

Nikos A. Salingaros *Architecture, Patterns,  
and Mathematics*

Nikos Salingaros posits the importance of architectural pattern in man's intellectual development, examining how twentieth century architectural attitudes towards decoration and pattern have impoverished man's experience of both mathematics and the built environment.

*Introduction*

The traditionally intimate relationship between architecture and mathematics changed in the twentieth century. Architecture students are no longer required to have a mathematical background. While a problem in itself, a far more serious possibility is that contemporary architecture and design may be promoting an anti-mathematical mind-set. The modernist movement suppresses pattern in architecture, and this has profound implications for society as a whole. Mathematics is a science of patterns, and the presence or absence of patterns in our surroundings influences how easily one is able to grasp concepts that rely on patterns. Eliminating patterns from twentieth-century architecture affects our capacity to process and interpret patterns in thought. Mathematics, and the intellectual patterns it embodies, lie outside our contemporary, explicitly anti-pattern architectural world-view.

Mathematics teachers are bemoaning the fact that there is less and less interest in mathematics, which has resulted in a declining mathematical capacity among students. This stands in sharp contrast - indeed a contradiction - with the increasing technological advances we are witnessing in our times. Here, it is proposed that an environmental factor might contribute to the overall decline of mathematics in our society. This theory arose from the author's interest in the theoretical basis behind architectural styles from different periods and regions. It has recently been shown how traditional architectures obey rules that are intrinsically mathematical [1,2]. Those rules lead to buildings that, whatever their form, encapsulate to a greater or lesser extent multiple mathematical qualities and information. The architecture of the twentieth century has achieved novelty, and a break with the past, precisely by eliminating those qualities.

In this paper, the word "pattern" denotes a regularity in some dimension. The simplest examples are repeated visual units ordered with translational (linear) or rotational symmetry.

Patterns also exist in a scaling dimension, where similar forms occur at different magnification. When geometric self-similarity is defined on a hierarchy of scales, a self-similar fractal is created. The concept of a pattern also extends to solution space, in that solutions to similar problems are themselves related and define a single template that repeats - with some variation - every time such a problem is solved. The underlying idea is to reuse information; whether in repeating a unit to generate a two-dimensional tiling design, or in reusing the general solution to a class of differential equations.

Environmental psychologists know that our surroundings influence not only the way we think, but also our intellectual development. Ordered mathematical information in the environment generates positive emotional responses. If we are raised in an environment that is implicitly anti-mathematical, that adversely affects our interest in mathematics; possibly even our ability to grasp mathematical concepts. Does spending one's whole life in a pattern-less world weaken or even destroy the crucial capacity to form patterns? Even though the definitive answer to this question is not known, its implications are alarming. While there is very strong criticism of contemporary architecture for its lack of human qualities [3,4], the present criticism goes far deeper. This is not an argument about design preferences or styles; it concerns the trained functionality of the human mind.

### *A science of patterns*

Mathematics is a science of patterns [5]. The mind perceives connections and interrelations between concepts and ideas, then links them together. The ability to create patterns is a consequence of our neural development in responding to our environment. Mathematical theories explain the relations among patterns that arise within ordered, logical structures. Patterns in the mind mimic patterns in nature as well as man-made patterns, which is probably how human beings evolved so as to be able to do mathematics. Mankind generates patterns out of some basic inner need: it externalizes connective structures generated in the mind via the process of thinking, which explains the ubiquitousness of visual patterns in the traditional art and architecture of mankind.

Patterns in time are also essential to human intellectual development. Daily activity is organized around natural rhythms. Annual events become a society's fixed points. Moreover, these often link society to an emerging scientific understanding of periodic natural phenomena such as seasons and their effects. Mathematics itself arose out of the need to chronicle observed patterns in space and time. On smaller scales, repeating gestures become theater and dance, and are incorporated into myth, ritual, and religion. The development of voice and music responds to the need to encapsulate rhythmic patterns and messages. All of these activities occur as patterns on the human range of time scales.

Complex physical and chemical systems are known to generate patterns in space or time, as a result of self-organization. The system's organized complexity is manifested on a macroscopic scale as perceivable patterns. This is not only true for the innumerable static patterns found in nature; patterns also represent collective motions or other forms of organized, dissipative behavior. The observation of steady-state patterns in dynamic systems is often indicative of the system assuming an optimal state for energy transfer (examples

include convection cells, ocean currents, and whirlpools in rivers). By contrast, there is very little going on in a homogeneous state.

Before the era of mass education, and for a great many people still today, architectural patterns represent one of the few primary contacts with mathematics. Tilings and visual patterns are a “visible tip” of mathematics, which otherwise requires learning a special language to understand and appreciate. Patterns manifest the innate creative ability and talent that all human beings have for mathematics. The necessity for patterns in the visual environment of a developing child is acknowledged by child psychologists as being highly instrumental. One specific instance of traditional material culture, oriental carpets, represent a several-millennia-old discipline of creating and reproducing visual patterns. A close link exists between carpet designs and mathematical rules for organizing complexity [6,7]. A second example, floor pavements in Western architecture, is now appreciated as being a repository - hence, a type of textbook for its time - of mathematical information [8].

### *Alexandrine patterns as inherited architectural solutions*

An effort to define patterns in solution space was made by Christopher Alexander and his associates, by collecting architectural and urban solutions into the *Pattern Language* [9]. These distill timeless archetypes such as the need for light from two sides of a room; a well-defined entrance; interaction of footpaths and car roads; hierarchy of privacy in the different rooms of a house, etc. The value of Alexander's *Pattern Language* is that it is not about specific building types, but about building blocks that can be combined in an infinite number of ways. This implies a more mathematical, combinatoric approach to design in general. Unfortunately, this book is not yet used for a required course in architecture schools.

Alexandrine patterns represent solutions repeated in time and space, and are thus akin to visual patterns transposed into other dimensions. Every serious discipline collects discovered regularities into a corpus of solutions that forms its foundation. Science (and as a result, mankind) has advanced by cataloguing regularities observed in natural processes, to create different subjects of ordered knowledge. The elimination of visual patterns, as discussed later, creates a mind set that values only unique, irreproducible cases; that has the consequence of eliminating all patterns, visual ones as well as those occurring in solution space. Fortunately, the structural solutions that architects depend upon remain part of engineering, which preserves its accumulated knowledge for reuse.

Basic laws for generating coherent buildings follow Alexander's more recent work [10]. Successful buildings obey the same system laws as a complex organism and an efficient computer program. This author's theoretical results [1,2], which support the efforts of Alexander, may eventually become part of a core body of architectural knowledge. The design of common buildings is already being taken over by the users themselves in the case of residential buildings, or by the contractors of commercial buildings. Builders have developed their own repertoire of (usually very poor) architectural patterns, motivated by the desire to minimize cost and standardize components rather than to optimize usability. Architects increasingly design only “showcase” buildings, which are featured in the architectural magazines, but represent a vanishing percentage of what is actually built today.

Architectural education tends to focus on trying to develop “creativity”. A student is urged to invent new designs - with the severe constraint not to be influenced by anything from the past - but is not taught how to verify if they are solutions. This approach ignores and suppresses patterns in solution space. Contemporary architectural theory can only validate designs by how closely they conform to some arbitrary stylistic dictate. The only way to avoid coming back to traditional architectural patterns - which work so well - is to block the deductive process that relates an effect with its cause. By deliberately ignoring the consequences of design decisions, architectural and urban mistakes are repeated over and over again, with the same disastrous consequences each time.

### *Mathematics and architecture*

Historically, architecture was part of mathematics, and in many periods of the past, the two disciplines were indistinguishable. In the ancient world, mathematicians were architects whose constructions -- the pyramids, ziggurats, temples, stadia, and irrigation projects -- we marvel at today. In Classical Greece and ancient Rome, architects were required to also be mathematicians. When the Byzantine emperor Justinian wanted an architect to build the Hagia Sophia as a building that surpassed everything ever built before, he turned to two professors of mathematics (geometers), Isidoros and Anthemios, to do the job [11]. This tradition continued into the Islamic civilization. Islamic architects created a wealth of two-dimensional tiling patterns centuries before western mathematicians gave a complete classification [12].

Medieval masons had a strong grasp of geometry, which enabled them to construct the great cathedrals according to mathematical principles. It is not entirely fair to dismiss the middle ages as being without mathematics: their mathematics is built into structures instead of being written down. The regrettable loss of literacy during those centuries was most emphatically not accompanied by a commensurate loss of visual or architectural patterns, because patterns (as opposed to the abstract representations of a written script) reflect processes that are inherent in the human mind.

We are interested here in what happened in the twentieth century. The Austrian architect Adolf Loos banned ornament from architecture in 1908 with these preposterous, unsupported statements:

*The evolution of culture is synonymous with the removal of ornament from utilitarian objects. ...not only is ornament produced by criminals but also a crime is committed through the fact that ornament inflicts serious injury on people's health, on the national budget and hence on cultural evolution. ...Freedom from ornament is a sign of spiritual strength. [13]*

This hostile, racist sentiment was shared by the Swiss architect Le Corbusier:

*Decoration is of a sensorial and elementary order, as is color, and is suited to simple races, peasants and savages.... The peasant loves ornament and decorates his walls. [14]*

Thus they condemned the material culture of mankind from all around the globe, accumulated over millennia. While these condemnations may seem actions of merely stylistic interest, in fact they had indirect but serious consequences. The elimination of ornament removes all ordered structural differentiations from the range of scales 5mm to 2m or thereabouts. That corresponds to the human scale of structures, i.e., the sizes of the eye, finger, hand, arm, body, etc. In the Modernist design canon, patterns cannot be defined on those scales. Therefore, modernism removes mathematical information from the built environment. Looking around at twentieth century buildings, one is hard-pressed to discover visual patterns. Indeed, their architects go to great lengths to disguise patterns on human scales that are inevitable because of the activities in a building; they arise in the materials, and as a consequence of structural stability and weathering.

It is useful to distinguish between abstract patterns in plan, and perceivable patterns on building façades, walls, and pavements. Only the latter influence human beings directly, because they are seen and experienced instantaneously. Symmetries in a building's plan are not always observable, even if the structure is actually an open plaza, because of the perspective, position, and size of a human being. In a normal walled building, the pattern of its plan is largely hidden from view by the built structure. A user has to reconstruct a building's plan in the mind; i.e., it is perceivable intellectually, and only after much effort. Visual patterns have the strongest emotional and cognitive impact when they are immediately accessible.

Proportional ratios may be included with architectural qualities that are perceived only indirectly. The presence of the Golden Mean ( $\phi = 1.618$ ), the ratios 5:3, 8:5, and the  $\sqrt{2}$  proportion are found throughout all of architecture, and this topic provides a rich field of study. Nevertheless, no specific mathematical information is communicated to users of a room or façade having the requisite overall proportions, and the effect remains an aesthetic one. What actually occurs is that the use of proportional ratios often also subdivides forms so as to define coincident scales, and this has a strongly positive effect.

### *Architectural counter-arguments*

Books on architectural history emphasize how Modernist twentieth-century architecture is rational, being founded on mathematical principles [15]. The writings of the early modernists fail, however, to reveal any mathematical basis. Proposing pure geometric solids as "mathematical" is totally simplistic. If one looks hard enough, one comes away with a few unstated principles deduced from the buildings themselves [1,2]. One of these is hierarchy reversal: "build structures on a large scale that are natural only on the small scale; they then appear out of place, and therefore novel." This reasoning produces giant pyramids and rectangular boxes that are pure Platonic solids. Building unnatural structures to impress people goes back to the ancient Egyptians, and is definitely not limited to twentieth-century architects.

Much is made of Le Corbusier's modulator system of scales as being a link between Modernist architecture and mathematics. This is a dimensional rule that uses multiples of the Golden Mean,  $\phi = 1.618$ , anchored on the height of the "standard man" at 6ft (183cm) [15]. A careful reading of this design system reveals that it is not, and was never intended to be, a method for generating patterns. Le Corbusier himself did not apply it for surface design, preferring empty surfaces of raw, "brutalist", concrete. When he did use it (with his assistant,

the Greek composer Iannis Xenakis) on the Monastery of Sainte-Marie de la Tourette, it produced a random, purely ornamental façade, and not a pattern.

What about city planning? Didn't Modernism straighten out curved streets, and order unevenly-distributed buildings into neat rows of repeated identical forms? Yes, but by imposing a simplistic geometry on city form, post-war planning drastically reduces the rich mathematical complexity of the urban environment [16,17]. That is perhaps analogous to reducing the Spinor group in  $n$  dimensions into the trivial Abelian group  $Z^2$ . With hierarchy reversal, the monotonous patterns defined by modernist buildings and streets are visible only from an airplane. Urbanists of the early twentieth century didn't understand complex systems, so they were eager to simplify human interactions as much as possible. They removed the essential patterns (not only the spatial ones, but more importantly, the dynamical ones) present in the great historical cities, to create empty suburbia and monstrous office buildings.

Architects complain that new buildings are bad because they are cheap and tacky; implying that they could be improved by a more generous budget. One hears that "the reason beautiful buildings cannot be built today is because of the high cost of materials and workmanship". This statement is belied by the wonderful variety of folk architecture built the world over using inexpensive local materials. Architecture is about creating patterns and spaces; a preoccupation with materials only obscures more important issues. It is perfectly possible to build mathematically-rich structures on any budget, by applying the timeless rules derived by Alexander and elaborated by this author. New buildings are usually bad - in particular, those with a big budget - because they are generated by a negative set of mathematical rules [1,10].

Natural materials embody organized complexity in the scales below 5mm, and thereby provide mathematical information to a viewer through their microscopic surface structure. Modernist architects have abused this property. Emotionally uncomfortable buildings, starting with the Austrian architect Joseph Hoffmann's Stoclet house in Brussels (1906-1911), camouflage a mathematically deficient design through the use of expensive materials. Attention is drawn to the richness of detail in the materials, and away from the deliberate breakup of spatial coherence. This was a favorite method used by the German architect Ludwig Mies van der Rohe to spice up his transparent, minimalist boxes. The extreme example was his German Pavilion at the Barcelona Exposition of 1929, where giant slabs of colored and travertine marble hid the removal of all other mathematical information.

### *Classical and modern mathematics: is there an architectural analogy?*

The core mathematics curriculum consisting of calculus and its prerequisites (trigonometry, some algebra and geometry) does not yet include newer topics such as fractals and chaos. As calculus was derived by Sir Isaac Newton, our world is solidly based on a Newtonian foundation [5]. At the same time, the latter topics attract student interest, and many educators are trying to find a way to incorporate them into the curriculum. Fractals exist in a hierarchical space that relates distinct levels of scale, and self-similar fractals embody patterns in the scaling dimension. Teaching fractals at an early stage would reveal many of the inadequacies of architecture and urbanism in our time.

Classical and neoclassical architecture, which tries to imitate the spirit and style of the



Greco-Roman tradition, is ordered in a simple, rectangular geometry (which originally included sophisticated non-Euclidean corrections due to “entasis”, the subtle curvature on Greek temples [18]). Vernacular (folk) architecture, which represents traditional cultural styles around the world, tends to be either more or less curved, and is sometimes profusely decorated. There have been periods when official architectural movements incorporate curvature and decoration into the prevailing style; for example, Asian and Far-eastern architecture, 16th Century Manueline Portuguese architecture, Baroque architecture, and Art Nouveau architecture [19].

Modernist architects took the rectangular geometry of classical architecture, but eliminated subdivisions and subsymmetries (i.e., columns, cornices, fluting, and sculptural friezes). By explicit stylistic dictate, modernist architecture has no fractal properties, and that is one reason why it appears unnatural [20]. Traditional architecture, on the other hand, including that in a Classical style, tends to be explicitly fractal. Fractal subdivisions and scaling can be found in buildings of all periods and styles, and that crucial characteristic divides contemporary architecture from much of what has been built before. The exceptions are those older buildings wishing to disconnect from the pedestrian, usually in order to express power and to intimidate. The latter include monumental Fascist architecture, and its precursors in deliberately imposing, grandiose temples, palaces, and defensive military buildings of the past.

An analogy was recently proposed between Modernist architecture and Newtonian mathematics [21], which, however, is based upon a misunderstanding. The simplistic vocabulary of rectangular Modernist forms has very little mathematical content. Although some modernists did build curves and arches, those are exceptions. Modernist architecture does not represent Newtonian mathematics; it stops long before ancient Egyptian mathematics, at simple squares and rectangles. (The best these can do is to obey some proportional ratio such as the Golden Mean). Where do periodic and differentiable functions, derivatives, curvature, and Taylor series fit into empty rectangles? They don't. The only clear mathematical analogy between architectural styles is the presence or absence of patterns.

### *The anti-fractal movement*

Modernism removes fractals from our environment. Pure Platonic solids and fractals are incompatible, because the former exist only on a single level of scale. One definition of a fractal is a structure in which there is substructure (i.e., complexity) at every level of magnification. Magnifying a fractal by a fixed scaling factor, say 3, will give a set of pictures at magnification 1, 3, 9, 27, etc., all of which show structure and complexity. A “self-similar” fractal has the additional property that all these pictures are related by geometrical similarities (as long as one uses the scaling factor intrinsic to that fractal). The buildings of Le Corbusier and Mies van der Rohe intentionally violate this rule, in an attempt to distinguish themselves both from natural forms, and from traditional building styles [1,2]. Some exceptions are discussed later.

Recently, fractal dimensions have been calculated for Frank Lloyd Wright's and Le Corbusier's buildings, using the method of increasingly smaller rectangular grids [22]. The results show that (at least some of) Frank Lloyd Wright's buildings display a self-similar

characteristic over a wide range of scales, from a distant view to finger-tip size detail, so those buildings are intrinsically fractal. In this, Wright was following the brilliant example of his teacher, Louis Sullivan. By contrast, Le Corbusier's architecture displays a self-similar characteristic over only two or three of the largest scales; namely, those corresponding to a distant view. Up close, Le Corbusier's architecture is flat and straight, and therefore has no fractal qualities. A fractal dimension between one and two characterizes a design that has an infinite number of self-similar levels of scale, whereas the fractal dimension of Le Corbusier's buildings immediately drops to one.

### *Post-modernist and deconstructivist styles*

Architects reacting against minimalist "international style" buildings have reintroduced both curvature and subdivisions into their designs. (Here, one may include earlier modernist buildings that are curved.) This movement is beginning to bring more mathematical information into the environment. With very few exceptions, however, that does not lead to patterns. The overall forms of some famous examples of curved modernist and post-modernist architecture (e.g., the Chapelle Notre-Dame-du-Haut at Ronchamp by Le Corbusier, the Sydney Opera House, the Denver International Airport and the Guggenheim Museum in Bilbao by Frank Gehry) are defined by non-trivial mathematical functions. Mathematics is evident here on the largest level of scale. Nevertheless, these buildings are less mathematical than, say, St. Peter's or the Parthenon, precisely because the latter have a linked hierarchy of ordered subsymmetries, right down to the microstructure in the materials [1,2].

Some people relate the latest deconstructivist architectural styles, characterized by unbalanced, chaotic forms, to more modern mathematics such as chaos and fractals [21,22]. Whereas self-similarity in pure fractals tends to be exact, natural (and architectural) self-similarity is often statistical: the degree of complexity, though not the same pattern, repeats at different scales. Deconstructivist buildings can indeed approach a stochastic fractal, but they have no patterns, either on a single scale, or across different levels of scale. Innovative architects may wish to generate fractal rhythms in order to explore complexity at the interface between organization and chaos, and to link it to musical rhythms [22]. The complexity of such patterns will necessarily depart from simple repetition.

In this author's opinion, patterns are essential to architectural form. Mathematical chaos is the study of hidden patterns in systems that are only apparently chaotic. There is no change in the fundamental aim of mathematics - which is to discover patterns - in going from Newtonian to chaotic models. Despite the enormous possibilities of applying fractals to built forms in an innovative manner, deconstructivist buildings have only led to randomness. Built examples jump from one extreme to another: from the empty modernist model straight into random forms. Any decoration appearing on contemporary buildings is either so minimal as to be hardly visible, or it is intentionally disarrayed and broken so that it is incoherent. So far, deconstructivist architects bypass and avoid organized complexity, which is what most of mathematics is all about.



### *A mathematical template for our environment*

The built environment of the last few decades eliminates ordered, fractal structures (trees, rocks, rivers, and older buildings), and replaces them with empty rectangles and planes. Lately, chaotic, random forms appear in the landscape; still contradicting and displacing forms with organized complexity. This provides a strong message that complex patterns are not allowed as part of our contemporary world. Subconsciously, people learn that such objects are “not modern”, and so there is no reason either to build new ones, or to preserve existing ones from destruction. Notice with what fervor third-world cities eliminate their most beautiful buildings and urban regions, to replace them with a barren emptiness of faceless rectangles; ostensibly in order to imitate the more “developed” world. The latter, in turn, now competes in building disorder.

Most of us regret the loss of organic forms such as trees from our surroundings, yet the assault is actually far broader: it is against essential mathematical qualities. Our civilization has turned against those structures, animate as well as inanimate, that possess organized complexity. We are taught by our schools and media to eliminate mathematical information from our environment. We have reversed our mathematical values on the misguided impression that that is necessary for technological advancement. That is both false and dangerous. Emptiness has no content, and chaos is profoundly disturbing; human beings evolved by organizing biochemical complexity, and that is what should be valued above all else. As soon as our priority is on objects with organized complexity, we will again appreciate nature and mankind’s greatest achievements.

### *Information and complexity*

Any effort to quantify the degree of pattern in a structure or design leads one to consider its information content. There are two separate variables here: (i) the actual information and its presentation [23], and (ii) how that information is organized [24, 25]. Blank walls convey no information other than their outline. Ordered patterns on the one hand, and chaotic designs on the other, offer a large quantity of information; but it is organized very differently in these two cases. Complex, ordered patterns have a large information content, which is tightly organized and therefore coherent. Chaotic forms, however, have too much internally uncoordinated information, so that they overload the mind’s capacity to process information. Random information is incoherent: by failing to correlate, it cannot be encoded [25].

At the empty (modernist) extreme, monotonous repetition provides little information, although if it does contain any, it is well organized. Repetition (translational or other symmetry) does not necessarily create patterns with any content; one needs contrast as well [10]. Monotonous repetition without subsymmetries represents a minimal pattern on a single level of scale. It differs from more complex patterns whose information is contained in their different scales, and also in the interconnections between those scales [24,25]. Modernism uses very repetitive designs as a way of eliminating complexity and information, thereby simplifying the built environment. Moreover, repetition is always applied to the large scales, and avoided in the small (i.e., human) range of scales, which further diminishes its impact as an observable pattern.

Architectural history says that the modernists valued honest structures and rejected “gingerbread”; but they clearly went too far. Symmetric floor tilings were eliminated as not being closely related to the use of the architectural structure. Nevertheless, the opponents of ornament misunderstood the function of a patterned floor tiling. By connecting to the pedestrian through information, the space is made more immediate -- hence, more useful -- and at the same time it supports any ancillary functions of the whole building. Incredibly, Le Corbusier totally missed the fundamental role of information in architecture and equated two instances, one with organized complexity index [23] close to 100, with another close to zero:

*The uniformity of the innumerable windows in this vast wall on the Piazza San Marco gives the same play as would the smooth side of a room. [26]*

### Conclusion

Does architecture influence our civilization? Quite definitely. To evaluate this effect in earnest, we should be investigating the relationship between architecture and mathematics. In the past, the connection was two-way, reinforcing, and mutually beneficial. There are indications that architecture has separated itself from mathematics in a key aspect, first under the influence of the overly simplistic, politically-driven Modernist social ideology, and now even further by following the anti-scientific deconstructivist philosophers. As architecture is ubiquitous, the ideas it embodies influence our everyday life and way of thinking to a remarkable extent. We cannot afford to ignore this influence on our culture, especially because of the strong possibility that it may already have had negative consequences. We have trained people to reject mathematical information in the built environment. This reversal of mathematical values not only applies to buildings and urban regions; it defines a pervasive aesthetic.

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