The Search for Stress-reducing Fractal Art: From Jackson Pollock to Frank Gehry

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The Manhattan skyline is a familiar sight, with its many skyscrapers reaching into the clouds. Imagine if one of the skyscrapers was shaped like the clouds surrounding it. In 2001, the Guggenheim Museum proposed turning this image into reality when it unveiled a design by Frank Gehry for a 'cloud-like' building to house its modern art collection. With its swirling layers of curved surfaces spanning three piers, the proposed forty-five story structure was predicted to re-shape New York's waterfront. If the project moves ahead, how will people respond to this unusual architecture? My recent studies of people's perceptual and physiological responses to fractal patterns indicate a bright future for buildings that incorporate nature's shapes into their design. In particular, fractal architecture could be used to significantly reduce people's stress levels.

From the first moment I saw one of Frank Gehry's buildings, his architectural style reminded me of the creations of another radical visionary – the abstract painter Jackson Pollock (1912–1956) [1]. Pollock rolled vast canvases across the floor of his studio and then dripped paint directly onto the canvas, building majestic swirling patterns. Over the past fifty years, Pollock's paintings have frequently been described as 'organic', suggesting his imagery alludes to Nature [2]. 'Organic' seems an equally appropriate description for Gehry's creations. Lacking the cleanliness of artificial order, the imagery created by Pollock and Gehry stands in sharp contrast to the straight lines, the triangles, the squares and the wide range of other shapes belonging to Euclidean geometry. But if Pollock and Gehry's creations celebrate nature's organic shapes, what shapes would these be? Do organic objects, such as trees and clouds, have an underlying geometry, or are they 'patternless' – a disordered mess of randomness?

Whereas the artificial shapes of Euclidean geometry have been studied since 300 B.C., the complexities and apparent irregularities of nature's organic patterns – wherever they appear in our every day lives – have proven more difficult to define. One approach, doomed to failure, was to model nature's imagery using Euclidean shapes [3]. "In retrospect," noted Benoit Mandelbrot, "clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in straight lines" [4]. The correct approach arrived in the 1970s, when Mandelbrot identified a subtle form of order within the apparent disorder of nature's scenery. Many natural objects were shown to consist of patterns that recur at increasingly fine magnifications. Mandelbrot christened this repetition as 'fractal' (a term derived from the Latin 'fractus', meaning fractured) to emphasize their irregular appearance when compared to the smoothness of Euclid-

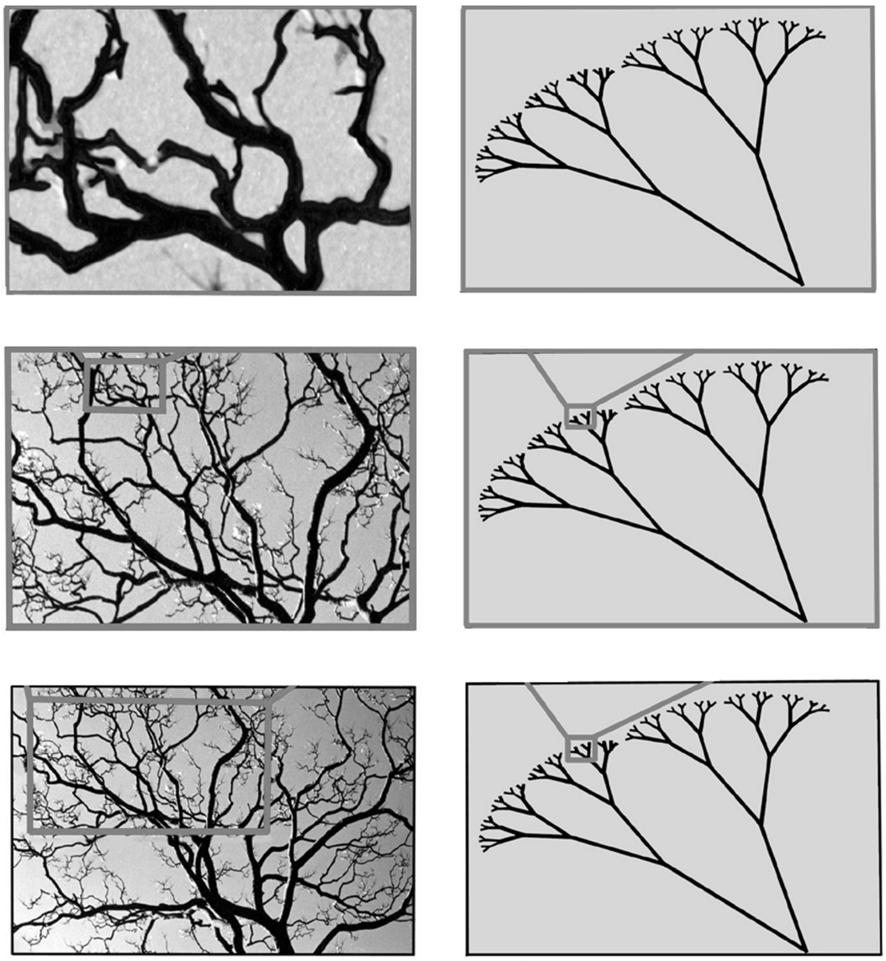

Fig. 1. *Left*: Nature's fractals in the form of trees (known as statistical fractals). *Right*: Exact fractals, where the patterns repeat exactly at different magnifications. Photographs by R.P. Taylor.

ean shapes. Catalogued in Mandelbrot's *Fractal Geometry of Nature* [4], a diverse range of natural objects were shown to be fractal, including mountains, clouds, rivers and trees. Natural fractals, such as the tree shown in Fig. 1 (left), are referred to as statistical fractals. Although the patterns observed at different magnifications aren't identical to each other, they have the same statistical qualities. This type of fractal pattern stands in contrast to exact fractals, shown in Fig. 3 (right), where the patterns repeat exactly at different magnifications.

Given the prevalence of fractal objects in nature, the concept of fractal architecture is very popular (see, for example, [5–9]). Fractal architecture builds on more general proposals of 'biophilia' and the drive to incorporate nature into urban landscapes [10]. However, these earlier proposals are not often practical for cities, where the building density limits or even excludes exposure to nature. A more direct approach to introducing nature's imagery into cities is to design buildings' appearance based on fractal geometry.

However, is it possible to construct fractal buildings? The challenge, of course, lies in the ability to repeat the construction process at different scales. Exact fractals are the simpler proposal because the same shape is employed at each magnification. For this reason, exact fractals have appeared regularly throughout the history of art, dating back to Islamic and Celtic patterns. More recent examples include Katsushika Hokusai's wood-cut print *The Great Wave* (1846) [4], and M. C. Escher's *Circle Limit III* and *IV* (1960). Escher is particularly well-known within the art world for his mathematical dexterity and his ability to manipulate repeating patterns at different scales [11]. This exact repetition can be extended to the arrangement of physical objects in a two-dimensional plane (such as rock distributions in the Ryoanji Rock Garden in Japan [12]) and to three dimensions (an obvious example is that of Russian dolls, where a large doll hides an identical but smaller doll inside, which then hides an even smaller doll).

In terms of architecture, the Castel del Monte, designed and built by the Holy Roman Emperor Frederick II (1194–1250), has a basic shape of a regular octagon fortified by eight smaller octagonal towers at each corner. A more recent example is Gustave Eiffel's tower in Paris, where the repetition of a triangle generates a shape known amongst fractal geometrists as a Sierpinski Gasket [13]. The Eiffel Tower (1889) serves as a demonstration of the practical implications of fractal architecture. If, instead of its spidery construction, the tower had been designed as a solid pyramid, it would have consumed a large amount of iron, without much added strength. Instead Eiffel exploited the structural rigidity of a triangle at many different size scales. The result is a sturdy and cost-effective design. Gothic cathedrals also exploit fractal repetition in order to deliver maximum strength with minimum mass. The fractal character also dominates the visual aesthetics of the building. A Gothic cathedral's repetition of different shapes (arches, windows and spires) on different scales yields an appealing combination of complexity and order [6]. In contrast to the 'filled-in' appearance of the Romanesque structures that pre-dated the Gothic era, the carved out character of the Gothic buildings delivers a distinctive skeletal appearance that results in their remarkable luminosity. More recently, the visual appeal of Frank Lloyd Wright's Palmer House in Ann Arbour (USA) of 1950–51 has been analysed in terms of Lloyd's use of triangular shapes at different scales [8].

In contrast to the exact fractals discussed above, statistical fractals represent a far greater challenge to both artists and architects. Leonardo da Vinci is renowned for his scientific illustrations of turbulent water dating back to 1500, yet his representations of swirling water fail to capture the statistical fractal quality generated by turbulence. Nevertheless, artistic creation of statistical fractals is possible. In 1999 I showed that the drip process developed by Jackson Pollock generated statistical fractals similar to those found in Nature's patterns [14]. Pollock's astonishing achievement has been christened as 'fractal expressionism' [15], to distinguish it from the statistical fractals that appeared with the advent of *computer art* in the 1980s. Pollock's method wasn't one of 'number crunching' and intellectual deliberation but was an intuitive process in which the fractal character was established after only

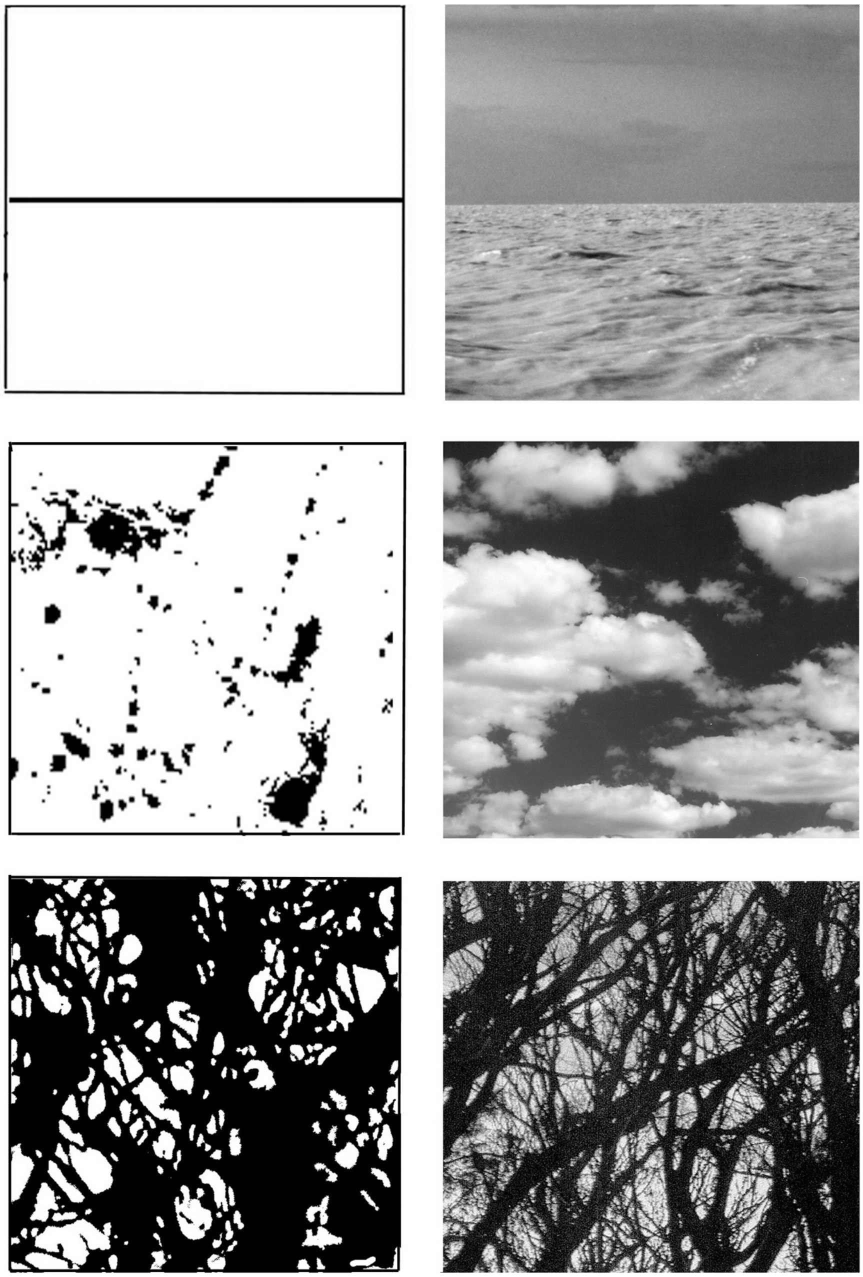

Fig. 2. Examples of drip paintings (*left column*) and natural scenery (*right column*). *Top*: a smooth line (D = 1) and the horizon (D = 1). *Middle*: Pollock's painting Untitled (1945) (D = 1.10) and clouds (D = 1.3). *Bottom*: Pollock's painting Untitled (1950) and a forest scene are fractal patterns with D = 1.89. (Photographs by R. P. Taylor).

two minutes of intense and swift activity. The precise way in which Pollock managed to generate the statistical fractals remains the subject of my current research. However, Lee Krasner (Pollock's wife and a respected artist in her own right) believed that his talent lay in an ability to paint three dimensional patterns in the air and to anticipate how this paint would condense on to the two dimensional surface of the canvas. Pollock's paintings therefore demonstrate that it is possible for someone to create statistical fractals in three-dimensional space. However, to design a building based on statistical fractals, an architect would have to create three-dimensional statistical fractals similar to Pollock's, but with the added restriction that the design would then have to be assembled into a structurally-sound object.

What are the possible motivations for creating a building based on statistical fractals? Such fractals have a large surface area to volume ratio. For example, trees are built from statistical fractals in order to maximize exposure to the sunlight. Similarly, bronchial trees in our lungs maximise oxygen absorption into the blood vessels. Possible advantages of this large surface area for buildings therefore include solar cells on the rooftops and windows that deliver a large amount of light to the building's interior. However, the main reason for such a design focuses on the associated aesthetics and the hope of mimicking a natural 'organic' shape. How would an observer react to an artificial object that assumes a natural fractal form ? The study of aesthetic judgement of fractal patterns constitutes a relatively new research field within perception psychology. Only recently have researchers started to quantify people's visual preferences for fractal content. The visual appearance of a statistical fractal object is influenced by a parameter called the fractal dimension D. This quantifies the visual complexity of the fractal pattern. Its value lies between 1 and 2 and moves closer to 2 as the visual complexity increases. This is demonstrated in Fig. 2 for drip paintings (left column) and corresponding natural scenery (right column). Starting with the top row, the smooth straight line is visually uncomplicated and has a base D value of 1. An equivalent pattern in nature is the horizon. Moving to the middle row, the fractal drip painting is a very sparse, simple pattern with a D value of 1.3. Equivalent fractal patterns in nature are clouds. Moving to the bottom row, the fractal drips are very rich, intricate and complex with a much higher D value of 1.9. Equivalent fractal patterns in nature are trees in the forest.

Since the D value of a fractal pattern has such a profound impact on its visual appearance, a crucial question concerns whether people prefer patterns characterised by a particular D value. During 1993–1996, Deborah Aks and Julien Sprott used a computer to generate fractal patterns with different D values and found that people expressed a preference for fractal patterns with a mid-range value of 1.3 [16]. However, in 1995 a survey by Cliff Pickover also used a computer but with a different mathematical method for generating the fractals [17]. This survey reported much higher preferred values of 1.8. The discrepancy between the two surveys seemed to suggest that there isn't a universally preferred D value but that the aesthetic qualities of fractals instead depend specifically on how the fractals are generated. To determine if there are any 'universal' aesthetic qualities of fractals, I collaborated with psychologists Branka Spehar, Colin Clifford and Ben Newell. We performed perception studies incorporating the three fundamental categories of fractals – 'natural' fractals (scenery such as trees, mountains, clouds etc), 'mathematical' fractals (com-

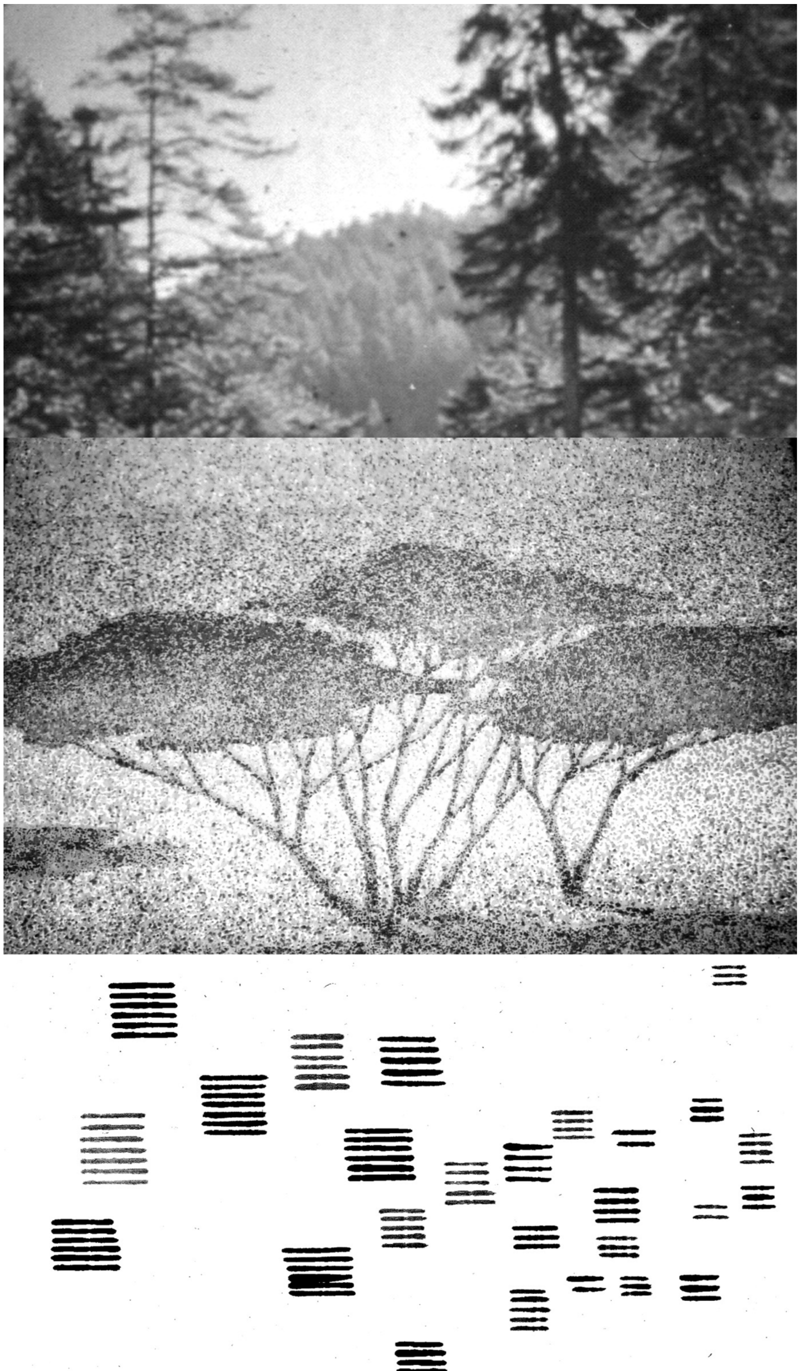

Fig. 3. Images used in the stress experiment: a realistic photograph of a forest scene (*top*), an artistic rendition of a natural landscape (*middle*), a pattern of painted lines (*bottom*).

puter simulations) and 'human' fractals (cropped sections of Pollock's dripped paintings). Participants in the perception study consistently expressed a preference for fractals with D values in the range 1.3 to 1.5, irrespective of the pattern's origin. Significantly, in a recent collaboration with Caroline Hagerhall, experiments indicate that perceived 'naturalness' of fractal patterns also peaks for fractals with mid-range values. Furthermore, many of the fractal patterns surrounding us in Nature have D values in this mid range. These facts raise the possibility that the eye is aesthetically 'tuned' to the fractal character surrounding us in nature's scenery.

Recent scientific investigations indicate that the appeal of mid-range fractals extends beyond that of visual aesthetics – these fractals actually reduce the stress of an observer. In a study by James Wise [18], people were seated facing a 1 m by 2 m artwork and were asked to perform a sequence of stress-inducing mental tasks such as arithmetic problems, with each task separated by a one-minute recovery period. During this sequence, Wise continuously monitored each person's skin conductance. Skin conductance measurements are a well-established method for quantifying stress – heightened stress increases the skin conductance. The amount of stress induced by mental work can therefore be quantified by the increase in skin conductance ΔG between the rest and work periods – a large ΔG value indicates high stress. Wise used the three art works shown in Fig. 3: a realistic photograph of a forest scene (top), an artistic rendition of a natural landscape (middle), a pattern of painted lines (bottom) and a uniform white panel serving as a control (not shown). ΔG was found to depend on which artwork was observed. For the 'artificial' pattern of lines (bottom), ΔG was 13 % greater than for the white control panel indicating that the presence of this artwork actually increased the observer's stress. In contrast, the ΔG values for the 'natural' images were 3 % (top) and 44 % (middle) lower than for the control indicating a reduction in stress. This result confirms an earlier proposal that natural images might be incorporated into artificial environments as a method for stress reduction. Why, though, was the middle image far more effective in reducing stress than the top image? To answer this question I recently teamed up with Wise and performed a fractal analysis of the two images. Significantly, the D value of the middle natural image was found to be 1.4, lying within the category of fractals previously established as being visually appealing. In contrast, the top image had a D value of 1.6, lying outside of the visually pleasing range. It appears then that the appeal of mid-range fractal patterns (D = 1.3 to 1.5) extends beyond simple visual aesthetics and is sufficient to deliver a profound physiological impact on the observer [19].

This is potentially exciting news for Frank Gehry and his 'cloud-like' design for the Guggenheim Museum: clouds are fractal patterns with a D value of 1.3 that lies within the 'magic' range of preferred visual complexity [20]. But will Gehry's design be capable of mimicking the fractal character of nature's clouds? The challenge may not be as difficult as it seems. Nature's fractals do not repeat over many magnifications. Whereas computer-generated fractals repeat from finitely large to infinitesimally small magnifications, typical fractals only repeat over a magnification range of twenty-five [21]. Thus, for a *cloud-like* building, the largest features would only have to be a factor of twenty-five bigger than the smallest features. This is challenging but not impossible. Furthermore, the low D value of a cloud ensures that the fractal structure will be relatively smooth and sparse (see Fig. 2). If Gehry had chosen a forest-like fractal structure, the intricacy and complexity of this high D fractal structure would have been significantly more difficult to incorporate into a building. Recent architectural studies are also fortuitous for Gehry's design – perception experiments indicate that it is not necessary to match the building's fractal character to the background fractal scenery in order to deliver an aesthetic impact [9]. In particular, this excludes the highly undesirable prospect of having to match the building's cloud shape to clouds in the sky, which evolve throughout the day !

If Gehry's proposal becomes reality, it will be fascinating to see if people's fundamental appreciation of fractal clouds will inspire New Yorkers to embrace this revolutionary building design.

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