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New Trends in Science and their Impact on Conservation and Art – An Excursion around Restorer's Island

by ECKHARD STRÖFER-HUA

The current change in western thinking is a result of the evolution of modern science. This development changes the way the sciences see themselves. This change, which does not come from outside but inside the sciences, deeply upsets our mechanistic view of the world and will have a strong influence on our philosophy and ethics. A new kind of science is creating tools that help to grasp the complex structure of the world; this means the complex structure, too, of objects of art and the materials with which the conservator works. The synthetic aspects - the building of structures in nature and art - and the analytic aspects - tools to describe the world of restoration - are discussed here. Our understanding of the arts will change and broaden, and the barriers between the worlds of art, nature and western science might be recognized as artificial.

EVOLUTION OF SCIENCE - TOWARDS A COMPLEX WORLD

Modern physics-based science is a child of the Occident. Philosophers and historians struggle about the question of why this powerful tool to conquer the world, to improve living standards and to create a world culture did not develop in another advanced civilization of the world.[1] For several hundred years, this science has been characterized by:

- a mechanistic view of the world: each cause has a well defined effect, the world - a big machine, the world - a clockwork;
- dissecting complex systems into closed ones that are easy to survey and neglecting complex interactions, often because of the lack of tools to handle such interactions (such as computers), and
- the belief that science primarily is good and that its progress will bring paradise on earth.

This view of the world is shaken by the development of science itself.

Irreversible thermodynamics[2]

Thermodynamics is the classical science of the steam engine and handles the problems of energy, the work that may be gained from energy and order and disorder. A system that wants to build up or to maintain a high standard of order has to export disorder (entropy). A flux of energy flows through the system. Our world is such an open system; the flux of energy is sunlight or the energy stored in oil, gas and coal. Evolution drives life to higher and higher orders; with the increase in complexity of that order, the export of disorder increases. An example from everyday life: building a highly ordered house from the disorder of identical bricks takes a lot of energy and creates a lot of perspiration, waste, dust and garbage. The same is true for the creation of an artistic masterpiece from simple pieces of matters and different colours. The arrow of time is a result of the irreversible character of processes in real systems; it never flows back. History cannot be reversed: if you demolish your house to get back the bricks, you do not get back the energy you invested in building it. If you dissect a piece of art, you do not get back the energetic pulse of the master's creativity.
The term "reversibility" as used by the conservator[3] is not as rigid as the scientific term of reversibility. In science all processes in the real world, being an open system are irreversible: reversibility is a technical term to describe the optimal condition of extraction of work from a special environment. In restoration you have to invest work to fight the natural irreversible destruction of a piece of art.

Synergetics[4,5]

Synergetics is the teaching of interactions: how are ordered structures formed from the disorder, the chaos? How can the sudden phase transition from the chaotic movement of water molecules to the highly structured order of a crystal of ice be understood? What is the underlying principle of oscillating reactions in chemistry and of the fluctuation of populations in biology? Why do the different quantums of light arrange to the powerful coherent beam of a laser? And finally, how do biological organisms form from the chemical soup in former oceans? How do cultures or economics develop, why and when do revolutions happen - revolutions in politics or revolutions in art? Synergetics enables us to present different phenomena that belong to different disciplines by one comprehensive unifying approach. The underlying mathematical theory describes phase transitions, evolution of new species and revolutions by bifurcations. Small fluctuations may result in a sudden change towards order or chaos. These small fluctuations may be not measurable and may not be foreseen. Only the framing conditions under which fluctuations and changes are possible may be given.

Look at a conflict situation in everyday life: there are two choices; what should you do? By ratio you find as many arguments for the one decision as for the other. Finally a feeling, an event on the street, a sentence spoken by a stranger drives you to one decision: bifurcation. So we once decided to open a workshop on paper restoration after having worked in the fields of art history, painting, graphics, pollution control, chemical engineering, philosophy and reaction kinetics.[6]

Evolutionary theory of knowledge[7]

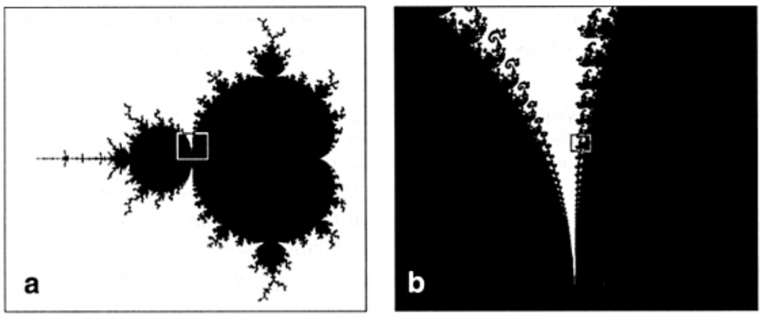
It is not our sensory and perceptual activity that forces nature into a straitjacket of mathematics. It is nature that, in the process of our evolutionary development, has impressed mathematics into our reason as real, existing structure. The wing of the bird reflects the laws of aerodynamics and the fin of the fish reflects the nature of water, of hydrodynamics. In the same way our reactions to environmental stimuli are judgements in advance that have been tested and implemented by the mechanisms of evolution under certain special conditions. The more these judgements in advance are used under conditions different from the original ones, the more they change to prejudices. Our deterministic thinking, our action in chains of cause and effect, our preference for the simplest explanation may result in prejudices in a complex world. See a lion - run away, okay; but build a nuclear power plant - yes or no? What is the very best way to restore a piece of art taking its special history and future into consideration? So our innate teachers may lead to fallacy. But there is hope, too: the ape from which we are descended had a very accurate idea of the geometry of actually existing space since he or she did not fall out of the tree and break his or her neck. Similarly, the evolution of our abilities for abstraction and manipulation of logical symbols must be oriented to the actually existing structures in the real world.

Life itself is a process of recognizing, of gaining knowledge. So the appearance of culture and art is based on the history of nature. Evolution, of course, is ambivalent: death came into the world with the appearance of multicellular beings, the pain with the evolution of the nerve system and fear, sorrow, ugliness and evil with consciousness.

STRUCTURES OF NATURE AND MATH ... AND ART

Our view of the world is changed by the evolution of sciences itself, which is comprehended in the mathematics and physics of nonlinear systems.[5,8,9] Mathematical physics for a long period of time only handled linear systems. These systems reflect the deterministic thinking of one cause - one effect. Nonlinear systems were difficult to handle because of the lack of calculators and so nonlinear effects were often neglected and in consequence not observed. So the effects that govern the interesting prospects of our world were not observed - their existence denied. But our world is not a clockwork.

The simplest nonlinear equation is $x = x^2$ (Fig. 1). The equation means: take an initial number, square it and remember the result. Then take the result and square it again. And so forth. If the initial x is smaller than 1, you will always approach the zero point, the centre of the circle after many loops. The zero point is an attractor for all initial values smaller than 1. It is a stable point symbolizing order. If the initial value of x is larger than one, the loop approaches infinity. If you take the equation $x = x^2 + c$, with c being a constant and if you work with complex numbers doing the iteration on a computer and plot the result, you get - surprise, surprise - the images of Fig. 2.[10,11] In these images you may recognize the playful structures of nature: shells, crystals, flower gardens and dendroids. Pickover[9] has even created a "biomorph zoo". If you have a computer, you may create your own complex worlds.[10]



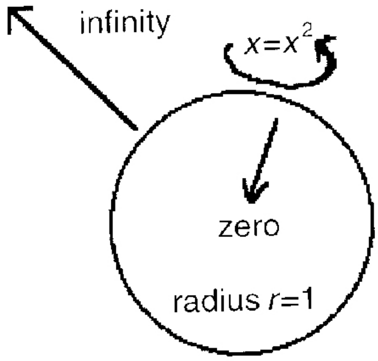


Fig. 2a. The Mandelbrot fractal. Source: Peitgen[8]. The marked part is zoomed in in Fig. 2b.
Fig. 2b. The self-similarity of Mandelbrot

The structures in Fig. 2 have one more important property: the crumpled course of the boundary is self-similar and has a complex structure at all scales. If you take a magnifying glass and look more closely at the boundary, you find that it looks exactly as crumpled as without the glass. If you take a microscope - again the same crumpling. This fractal structure is an important feature of many complex natural structures.[11-13] It reminds one of coastlines, of mountains and clouds, of waves and plants, of many natural boundaries that apparently become longer the finer the scale on which we measure them. These fractal structures have the important property that they are characterized by a fractal dimension that is neither one nor two nor three; it is a broken number in between. The fractal dimension of an object is a measure of its degree of irregularity considered at all scales, and it can be a fractional amount greater than the classical geometrical dimension of the object. The fractal dimension is related to how fast the estimated measurement of the object increases as the measurement device becomes smaller. A higher fractal dimension means the fractal is more irregular and the estimated measure increases more rapidly. The British coastline is a curved line with a fractal dimension of about 1.25.[13] The perimeter of oak leaves from the same oak tree appears to have essentially the same fractal structure with a fractal dimension of about 1.3.[12] A gold colloid aggregate containing thousands of subspheres was found to have a fractal dimension of 1.75.[11] All these curves are space-filling curves, and the more irregular they are the more space they fill and their fractal dimension approaches two, which is the classical dimension of the plane. A rugged surface can be given a number between two and three, which indicates how the structure fills the space it occupies. Thus a sponge of the fractal dimension 2.4 would occupy space more efficiently and have more surface area than a 2.3 fractal dimension sponge. A biological protein, the enzyme lysozyme, has the fractal surface dimension 2.2 but the inorganic silica gel has the dimension 2.97.[5] That correlates with the higher biological selectivity of the enzyme. The dimension of fractal objects is not even, which is the dimension for an object in classical geometry. For objects of classical geometry, the dimension of the object and its fractal dimension are the same. A fractal is an object that has a fractal dimension that is greater than the classical dimension.

Vice versa: being able to determine the fractal dimension, we have a measure for the irregularity and the space-filling character of an object. The irregularity of proteins influences their biological selectivity, the surface character of a catalyst influences its catalytic activity and the reaction rate and the irregularity of a fibre felt influence its filtration property.

Fig. 3 summarizes the discussion above. It is taken from Pickover.[9] It shows the structures of nature, mathematics and art. Self-similar objects are divided depending on scaling symmetry in classical Euclidian objects such as squares and circles and such fractal objects as crystals, coastlines, lakeshores, powders, holes in paper, paintings etc. Objects with an exact scale invariance comprise, for example, ice crystals. Statistical scale invariance of fractal behaviour is found in nature, society and art for objects and phenomena (cancerous growth, phase transitions, information transmittance and cultural events). This is reflected by nonlinear mathematics and computer art: pattern, symmetry and beauty: synthesizing nature, synthesizing ornamental textures, genesis equations and dynamic systems.[9]

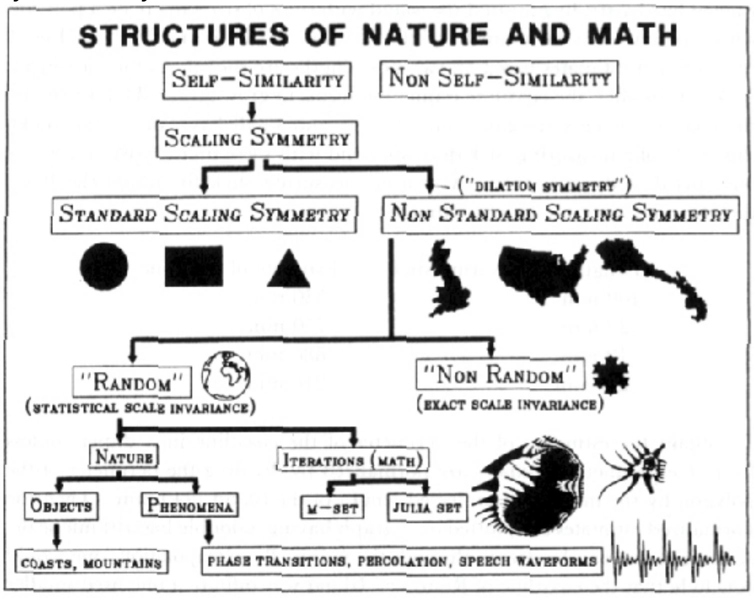


Fig. 3. Structures of nature and math. Source: Pickover[9]

MORE ON FRACTALS IN CONSERVATION

The practical consequences of remarks made in the foregoing chapters can be illustrated by three examples.

Fig. 4 shows Restorer's Island.[14] It is a piece of historical paper that was degraded over centuries by many different effects. Each effect obeyed simple rules. These effects in their chronological succession and superposition finally resulted in the characteristic appearance of this old sheet with its specific history of life. Among the effects were mechanical forces, oxidation by oxygen and pollutants, attempts at restoration and changes in humidity and temperature. Nobody can tell us anything about the age of the paper from simple experiments. But Restorer's Island can help us understand the nature of measuring fractal dimensions. One can attempt to measure the length of the rugged line by striding around the island with steps of size s to create a polygon whose perimeter is an estimate of the coastline of the island.[10,11,13] In Fig. 4 two different estimates based on two side lengths are shown. As the measuring stick gets smaller, the coastline estimation seems to grow larger. That's because the coastline is very irregular, full of large and small bays, inlets and rocky shores. A long measuring stick does not bend with these many twists and turns but cuts directly over them. A shorter measuring stick fits inside the bays, thereby increasing the length estimate.

Length of measuring stick	Estimate of coastline
100 mm	530 mm
20 mm	770 mm
10 mm	880 mm
2.5 mm	1210 mm

To obtain the estimates of the perimeter of the coastline in a dimensionless form, the perimeter estimates are normalized by dividing the perimeter of the polygon by maximum projected length of the island (240 mm). Then the normalized estimates are plotted on a graph having a double logarithmic scale. A straight line can be drawn through the points. By extrapolation, one would conclude that the coastline of Restorer's Island was infinite if one used smaller and smaller steps in the estimation.

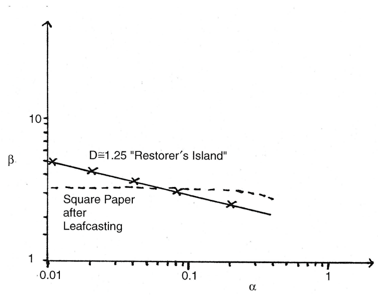


Fig. 4a. Restorer's Island (by courtesy of Institut für Buchrestaurierung, Bayerische Staatsbibliothek, Munich, Germany). The perimeter measured with different scales

Fig. 4b. Calculation of fractal dimension of the island. Double logarithmic plot of measuring scale against measured parameter (perimeter) for Restorer's Island and for the squared sheet after leafcasting. α = measuring scale (normalized length of measuring stick), ß = measured parameter (normalized perimeter of the island), D = fractal dimension

The plot of the log (estimate of the coastline) against the log (length of measuring step) gives a dataline with slope m. The fractal dimension of the object is given as (1 + m) by Kaye.[11] With m = 0.25 it is 1.25, demonstrating the space-filling character of Restorer's Island. 1.25 is the average fractal dimension of the coast of Great Britain, too.

This demonstrates that the erosive forces working in nature and in destruction of art are similar in principle and obey the same simple rules!

Now Restorer's Island is restored by leafcasting: the bays, rivers, rocky strands are filled with paper pulp.[15] After the procedure and cutting the paper sheet to a symmetrical Euclidean form (a square), the character of Restorer's Island has completely changed. It's no longer a fractal! If you measure the perimeter of the Euclidean square by the same procedure as described above, you do not get a straight line with a finite slope m. The double logarithmic curve converges with decreasing length of measuring step quite fast to the well-known perimeter of a square, which is four times the side length. Obviously the more aged an object of art the higher the fractal dimension; the activity of the restorer reduces the fractal shape to an Euclidean one.

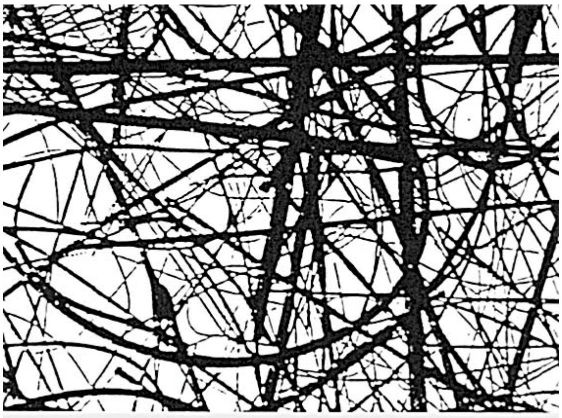
A similar method can be applied to study the fractal behaviour of fibrous filter felts.[11,16] Formation of felts is important, for example, in the paper industry and leafcasting. Felts may be handled as a carpet, a Sierpinski carpet. Sierpinski fractals of felted fibre systems are efficient descriptors of the structure of the felt. In a model of Kaye during the felt-making process, by fibres arriving and deposing, the fractal dimension steadily increases, for example, from 1.53 to 1.82. He noticed that, because of the relatively low rate of liquid drainage through the assembled mass, there is no basic flow towards the large holes in the felt assembly process. So a few large holes persist.

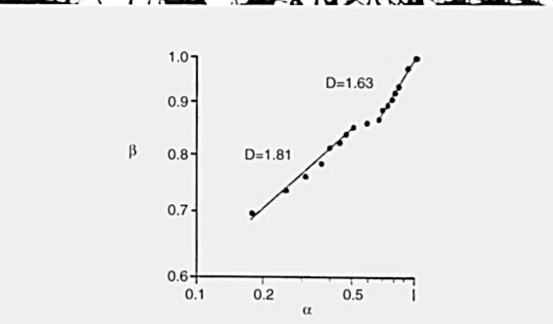
When the data taken from the electron micrograph of the fibrous fibre felt in Fig. 5 are plotted on the log-log scales, there appear to be two different data lines with two different slopes.[16] This dual slope system corresponds to two different mechanisms in felt formation. Two different sized fibres have been used to construct the felt. Fine fibres were added to a coarser support matrix of thicker fibres. Larger holes seem to persist as the filter felt was created.

Perhaps one day the *International study on standardizing art papers*[17] will contain fractal dimensions, too. In cooperation with the James River Corporation (Neenah, WI, USA), Kaye determined the Sierpinski fractals of paper.[11] And how did the fractal dimension of the paper surface morphology change,[18] and what were the consequences of that?

If paper has a fractal structure, then the reactions in paper and their actions on ageing, too, take place in a fractal environment. Diffusion-controlled reactions show fractal kinetics with a time dependence of the constant.[19] So reactions in paper cannot be handled like homogeneous reactions in three-dimensional systems. Are there consequences for accelerated ageing?[20]

Fig. 5a. A fibrous filter felt. Source: Kaye[16]
Fig. 5b. Calculation of fractal dimension of the fibrous felt. α = measuring scale (normalized size of holes resolved of the Sierpinski, ß = measured parameter (normalized background area remaining of the felt), D = fractal dimension





The industry is very much interested in describing the characteristic features of fillers and pigments such as carbon black, $CaCO_3$ or TiO_2. The fractal dimension will probably govern the optical behaviour of the pigment fine particle when embedded in a matrix. Commercially available pigments contain within any one population of pigment fine particles a whole range of boundary fractal dimensions. The typical fractal dimensions of carbon black produced by combustion processes is between 1.07 and 1.43.[12] Maybe one day, in discussing fillers for leafcasting, the fractals will be of importance.[21]

Even single fibres may show fractal behaviour. The fractal dimension of cellulose fibres has been examined by small angle X-ray scattering. [19,22,23] There is still the experimental problem of measuring the small angle scattering intensity over several decades. Depending on the measuring and spinning conditions, the fractal dimension ranged from 1.16 to 1.76.

The work of Calvini is most related to conservation science.[24,25] Structures on a degraded sheet such as illuminations, mould, stains and migration of a degrading agent can be described by fractal geometry. Chemical foxing showed a nonfractal shape. So biological attack and other mechanisms of destruction and discoloration can be distinguished by analysis of dimension.

Dynamic systems such as weather can exhibit behaviour that is stable or chaotic. A dynamic system is a collection of parts that interact with each other and change each over time. A dynamic system may show chaotic behaviour if small changes in the initial conditions of the system make large changes in the system at later times. Calvini suggested determining the fractal dimension of temperature and humidity data to construct dynamic models to investigate the weather (indoor climate) in your museum or library. The fractal dimension can be revealed from thermohygrometric graphs.

The classical tests reveal fragmental knowledge of a piece of paper: its strength, content of chemical elements and compounds, its radical character and its state of oxidation.[26,27] In these tests the computer is only needed to process and to manipulate huge quantities of analytical data. Often the use of the computer application is limited to basic calculations such as in the leafcasting program for paper restoration.[15] Or it may be used for simple synthetic purposes: the art historians may analyse an artistic style by unveiling the underlying grammar.[28] By aid of the computer, they may synthesize new compositions in their style. The algorithmic description of painting style reduces the piece of art to its elements and the artist's method of juxtaposing these elements.

The evolution of science of nonlinear systems and the latest developments in computer hardware and software are closely related. The paper industry participates in on-line measurements and quality control by image analysis.[29,30] The computer in connection with peripheral instrumentation is used for pattern recognition.[31,32] In the shroud of Turin study, the structures on the shroud are extracted from the noisy background by application of Fourier transformation and other image-processing techniques.

The term fractal, which expresses a fundamental new view of the world around us, developed in close connection to the nonlinear computer experiments mentioned above. Here the work with the computer mutated from just shuffling data and an aid in calculation to a new quality of understanding nature and the world around us.

The fractal character of surfaces, colloids and polymers[19] cannot be disregarded by restorers because they handle art whose surface dominates the artistic value: paper, stone and textiles. They handle colloids such as paints, emulsions and suspensions and such polymers as cellulose, starch and plastics.

ART THAT NEEDS NO RESTORATION

Art that needs no restoration may include a piece of art that does not exist any more as an original but just as a digitized copy on a hard disk in a computer. The picture, as scanned in, still shows all the faults and damage history and time have done to the true original. In the process of data manipulation, the blurs, the shadowing, the holes and the dirt are smoothed and filtered out. All the "information" added to a piece of art by its individual history is wiped out by a numerical process in the computer, and the piece of art is reduced to what we mean is the essence of information. The image analysis experts call this the restoration of noisy images. In this way we may extract the basic information from the shroud of Turin[32] or we may restore the digitized Restorer's Island without real-life leafcasting.[14]

Art that needs no restoration: this sounds like a *koan*, an enigma from Zen meditation that is not solvable by logical thinking. But this kind of art evolved, and so the enigma was solved by the evolution of modern science.[33,34] This evolution was supported by the developments in computer science and numerical calculation and by the change in the way science sees itself.[35] The art that can be created from simple mathematical regression formulas reflects the beauty of natural structures: fractals and an art for the sake of science.[36] It can be copied endlessly in time and space - and so, like nature it only needs care but no restoration. Walking around in your fractal world, you will always find places no human being has ever seen before you. The underlying laws to create this complex world are simple. This art, in its complexity, is different from classical industrial production, which showers us with copies of artefacts that often claim to be art, too, but do not reflect the underlying structures of life, evolution and nature. Fig. 2 was a black-and-white copy of the Mandelbrot, the mother of all computer art I talk about. It is created by Wegner et al.[10] or taken from the book of Peitgen & Richter, *The beauty of fractals*,[8] which contains many pictures created in the computer graphics laboratory Dynamic Systems at the University of Bremen. Their exhibition Schönheit im Chaos/Frontiers of Chaos has been shown at many places. Other artists have taken the theme. There are fractal holopoetry and randomness in design, chaos theory and its impact on art and order and disorder in computer art:[37-40]

"Science and art: two complementary ways of experiencing the natural world - the one analytic, the other intuitive. We have been accustomed to seeing them as opposite poles, yet don't they depend on one another? The thinker, trying to penetrate natural phenomena with his understanding, seeking to reduce all complexity to a few fundamental laws - isn't he also the dreamer plunging himself into the richness of forms and seeing himself as part of the eternal play of natural events?"[8]

SUMMARIES

New Trends in Science and their Impact on Conservation and Art - An Excursion around Restorer's Island

The history of nature is a steady process of increasing knowledge. Modern science has created tools to understand the world in its total complex structure: irreversible thermodynamics, synergetics and the theory of chaos and of fractals. So art and nature turn out to be two complementary ways to grasp the world. The tools mentioned have both a synthetic and an analytical character. Simple examples demonstrate how fractals influence the work of the conservator and restorer and where the future potential for application is.

De nouvelles tendances en science et leur impact sur la conservation et l'art - Une excursion autour de l'île du restaurateur

L'histoire de la nature est un procédé sûr pour augmenter la connaissance. La science moderne a créé des outils pour comprendre le monde dans sa structure totale complexe, thermodynamiques irréversibles, synergies, théorie du chaos et des formes à caractère fractal. Ainsi I'art et la nature se révèlent deux manières compémentaires de comprendre le monde. Les outils mentionnés ont un caractère synthétique et analytique. Des exemples simples montrent comment des formes à caractère fractal influencent le travail du conservateur et du restaurateur et où se trouvent des applications potentielles futures.

Neue Denkwege der Naturwissenschaft und ihr Einfluss auf Kunst und Konservierung - Eine Reise durch die restauratorische Inselwelt

Die Geschichte der Natur ist ein Prozess der fortlaufenden Gewinnung von Erkenntnissen. Die moderne Naturwissenschaft hat mit der irreversiblen Thermodynamik, der Lehre vom Zusammenwirken (Synergetik) und der Theorie des Chaos und der Fraktalen sich Werkzeuge geschaffen, die die Welt in ihrer ganzheitlichen komplexen Struktur verstehen helfen. Damit entpuppen sich Kunst und Natur als zwei komplementäre Wege, die Welt zu erfassen. Die genannten Werkzeuge haben synthetischen und analytischen Charakter. An einfachen Beispielen wird aufgezeigt, wie das Fraktale in die Arbeit des Konservators und Restaurators hineinwirkt und wo Potentiale für zukünftige Entwicklungen liegen.

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Eckhard Ströfer-Hua
Karl Kuntz Weg 9
D-68163 Mannheim
Germany