

COMMITTEE IV

The Relationship Between Science
and The Arts and Its Relevance to
Cultural Transformation

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ARS SINE SCIENTIA NIHIL EST
(On Architecture and the Sciences)

by

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E.Y. Galantay
Lausanne, July 31st, 1986

CHAPTER I. INTRODUCTION.

The title of this paper is taken from the stenographic record of the hearings conducted by the Building Committee of Milan Cathedral on A.D. January 25th 1400. The proceedings were concerned with the problem of how to correct the top-heavy leaning pillars built on inadequate foundations or how to complete the overdimensioned edifice. Problems and hearings continued for a hundred years, bridging the transition from the medieval world-view to the rise of modern science*1.

Discussion focused on whether ARS - artisanal know-how based on intuition and practical experience - suffices in itself or whether factual knowledge needs to be related to theory - SCIENTIA - in order to have meaning and predictive power. Predictive knowledge was required to assure that a projected lantern tower - to be built over the crossing of the transept and the nave - will not collapse like so many others before, i.e. in Beauvais. Numerous foreign consultants were called including the French Architect Jean Mignot. On January 25th, 1400, his postulate "Scientia Sine Artem Nihil Est" has been rejected and he was obliged to admit the opposite: "Art Without Science is Nothing".

Varying interpretations have been given to the meaning of the words ARS and SCIENTIA: Suffice to say that for the purposes of this paper I take Mignot's statement as a pretext to develop my own argument. I shall try to prove that information flow from the Sciences has been essential for the development of the Arts while the contention "Scientia Sine Artem Nihil Est" was indeed false since relatively little inspiration came to the Sciences from the Arts.

The "Milan debate" still rages among architects: some nostalgics doggedly contend that Architecture is an "autonomous" field - in a sense a closed system - with its own history, self-sufficient theory and stock of references. I intend to prove that the history of architecture is not the result of hermaphroditical or incestuous procreation but on the contrary: under the umbrella of general epistemology architecture has frolicked and interbred with the theories and methodologies of all sciences.

In this paper the term 'Architecture' will be used in its broadest meaning

including all design aimed at the ordering and shaping of the physical environment from the production of buildings to city and regional planning. In examining the relations among the Arts and the Sciences we are limiting our investigation to parallelisms and linkages between the development of Architecture and the Physical and Life Sciences - excluding the influence of the liberal Arts and of the Social Sciences with which architecture is so closely interwoven that no clear boundaries can be defined.

Further, we are limiting our survey to Western Civilisation - dating back to the reign of Charlemagne. The slower pace of medieval life permits us to telescope the first 500 years to begin our more detailed analysis around the year 1400 and the Milan debate. Having thus defined and limited the subject of our investigation we now propose a two-fold methodology:

- 1) The selective scanning of major works on architectural theory for references to scientists and to the sciences: terminology, methodology, concepts - searching for direct "linkages".
- 2) The comparative and critical analysis of major projects, plans and buildings looking for analogies and affinities with contemporary trends in the sciences in the interpretations of space, time, structure and growth - as evidence of "parallelisms".

What the Arts and the Sciences have in common is that by constantly enlarging our consciousness they create history and thus give sense to human society.

As the Economist Georgescu Roegen pointed out at ICUS XIVth "Man is not just a biological creature seeking to feed, defend and to perpetuate itself"*2

- although most people - farmers, workers, dentists, soldiers and bankers are concerned precisely with these functions. By contrast, artists and scientists are "Kulturträger" - creators and "carriers" of civilisation. Further, both art and science are concerned with "order": Science begins with the assumption that the world is orderly, architecture with the intent to create orderly structures by human intervention* 3.

There are of course obvious differences: art being man-made is "artificial", its product is an "artifact". The artist or architect creates his structures and plans and controls the process of his creation. The phenomena of nature studied by the scientist are not his own creation nor are the processes

which he can influence and observe rather than invent and create. Finally, the notion of growth - fundamental to the life-sciences - cannot find its exact equivalent in the Arts - although it has a place in planning since the most convincing description of the city is as an ecological system based on the interrelationship of organisms and the environment*⁴

. This concept of the city is based on a notion of growth which goes beyond mere extension but includes gradual transformation and the change of proportions.

In examining the transfer and transposition of scientific concepts and methods to architecture we must be aware of the fact that successful architects are preoccupied with their work find little time to study up on science - and with the exception of some "hi-tech" architects like Norman Foster - would not attempt to read scientific works in their original formulation. Instead, information filters down through the work of explicators, vulgarisation, and a sort of "media osmosis". This goes a long way to explain a certain time-lag before scientific breakthroughs find their repercussion in architecture.

It must be added that in some cases scientific concepts are misread, or only partially understood. Much abusive use is made of borrowed terminology hiding fuzzy thinking behind a smoke screen of verbal mystification. The negative reactions of the architectural "autonomists" are partly based on a revulsion from seeing lack of talent parading in a "clothes of the emperor"-type rhetoric brilliance hiding a lack of substance. Still other architects view with suspicion the invasion of rationality in a field long dominated by intuition and the reduction of intuitive creation to an iterative process of problem solving or optimization by error-reduction.

This explains why some major works on architectural theory, i.e. by R. Banham, R. Krier & A. Rossi, do not contain a single reference to contemporary science. However, this is compensated by other authors making the best use of parallelisms and linkages. Suffice to cite S. Giedion (physical sciences), C. Doxiades (Life Sciences) or the versatile Charles Jencks, a chief propagandist of "Post-Modern" Architecture.

In the following two chapters I shall try to reexamine S. Giedion's

E.Y. GALANTAY: "Ars Sine Scientia Nihil Est".

4.

contention "that emotions and expressive means vary concomitantly with the scientific concepts that dominate the period"* and search for "perception shifts" due to the changing world-view as suggested by Maurice Goldsmith.



THE CREATOR represents himself as an artist

CHAPTER II. ARCHITECTURE AND THE PHYSICAL SCIENCES.

II.1. The Medieval Architect as Scientist

Arguably, the architect was the scientist of the middle ages. Vitruvius demanded that he be versed in music: medicine, law, astronomy, optics, arithmetic and geometry. While few master builders could lay claim to such a range of knowledge most of them knew a lot about geometry and mechanics. Architects were called upon to build all sorts of lifting devices, locks, mills, engines of war and clocks. In fact, the most important "output" of medieval economy was in buildings; within three centuries (1050-1350) in France alone 80 cathedrals, 500 big churches and some 10'000 parish churches have been erected. There was a church or chapel for each 200 inhabitants* 4. No wonder the architect's position was central in society. The middle ages left more portraits of architects than of any other profession except clergymen* 5. Even God the Creator is often depicted with compass in hand as "architector" of the universe (Fig. 1).

Romanesque architecture was still imbued with the antique preference for solidity and heavyness. Buildings were conceived as the body of a statue - corresponding to a mathematics of full numbers* 6.

But, as Giedion pointed out * 7a - if the Greeks lived in a world of constants and of eternal ideas - Christianity conceived of a world set into motion by an act of will. Gothic architecture is characterized by a "Faustian" stretching of the limits to maximum height and span; the goal was to enclose the maximum volume with the minimum deadweight. Gimpel (1980)* 7b

speaks of a veritable "esprit de records". Inside the choir of Beauvais cathedral (1225) one could have placed a skyscraper 15 floors high without touching the vault. The tower of Strassbourg equals the height of a skyscraper of 40 floors, yet it is capable of withstanding lateral wind pressure of 160 km/hour! The secret of the master masons was to be able to derive all the dimensions of the sections and elevations from the plan. As the unit of length for measurements varied from one town to another the architects didn't use numerical dimensions on their plans but instead relied on a system of proportions which permitted to translate design drawings into real dimensions. As F. Bucher proved the most important method for relating the

dimensions of component parts of a gothic building consisted in rotating successively inscribed squares in a plane*8. The corresponding mathematical description would yield an infinitesimal series of irrational numbers and amounts to the destruction of the antique concept of a statuary procession of full numbers. This permitted Spengler (1917) - a mathematician by training - to state that "in gothic architecture the idea of infinitesimal calculus is anticipated* 9.

We know little of the mathematical knowledge of the master builders but it was for their use that Robert of Chester (1145) translated from the arabic the algebra of Al-Khawarizmi and Gerard of Cremona (1150) the trigonometry of Al-Zarqali which explains the use of the sinus and the tangent*10. Although the gothic masters relied on the geometric generation of basic shapes and dimensions, their method was also daringly experimental, pushing toward the extremes - frequently resulting in collapses. As to their interest in mechanics suffice to mention the sketchbooks of Villard d'Honnecourt - dating from 1215-1233 - which contains some 13 pages on machinery including an underwater saw and a perpetual motion machine. But geometry was considered the king of sciences and the master masons were the guardians of its secrets:

"Don't marvel that all science lives by the science of geometry... geometry is the measure of the earth... therefore... all men live by geometry" (from "The Constitutions of Masonry" around 1400 cited by Bucher p. 14)*11.

II.2. The Rise of Modern Science and Architecture

I group in this subchapter the periods distinguished as Renaissance, Baroque and Rococo in architectural history, since the three centuries from the "age of Discovery" to the onset of the Industrial Revolution seem to constitute an indivisible entity. Above all, the "Renaissance" was less a turning back to the ideas of classical antiquity than a search for new insights. First, in lieu of the antropomorphic proportions of classical antiquity, harmonic or musical proportions were preferred (Wittkover 1962*12). Second, the interest in depth - leading to the development of lineal perspective - was alien to the Greeks and at best of marginal interest to the Romans. Renaissance design is calculated for one observation point only, the unique

point of view of the individual observer. It is only valid for a strictly limited range of distance and demands a measurable point of optical arrest like the obelisks-placed at regular intervals to be intervisible-in the plan of the Rome of Sixtus Vth (1585-1590). By contrast the later development of the baroque perspective opens up a limitless field of vision - as in the parks of Versailles or Karlsruhe - all the way to a vanishing point on the horizon. This architectural interest in the linear perspective undoubtedly served as a stimulus in the development of the telescope by Galilei.

The Renaissance did rediscover focal space - first explored by the Romans in the Pantheon () - a space as if "blown up from the inside" but a static space nevertheless-that can be fully perceived from a single point of view.

We can gage the importance of focal space and linear perspective in the notebooks of Leonardo da Vinci. In addition to Art three subjects fascinated the unique mind of Leonardo: structural anatomy - to be discussed in the next chapter - the internal workings of machines, and hydraulics. His drawings of pulleys, cogwheels and serial mechanical operations perpetuate a tradition which we have already noted in Villard de Honnecourt. But Leonardo's interest in hydraulics*13 - closely related to his research of the circulatory systems of the human body led him to the discovery that water supply, storm sewerage, sanitary sewers and irrigation canals, as well as human and vehicular traffic are "circulation systems" for which he proposed grade-separated networks in his town-planning schemes (1487). This interest in hydraulics led Leonardo to an intuitive understanding of gravity as a sort of fluidum that must be led from the highest vaults of a building to the foundations, by the shortest possible path. In his letter to the building committee of the Duomo of Milan in 1490 he claims to know "the causes that assure the stability of a building and the properties of weight and of forces; how they can be combined and linked with one another and what impact they will produce together..."

Leonardo was also interested in fortifications, a matter of scientific concern of his age since the shape and disposition of the bastions was

determined by ballistics and the flooding of the moats required a combination of mechanical and hydraulic engineering. These problems also interested Descartes who seriously considered becoming an army engineer. In his "Discours de la Méthode", Descartes makes proposals for regularizing the street pattern of towns and uses the well-ordered city as a metaphor for the state*14. However it is Descartes's geometry (1637) which influenced architecture. In Descartes's system the number as a dimension is replaced by the number as a function and the sensual element of the concrete length replaced by the abstract element of a point or the variable spatial relations of points in space. Of interest to architect was also the work of Pascal on conic sections (1639) and his work on the mathematical implications of infinity. The contemporary architects Guarino Guarini (1624-1683), Bernini (1598-1680) and Borromini (1599-1667) produced interiors which embody mathematical speculation of a high order of complexity. For example, the coupola of Borromini Sant'Ivo in Rome (1642-1662) is composed of intersecting conical and spherical segments over a hexagonal plan, supporting a spiral lantern! Guarini's Turin churches show even more complex geometry. Guarini was a talented mathematician and his published work anticipates the work of Gaspar Monge (1800) on descriptive geometry.

A contemporary of Descartes, the Dutch mathematician, Simon Stevin, was the first to apply quantitative methods in town planning, proposing minimal but adequate room sizes; modular plot-plans and street networks; and orderly growth by planned linear extensions (1660)* 15. It is interesting to note that it is in the late 17th century that the plan of houses becomes functionally differentiated and compartmentalized - rooms served by corridors are separated by doors and no longer open into each other.

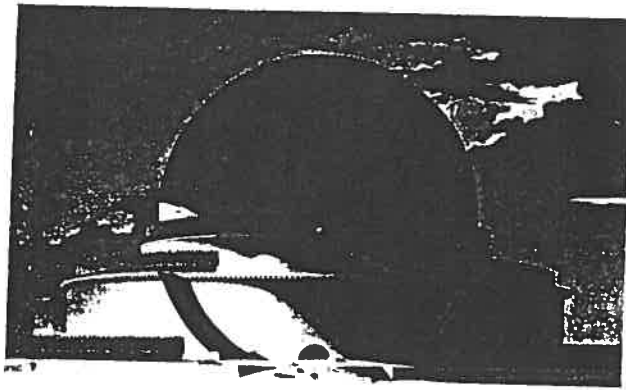
One might expect a great impact of science on the architecture of Sir Christopher Wren - the former Savilian Professor of Astronomy in Oxford and friend of Sir Isaac Newton. Wren designed the Greenwich observatory (1666) where Flamsteed then entertained both Wren and Newton at a dinner in 1700. In 1715 - when the Commissioners of St. Paul's Cathedral ordered Wren to put up a balustrade around the roof of his building - it was Newton

who was dispatched to obtain Wren's approval. Yet, Victor Fürst - who made a careful analysis of Wren's writings - admits, that Wren's training in mathematics and astronomy found no reflection in his architecture* 16. Maybe it was Newton's disdain of speculation expressed in his "I don't make theories..." that reinforced Wren's empirical bias and his rejection of philosophical concepts weaving architecture, mathematics and astronomy in an intellectual ensemble. He rejected Blondel's theory of beauty resulting from antropomorphic or harmonic proportions and claimed that "beauty is begotten by the use of our senses", due to geometry and familiarity with forms or "objects which are usually pleasing to us for other causes". Fürst points out that with this view he anticipated Hume's dictum that "Beauty is no quality in things themselves: it exists merely in the mind..." Wren's friend Newton is one of the few scientists to whom plans for architectural monuments have been dedicated. The first - by Etienne-Louis Boullée (1784) - is in the form of a globe 400 ft. high and according to Pevsner "one version has an armillary sphere suspended inside; the other has the starry sky represented by tiny star-shaped openings grouped like celestial constellations" recalling a modern planetarium* 17. Rosenau notes that this "Cenotaphe" represents a hollow globe - a form at present familiar from atomic reactors (Figs. 2). In 1785 the French Academy of Architecture launched a competition for the Prix de Rome with a brief on a "Cenotaphe pour Newton" and the theme was taken up again in 1800 in the project Gay. Pevsner asks just why the French architects were so keen to celebrate Newton and he cites a laudatory poem dating from 1738:

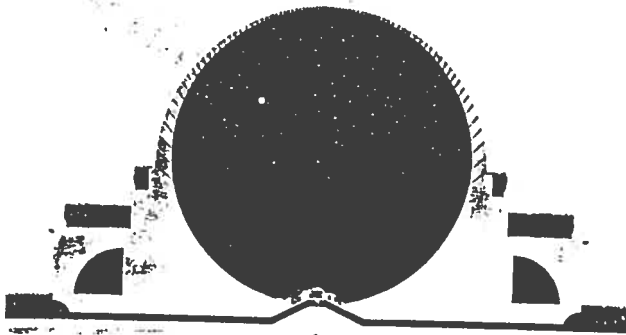
"Le compas de Newton mesurant l'univers
lève enfin ce grand voile et les cieux sont ouverts..."

Newton was popular with architects since he seemed to have proved that the universe is governed by simple mechanical laws that they could understand. Pascal was terrified by the "eternal silence of these infinite spaces" but Newton demystified immensity and the workings of the universe could be as easily visualized as a game of billard.

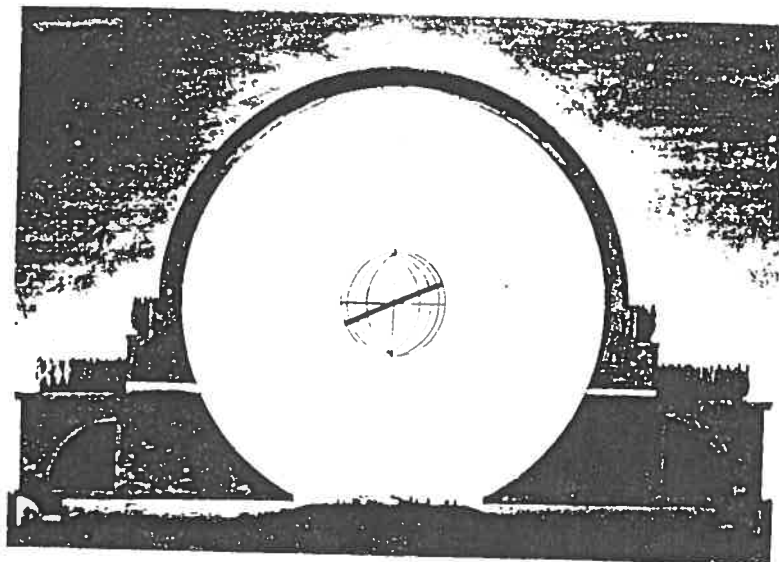
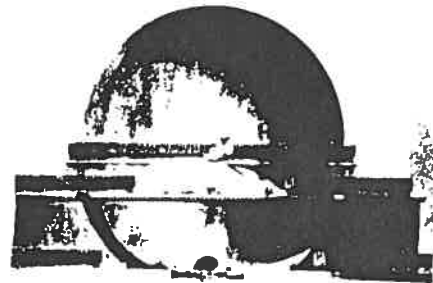
Fig. 2: Representations of Etienne-Louis Boullée's 1784 project for a Newton Memorial - "Cénotaphe de Newton"



Newton Memorial—Cénotaphe de Newton.



Newton Memorial, Interior—Coupe.



Bronowski points out that in the 18th century attention paid by members of the Royal Society and of the French Academy to light and in particular to the colours of the spectrum made it natural for contemporary poets to use frequent references to colours. "Interest is replaced from the solid form to the surface, that of appearance..."* 18.

This is certainly paralleled by the "dematerialization" of rococo architecture. This was achieved partly by the use of swinging and undulating forms; partly by the theatrical treatment of light - such as the provision of an "oculus" to bring down light on top of the altar or on statues and also by illusionistic ceiling decoration like the floating angels of Tiepolo. In such "trompe-l'oeil" paintings the ceiling dissolves and one is looking up to infinity.

At the same time the geometry of space became highly sophisticated: in a church like B. Naumann's "Vierzehnheiligen" the ceiling is formed by interpenetrating spherical and ellipsoidal surfaces intersecting in curves of the third degree contained in three-dimensional warped planes. The mathematical description of such curves needing integral calculus was worked out considerably later than their representation in stone. It is not impossible that the mathematician's inspiration was triggered off while contemplating these forms and listening to contrapuntal organ music during mess. It is worth mentioning that in city planning single, focal urban squares were increasingly replaced by planned sequences of spaces as in Nancy, Kopenhagen, Bath and Edinburgh.

At the end of the 18th century technical education for architects splits off from their artistic training with the creation of the Ecole Polytechnique (1794). In contrast to the Ecole des Beaux-Arts the Polytechnique insisted on introducing practical applications of the discoveries in the mathematical and the physical sciences. This was the start of the cleavage of architecture as an art, from architecture as the science of building.

II.3. Determinism (1800-1918)

We shall demonstrate in the next chapter that during the 18th and 19th centuries the life sciences - (botany, zoology and the emerging theories of evolution) - had a greater impact on architecture than the contemporary physical sciences, obsessed with the description of facts.

The final objective of science - wrote Helmholtz in 1869 was to "find the driving forces behind movement... and to translate them into mechanics" while in the words of Lord Kelvin "if you measure of what you speak of and you can express it by a number, you know something of your subject". Qualitative sensations were to be described in terms of quantitative values, and nature was to be reduced to an unified order of measurable structure*19.

This preoccupation finds its counterpart in the town planning practice of the late 19th century in Hausmann's quantitative orientation in the rebuilding Paris; in I. Cerdà's 1859 Plan for the extension of Barcelona and his "Teoria General de Urbanización"*20 (Fig. 3) which views the city as a mechanism assembled from distinct components - a notion later popularized by Le Corbusier with his claim that the house is a "machine for living". Further examples of mechanistic town planning are Tony Guarnier's proposal for a "Cit  Industrielle"*21 and its descendents, the planned industrial towns of the Soviet Union based on a rigid hierarchy of functionally nested services and residential areas: "Kvartals", "microrayons", "rayons" etc. The Soviet town is of course viewed as a "machine of production" in fact as an "intermediate product of the production process" *22.

Research on molecular structure also had considerable influence on architectural thinking. In 1858 Kekul  found that the six carbon atoms of the benzene molecule are disposed in a ring hexagon shape - superimposed these result in soft graphite - interlaced three-dimensionally they form hard diamonds. The emergence of building designs based on hexagonal grids; or the hexagonal networks of E. Howard's Garden Cities (1898-1902) and later of L sch (1940) and of Chrystaller (1933) may have been inspired by the benzene pattern (Fig. 7).

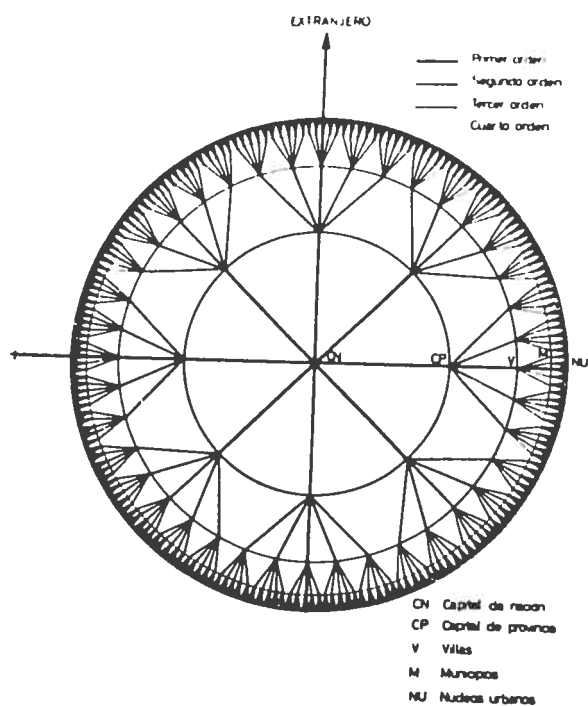


Fig.3 left. I. Cerdà's rigidly hierarchical "mechanistic" model of a regional settlement pattern. (as redrawn by M.Tarrago for the "2-C" magazin.

Fig.4 below.
One of Buckminster Fuller's structures resembling a "fly's eye".



In 1912 Max von Laue demonstrated that the atoms of all crystals are disposed in regular patterns and in 1913 Bragg discovered the cubic crystal structure of salts. The architects' fascination with the spatial structure of crystals found a belated echo in such projects as L. Kahn's Philadelphia City Hall project, and the numerous "megastructure" proposals of the 1960's * 23.

In 1895 Röntgen discovered the X-rays and this focused architectural interest on "transparency". In this case we may well speak of "parallelism" since the architectural exploration of "transparency" and the showing of the skeleton considerably predates Röntgen's discovery: Decimus Burton's Kew Garden Palmhouse (1848), Baltard's 1853 Paris, 'Les Halles' and Paxton's 1851 "Crystal Palace", all permitted the simultaneous view of the outside and inside of the building. These were followed by pavillons of the 1867 and 1878 Paris Exhibitions - notably the superb "Galerie des Machines" described by contemporary observers as a structure of "apparently weightless transparent surfaces" in which "air and light mix in an imponderable fluidity"*24,

One might mention in this context Linus Pauling's later work on structure in chemistry (1932) Fig. 12, discovering that the molecules of metals were arranged in the form of incatenated tetrahedres. This paralleled research on tetrahedral structures by Buckminster Fuller the most scientific of architects and father of the geodesic spheres (1933). The existence of such geodesic spheres in nature was later confirmed by electron-microscope studies of the structure of diatoms - (algae composed of silicium) - by the micromorphologist Dr. Hemke (Fig. 4).

Bronowski recalls that what interests us in crystals today is not of what they are made but how they are put together. Modern research is less concerned with arithmetical relations than with configuration, spatial geometry, and topological relations*25. The architect Sir Leslie Martin concurs: the new mathematical tools of sets groups and graphs "enable us to describe structural relationships which cannot be explained in metrical forms, i.e. 'adjacent to' and 'contained by'..."*26. Similar trends can be observed both in musical theory and in some fields of the social sciences such as de Saussure's "structural linguistics" and Levy-Strauss's

"structural anthropology". The first pioneer publication applying the new mathematics to architecture was C. Alexander's (1964) "Notes on the Synthesis of Form" subsequently expanded into a "Relational Theory"*27.

Apart from Alexander's work at Berkeley Cal. significant research on "The Geometry and Environment" is also carried on at Cambridge U. under the direction of sir Leslie Martin and Lionel March. Alas, due to the abstract, mathematical formulation of their results few architects read them and their impact on architectural practice is negligible*28.

Interest in topological relations and configurationism let to the understanding that the city in its totality is more important than the sum of its component elements and the realization that urban design is far more important than the architecture of individual buildings.

II.5. From Space/Time to Dissipative Structures:

According to S. Giedion - historian and chief propagandist of the International Modern Architectural Movement (CIAM) - the questioning of the concepts of absolute space and time occurred simultaneously in the Arts and in theoretical physics.

Giedion credits the mathematician Herbert Minkowski*29 as the first to conceive a world in four dimensions with space and time coming together to form an indivisible continuum. In fact Minkowski's "Space and Time" (1908) begins with the grandiloquent statement "henceforth space by itself and time by itself are doomed to fade away into mere shadows and only a kind of union of the two will preserve an independent reality". Of course, in 1905 Einstein has already discarded the baroque concept of time and space as absolute entities and viewed them as relative to moving systems or frames of reference. He also begun his "Elektrodynamik bewegter Körper" with a careful definition of simultaneity.

As Giedion points out contemporary cubist painters also sought to view an object simultaneously from all sides - a fact noted in 1911 by Guillaume Apollinaire. Simultaneity and time/space "interpenetration" were also explored by the "futurist" painters no doubt stimulated by the exploration of movement by photography. (E. Muybridge's photography of an "Athlete

descending a staircase" - 1880 predates M. Duchamps' 1912 "Nude descending a Staircase" by 32 years!).

In architecture the concepts of "simultaneity" and "interpenetration" can be traced back to F.L. Wright's destruction of the geometrically preconceived envelope and its replacement by a "free plan" radiating from a single core, and his dissection of the volume in vertical and horizontal planes. (Robie House 1908 Falling Water...). The same elimination of compartmentized rooms can be observed in Theo Van Doesburg's research (1920): in Mies van der Rohe's (1923) Barcelona Pavillón with its vertical planes protruding from the inside of the building to the outside and seemingly to infinity - traversing insubstantial glass partitions between "inside and outside"; followed by Le Corbusier's influential "plan libre" hollowing out large portions of the house, doing away with partitions and using skeleton construction to free the façade as in the Villa Savoy (1928). The same project also includes a long ramp linking two floors, introducing an element of virtual movement - and a sort of time/space fluidity - within the volume.

The use of the ramp device reaches its zenith in F. L. Wright's 1943 project for the Guggenheim Museum in New York (built 1956-1959) in which a conical interior space is to be experienced by the descent on a spatial spiral ramp.

"Transparency" as a device of implying "inside-outside" continuity has already been explored by 19th century greenhouses and exhibition pavillons. In the 1926 workshop building of the Bauhaus in Dessau W. Gropius uses the glass curtain walls turning the corner in an attempt to use transparency to imply simultaneity. Le Corbusier's 1932 "Maison Clarté" building in Geneva is an all-out bid to equate transparency with simultaneity in the perception of space in function of the displacement of the observer. Finally I would like to mention Gropius's "Total theater" project of 1937 which tries to maximize the time/space experience by a mechanical shifting of the actor-spectator areas in an attempt to create an "actor-spectator continuum".

Given the importance of the "Space/Time" concept in architectural theory

it would be intriguing to learn what Einstein thought of the use made of his theory of relativity in the arts. He could have discussed this since he met with Le Corbusier in 1946 at the Institute of Advanced Research in Princeton. Unfortunately Le Corbusier - entirely occupied with his own concerns - didn't ask Einstein any questions about relativity or, at any rate there is no record of what Einstein told him about Science.

Einstein commented kindly on Corbusier's "Modulor" - a system of proportional relations based on the "golden section" and the Fibonacci-series; "it is a language of proportions which makes bad design difficult and good design easy"*30 (Figs. 5, 6).

For this work on the "Modulor" the University of Zurich awarded Le Corbusier the degree of Dr. H.C. in Mathematics! The Modulor also provides as an interesting example of "parallelism" between musical theory and architecture. In his design work Corbusier strived to achieve what Lendvai says of Bartok's tonality - namely "combining linear structures and pentatonic Golden Section proportions based on Fibonaccian sequences constituting a closed chain"*31 (Microcosmos 1937). In urban design the notions of "space/time" and "equitemporality" found their equivalent in the perception of urban space by "the Moving Eye"*32 (Tyrwhitt 1959) and E. Bacon's principle of "simultaneous continuities"*33 . The "moving eye" theory is based on the observation that the experience of built space is not one of sequences of "now"s - limited to the sensations of an observer at a fixed moment and in a fixed place - but it includes the memory of what he has observed before and the anticipation of further experiences forming a continuum of sensual experience.

Bacon's design method for "simultaneous movement systems" is taking into account the fact that the macroform of the modern city is experienced simultaneously by different observers moving at different speeds (pedestrian, car, train etc.). In Bacon's view such movement should be considered the main generator of public urban space and of the volumes defining it.

At this point we might as well mention the key architectural monument associated with Einstein's name: F. Mendelsohn's (1932) "Einstein Tower" in Berlin. Built in sinuous "organic" forms in monolithic concrete, its

cross-sections recalls the morphology of a crustacean. I do not find it in any way expressive of the new world-view. If modern architecture better symbols for the new science could be found in the hyperboloids used as cooling towers and in Le Corbusier's Chandigarh Assembly Hall; or roofs in the form of hyperbolic paraboloids - saddle shaped, or forming a warped rectangle as in Candela's famous church in Mexico City. In contrast to the spherical or ellipsoidal domes of the Renaissance and baroque - which symbolized a closed universe - the new shapes seem to be finite segments cut out of warped surfaces stretching to infinity.

The impact on architecture of Quantum mechanics is more difficult to evaluate. No doubt Max Planck's 1900 hypothesis of discontinuous energy transfer and Bohr's (1908) principle of "complementarity" helped to destroy the materialistic conception of reality and of determinism*34.

Inasmuch as quantum mechanics replaces causality by statistical and probabilistic description and in its emphasis on "open systems" it has been influential in the theory of city planning and the modeling of urban systems :

Urban planning is making use of "conceptual models" which provide a simplified and intelligible picture of reality and of "analogue models" based on the assumption that "if things have some similar attributes they may have other similar attributes as well"*35. It may serve as a measure of the time-lag in planning theory behind the physical sciences that up to 1960 most planning models were based on deterministic/mechanistic concepts. For example traffic flow models: models linking transportation and urban land values; and growth allocation models are mostly based on analogies with hydraulic flow or make use of a generalized version of the theory of gravity. (For example W.S. Reilly's law of retail gravitation states that: "The attraction of a town is proportional to its population and inversely proportional to the square of the distance from it" (1931)*36. Other models introduce the concept of attraction and repulsion between "charged" particles to take into account the fact that the interacting human and urban activities - unlike physical particles - are from being homogeneous. Electrical network theory and information theory have also

been tried, but all these methods are far too deterministic. In city planning the behavior of the individual affecting the urban system cannot be predicted. The macroscopic or "gross behavior" of the system has to be examined in terms of the relative probability of the future position of urban actors: - individuals, groups, activities - i.e. in terms of their preferences or opportunities of access to residential or job locations

The principle of Stochastic modeling of group behavior by analogy to thermodynamics is graphically described by Bronowski (1960): "A society moves under material pressure like a stream of gas, and on the average its individuals obey the pressure, but at any instant any individual may - like an atom of gas - be moving against or across the stream"*³⁷

For the modeling of the behaviour of small groups or individuals increasing use is made of the "Theory of Games" developed by Von Neumann and Morgenstern)*³⁸. Such stochastic models leave a place for randomness and erratic individual behavior.

The use of thermodynamics in analogy theories for urban planning requires a clarification of the notion of "entropy" in urban systems. It could be interpreted as the gradual disappearance of structures, such as the rural-urban dichotomy, class structures, inequities in accessibility of the population to fixed resources of all kind - and generally as a trend toward a more homogeneous distribution of population and resources in the geographic space.

Such a teleological view is not incompatible with the idea of homeostasis or the rise of structures by self-organization in urban systems far from the equilibrium. Research in a possible transposition to urban planning of Prigogine's theories of "dissipative structures" has been encouraged by Prigogine's observation that "a town as an open system is analogous to a cell" and that "the simplest example of a dissipative structure is a town"* . Prigogine hypothesizes of "bifurcation phenomena"- shifts from one state or structure to another out of randomness, or "chaos to order transitions"-are useful in the modeling of spontaneous human agglomerations such as the vast squatter settlements of the Third World*³⁹

(Galantay & Ebenegger 1981).

The analogy is useful since the time-scale of the total process of the formation of a squatter settlement is distinctly larger than the time-scales involved in the lower-scale processes (densification; segregation; cluster formation) and the interactions between subsystems and among subsystems are not identical. The difficulty is in finding the appropriate "order parameters" as well as their correct sequence and hierarchy.

CHAPTER III. ARCHITECTURE AND THE LIFE SCIENCES.

III.1. The Architect as "Physicist": Leonardo to 1750.

The belief that the logics of nature expresses itself in the disposition of geometrical forms permeates antique thinking. For the Greeks the naked human body was the embodiment of perfection. For Vitruvius "man was the measure of all things" but speaking of men he was referring to the inanimate body - its volume and surface - at best recognizing its vertebrate symmetry. Leonardo was perhaps the first "looking for the life under the skin, not for the body 'per se' like Signorelli"* 40. His interest in structural anatomy led him to explore the coordinated disposition of muscles and bones. His concern with hydraulics led him to study the circulatory system of the blood, thus anticipating Vesalius's anatomy (1543) and Harvey's work on blood circulation - published a century later (1628). His drawings - showing the skull under the face and the guts and the skeleton under muscles and skin - herald Röntgen's discovery of the X-rays (1895). But Leonardo was also an architect and in his notebooks sketches of buildings and of human anatomy often figure on the same page. No wonder that - called in by the Building Committee of the Duomo of Milan (1490) to give his advice on the leaning pillars - he refers to himself as "a physician who knows how to remedy the sick cathedral..."* 41. In his later town planning studies for Milan (1487 and 1493) he extended the analogy with the human body to the city which consumes water and materials and excretes sewage, trash and garbage. He discovered that human and vehicular traffic form another "circulation system" and recognized the advantage of separating

these systems on different levels*42.

The publication of Vesalius's "De humani corporis fabrica" fascinated architects; not the least because of the remarkable illustrations by Jan van Calcar. Architects continued to dabble with anatomy, Sir Christopher Wren appears as a doctor of medicine on the Charter of the Royal Society! Yet it is likely that at that time every member of the Royal Society had some experience in anatomy; just as they also had a smattering of knowledge in architecture: according to Summerson each could have filled Wren's surveyorship without discredit"* 43. Thus it is no wonder that in contemporary France the king preferred Perrault - a physician - to Bernini for designing the façade of the new Louvre! - It is interesting that Perrault and Wren - trained in entirely empirical science - both rejected Blondel's attempts to force building elements to conform to the proportions and shapes of the human body - as "contrary to the nature of architecture".

III.2. 18th Century vitalism and Botany

According to Bronowski if science is considered as an orderly language for describing some events and predicting others" the botany of Linnaeus is the best example for "order in a non-mathematical science" *44.

In fact the publication of Linné's systematic botany (1735; 1753) had a great impact on architecture by calling attention to the existence of building types. Blondel's "Architecture civile - 1771) followed by J.N. Durand's "Receuil et parallèle d'édifices de tout genre" (1801) recognize that a building type - like a theater or a town hall - has a genealogical ancestry. The "memory" of numerous design solutions to the same problem constitutes a sort of "heredity" exerting an influence on the next architect struggling with a similar design problem.

Linne's work was not unknown to Goethe who - starting 1777 - seriously studied biological morphology. His approach to science was "one of sensuous experience and poetic intuition"*45, giving equal significance to outward form and inner substance. He gained the insight that life is not explicable by the laws of chemistry or physics alone but is in part self-determining and in his search for a form-giving cause came to an intuitive understanding

of evolution. In discovering the rudiment of the intermaxillary bone in man (1787) he corroborated the theories of Buffon and Larmarck.

Goethe's work was, of course, widely known even among architects and it is to him that we can trace the surging interest in "urban morphology": the evolution of the patterns of settlements, particularly those of unplanned agglomerations. In contrast to the heroic view of city development which claims that the form of the city is the result of successive acts of will and of great design ideas - the mushrooming growth of the cities of the industrial revolution provided increasing evidence that economic and social forces can combine into a sort of evolutionary mechanism.

In 1859 - the year of the publication of Darwin's "Origin of the Species" - Antonio Rovira y Trias won first prize in the competition for the extension of Barcelona: his plan was accompanied by an evolutionist manifesto stating that "A city is created by time rather than by architects..." directly challenging I. Cerdà's mechanistic/deterministic views of the urban system⁴⁶.

III.3. Architectural Darwinism

Darwin's idea of organic evolution by "descent with modification" due to the struggle for the "survival of the fittest" became soon confused with social darwinism, and - after the publication of Marx's "Das Kapital" in 1867 - with dialectic materialism. Nevertheless the continued influence of Darwinism on town planning theory can hardly be underestimated. In the interpretation of Darwinism for architects Patrick Geddes (1854-1932) played a key role. Having studied biology under T.H. Huxley he first served as Professor of Botany before becoming involved with town planning. In his influential "Cities in Evolution" (1915), he recognized the city as an essential organ in cultural evolution. Lewis Mumford - who also studied biology before becoming a planner - confirms that "it was Geddes' original training as a biologist that brought home... the immense complexity of the city as it develops in space and time"⁴⁷.

The study of botany and of zoology introduced the notion that there are natural limits to organic growth. If the city is viewed as an organism than it must have an "optimum size" and growth beyond this size must be

a form of "maldevelopment". This reasoning convinced E. Howard that London and other British cities were far too large to be healthy, leading to his promotion of garden cities of optimal size "neither too small nor too large" (1898, 1902)*48. From Howard's Garden Cities one can trace a clear path of "descent by modification" to the post-W.W.II British New Towns and new town planning elsewhere. The "optimum size" concept is still of operational relevance today*49.

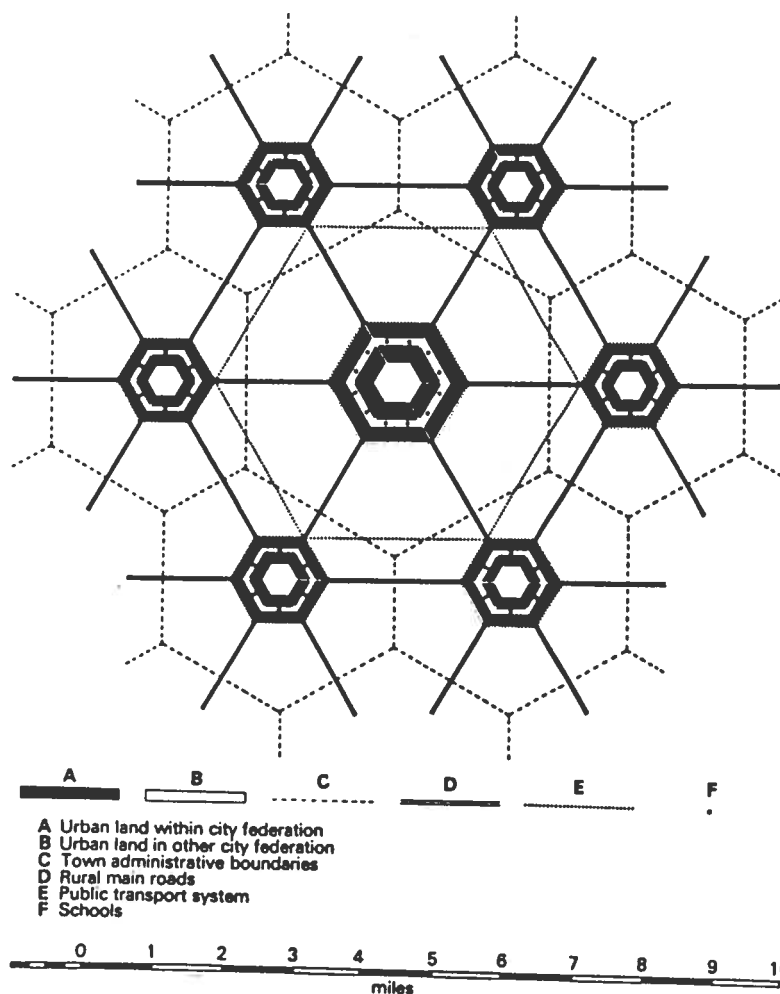
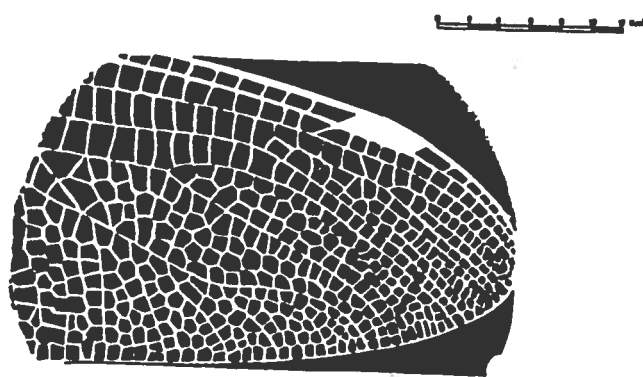
Since Howard and Geddes, planning theory remains permeated by Darwinian terms: i.e. in their seminal study of "The City" - modeled on Chicago - (1925), Park, Burgess and McKenzie describe man's relation to his environment as a process of competition for a number of limited resources (land, jobs, etc.) and a continuous adaptation to changing conditions of the environment as the key factor shaping the city*50.

The growing acceptance of Darwinism in architectural theory can be illustrated by the following citation from an article of Montgomery Schuyler published in New York in 1894*51. "In art as in nature an organism is an assemblage of independent parts of which the structure is determined by the function and of which the form is an expression of the structure". Just as a paleontologist could reconstruct the shape of a dinosaur from a few bones so "a person sufficiently skilled in the laws of organic structure can reconstruct from the cross-section of a pier of a Gothic cathedral the whole structural system of which it is the nucleus and prefigurement". The design of such a building... is an imitation not of the forms of nature but of the processes of nature". It was for the theory of biological evolution to show how design "of living organisms occur through an immensely protracted process of trial and error. Genetic mutations occur accidentally at random. In the struggle for existence natural selection eliminates the unfavourable mutations. In architecture there are also dead-paths of development, only the favourable patterns are preserved and developed further".

This is a succinct statement of evolutionary typology and at the same time a first formulation of the "form follows function" slogan of the modern architectural movement. According to the architectural historian J. Ackerman*⁵¹, the theory of natural selection explains convincingly the apparently

Fig. 7: Ebenezer Howard's cluster of garden cities (1902) forming a city federation of 250 000 persons. (From L.Martin & L. March; "Urban Space & Structures").

Fig. 8: below. Cellular structure of a dragonfly wing.



Ebenezer Howard's cluster of garden cities forming a city federation of 250,000 persons.

The inner structure of the regional plan for Greater Mussayib in Iraq (above) is similar to a dragonfly's wing

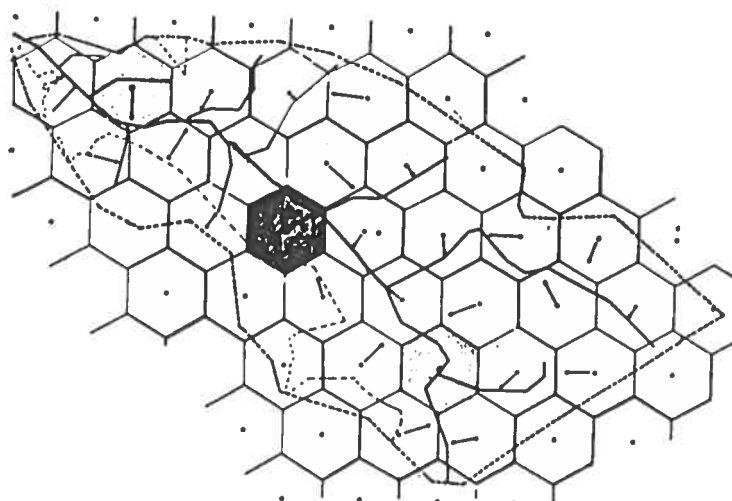
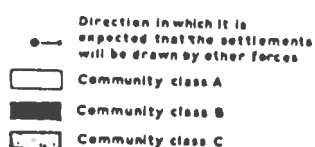


Fig. 9: left. C. Doxiades's plan for the structure of the Greater Mussayib region in Iraq. (from "Architecture in Transition").



systematic evolution of styles toward optimal solutions. In the problem - solving process involving design - variants occur of which some are "well adapted" and others are not. The adaptation in this sense is the capacity to stimulate an emulation and a favourable acceptance by society at large. What makes a city evolve is the incorporation of new characteristics in the complex. Each generation of architects and clients keeps from the previous generation what it likes and rejects what it dislikes. There cannot be a predictable development trend since the process depends also on the faculty and willingness of architects and clients to adopt and to internalize the achievement represented in earlier solutions.

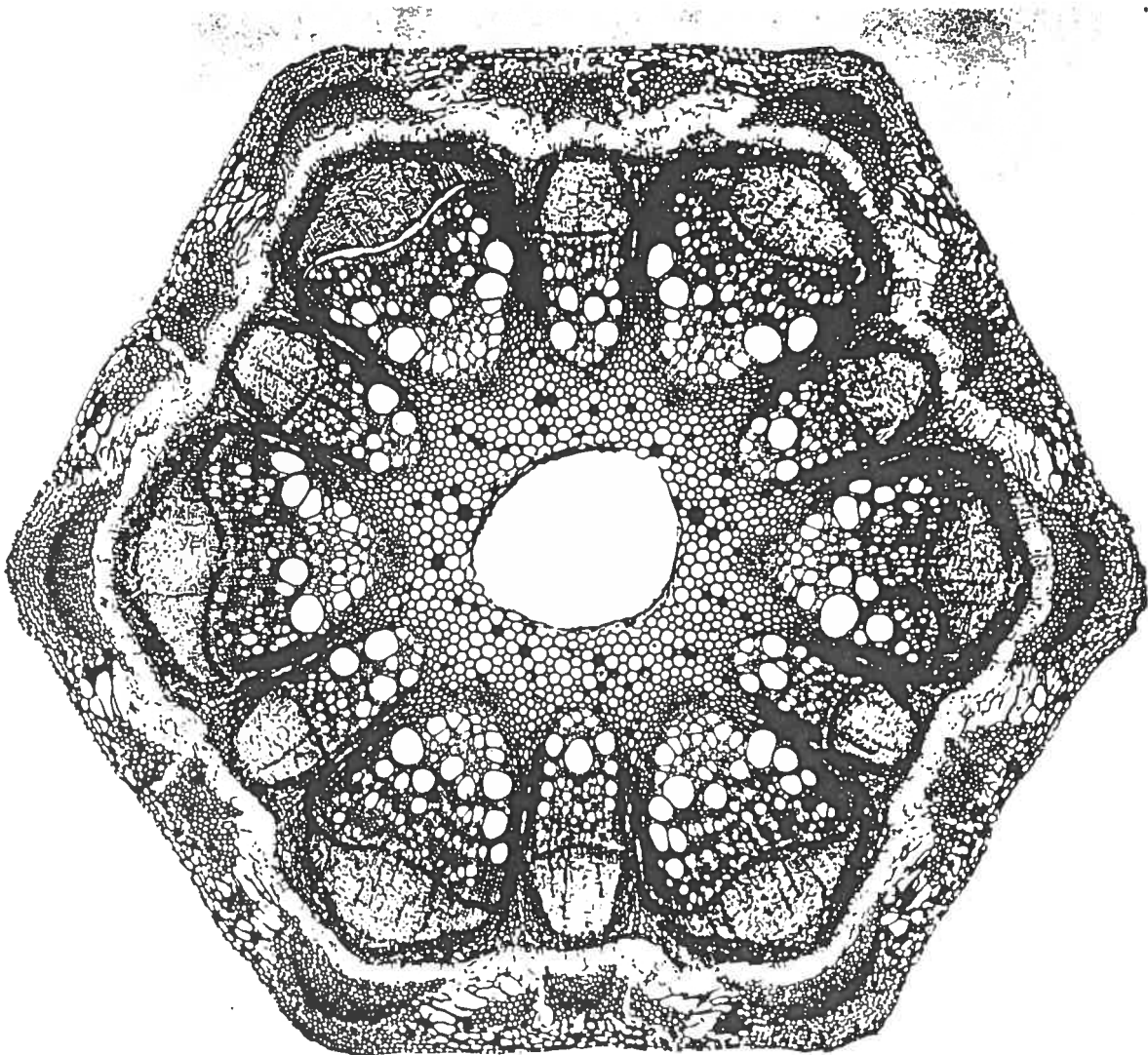
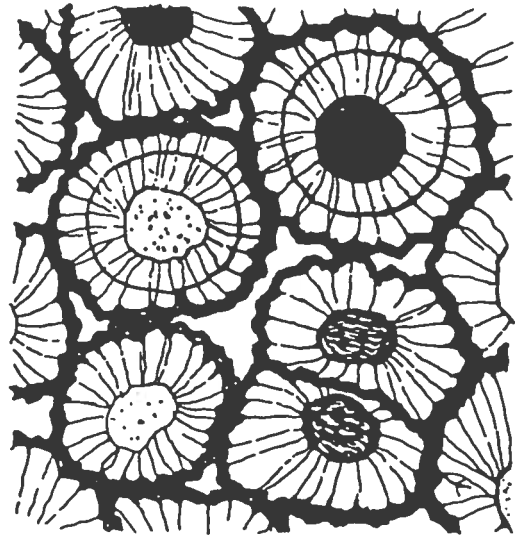
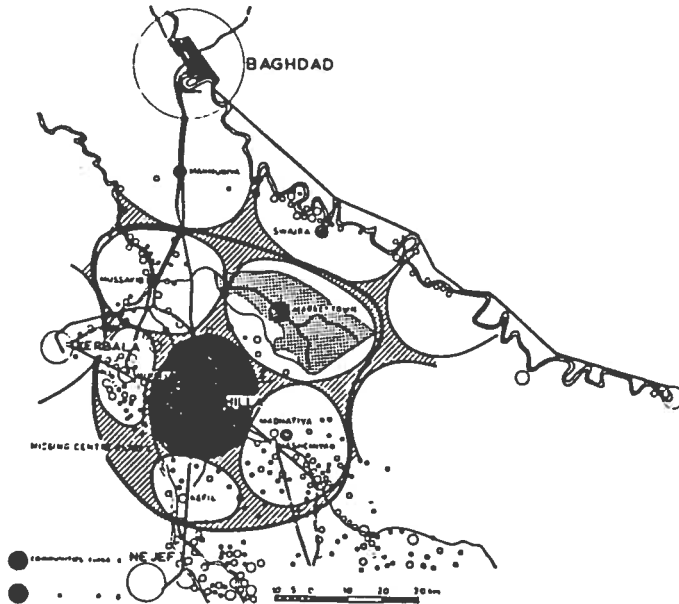
L. Benevolo - author of "The Origins of Modern Town Planning" - holds similar views. His books make frequent references to the life sciences and use biological analogies. According to Benevolo urban development is the adaptation of the "container" - the built environment of the city - to the "content" - its population. The rules of this adaptation can be defined as a response to the needs of the population*53.

Let us finally cite the most influential spokesman of architectural Darwinism C. Doxiades, founder of "Ekistics" the science of human settlements. Doxiades adopts Sir Julian Huxley's classification of living systems: "cells are biological individuals of the first order; bodies biological individuals of the second order; societies the third order". This would of course group human settlements together with beehives and termite hills. Undoubtedly Doxiades explains that "analogies need not necessarily exist between phenomena in order to be useful - it is enough if they exist between approaches". Growth is, of course, "fundamental to biological structure" (Medawar, 1945) and biological growth involves the gradual modification of proportions during development. Doxiades grows to great length to demonstrate that such growth is possible in the structure of human settlements although obviously not in the case of a building which is simply an artifact. It is amusing to note that Doxiades returns to Leonardo's concept of the architect and urban planner as a "physician".

Of the ten chapters of his "Ekistics" five are entitled Ekistics Morphology; Ekistics Evolution; Pathology; Diagnostics and Ekistics Therapy*54 (Fig. 8, 9, 10, 11).

Fig. 10: C-Doxiades's regional plan for Greater Mussayib in Iraq with an image of concretions of calcium carbonate (right)

Fig. 11: Below. Photomicrography of the cross-section of a branch resembling the pattern of spontaneous human settlements.



III.4. Genetics and Micro-Biology

Genetics refined the fundamental principles of evolution and also provided further proof of Darwin's ideal by revealing the mechanisms of natural selection.

A useful concept borrowed from botany is "tropism" - an innate tendency to react to stimuli in a definite manner. In urban morphology this term is used to describe pattern formation in response to fixed resources (i.e. the location of bus-stops or water taps in a quarter settlement). In architectural design "geo-tropism" or "helio-tropism" are structuring forces determining the most logical ways to respond to gravity or to "unfold" the building to permit the maximum amount of light to penetrate its interior. For example the "Torre Velasca" in Milan (1955, Archts. Rogers & Belgioioso) flares out about the level of the roofs of the surrounding buildings to optimize exposure to the sun.

The human anatomy continues to provide architects and planners with useful metaphores and conceptual models. We have already noted that Doxiades reconfirms the image of the architect as a "physician". Even before Doxiades, Richard Neutra - an architect

with some medical training - derived interesting insights from histiology - observing that in human tissue "it is in the cell-walls that the essential electro-chemical exchanges take place - rather than in the interiors of the cells" (1941). Subsequently this insight has been applied to planning theory leading to the new doctrine that road networks should not be used as dividers or "buffers" between cells, neighbourhoods or "environmental areas" - but rather as "activity corridors" where the interface between the inhabitants of different cells can take place, and where intercell exchange of goods and of information should occur. The best example of the application of this principle can be found in the Plan for the British new Town of Milton Keynes, another example is the writer's own plan for Owerri, New Capital of Imo State in Nigeria*55.

The ecological adaptation of a population to environment and the resulting changes of individual and social behavior can be viewed as yet another aspect of the Darwinian "struggle for life". Ecological concepts are fasci-

nating to architects and there have been many proposals for "ecology-optimizing" settlements from the maverick Paolo Soleri's "Arcologies" to the Kiyonori projects of the Japanese "Metabolist" group such as Kiyonori Kikutake's "Ocean City" (1962)*56.

In connection with the "optimum size" theories a consensus developed that there are "density thresholds" beyond which individual performance and social behavior start to degrade. Architects always felt that by paying attention to the qualitative aspects of the built environment, individual stress and social pathology can be minimized and higher densities can be tolerated* 57. However, such a hypothesis cannot be proved experimentally since groups of humans cannot be confined within boundaries for lengthy observation periods, particularly if the adaptation-to-environment process needs to be observed over several generations. Thus one is obliged to rely on analogy models based on animal experiments. The research of John B. Calhoun at the U.S. National Institute of Health at Bethesda, Md, proved very stimulating: Calhoun studied generations of rodent populations confined to a "closed utopian universe" and concluded that the incidence of social pathology is indeed dependent on the configuration of the physical environment, with an optimum range between monotony and over-stimulation. Although generalization from Calhoun's experiments to human society has been criticized by V. Bertalanffy as a "ratomorphic fallacy" there can be no question that Calhoun's work has proved fruitful to planning theory* 58.

Last, not least, if the city is to be considered as an organism, the most important insight gleaned from biology is that growth is all-important. Thus the city cannot be planned in terms of a preconceived "Master Plan" and strategic planning is required to take into account dynamic change based on a bundle of different scenarios.

III.3. Inputs from Genetics and Micro-Biology

Genetics refined the fundamental principles of evolution and also provided further proof of Darwin's ideas of the mechanisms of natural selection. From genetics architecture first borrowed the concepts of the genotype-phenotype dichotomy. Applied to architectural typology, the genotype is the sum total or "memory" making up the heredity of a building type in contrast to the phenotype which is interpreted as the visible property

of an individual design representing an adaptation of the genotype to a given specific environment.

Next, architects were elated to learn from Crick & Watson that the code of heredity is not confined to abstract arithmetical relations but resides in the spatial disposition of the atoms - i.e. in geometrical structure. Besides, the DNA molecule has a visually elegant form and Watson himself compared it to a spiral staircase*59. In fact Crick and Watson could have referred to the model of the splendid central staircase of the Renaissance Château de Chambord - built in two separate overlapping spirals - presumably to avoid embarrassment to the Queen mounting the stairs, of encountering François I's mistresses descending at the same time!

Alas, there is no evidence that Crick or Watson have ever visited Chambord. There are, however, many examples of a direct impact of the "double helix" image on architecture (Fig. 13). The discovery of the structure of the DNA molecules was published in 1953 and already next year I.M. Pei's thesis project at MIT featured two "helix"-shaped towers to be built in Boston Harbour. This was followed by K. Kurokawa's helicoidal project for the Ginza (1961) and other related projects.

Recently, an unexpected stimulus to architectural theory came from the Göttingen school of microbiology and the research of Herbert Kuhn and Manfred Eigen. What fascinates architects is the notion of pattern-formation by self-organization - a relatively minor aspect of the theories on the origins of life. Kuhn for example, insists that the crucial aspect of his theory is not pattern-formation but the discovery of a "device possessing self-replication and transition machinery"*60.

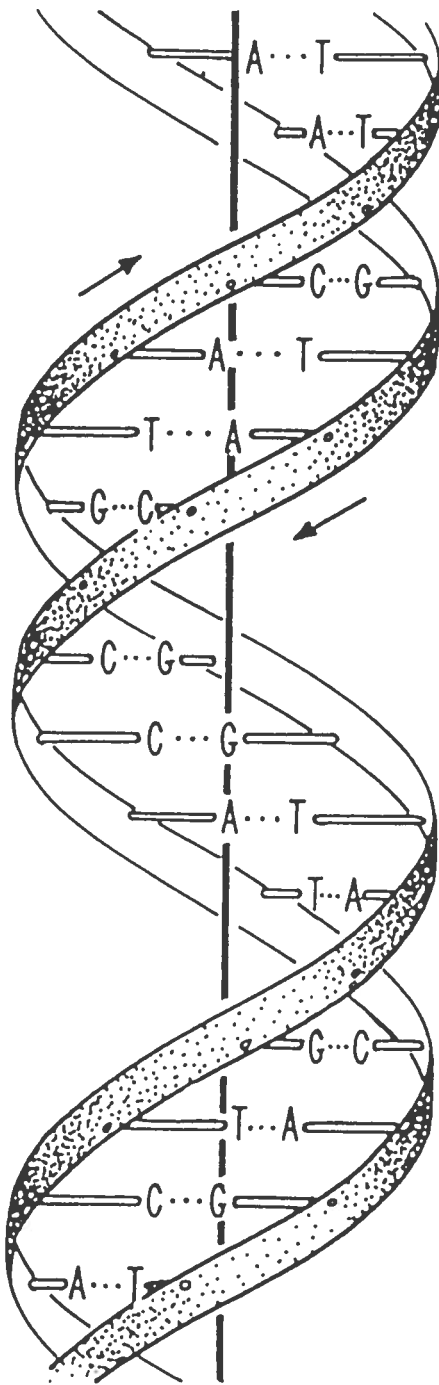
Nevertheless, the notions of homeostatic pattern-formation and the possibility of mutations due to copying errors proved very useful in explaining the largely self-conscious design processes of architecture, which - unlike computer operations - are not deterministic processes but include subconscious, random inputs. In fact, the architect's brain goes through the process of matching image-type information retrieved from memory with the functional requirements, and discarding "misfits" between form and content in an iterative process aiming at a "good fit"*61. A "happy" fit" is sometimes achieved through an error in the matching process! Christopher

Fig. 12 Right. Linus Pauling with the structural model of a molecule -the inspiration of some architectural "megastructures"

Fig. 13 Crick & Watson's double helix concept of the DNA-molecule



Linus Pauling with his atomic models



A schematic illustration of the double helix. The two sugar-phosphate backbones twist about on the outside with the flat hydrogen-bonded base pairs forming the core. Seen this way, the structure resembles a spiral staircase with the base pairs forming the steps.

Alexander's "Pattern Language" may serve as an example for the use of a language related to that of micro-biology*62.

Homeostatic pattern-formation also proved useful in the modeling of the evolution of spontaneous human settlements, such as the vast squatter slums of Third World countries*63.

Could one imagine any feedback from these architectural explorations to biology? The analysis of the mental processes involved in design could prove fruitful in research on brain function. Could one hypothesize a genetically determined predisposition for the preferential use of one hemisphere of the brain rather than the other? Could there be a sort of built-in handicap in "artistically" programmed individuals in the processing of abstract information - on the other hand could the "scientifically" predisposed brain be slightly blind to the type of visual-sensual pattern-information central to the thinking of artists and architects?*64.

CHAPTER IV. CONCLUSIONS.

"What our period needs is to gain understanding and a general view of the dominant methods in different fields. It is through their increasing similarity of method that the various activities of our times are drawing together to constitute "one culture". Thus wrote Siegfried Giedion in the introductory chapter of his "Space/Time and Architecture" (19..)*65.

Before him Oswald Spengler already called for a "comparative study of methods in different realms from biology to music" a true "morphology of the arts and sciences" (1917)*66.

Yet, both Spengler and Giedion had forebodings that due to the great strides made by modern science, henceforth "thinking and feeling may proceed on different levels and in opposition to each other". Thus, C.P. Snow's much quoted Read lecture about the "Two cultures" only summed up a prolonged malaise about a threatening split in Western culture*67.

But Giedion also asserted that scientific discovery must find its repercussions in the realm of feeling; to say that it is unnatural for a theory in mathematical physics to meet with an equivalent in the arts " is to

forget that the two are formulated by men living in the same period, exposed to the same general influences, and moved by similar impulses".

In formulating his "cultural earth-quakes theory" Maurice Goldsmith also assumes that major events in the Arts and the Sciences are somehow tectonically interrelated. To test this claim, I examined in the two previous chapters the evolution of the physical sciences and the life sciences for "parallelisms" and "linkages" with contemporary architectural and planning theory. Both "parallelisms" and "linkages" can be related to Goldsmith's metaphor of the cultural earthquakes: Parallelisms correspond to simultaneous tremors in remote areas; linkages to the secondary impact following a major irruption (such as the ecological changes at work long after Mt. St. Helen has quieted down).

My findings are that "parallelisms" can certainly be demonstrated between Science and Architecture, from the baroque period all the way to the present. Perhaps even more important for architectural theory and practice have been direct "linkages" - the flow of information from the physical and life sciences - which stimulated architectural thought. It matters little that the architects did not always understand, or interpret correctly the scientific findings or theories. Borrowed concepts or analogies need not be perfect to be useful and to yield results. It is also significant that the impact of information is not in proportion to its importance in the "donor" science but to the needs and 'receptivity' of the contemporary architects. Thus the very major changes in our world-view due to Copernicus, Kepler and Galilei found but little echo in architectural theory - although they degraded the originary value of the human scale, as "man was no longer in a central position in his conception of himself and of the universe"*68

What is remarkable about "linkages" is that information flow seems to be strictly one way - there is no evidence that architectural theory or practice has any influence on the methodology or theories of science. It is not impossible that the Arts - including Architecture - exert some latent, subconscious influence on the thought-processes of scientists but for this there is no proof. In searching for a conceptual model for the structure of the DNA molecule, Watson could have been inspired by

contemplating the helix stair of Chambord, but it is more likely that seeing it as a tourist - his mind would not have linked the image of the stair to his scientific concerns. Looking at the same object and receiving the same sensorial information the brain of the scientist produces different responses and formulates different questions from that of the artist.

Giedion expressed his hope for a greater convergence between the Arts and the Sciences. In fact, some "intraspecific" convergence exist within scientific fields on the one hand and among the Arts, Music and Architecture on the other hand.

Already Spengler noted that the once well-differentiated fields of physics - corresponding to our sensory organs - acoustics, optics, thermics - have merged in dynamics; that once distinct disciplines like chemistry and physics can no longer be separated; that physiology has become a chapter of organic chemistry; that microbiology and thermodynamics are using the same type of mathematical tools...⁶⁹.

There is also undoubtedly convergence between the theories of Music and Architecture. Some of the manifestoes of contemporary musicians could apply with hardly any modification to "post-modern" architecture. The recent disdain of cause and effect relations and of the "form-follows-function" dogma find their parallels in post-modern music where "forms are things in themselves rather than means toward an end"⁷⁰. Venturi's call for "Contrast and Contradiction in Architecture"⁷¹ parallels Cage's call for the "emancipation of noise through chance operations". The search for the "equality of various parameters"; for "equitemporality"; for "equal rights to all forms in their difference - conjuring forth the past, present and future -" quoted by Prof. Daniel Charles as characteristic of modern musical tendencies - could as well be used to describe the intentions of James Stirling designer of the Stuttgart Museum.

Yet although admitting the existence of trends toward "intraspecific" convergence, I can detect little evidence of the emergence of an "Art/Science Continuum". Asked whether the "sciences are becoming ever more like the arts and the arts like sciences" I feel the same unease as when I am confronted with the question: "Are men becoming ever more like women and women like men?".

The coming of "unisex" seems to me as unlikely as the merging of the Arts and the Sciences, but above all the question arises would such a merge be desirable? Maybe humanity is better served by the division of labour between two complementary but different sensitivities!

Art approaching science may turn into "Byzantism" by loosing all relevance except to a handfull of initiates. There is always a faint odour of sterility around buildings designed according to rigorous theories and music written as an intellectual exercise rather than by inspiration. On the other hand science moving toward the Arts risks becoming a pseudo-science or science-fiction.

Perhaps, at this point I migh introduce an irreverant metaphore: At a recent voyage to an East African game reserve, the game warden called my attention to mixed herds of wildebeasts and zebras grazing together. They seemed to tolerate each other without much interspecies communication. They always move together in search of unexplored resources; new pastures, watering holes. The wildebeast eat the thorny weeds, thus uncovering the tender grasses which the zebras prefer: they disdain the dry thistles which would hurt their sensitive muzzles. The ungainly but hardy wildebeast remind me of the scientists; the decorative zebras of the artists; what keeps them apart is not incomprehension but a certain indifference.

Scientists and artists - like wildebeast and zebras - are single-minded in the pursuit of their divergent interests and this limits the desire for interspecies contact. Architects socialize by preference with other Architects or Artists, and by necessity with potential clients: politicians, bankers and other decision-makers. Few have scientist friends and if they do, they seldom discuss their work. This is partly due to the lack of receptivity by the architects for information of an abstract nature, and the inability of the scientists of explaining their work in simple "image-able" terms.

To create a more fruitful dialogue the scientists would need some early exposure to the arts similar to the programs now offered by the Visual Arts Centers of Harvard and at MIT. Science also needs more first-rate expositors like A.S. Eddington, E. Schrödinger or C.H. Waddington. it is often the style of the writing which makes scientific theories incompre-

hensible. A.N. Whitehead's prose, for example, is characterized by the introduction of too many new terms and obscurities.

Or, take Boltzmann's definition of the second law of thermodynamics:

"Der Logarithmus der Wahrscheinlichkeit eines Zustandes ist proportional der Entropie dieses Zustandes" (the logarithm of the probability of a state is proportional to the entropy of this same state). No architect can make head-or-tail of this phrase yet the same law in Clausius's first formulation is easily understood: "Heat always passes by itself from the warmer to the colder body, never in reverse".

Problems of language and style largely explain why the life-sciences have exerted a greater influence on architectural theory than the physical sciences. (Key concepts transposed from the life-sciences are: architectural typology; urban morphology; critical size theory and self-organization of spontaneous settlements). The reasons for this also lies in the greater "imageability" of biological processes (plant morphology, vertebrate zoology, embryology, pattern formation in microbiology etc.) in contrast to the abstract nature of the relations of inanimate matter and their mathematical description.

I emphasize the need for easier communication from the sciences toward the arts because there seems to be little information coming from the Arts that could be useful for the scientists. The flow seems to be as irreversible as in my metaphore of the mixed herd: the wildebeasts always munch away the thistles before the zebras get to the grass, never in reversed order.

There is no easy explanation for this but my own feeling is that Art is the final sublimation of the human experience. Science is engaged in the Kafkaesque pursuit of openings doors only to reveal more doors that need to be cracked open. The Arts permit to "interiorize" the latest discoveries about nature by turning theories into symbols, and by reinforcing the individual's identity in the universe.

Science creates "Angst" but the Arts exorcize it. It takes two to play this game and the flow of information must be irreversible. For this reason I believe that the Arts and the Sciences will maintain their separate identities and their time-honoured position of interface.

- End -

* * *

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