by Leonardo da Vinci.

\begin{thebibliography}{9}
\bibitem{103} Ibid., p. 27.
\bibitem{104} Ibid.
\bibitem{105} Ibid., p. 996-7.
\bibitem{106} Ibid.
\bibitem{107} Kahn’s letter recommending Tyng to John D. Entenza, director of the Graham Foundation for Advanced Studies in the Fine Arts, 2 March 1965, 030.II.A.55.63, LIKC.
\end{thebibliography}
that she used in her article “Geometric Extensions of Consciousness,” published in Zodiac in 1969. According to Tyng, these polyhedral forms – the “archetypal dice” – were the ones from which all others derived, and as the electronic microscope revealed, they “are involved in the way in which ‘fundamental’ particles – protons and neutrons – are built up into atoms of about a hundred different elements [...].”

Initially presented in Plato’s Timaeus (c. 360 B.C.), these constellations were the only possible polyhedra to enclose space uniformly, and each one represented one of the classical four elements (rhizomata) as established by Empedocles of Agrigentum in Peri Physeos (“On Nature,” Fr.6): the tetrahedron corresponded with fire, the cube

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110 According to Vitruvius, “Phythagoras, Empedocles, Epicharmus, and other physicists and philosophers affirmed that there are four principles: air, fire, earth, water [...].” Vitruvius, On Architecture (London: William Heinemann, 1931; edited from the Harleian Manuscript 2767; De
with earth, the octahedron related to air, the icosahedron to water; and lastly, the
dodecahedron, a fifth element added by Plato, represented the all-encompassing
receptacle or aether. However, these elements and their geometric bodies were not
stable, but continually passed into one another through a process of rarefaction and
condensation to combine in an array of indefinite proportional relationships, thus,
creating the manifold constitutions of the material world.

If it was essentially Tyng who influenced Kahn’s interest in such formative
matters, three sources from which her own knowledge of these geometrical bodies
derived should be mentioned: first, her contact with the German architect Konrad
Wachsmann; second, the multi-layered spatial arrangements of Alexander
Graham Bell’s early flight-machines; and third, the synergetic philosophy of Fuller.
Wachsmann, who had immigrated to the United States in 1941, initially awakened
Tyng’s enthusiasm for modular geometric coordination. After graduation, she worked
briefly in his New York office, remarkably at a time when he developed the Mobilar
Structure for the Atlas Aircraft Corporation (1945): underneath a wide cantilevering

Fig. 19: Leonardo da Vinci’s Platonic Solids, 1509, in Anne Griswold Tyng, “Geometric Extensions of
Consciousness,” 1969.

architectura libri decem, 1st century BC) VIII, Preface, § 1. Describing a universe that is cyclically
generated and destroyed by the opposing forces of love (philia) and hate (neikos), Empedocles,
who according to legend died in the fires of Mount Etna, added to Thales of Miletus’s water (hudor),
Anaximenes of Miletus’s air (aer), and Heraclitus of Ephesus’s fire (pyr), the fourth substantial
element, earth (ge), and clarified: “No, these are all, and, as they course along through one another,
now this, now that is born – And so forever down eternity.” Empedocles, Fragments (Chicago: The
Open Court Publishing Company, 1908) Fr.17.
roof consisting of a single layer triangulated truss, secondary mobile space partitions enabled a flexible division of the ground. Wachsmann’s proposal would be influential for Tyng’s project of an Elementary School in Bucks County (Figure 20), which she developed independently between 1949 and 1951. Using tetrahedron-octahedron geometry, she recalled,

instead of being used as a single layered space frame truss, the geometry was thickened in layers toward the point of support to become its own vertical support as a ‘tree trunk’.\textsuperscript{111}

Tyng’s idea to use a multiple layer space-structure was subsequently also taken up by Wachsmann, who, having been contacted by the American Air Force, conceived another, much larger hangar between 1951 and 1954 (Figure 21). Applying industrialized production methods that gave new life to Paxton’s credos, he developed a standard unit, which permitted flexibility in arrangement and fast assembly. For Wachsmann, numerous structural cells termed “building molecules” should converge to establish the final shape.\textsuperscript{112} He was well aware that this synthesis of smaller elements to form a stronger whole was comparable to Roman masonry construction, where single bricks as “building atoms” arranged in a proper way collectively spanned vast distances.

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Similarly, Bell had been a pioneer in the experimentation with kites of cellular structure such as the tetrahedron-octahedron “Cygnet” (1907) that Tyng used again as an accompanying illustration in “Geometric Extensions of Consciousness” (Figure 22). The American inventor realized that tetrahedral and octahedral cell configurations possessed “three-dimensional strength,” and was astonished by their lightness, but also their functional logic following the principle of addition: a large number of single rods, themselves weak, when connected in an appropriate way manifested a much stronger entity.\footnote{Cf. Beatriz Colomina, Annmarie Brennan and Jeannie Kim, (eds.), \textit{Cold War Hothouses} (New York: Princeton Architectural Press, 2004) p. 159.}

The case of Fuller is insofar more complicated, as both Tyng, who heard a two-day talk delivered by him at the University of Pennsylvania in 1949,\footnote{Cf. Tyng, “Geometric Extensions of Consciousness,” p. 173. Buckminster Fuller lectured on relationships of close-packed spheres with atomic configurations in 1949, printed as Item 0 by the North Carolina State School of Design in 1955. As indicated in later correspondence between Fuller and Tyng, their families were distantly related through the artist Margareth Fuller Tyng. Cf. Tyng’s letter to Fuller, 27 March 1965, 074.II.A.6, AGTC.} and Kahn,
who knew him since the early 1930s, were familiar with his ideas.\footnote{It is possible that Kahn was also aware of Bell before his acquaintance with Tyng, since he remembered becoming “at a very early time very interested in some of the experiments which Graham Bell had made in just the turn of the century, of the concern of those shapes.” Jules Prown and Karen E. Denavit, (eds.), \textit{Louis I. Kahn in Conversation: Interviews with John W. Cook and Heinrich Klotz 1969-70} (New Haven: Yale University Press, 2014) p. 194.} Fuller had been developing his \textit{Dymaxion} philosophy since the late 1920s, which envisioned an industrially fabricated, easily transportable and mountable lightweight house. The Dymaxion House bore no geographical stamp; it just used on-site resources, could be erected within a day and delivered by airplane. In the best sense of optimization, Fuller announced that he had found a way to reap the largest dividend of human advantage from the most economical appliance of energy and material resources. Kahn had become familiar with his concepts during the depression years, when Fuller contributed a series of articles entitled “Universal Architecture” to \textit{T-Square}, and even replaced Howe as editor in 1932. The renaming of the publication as \textit{Shelter} underlined his holistic design approach: Acknowledging the harsh consequences of the economic crisis, but also noticing what potential damages hurricanes, earthquakes, fires and floods might cause, Fuller turned into an early \textit{ecological prophet}. He was alarmed

\begin{figure}[h]
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\includegraphics[width=\textwidth]{Fig.22.png}
\caption{Alexander Graham Bell, “Cygnet,” 1907.}
\end{figure}

\textit{Fig. 22: Alexander Graham Bell, “Cygnet,” 1907.}
that a “quasi Functional Style,” which was merely dogmatic in its formalism and withdrawn from its original economic roots, was infiltrating the United States.116 Polemically he interrogated his readers: “How much does your house weigh?”117

Fuller’s concept of ephemeralization or “doing more with less” derived directly from his observations of sea- and airborne weaponry during his time as a Navy officer. Following the rather one-dimensional military logic that supremacy was to be achieved by carrying the greatest fire power a maximum distance in the shortest time with ever-increasing accuracy, ever lighter and at the same time more stable rockets had to be constructed.118 Taking into account that all the forces operative in nature resulted in a complex progression of least-effort arrangements, Fuller conceived triangulated webs, which, following a mathematical logic, represented the most economic networks of energy distribution in plane and space. He asserted that tetrahedral forms had been overlooked in man’s illogical obsession with “rectilinearity,” and in his opinion, nature did not use the fragile square, but employed the stable triangle.

The concepts of both mass-produced lightweight house and tetrahedral arrangement were synthesized in Fuller’s research on the Geodesic Dome. Setting a network of 60° parallels across a sphere, his dome-structure unified the structural virtues of both the sphere and the tetrahedron: while the sphere enclosed the most space with the least surface and was strongest against internal forces, the tetrahedron enclosed the least space with the most surface and was most rigid against external pressure. Synergy, as Fuller defined it, arose when the behavior of the whole system could not be predicted by any of its parts or subsystems. Thus, being just another term for the principle of addition, synergy produced a compound structure with vastly improved properties. In the summer of 1948, Fuller realized his first geodesic structure at Black Mountain College. Even though it collapsed, he continued his endeavors, and in 1954, the first airlift of a dome took place.119

Alongside, a number of scientific discoveries proved Fuller’s assumptions regarding nature’s geometrical coordination to be correct. As early as 1885, Jacobus Van’t Hoff, laying the foundations of mathematical chemistry, had discovered that carbon, a basic constituent of organic life, was tetravalent. During the 1930s, the German-American chemist Linus Pauling discovered via x-ray analysis that metals were tetrahedrally arranged as well, and verified that protein shells were a type of spherical geodesic structure. Furthermore, algae known as diatoms and the

117 Ibid., p. 35.
119 Fuller’s explorations culminated in the Biosphere that he erected at the Expo in 1967. The gigantic dome’s outer layer was inset with transparent acrylic panels that were adjustable via a computer program to allow a controlled amount of light to enter. As a model of a self-contained and hermetically sealed environment, a year afterwards Fuller proposed a giant dome with a radius of one mile to cover New York City.
A Breathing Ceiling in a Modernist Setting

Kahn often met with Fuller in 1952, a year in which both made frequent railway trips to New Haven, where they acted as visiting critics at Yale University. Fuller remembered having personally introduced Kahn to certain fundamentals of nature’s structuring principles during these journeys. Kahn also took the opportunity to closely observe the erection of a geodesic dome in New Haven between September and November of the same year, and kept a number of images of this event in his slide collection (Figures 24, 25). In the second issue of *Perspecta* (1952), Yale’s newly founded architecture journal, Kahn underlined his interest in nature’s strategy to obtain efficient structures:

> In Gothic times, architects built in solid stones. Now we can build with hollow stones. [...] The desire to express voids positively in the design of structure is evidenced by the growing interest and work in the development of space frames. The forms being experimented with come from a closer knowledge of nature and the outgrowth of the constant search for order.

As quasi-proof for his argument, in the following issue of *Perspecta* Kahn presented his recently finished design of the Yale Art Gallery (1951-3). He had received its

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121 The German zoologist Ernst Haeckel had carefully investigated these minute shell structures built by unicellular organisms called foraminifera in the late 19th century.
122 In October 1947, Kahn had become visiting critic at Yale University’s School of the Fine Arts, replacing Niemeyer, whose admission to the United States had been blocked due to his overtly communist views. Having rejected a year earlier the opportunity to teach at Harvard, Kahn discovered himself in New Haven in a stimulating atmosphere that included Saarinen, Johnson, Kiesler, Stone, Pietro Belluschi and Paul Rudolph among the faculty.
123 From Fuller’s letter recommending Tyng to John D. Entenza, 5 April 1965, O30.II.A.55.62, LIKC.
124 As Stan Allen rightly observed, this shared interest in geometry would ultimately lead to completely opposite results: while Kahn’s architecture of compression eventually became defined by solidity, mass and an intrinsic wedding to the ground; Fuller, by contrast, developed structures of pure geometry that were indifferent of place and material. Cf. Allen, “Postscript: R. Buckminster Fuller and Louis I. Kahn,” in Daniel López-Pérez, *R. Buckminster Fuller: World Man* (Princeton: Princeton University Press, 2013).
Fig. 23: Ernst Haeckel, *Aulosphaera*, 1873-6.
Fig. 24: Richard Buckminster Fuller, Geodesic Dome, New Haven, Connecticut, 1952.

Fig. 25: Richard Buckminster Fuller, Geodesic Dome, New Haven, Connecticut, 1952.
commission, an addition to a historicist Romanesque palazzo by Egerton Swartwout, during a four-month stay as architect-in-residence at the American Academy in Rome. On January 8, 1951, Charles H. Sawyer, the dean of the school, informed Kahn that,

> Philip Goodwin, who has been [...] the architect for the Art Gallery building, faces an emergency operation on one of his eyes [...] George Howe, Eero Saarinen and I had a meeting here on Sunday and came to the unanimous conclusion that we would recommend to the University an association between you and the office of Douglas Orr [...].

Therefore, while in Europe, contemplating the ancient monuments of Italy, Greece and Egypt, Kahn could with pleasant anticipation prepare his return. During his stay in Rome, Kahn came to “realize that the architecture of Italy will remain as the inspirational source of the works of the future.” A re-interpretation of the classic works was required, though,

> as it relates to our knowledge of building and needs. [...] I find it of little difficulty translating the masonry construction into steel and concrete [...].

The Pyramids of Gizeh (c. 25th century BC) especially (Figure 26), “the most wonderful things I have seen so far,” would have an immediate effect upon the upcoming design. Most conspicuously, the Yale Art Gallery openly concealed an artificial lighting and air-conditioning system within a concrete, multidirectional space slab (Figure 27) – a “breathing ceiling” made up of pyramid-like hollow cells that acted as the “servant” element to the “served” exhibition spaces beneath. According to Kahn, the ceiling was

> beautiful and it serves as an electric plug and as a lung. It breathes. Air is forced in through these vent pipes and through the corrugations [...].

Distinctly breaking up the two components of the functional and spatial, the loft-like gallery spaces were left undisturbed in the tradition of Mies van der Rohe’s universal space. In constructive terms, the concrete space frame – in appearance similar to Fuller’s hollowed out triangular structure of the Yale-Dome – was cast-in-place on

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125 Sawyer’s letter to Kahn, 8 January 1951, 030.II.A.107A42, LIKC. When Goodwin, who had been the partner of Stone in the design of the Museum of Modern Art in New York (1938-9), withdrew, he had initially proposed Johnson to replace him. However, Johnson, too, insisted on Kahn.


127 “No Pictures can show their monumental impact. They are any color you wish them to be and as clouds pass the movement and change of color is overwhelming.” 074.II.A.81-b, AGTC.

Fig. 26: Gizeh Pyramid Complex, Cairo, Egypt, c. 25th century BC. Postcard from Louis I. Kahn to Anne Griswold Tyng, 1951.
Fig. 27: Louis I. Kahn, Yale Art Gallery, New Haven, Connecticut, 1951-3.
prefabricated tetrahedral formworks (Figure 28), and from a structural viewpoint the ceiling defined a parallel chord, multi-planar truss system of equilateral triangles with the entire top surface filled in to provide the actual floor. In order to avoid a construction joint between the floor slab and the space frame, one side of the tetrahedrons was solid, and thus the resulting longitudinal ribs additionally functioned as beams.

The enhanced plans from Perspecta show the layout of the reflected ceiling plan with two overlaid transparent layers (Figure 29): the first indicating the ventilation network, the second the electrical ductwork. Pursuing his objective to liberate a maximum of space with a minimum of structure, Kahn also made in the composition of the ground plan a broad distinction between a primary column structure carrying the vertical loads and a non-bearing, but space-defining and functional middle zone. The cylindrical, apparently massive, and freestanding concrete shaft containing a triangular stair fulfilled no structural role, as it did not even touch the ground. This compositional element is noteworthy for several reasons: first, its application of a primary canon of forms; second, its utilization of zenithal light, and third, if structurally activated, it would have been Kahn's first “hollow column,” which like the Pillars of Victory erected for Roman emperors accommodated additional uses in their voided hearts.

The reasons for employing concrete – with its plastic properties diminishing the possibilities of synergetic behavior – were primarily pragmatic: on the one hand, as a consequence of the Korean Conflict in 1952, steel had been rationed by the government, and on the other, fireproofing restrictions made a three-dimensional metal space frame impossible. Nevertheless, heated discussions arose concerning the future ceiling. In a meeting on March 11, 1952, the building committee decided to abandon the tetrahedron floor system and proposed to use a common beam and slab floor system instead. The committee found no justification in Kahn’s proposed system, as it made 90% more use of steel and required three times as much formwork at a higher unit cost. In their opinion, the depth-weight ratio was far from optimized due to the thickening of the concrete beyond theoretical requirements to satisfy local fireproofing regulations, and real-size test structures had to be built. Dean Sawyer, however, stuck to Kahn’s proposal, considering it worth the additional costs.

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129 Cf. Description of the structural system by the consulting engineer Henry A. Pfisterer, 23 February 1954, 030.II.A.10742, LIKC. The Philadelphian office of Keast & Hood assisted Pfisterer, the local engineer. Within their team, Nicholas Gianopulos was responsible for the mathematical analysis of the tetrahedral structure. However, “the analytical tools to assess the structure did not exist yet,” and “the only way to test it was to build a full-size model, load it with sandbags, and measure it with instruments.” Wendy Lesser, You Say to Brick: The Life of Louis Kahn (New York: Farrar, Straus and Giroux, 2017) p. 139.

130 Cf. Vernon Read’s draft “Tetrahedral Floor System” for The Architectural Forum, 030.II.A.10744, LIKC.

Fig. 28: Louis I. Kahn, Yale Art Gallery, New Haven, Connecticut, 1951-3.
Fig. 29: Louis I. Kahn, Yale Art Gallery, New Haven, Connecticut, 1951-3.
and structural complications involved. He defended the multifunctional ceiling by pointing out that it first, gave a greater sense of space; second, provided better acoustical properties; and third, allowed for a flexible distribution of light.\footnote{132}

What Kahn did not foresee in his conception was the simple fact that the space could be altered and changed. Having learned from the dispute with his colleague Paul Rudolph, who in 1956 had modified the flexible space divisions without consulting him, Kahn tried to abandon similar spatial continuums in the future. In fact, many of the Modernist principles he had applied in this first significant public commission of his career were questioned in later projects. Altogether, the gallery building was absolute in its contextual placement: from the south, the bare brick façade, attached like a mask to the inner skeletal structure (Figure 30), was a monumental urban statement.\footnote{133} In contrast to its emphasis on tactile properties stood the otherwise more visually appealing usage of glass and steel that opened the gallery towards the west and north with its annexed sculpture gardens (Figure 31). A truly integrative setting between context and building was denied; in fact, nature was actually repelled by mirroring, as in Mies van der Rohe’s buildings on the IIT campus (Figure 32). Principally developed from the inside out, the building was quiescent and resolute in its outer appearance. Its architecture of complete encapsulation called for technical assistance and foreclosed an open dialogue with the natural surroundings.

It should be noted, however, that Kahn put considerable effort into the planning of the northern sculpture garden – a kind of terraced landscape with concrete and masonry walls projecting outwards from the building to connect the garden and the building – as the accompanying drawing and letter to Lamont Moore, a local consultant, indicates (Figure 33). In this intermediate scheme, Kahn proposed the planting of ivy against the garden’s northern wall, and the placement of five crabapple trees with a small fountain on the terrace next to it, which together would produce a “green wall” facing the Gallery. Kahn’s actual landscape architect on the job was Christopher Tunnard, the author of Gardens in the Modern Landscape of 1938, the principal manifesto on landscape architecture in the first half of the 20th century.

Tunnard had started teaching at Harvard in 1939, and he remained there until the outbreak of the war. Afterwards, he received an invitation from Yale to conduct research on city planning, during which time he also encountered Kahn, since they co-taught a course in the fall semester of 1952. Tunnard gave Kahn further advice on the South-West Temple and Poplar Redevelopment and Housing Scheme (1950-2; not built), which formed part of the larger Mill Creek Redevelopment Plan (1950-54) in Philadelphia. On this occasion, they developed the “greenways” concept that should prefigure Kahn’s “city of movement” (Plan for Midtown, 1952-3). The greenways were

\footnote{132} Cf. Sawyer’s letter to Kahn, 17 April 1952, 030.II.A.107.42, LIKC.
\footnote{133} Only three stripes of drippstones gave a certain measure of scale: “As a matter of fact, I considered rain so important that I did not want it to wet the wall for so many feet, so I stopped the rain from wetting the wall every so often with a little wash.” Prown and Denavit, Kahn in Conversation, p. 30.
Fig. 30: Louis I. Kahn, Yale Art Gallery, New Haven, Connecticut, 1951-3.
Fig. 31: Louis I. Kahn, Yale Art Gallery, New Haven, Connecticut, 1951-3.
Fig. 32: Mies van der Rohe, Illinois Institute of Technology, Chicago, Illinois, 1938-58.
Fig. 33: Louis I. Kahn, Yale Art Gallery, New Haven, Connecticut, 1951-3; Landscape Design by Christopher Tunnard.
intended to turn the central axes of the urban proposal into lushly planted and shaded promenades, to connect important landmarks, and to produce a network of greenery for common use in the city fabric.\textsuperscript{134}

Originally from Canada – although he spent his formative years in England – Tunnard, like Kiley, Rose and Eckbo, sought to extend Modernism’s rational approach to the planning of landscapes and gardens:

\begin{quote}
Just as the design of the locomotive, the aeroplane, and, for that matter, the modern house, is being changed by scientific invention, in a similar way science will transform the garden of the future.\textsuperscript{135}
\end{quote}

Eschewing all the ostentatious rhetoric of both formal and informal gardening styles,

\begin{quote}
[the modern garden should be the logical outcome of the principle of economy in statement and the sociological necessities which have influenced modern architecture.\textsuperscript{136}
\end{quote}

Altogether, for Tunnard, the functional was not really a question of style, but rather an attitude expressing fitness in response to utilitarian purposes. Both his garden designs for Bentley Wood in Halland, Sussex (1935; architecture by Serge Chermayeff) and for his own residence at St Ann’s Hill in Chertsey (1936-7; designed by Raymond McGrath) turned out to be perfect examples of how Modern houses and gardens could coalesce within the context of grander picturesque estates. The same holds true for the Yale Art Gallery: while on an experiential level the rupture between an artificial interior climate and the exterior reality was as sharp as the thin layer of glass dividing it, in terms of integrating the project within the wider environment, Tunnard’s Modernist approach helped unify both the building and garden as it used the same underlying formal logic.

\textsuperscript{136} Ibid., p. 75. The resulting asymmetry was emphatically understood as deriving from far-Eastern models of spiritual balance. According to Tunnard, landscape architects were again to incorporate the directives of contemporary art as well – the abstract and fluid tendencies in the work of Joan Miró, Wassily Kandinsky or Paul Klee, for instance – just as in the past they had profited from painters such as Poussin or Le Lorraine, and later, from Monet or Van Gogh.
1.8 New Unity of the Arts and Sciences

A pivotal aspect of the Yale Art Gallery was its blatant revealing of the mechanical entrails and material traits. No trace of the construction process was concealed; the undisguised formwork imprints of the narrow, vertical wooden boards remained visible and everything spoke of genuine being and truth. For Kahn, in an Existentialist sense, a building was “a struggle, not a miracle, and the architecture should acknowledge this.”\textsuperscript{137} Kahn – himself marked by facial scars from a severe fire accident he had as a child – in revealing the authentic nature of materials and by not hiding the mechanical services, strongly opposed Modern practice that had stashed away all technological aids. Searching for reasons for his unveiling of the supportive intestines, he stated:

\begin{quote}
I do not like ducts; I do not like pipes. I hate them really thoroughly, but because I hate them so thoroughly, I feel they have to be given their place.\textsuperscript{138}
\end{quote}

The forthrightness of Kahn’s project made apparent a central contradiction within Modernist ideology: having preached truthfulness and straightforwardness above all matters, the International Style visually denied the existence of the devices that artificially controlled its interior atmospheres. A major flaw, Modernism’s \textit{Achilles heel} so to speak, had been uncovered: in order to achieve its pure volumes and flexible spaces, \textit{honesty}, one of the movement’s most basic imperatives, was flouted.

Different contemporary developments informed Kahn’s sincere architectural expression. During his stay at the American Academy, Kahn had visited the construction site of Le Corbusier’s Unité d’habitation in Marseille (1945-52). With its \textit{béton brut} aesthetic, the Unité appeared rather hand crafted than machine made,\textsuperscript{139} and the sculptural foul-air stacks on the roof announced visibly its mechanical core. In America, \textit{Abstract Expressionism} – derived from \textit{art brut} and \textit{tachisme} in France – emerged as a major creative outlet in the post-war years. Willem de Kooning, a seminal exponent of the movement, joined the Yale faculty in 1950. Besides, the German artist Josef Albers, a former Bauhaus educator who later taught at Black Mountain College, arrived at Yale following Kahn’s suggestion.\textsuperscript{140} Albers prompted his students to focus

\textsuperscript{137} Cooper, “The Architect Speaks.”
\textsuperscript{139} William S. Huff recalls an anecdote regarding a visit of Le Corbusier to the United States that he had also told Kahn: “Why do you people have all those fussy little boards in your concrete?” The reply was, ‘Because you do it, master.’ Corbu then said, ‘But you have all that wonderful plywood that comes in great sheets; in Europe we are poor and must use old floor boards, taken up from buildings being demolished, for our formwork.’” Latour, \textit{l’uomo, il maestro}, p. 423.
\textsuperscript{140} Kahn helped persuade Albers to join the Yale faculty, first as a visiting critic in 1949 and later as a full-time professor. Cf. Pelkonen, “Toward Cognitive Architecture,” p. 139. In late 1949 and early 1950, they co-taught a course called “An Idea Center for Plastics.” Kahn outlined in the brief that it should be a “setting for the demonstration of the effect that light, color and force can have on plastics
on the creation of objects that were not representations of something else, but rather presences in themselves; that is, paintings or sculptures should be treated as things, not signs. The German artist encouraged his students to discover that there was “no extraordinary without the ordinary,” and heightened their awareness of unfinished artifacts during the artistic process. Working with basic geometric forms that slowly transformed into more complex patterns, also for Albers’ wife Anni artistic creation did not imply “the desire to do something, but listening to that which wants to be done, the dictation of the materials.”

Adding the work of the British architect couple Alison and Peter Smithson, who in their Hunstanton Elementary School (1950-4) had openly revealed the buildings’ electrical conduits, plumbing devices and sanitary fixtures, a general countertendency to the smooth and stereotyped buildings of the International Style appeared. Initially grouped by Reyner Banham in his article “The New Brutalism” in 1955, the Brutalists based their approach on the “valuation of materials for their inherent qualities ‘as found.’” The Smithsons in particular endeavored to construct a genuine rhetoric from the raw facts of reality, or as Alison recalled: “We were concerned with the seeing of materials for what they were, the woodenness of wood, the sandiness of sand.” As part of the Independent Group with the photographer Nigel Henderson and the artists Eduardo Paolozzi and Richard Hamilton, their new empiricism approached poetically the prosaic normality and willingly accepted the ugly solution that answered the ugly problem. In 1951, still a student, Hamilton had organized the “Growth and Form” exhibition at the I.C.A. under the conceptual lead of Henderson (Figure 34). In their opinion, modern science had

made available a rich world of new forms and opened up a new source of inspiration to artists and industrial designers. Owing to the cleavage between science and art, this material, potentially revolutionary in its significance for modern design, has not yet been sufficiently noticed.

Presenting models, images and two films – one showing the growth of a snow crystal and the other the development of a sea urchin – the exhibition included

of various shapes and textures.” Proposal for Collaborative Problem to be discussed at Meeting, 9 July 1949, 030.11.A.61.27, LIKC.

142 Anni Albers, “Constructing Textiles,” in Design 47, no.8, April 1946, p. 22.
mathematical forms, atomic particle traces, plankton, vertebrates, a molecular model of dicalcium silicate, a photomicrograph of a lobster, an electronic micrograph of a rabbit, and a radiograph of a nautilus shell. Le Corbusier, delivering the opening speech, remembered being deeply moved by the show, as it represented a new “unity of thought”:
Earlier this evening before coming to the microphone, I was taken into a hall which is small as the Dome of Discovery is large. It is the Gallery where the ‘Growth and Form’ exhibition is held and there again I was enchanted.  

In the Independent Group’s follow-up exhibition “Parallel of Art and Life” (September 11 to October 18, 1953) at the I.C.A. – with an x-ray image on the poster of a man shaving that was borrowed from Moholy-Nagy’s Vision in Motion (1947; Figure 35) – this fascination with the visuality of science was further developed through the juxtaposition of images taken from life, nature, industry and the arts. The bewildering confrontation enabled a simultaneous grasp of the entire visible and invisible spectrum attainable by contemporary technological means. Insisting on the significance of technology, which had enabled the artist to expand his field of vision to a new dimension, the Group’s intention read as follows:

The exhibition will provide a key – a kind of Rosetta stone – by which the discoveries of the sciences and the arts can be seen as aspects of the same whole. Related phenomenon, parts of that New Landscape which experimental science has revealed and artists and theorists created.  

Coincidentally these new territories of scientific inquiry had also been exposed two years earlier at an American exhibition directed by Gyorgy Kepes. A Hungarian polymath and former student of Moholy-Nagy, Kepes had immigrated in 1937 and joined his teacher at the New Bauhaus. In the spring of 1951, the same year that Kahn met him while serving on a jury at Yale, “The New Landscape” exhibition opened at MIT, (Figure 36) where Kepes had been teaching since 1947. Once again juxtaposing works of art and science, the numerous telescope, x-ray and electronic microscope images stressed the fact that human beings only perceived the world through a narrow filter. Beyond that lay another fascinating universe; yet, in order to make it discernible, mankind relied on the most up-to-date technological aids. Both exhibitions signalized that the time was ripe for a more encompassing architectural expression – a new Renaissance – that regarded the arts and science in mutual cohesion.

Among the numerous visualizations presented at these exhibitions, the internal bone structure of a vulture’s wing was especially informative for Kahn. He kept a depiction of it with an enclosed delineation of the radiolarian Aulonia hexagona (Figure 37) – both taken from a page in Whyte’s Aspects of Form – in his slide collection. Nature’s octet truss, just like Kahn’s ceiling in Yale worked through

Fig. 35: Cover of the Exhibition-Catalogue “Parallel of Art and Life,” Institute of Contemporary Arts, London, England, 1953.
Fig. 36: Exhibition “The New Landscape,” Massachusetts Institute of Technology, Boston, Massachusetts, 1951.
a unification of the principles of continuity and addition. In Kahn’s case, while following the logic of addition in terms of the geometrical arrangement, his hollow ceiling did not incorporate synergetic modes of behavior due to the presence of a uniform material. Thus, Kahn effectively neutralized both concepts of continuity and addition to transform them into a novel state of connectivity.

Furthermore, Kahn’s ceiling structure assimilated with the unconditional clarity of the Concrete Gothicism as it had emerged in the work of Nervi. Following the example of Giacomo Matté Trucco’s Fiat Factory in Lingotto of 1926 (Figure 38), the Italian architect-engineer repeatedly employed a pattern of concrete ribs in his works to rigidify the lines of stress. For instance, the Gatti Wool Factory in Rome of 1953 (Figure 39), of which Kahn kept a clipping in his notes, corresponded in its distribution of ribs with the natural configuration of a leaf’s spandrels, both reflecting the paths of gravity acting on them. In addition, Nervi’s dome structures and airplane hangars near Rome from the late 1930s (Figure 40), of which Kahn also kept illustrations in his slide collection, functioned in a hierarchical order similar to Kahn’s design, since a spacious nervature reinforced a peripheral plate.
Fig. 38: Giacomo Matté Trucco, Fiat Factory, Lingotto, Italy, 1926.
Fig. 39: Comparison of Pier Luigi Nervi’s Gatti Wool Factory, Rome, Italy, 1953 (top) with a Leaf’s Ribs (middle) and a Joint (bottom).
Emphasizing the importance of Nervi, it is crucial to add that in 1953, while still working in Kahn’s office, Tyng applied for a Fulbright scholarship in Italy. The draft outline indicates her definitive awareness of the entire scope of contemporary developments in structural engineering. Tyng wanted to study, as it reads,

man’s architectural achievements spanning more than four thousand years. I have chosen Italy because it is the country, which perhaps possesses the most comprehensive examples of this evolutionary process, from the primitive ‘beehive’ huts of Trulli, Alberobello to the huge three-dimensional structures of the Italian engineer Pier Luigi Nervi. In Italy and Rome especially, I hope to see the numerous examples of structures built for the needs of service and movement, forums and markets, early bridges and elaborate water works. I also hope to see the early three dimensional structures of groined vaults and domes, experimental and intuitive in their designs, and the recent examples of huge stadia, aqueducts and especially, Nervi’s airplane hangars at Rome and his exhibition hall in Torino. These three dimensional structures, based on the principle of continuity pioneered by Maillart in Switzerland and Freyssinet in France, seem more advanced to me than the structures of Torroja in Spain, Samuely in England, and the work of Fuller and Wachsmann in this country.149

149 Draft on purpose of visit in Italy, 074.II.A.48, AGTC. Tyng did not receive the grant to study in Italy or her second choice France. She was offered a Fulbright scholarship to Finland or Germany, which she declined. Cf. Letters between Tyng and the Institute of International Education, 074.II.A.48,
Roman shell structures in particular attracted Kahn’s interest, too. Frequently referring to the grandness of the Baths of Caracalla, Hadrian’s Villa (early 2nd century AD) or the Pantheon by Apollodorus of Damascus (c. 126 AD; Figure 41), all shared in common the use of Roman concrete to span hitherto insurmountable distances. The use of layered coffins reduced the weight of the soaring ceilings, and in contrast to the perfect interior shape, the exterior silhouette was not hemispherical, but bowl-shaped in order to reduce the load of the shell from top to bottom. At the same time, the stony aggregates used in the concrete mixture decreased in weight in correspondence

Fig. 41: Apollodorus of Damascus, Pantheon, Rome, Italy, c. 126 AD.


By no means were the Romans the first to employ domes, but they substantially increased their size by changing the structural logic from one of addition to one of continuity. Already in Jericho during the Mesolithic period (c. 8350-7350) existed round and oval mud-brick houses that supported domed superstructures of clay-covered branches. Beehive-shaped *tholoi* in Arpachiyah (Mesopotamia, early 4th millennium BC) or in Khirkokitia on Cyprus (at least 5000 BC) with corbelled mud-brick domes indicate the continuous experimentation with such structures on a domestic scale. With the historic period, the Babylonians just like the Egyptians and later the Greeks, concentrated upon the outer effect of their temples as imposing artifacts in the landscape, since public contact with the deity in the shrine had drawn to a close. In Roman times with the rise of Christianity that urge reappeared and found immediate expression in the public scale of its interiors.
with the increasing height. In sum, these preeminent examples of optimization epitomized structural ease and spaciousness.

However, in America Kahn remained an exception in the use of concrete in space frame configurations. In the General Motors Technical Center in Warren, Michigan (1948-56), Saarinen combined the structural depth of a welded steel truss with the horizontal distribution of the mechanical conduits. Comprehending the ceiling as a multi-purpose membrane, Saarinen, just like Kahn, set in place a diaphanous space that was free from any obstructions. Similarly, Mies van der Rohe, who at the time was sharing a studio at IIT with Wachsmann, elaborated his conception of the universal space in combination with a space frame structure. His investigations coalesced in the unrealized design for a Convention Hall in Chicago (1953-4), where a nine-meter high octet truss covered a quadratic space of heroic dimensions. Kahn was well aware of this project, as a letter to Tyng indicates:

I keep dreaming about our space frames which are more and more important. Evidence of their importance is appearing in several places. [...] Mies van der Rohe put out an analyzed (tetrahedron) roof frame 600' x 600' with no columns on the inside.

At the time of the Yale Art Gallery’s construction, Kahn was also in contact with two of the European pioneers of space frame construction: the English Samuely and the French Le Ricolais. Samuely had designed a space frame roof for the Pavilion of Transport at the Festival of Britain in 1951, and three years later, while teaching at the North Carolina State School of Design, he visited Kahn’s office and lectured to his students at Yale. The latter recalled:

He believes that the tetrahedron is basic in all structures but does not call a tetrahedron of Fuller’s dimension the criteria. He believes that tetrahedra of any combination of angles becomes a structural basis of form.

Altogether, Samuely predicted, “people will look back on this time as being the one when construction changed over from ‘plane’ to ‘space’.”

James Walter Fitzgibbon, an Associate Professor at the North Carolina State School of Design, had introduced Kahn and Le Ricolais, the actual father of space-structures,
at the 1951 American Institute of Architect’s conference in New York.\footnote{Cf. Thomas Leslie, “Unavoidable Nuisances,” in Von Moos and Eisenbrand,\textit{ The Power of Architecture}, p. 212.} Two years later, in February 1953, Kahn visited Raleigh and informed Fitzgibbon, a partner of Fuller in the development of the Geodesic Dome, that Yale was considering him, along with Le Ricolais, Nervi and Torroja, as a visiting critic.\footnote{Cf. Fitzgibbon’s letter to Le Ricolais, 1 March 1953, 086.V.99, RLRC.} Fitzgibbon recommended Le Ricolais, who in his opinion showed “fine Engineering competence, [a] deep understanding of natural form [...], comprehensive topological and crystallographic know-how,” besides having a “1st rate omnidirectional structure mind.”\footnote{Fitzgibbon’s letter to Kahn, 3 March 1953, 030.II.A.56.86, LIKC.} Finally, in 1954, Le Ricolais and Kahn met for an extended meeting at Yale:

> Having had very friendly contact with Le Ricolais and Samuely now I feel they are very much the equal of Nervi in his way. I find Le R. of particular sensitivity and by far the purer engineer and philosopher. [...] He has a thick notebook of diagrams and formulas (of his own), which are based on Topological formulæ. It is precisely the scientific knowledge which an architect needs if he is at all interested in forms and plan and intends to work in the 3 D field.\footnote{Tyng, \textit{The Rome Letters}, p. 146; letter 13 June 1954.}

In sum, Kahn considered Le Ricolais’ works “full of wonder standing in their right as though they are of Nature itself [...].”\footnote{Kahn’s letter of recommendation for Le Ricolais to receive an honoree fellowship from the American Institute of Architects, 1 September 1971, 030.II.A.53.67, LIKC.} The latter, who had worked as a hydraulics engineer in France, arrived in the United States in 1951 to teach at the North Carolina State School of Design and at Harvard, before transferring to the University of Philadelphia in 1954. During his employment in France, Le Ricolais had investigated the easing of weight in telemetric tubes and “[a]round 1937 [...] approached the problem of Networks in Three Dimensions, striving to profit by the few notions of crystallography available [...]”\footnote{Robert Le Ricolais, “Forms and Structures,” in \textit{Zodiac}, no.22, 1973, p. 242.}

His pioneering article “Essai sur des systèmes réticulés à trois dimensions” of 1940 gave some architects their first introduction to the concept of the space frame. Le Ricolais proclaimed that the more directions a structure encompassed, the less it would deform. He did not regard spatial networks based on the square as unfit, but when dealing with external forces distributed in all directions of space, a triangular network simply yielded less deformation. During the mid-1940s, Le Ricolais first put his theoretical outlines into practice, for instance with the construction of a prototype wooden space frame hangar in Nancy (Figures 42, 43).

His mother having been a natural history professor, Le Ricolais also sought inspiration in the natural world for his structural philosophy: “I have found no better discipline in this unpredictable problem of form than to observe the prodigies created
Fig. 42: Robert Le Ricolais, Hangar, Nancy, France, mid-1940s.
by nature.”\textsuperscript{162} Spider webs, bee cells, eggshells, soap bubbles and the microstructure of crystals or bones all came under his scrutiny (Figure 44). He admired radiolarians, where the peripheral membrane was a minimal tensile surface and the inner skeletal core formed an optimized compression system (Figure 45).\textsuperscript{163} Likewise, the French engineer envisioned structures that clearly distinguished between the components in tension and such in compression through \textit{structural division}. In later years, he turned his interest to pure tension systems, attracted especially by their increased lightness. Also studying domed structures, the French engineer rejected Fuller’s semi-circular solution, “since the presence of evenly distributed loads imposes a parabolic profile.”\textsuperscript{164} Alongside this formal criticism, Le Ricolais also emphasized that a smaller amount of larger and heavier elements reduced the number of weakening joints:

What is striking is the fact that a geodesic dome has about twenty times more joints, and eighty times more members, than our system, and ours is still lighter in relation to the area covered.\textsuperscript{165}

\textsuperscript{163} Radiolarians from a plate of Ernst Haeckel’s \textit{The Voyage of H.M.S. Challenger} (1873-6) figured on the cover of a special issue of the \textit{North Carolina State College Student Publication of the School of Design} (spring 1953) that was dedicated to Le Ricolais’ work.
\textsuperscript{165} Robert Le Ricolais, “Things themselves are lying, and so are their Images,” in \textit{Via}, no.2, 1973, p. 83.
The accompanying illustration shows an overview of Le Ricolais’ experiments at the University of Pennsylvania (Figure 46), a sort of productive chaos that Kahn must have encountered occasionally, since they jointly taught a studio there from 1956 onwards.

1.9 Designing by Triangulation

The issues that Kahn had encountered with the Yale Art Gallery in terms of its alterability were not the only reason he was dissatisfied with the design, as a letter to Gropius shows:

My work on the Yale Art Gallery has led me to think about three-dimensional construction and its implications architecturally. I failed to command the forces which could have produced a truly significant building.166

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166 Kahn’s letter to Gropius, n.d., 030.II.A.60.35, LIKC.
Fig. 45: Radiolarians on the Poster of Robert Le Ricolais’ Lecture “Notions on Form” at The Architectural League, New York City, New York, 1968.
Designing by Triangulation

After its completion Kahn remodeled the entire composition. Now tetrahedral pillar-clusters, “hollow trunks” housing the stairs and the functional necessities, expanded in several layers from bottom to top like outspread fingers to carry a single-layered tetrahedral ceiling. At approximately the same time, Kahn was working on the design for the Adath Jeshurun Synagogue in Elkins Park, Pennsylvania (1954; Figure 47), for which he proposed a similar structure. Again, a layered space frame order was supposed to extend the three-dimensional logic throughout the entirety of the design, while the stairs and the services would be contained within the structural supports. Kahn argued: “It is what the space wants to be. A place to assemble under a tree.” Of course, these multilayered arrangements, in which the pillars grew into the ceilings, closely resembled Tyng’s earlier school design. Concurrently with the erection of the Yale Art Gallery, she had planned on her own a House for her Parents on the

Fig. 46: Studio of Robert Le Ricolais, University of Pennsylvania, Philadelphia, 1970.

eastern shore of Maryland (1950-3; Figure 48), which she published in *The Charette* (September 1953) under the resonant title “Design by Triangulation.” According to Tyng, in this first habitable space frame design, “the geometry was hollowed out for living spaces as in a bee’s honeycomb.”

Tyng and Kahn further emphasized this idea of scaling up a space frame in their City Tower proposal, a municipal building planned for the center of Philadelphia between 1952 and 1957. As “A Concept of Natural Growth” – the project’s title in an advertisement brochure by the Universal Atlas Cement Company (Figure 49) – the City Tower progressed vertically into a rotating shape, and was, according to Kahn,

an experimental exercise in triangulation of structural members rising upward to form themselves into a vertical truss against the forces of wind.

Pre-cast, pre-stressed hollow concrete struts, spanning four floors each, formed the lattice-like tetrahedral frame that was organically interrelated with all other parts through a system of unifying proportions. Most astoundingly, because of its triangulated structure, the tower did not demand any stiffening cores. Hollow tetrahedral floor slabs joined the vertical members and contained the air conditioning, lighting, horizontal wiring and piping, while human-size tetrahedral capitals housed the storage rooms, toilets and sub-stations for the mechanical services. In this complete integration of the functional elements within a hollow space frame structure, Kahn, as stated above, purposefully invoked the wind’s deforming influence. Reflecting a few years later on the contemporaneous design of the Seagram Building (1954-8), Kahn noted: “She is a

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168 Tyng, “Louis I. Kahn’s ‘Order’ in the Creative Process,” p. 287. Further examples of Tyng’s own exploration into habitable space frame construction are the Fred Clever House (Cherry Hill, New Jersey, 1957-61; in collaboration with Kahn), an addition to the Waverly Street House (Philadelphia, 1964-7), or the unrealized Four Poster House (Mt. Desert Island, Maine, 1971-84), where a square-octagon based space-structure was lifted up into the air by a central post.

DESIGN BY TRIANGULATION

Anne Griswold Tyng, Architect

In this project of an addition to a 200-year-old farmhouse near Cambridge, Md., Philadelphia Architect Anne Griswold Tyng utilized a three-dimensional framing system based on equilateral triangles to enclose the living space.

Modular space-frame extends vertically and horizontally for wall, ceiling and floor framing and for the framing of dormers, trellises and balcony entrance. Framing is exposed on either exterior or interior. Economical as well as unusual, this framing...

Fig. 48: Anne Griswold Tyng, House for her Parents, Eastern Shore of Maryland, 1950-3.
“In Gothic times, architects built in solid stones. Now we can build with hollow stones. The spaces defined by the members of a structure are as important as the members. These spaces range in scale from the voids of an insulation panel, voids for air, lighting and heat to circulate, to spaces big enough to walk through or live in. The desire to express voids positively in the design of structure is evidenced by the growing interest and work in the development of space frames. The forms being experimented with come from a clearer knowledge of nature and the outgrowth of the constant search for order. Design habits leading to the concealment of structure have no place in this implied order. Such habits retard the development of an art. I believe that in architecture, as in all art, the artist instinctively keeps the marks which reveal how a thing was done. The feeling that our present day architecture needs embellishment stems in part from our tendency to fear joints out of sight, to conceal how parts are put together. Structures should be devised which can harbor the mechanical needs of rooms and spaces. Ceilings with structure furry in tend to erase scale. If we were to train ourselves to draw as we build, from the bottom up, when we do, stopping our pencil to make a mark at the joints of pouring or erecting, ornament would grow out of our love for the expression of method. It would follow that the pasting over of the construction of lighting and acoustical material, the burying of tortured unwanted ducts, conduits and pipe lines, would become intolerable. The desire to express how it is done would filter through the entire society of building, to architect, engineer, builder and craftsman.”

Louis I. Kahn, architect and planner

Anne Griswold Tyng, architect associated
Member of Architecture, Newark Graduate School of Design, 1944. Instructor, Architectural Design, School College. Ten years associated in office of Louis I. Kahn, active with him in planning and administration.

Fig. 49: Louis I. Kahn and Anne Griswold Tyng, City Tower, Philadelphia, Pennsylvania, 1952-7.
beautiful bronze lady, but she is not true. [...] The building is not honest, because the wind forces are not being expressed." Not even arguing against the dishonest, applied steel profiles to enforce its vertical ascension, Kahn criticized the truthfulness of the Seagram Building in purely ideological terms:

What we have here is another example of the short-necked giraffe approach. It is forcing a thing into a preconceived notion as to what it might look like. With the other approach you simply allow it to look like what it wants to be; as nature does with the porcupine – you let it tell you something about it; about the forces of truth from which you can derive a way of life.  

Thus, no preconceived aesthetic ideal should infiltrate the City Tower as it was according to Kahn “full of enthusiasm for the natural way in which nature constructs [...]”. He considered the building as a logical materialization of the activating forces involved, and as a result an organic monumentality should establish itself, as Tyng further clarified:

Primordial principles of form, the bonding of atoms and molecules out of which life grows, are resources for dynamic, innovative structures that can easily resist the forces of wind and earthquake. The naturally ‘grown’ undulations anticipate such stresses – resistance is already built into their form, as the tree on the mountaintop grows its own shape in bends and gnarls to resist forces of the wind.  

Despite both Kahn and Tyng’s insistence that the tower’s shape was quasi-automatically derived from the given pre-conditions and the project’s underlying tetrahedral logic, its helical form also approached a form, notably one with far-reaching natural implications. The discovery of DNA by the American biologist James D. Watson and the English physicist Francis Crick in 1953 – precisely the time of the City Tower’s design – unveiled that two helically entwined molecular strands were joined together to constitute the basic letters of nature’s alphabet. What seemed to bring certain molecules to life was their special architecture of atomic arrangement.  

Through the discovery of DNA, nature was no longer the mysterious other that mankind was extradited into, but now quintessentially mutable through human will. Shortly after their discovery, Watson and Crick affirmed: “It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.” James D. Watson and Francis Crick, “Molecular Structure of Nucleic Acids,” in Nature, vol.171, no.4356, 1953, p. 737.
Fig. 50: Van Rensselaer Potter, DNA Model Kit, 1959.

Especially, this recourse to molecular orders underlined that Kahn and Tyng’s architecture of optimization was not formulated in response to a certain picturesque, imitative notion of nature, but based on more abstract geometrical principles of creation. Thus, they did not strive to copy nature’s superficial appearance, but attempted to make use of its rules of growth. Mimicry in this respect did not imply repeating nature’s apparent forms through formal analogy, but rather to comprehend its inner logic and order. As early as 1823, the French art historian Antoine Quatremère de Quincy had emphasized:

Fig. 51: Anne Griswold Tyng, “Anatomy of Form / Atom to Urban,” 1964.
To imitate does not necessarily mean to make a resemblance of a thing, for one could, without imitating the work, imitate nature thus, in making not what she makes, but as she makes it, that is one can imitate nature in her action [...].

As both their involvement with natural principles progressed, Kahn and Tyng became increasingly convinced that the molecular structure of natural substances adhered to strict geometrical rules that their architecture should also follow. Supporting their argument, in the introduction to a later edition of *Aspects of Form*, Whyte emphasized:

In the entire history of science there has been nothing similar to the dramatic advances in the new realm of molecular biology which occurred between 1945 and 1965.

Mathematics, physics, and biology had fused into the new integral science of biophysics – the study of the changing arrangements of chemical atoms during organic processes. Whyte did not doubt that at the deepest levels these structures combined rather strict forms of geometric ordering as he had been

...intrigued by the fascinating idea of an Eighteenth-century Jesuit, R. J. Boscovich, that ‘matter’ was nothing but interacting physical points arranged in various patterns.

Consequently, if the universe was an ordered complexity, the possible three-dimensional patterns were restricted, and it was therefore only logical that explorations into the realm of nature’s geometry converged.

During the course of the systematic human study of nature, the architect and the scientist, although dealing with different problems – the creation of an artificial world versus the explanation of the natural one – had to rely on similar parameters in order to establish a comprehensible order. This tool of communication between man and nature was geometry, deriving from the Greek, “measuring the earth.” Its development directly responded to the human desire to establish certainty in the flux of worldly sensations. Abstraction, thus, denoted the wrestling of an object from its natural context and its transcription into an absolute conceptual value. Ultimately, as Thompson affirmed, there was in both the animate and inanimate world “no exception to the rule that θεὸς εἰ γεωμετρεῖ [God always geometrizes].”

The figure of God the Geometer as famously depicted in the frontispiece of the *Bible moralisée* of 175

Quatremère de Quincy, *De l’imitation* (Brussels: Editions des archives d’architecture moderne, 1980; 1823) pp. ii-v; transl. by the author.


177 Whyte, *Focus and Diversions*, p. 15.

178 As a further indication of the general interest in atomic structures, André Waterkeyn’s *Atomium* was exhibited at the first post-war World Fair in Brussels in 1958.

c. 1250 was preeminent a symbol for the unalterable consistency thought to reign in the universe. Underlining that the conception of the lawfulness of the universe was unthinkable without referring to geometry, Galileo also stated:

Philosophy is written in this grand book – I mean the universe – which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it; without these, one is wandering around in a dark labyrinth.  

In the same vein, Johannes Kepler added:

Geometry is coeternal with the Mind of God before the creation of things; it is God himself [...]. With the image of God it has passed into man, and was certainly not received within through the eyes.

This quote, which stems from Kepler’s *Harmonices mundi* (1619) and was republished in “The Influence of Archetypal Ideas on the Scientific Theories of Kepler” by Wolfgang Pauli, which Tyng in later years repeatedly cited, underlined the German scientist’s belief that the mind was made to grasp quantities just as the eye was made to see. Defending Copernicus’ heliocentric worldview, Kepler developed a geometrical model for the distances between the planets that derived from the nesting of the Platonic Solids within each other (Figure 52). In Plato’s account of the world’s creation, Timaeus, a Pythagorean expert in astronomy, had offered a similar description of a mathematically configured universe. For him, scientific inquiry was inspired and enabled by “[t]he vision of day and night and of months and circling years,” which “has created the art of number and has given us not only the notion of Time but also means of research into the nature of the Universe.”

182 Tyng referred to the article in “Geometric Extensions of Consciousness,” (p. 173) while the title also appeared in the bibliography of her semester proposal “Morphology,” University of Pennsylvania, 1970; Cf. 074.I.B.16, AGTC.
Fig. 52: Johannes Kepler, *Harmonices mundi*, 1619.
1.10 The Spirit of the Hive

In parallel with the definition of the Platonic Solids, Democritus, elaborating the ideas of his teacher Leucippus, suggested with the theory of Atomism – derived from the Greek *a-tomos*, meaning “indivisible” – the reduction of all complex appearances to irreducible and imperishable units. Lucretius’ account *On the Nature of the Universe* (c. 55 BC) further elaborated this idea of the discreteness of matter, as his wish was to “reveal those atoms from which nature creates all things [...].” Likewise seeking to overcome the prevalent cosmology of the elemental tetrad, Robert Boyle in *The Sceptical Chymist* (1661) proposed that these foundational letters were not indivisible but composed of various chemical particles. The proof for his hypothesis came in the late 18th century in the chemical experiments of Antoine Laurent de Lavoisier, who demonstrated – initially with air, the most inconspicuous element – that all natural structures consisted of more elements than only the original four.

Contemporary with de Lavoisier’s chemical discoveries, French mineralogists such as Jean-Baptiste Romé de L’Isle and René Just Haüy recognized that in substances, if the internal form of a local unit repeated itself throughout a structure without dislocations, a crystalline lattice was obtained. Thus, a crystal was self-repetitive in every part of its constitution and obviated contextual interferences in order to emancipate its inner properties of cumulative growth. The impact of crystallography was heightened in 1912, when the German physicist Max von Laue demonstrated the regularity of crystal lattices using x-ray diffraction patterns. Since many materials – such as minerals, salts, metals, but also organic compounds – could form crystals, x-ray crystallography was soon not merely applied to determine atomic constellations in inorganic tissues, but also became crucial in indicating the structure of biological molecules such as DNA.

Previously, mathematical analysis had advanced considerably and led to the conclusion that there existed 230 possible crystal configurations. At the forefront of these investigations stood Lord Kelvin’s research on close packing or the study of the homogeneous division of space into equal and like parts. In consideration of planar

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185 First gathered in a periodic table by Dmitri Mendeleev’s in 1869, the insights gained from this wave of chemical developments were substantially modified at the dawn of the 20th century with Ernest Rutherford’s implementation of nuclear physics, i.e. the discovery that atoms were not solid and static bodies, but rather consisted of a dynamic interplay of electrical forces between a positively charged nucleus and surrounding electrons with a negative valence.

186 Cf. Lord Kelvin (Sir William Thomson), “On the Division of Space with Minimum Partitional Area,” in *Philosophical Magazine*, vol.24, no.151, 1887, pp. 503 ff., and Thompson, *On Growth and Form*, pp. 544 ff. For Thompson (p. 740), “here and elsewhere an apparently infinite variety of form is defined by mathematical laws and theorems, and limited by the properties of space and number. And the whole matter is a running commentary on the cardinal fact that, under such foedera Naturai as Lucretius recognized of old, there are things which are possible, and things which are impossible, even to Nature herself.”
arrangements, Kelvin acknowledged that only triangular, hexagonal and square repetitions could fill space uniformly. In terms of spatial dispositions, among the five Platonic Solids, only the cube tessellated space regularly. Besides the cube, eight other polyhedrons divided space homogenously, and among these the only Archimedean Solid to fill space without leaving intervals was Kelvin’s truncated octahedron or *tetrakaidecahedron* (a figure with 14 faces: eight hexagons and six squares).

Deduced from circular close packing, the hexagon was the most economical two-dimensional partition of space. Contemplating its significance in *The Six-Cornered Snowflake* (1611), another treatise referred to by Tyng, Kepler speculated:

> Is it because this is the first of the regular figures to be essentially flat, incapable, that is, of combining with itself to form a solid body? For triangle, square, pentagon, all form bodies.

Altogether, snow crystals define an infinite range of hexagonal patterns (Figure 53), which vary depending on the temperature and humidity when these ice-flowers materialize. Microscopic examinations revealed that their form, just as in the case of a crystal, was an outward manifestation of their internal atomic disposition as illustrated here with the hexagonal pattern of their oxygen (black) and hydrogen (white) atoms (Figure 54).

In addition, the Belgian physicist Joseph Plateau had in the second half of the 19th century conducted experiments with wire frames submerged in *liquide glycérique*. The resulting soap films, besides creating least surface areas, always met in threes and symmetrically arranged themselves at angles of 120°. In space, at all vertices four such borders intersected at an angle of approximately 109°, the *Maraldi* or Tetrahedral angle. The same angle occurred in the rhombic dodecahedron, whereas half of this solid added to a hexagonal prism and joined with others in the opposite direction is used by bees to uniformly fill space in their honeycombs (Figure 55). Evidently, bees economized wax to the utmost and illustrated nature’s striving for *geometrical*...

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187 The Swiss mathematician Jacob Steiner demonstrated in the middle of the 19th century that the least sum of distances joining three or more points always resulted in the hexagonal angle of 120°. Cf. Richard Courant and Herbert Robbins, *What is Mathematics?* (London: Oxford University Press, 1946) pp. 354-60.

188 Johannes Kepler, *The Six-Cornered Snowflake* (1611) p. 41. Tyng listed this treatise in the bibliography of “Simultaneous Randomness and Order: The Fibonacci-Divine Proportion as Universal Forming Principle” (Ph.D. diss., University of Pennsylvania, 1975). For Whyte, Kepler’s treatise was “the first attempt ever made to provide a mathematical theory of formative processes and to show exactly how regular forms come into existence.” Whyte, *Focus and Diversions*, p. 76.

Fig. 53: Snow Crystals.

Fig. 54: Atomic Structure of Snow Crystals.
optimization: while the hexagon is the densest of all planar space-filling arrangements, the rhombic dodecahedron encloses space with a minimal extent of surface.\footnote{190}

The hexagonal structure of snow-crystals, Plateau’s laws, the exceptional efficiency of the bees’ constructions, and crystalline forms of minerals were discussed at length in Thompson’s *On Growth and Form*. Emphasizing the frequent occurrence of hexagonal meshes in the cellular structure of organic tissues, he argued:

\[\text{[T]he conjunction, three by three, of almost any assemblage of partitions, of cracks in drying mud, of varnish on an old picture, of the various cellular systems we have described, is a general}\]

\footnote{190}{Cf. Tomaso Aste and Denis Weaire, *The Pursuit of Perfect Packing* (London: The Institute of Physics Publishing, 2000) p. 58. Not surprisingly, Peter Behrens as newly appointed design consultant of the general German electricity company (AEG) in 1907, chose the honeycomb as the enterprise’s new logo – clearly a visual allegory to the bees’ model of economy where the individual counted nothing with respect to the collective well-being of the hive.}
tendency [...]. When the partitions meet three by three, the angles by which they do so may vary indefinitely, but their average will be 120°; and if all be on the average angles of 120°, the polygonal areas must, on the average, be hexagonal.¹⁹¹

According to his wife Esther, Kahn had become fascinated with crystallography in the early 1950s.¹⁹² In addition, Tyng noted a decade later:

Today a comprehension of the nature and behavior of crystals, with their geometric growth patterns and axes of symmetry, is considered essential to most branches of science, particularly mineralogy, chemistry, solid-state physics, metallurgy and electronics.

Accordingly, she proposed that

[...] these indications of the profound validity of all three dimensional structure suggest that architecture could gain fresh insight and release sources of form derived from fundamental principles of physical structure revealed in the consistency and beauty of the underlying unity of all form.¹⁹³

This appreciation of nature’s geometries, most notably the hexagon, was recognizable on a practical level in a number of Kahn’s projects throughout the 1950s. Three larger hexagons, each with a fractal hexagonal substructure, interlocked in the ground plans of the City Tower (Figures 56, 57), while an almost identical cellular overall scheme, though slightly extruded, characterized the first version of the Bernard Shapiro House in Narberth, Pennsylvania (1959-61).¹⁹⁴

Recalling Tyng’s statement that the House for her Parents was being hollowed out like “in a bee’s honeycomb,” the clearest indication of Kahn and Tyng’s interest in the bees’ geometries was a small addition to the studio of the artist Wharton Esherick (Figure 58), built between 1955 and 1956 in Paoli, Pennsylvania, at a place quite fittingly called “Diamond Rock Hill.”¹⁹⁵ Esherick, the “dean of American craftsmen,” had abandoned city life intrigued by Henry David Thoreau’s Walden; or Life in the Woods (1854). In 1926, he began to build his woodworking studio incorporating with its curvilinear shapes the outlines that also characterized his biomorphic artworks and furniture designs. Kahn and Esherick met during the 1950s through Howe, when the artist required a further addition to his studio. Kahn’s organic proposal was quite the

¹⁹¹ Thompson, On Growth and Form, p. 515.
¹⁹² Cf. Goldhagen, Situated Modernism, p. 72.
¹⁹³ Tyng’s letter to the Ford Foundation, Fellowship Program for Studies in the Creative Arts, 30 October 1962, 225.II.A.283.15, VSBC.
¹⁹⁴ In addition, the early schemes of the Adath Jeshurun Synagogue were outlined with a hexagon. In the Row House Studies for the City Planning Commission in Philadelphia (1951-3; in collaboration with Dan Kiley) Kahn further experimented with hexagonal arrangements, while in the design for the American Federation of Labor Building (1954-6) he made use of elongated hexagonal openings in the Vierendeel trusses to contain the mechanical services.
¹⁹⁵ Interview by the author with Ruth and Mansfield Bascom (daughter and son-in-law of Wharton Esherick), the present owners of the estate, 12 June 2009.
Fig. 56: Louis I. Kahn and Anne Griswold Tyng, City Tower, Philadelphia, Pennsylvania, 1952-7.

Fig. 57: Louis I. Kahn and Anne Griswold Tyng, City Tower, Philadelphia, Pennsylvania, 1952-7.
opposite of the existing one: three prismatic hexagonal pavilions, each functionally responding to a particular stage in the woodworking process, were strung together to frame a small terrace. A regular rhomboid crowned each spatial unit, precisely as it was the case in a honeycomb.

While insects had mesmerized Kahn in general as his employee Jefferson Clark recalled, his interest in the geometrical principles of the bees was first triggered through the Israeli architect and Bauhaus student Arieh Sharon during the planning of the Palestine Emergency Housing in 1949.\textsuperscript{196} Sharon had been a beekeeper in a young kibbutz,\textsuperscript{197} and this experience would have a lasting impact on his later architecture, for example in the utilization of a hexagonal module in the design of Israel’s Pavilion at the Expo in Montreal in 1967. In the Israeli architect’s opinion, one could learn from


Fig. 59: Richard Buckminster Fuller, Dymaxion House, 1932.
the bees not only about modularity, but also “how to design, to organize and to build so as to combine function and form in a most economical way.”\textsuperscript{198} Altogether, Kahn was not alone in his attempts to create “spatial honeycombs;” Fuller had rigorously exploited the hexagon to structure the plan of his Dymaxion House (Figure 59); Wright had credited the bees’ geometries with being more flexible than cubic arrangements;\textsuperscript{199} and coinciding with Kahn’s efforts, the Dutch architect Aldo van Eyck employed the hexagon in his unrealized design for an Open-Air School in Amsterdam (1955).

Nevertheless, Le Ricolais probably most vehemently influenced Kahn’s hexagonal designs. Studying crystals, the French engineer, who taught his students that “[t]he discipline of seeing natural things is a mathematical one,”\textsuperscript{200} was astonished by their rich combinatory possibilities. He realized that the less difference there was between standard parts, the easier it was to assemble them in spatial structures. In February and March 1953 he sent Kahn a series of letters, which included several extensive reports on hexagonal projects. In one, called “Structural Approach in Hexagonal Design,” Le Ricolais referred critically to Wright’s attempts as not “structurally’ focused.”\textsuperscript{201} He argued that a hexagonal arrangement had the advantage of increasing distances between supports by a third; thus, leading to a reduction of required columns. Le Ricolais also sent Kahn plans for a single-story “Hexacore ‘Free Flow’ Building” composed of several hexagonal cells (Figure 60), each having at its center a hexagonal column that was partly used for air-conditioning and the evacuation of rainwater. This idea to attach an ancillary use to a column, making it do more than just being a structural element, was subsequently elaborated by Kahn in his configuration of the hollow column. For Le Ricolais to build with “hollow stones” was “a good concept for building,” since it meant “to build with holes, to use things which are hollow, things which have no weight, which have strength but no weight.”\textsuperscript{202}

However, this particular development entails issues of spatial optimization, including the seminal question of the “nature of the space,” which diverges from the core of ideas concerning structural and geometrical efficiency. It touches upon Kahn’s increasingly teleological reasoning to explain the morphological development of his

\textsuperscript{198} Ibid., p. 14.
\textsuperscript{199} Already in 1922 Wright had utilized the hexagon in the design for a Summer Colony at Lake Tahoe, while its built realization followed with the Honeycomb House for Paul and Jean Hanna in 1937. In an interpenetrating amalgam of open and closed spaces, the hexagonal geometry ordered the entire composition in a fluent manner.
\textsuperscript{201} The following reports were sent to Kahn by Le Ricolais: “Structural Approach in Hexagonal Design,” (February 1953) “Multicore Building Frame System,” (19 March 1953) and “Hexacore ‘Free Flow’ Industrial and Public Buildings;” (31 March 1953) Cf. 030.II.A.56.6, LIKC.
\textsuperscript{202} McCleary, \textit{Visions and Paradoxes}, p. 43.
projects albeit without neglecting his fundamental belief in the prevalence of law and order in the universe. Thompson subscribed to such a distinction:

Still, all the while, like warp and woof, mechanism and teleology are interwoven together, and we must not cleave to the one nor despise the other; for their union is rooted in the very nature of totality.203

While Kahn had demonstrated a fervent aspiration to employ nature’s most economic geometries and optimized forms in his early works, in the future this rational appeal appeared insufficient for incorporating the holistic forces shaping the diversity of life.