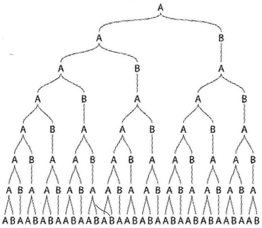
Lindenmayer systems



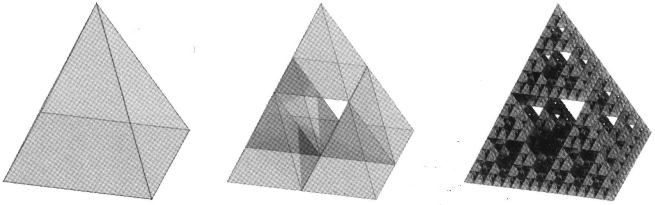
L-systems are named after the biologist and botanist Aristid Lindenmayer (1925–89), who studied the growth patterns of multicellular organisms, including algae and bacteria, to develop L-systems as a formal description of their development. Later it was extended to higher plants and complex branching structures. Lindenmayer's original L-system for modelling the growth of algae:

Variables : A B
Start : A
Rules : (A → AB), (B → A), which produce:

n = 0 : A
n = 1 : AB
n = 2 : ABA
n = 3 : ABAAB
n = 4 : ABAABABA
n = 5 : ABAABABAABAAB
n = 6 : ABAABABAABAABABAABABA
n = 7 : ABAABABAABAABABAABABA ABAABABAABAAB

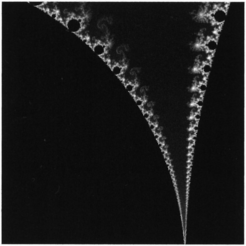
The number of letters in each successive line increases according to the Fibonacci sequence. L-systems follow recursive rules and result in fractal-like forms that exhibit self-similarity. They have been applied in the generation of artificial life.

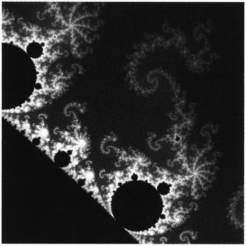
Recursion



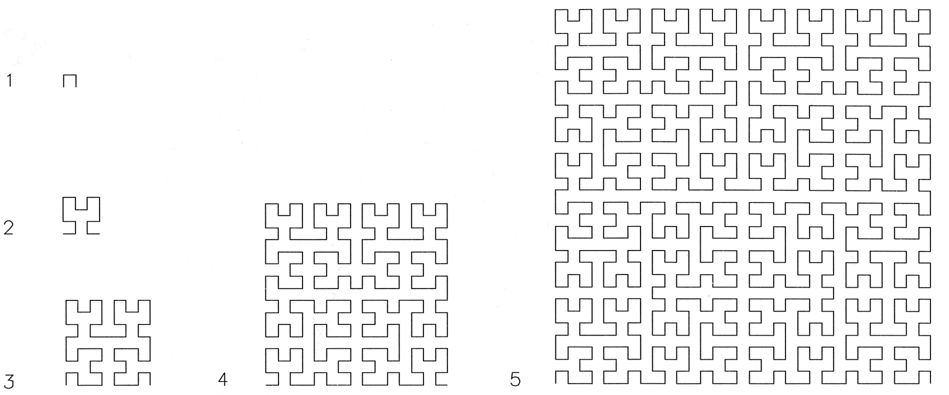
One of the most important concepts in complexity is recursion, a method of defining functions in which the function being defined is applied within its own definition. Within a procedure, therefore, one of the steps is to run the whole procedure again; another way of saying this is that the output of once applying the function becomes the input of the next iteration. The Fibonacci number sequence is well-known mathematical example of recursion, where n = (n-1) + (n-2), or the current term is the sum of the two previous terms in the sequence, each of which is the sum of two before it.

Fractals

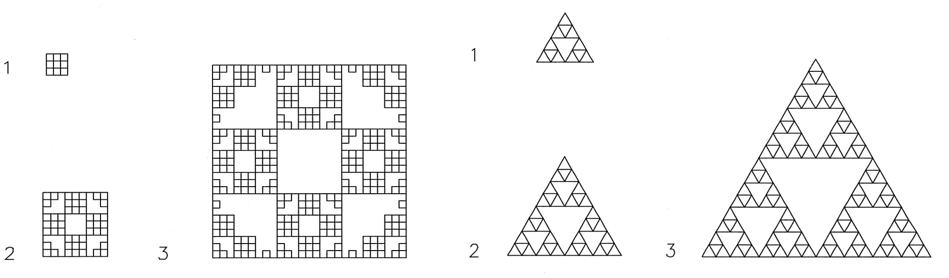




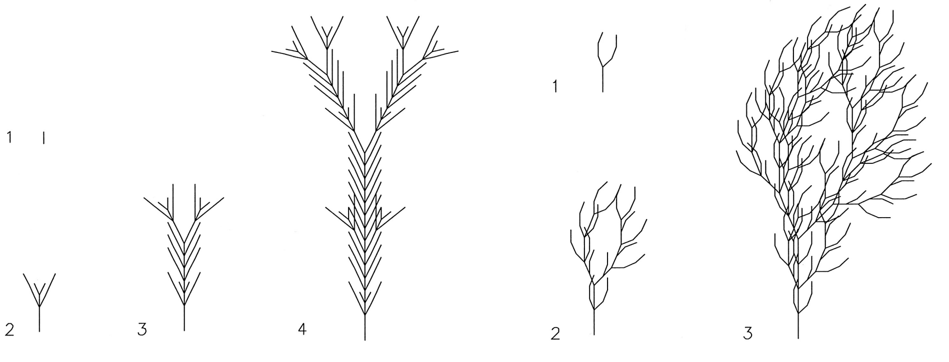
'Many important spatial patterns of Nature are either irregular or fragmented to such an extreme degree that Euclid… is hardly of any help in describing their form,' wrote Benoît Mandelbrot in 1976. Mandelbrot coined the term 'fractal', or 'fractal set', to collect together examples of a mathematical idea and apply it to the description of such natural phenomena as clouds and coastlines. The term is derived from the Latin *fractus*, meaning irregular or fragmented. A central concept in this new geometry is that of the fractal or Hausdorff-Besicovitch, dimension. This gives an indication of how completely a particular fractal appears to fill space as the microscope zooms in to finer and finer scales. Another key concept in fractal geometry is self-similarity, the same shapes and patterns to be found at successively smaller scales. There are two main approaches to generating a fractal structure: growing it recursively from a unit structure, or constructing divisions in the successively smaller units of the subdivided starting shape, such as Sierpiński's triangle (1915).



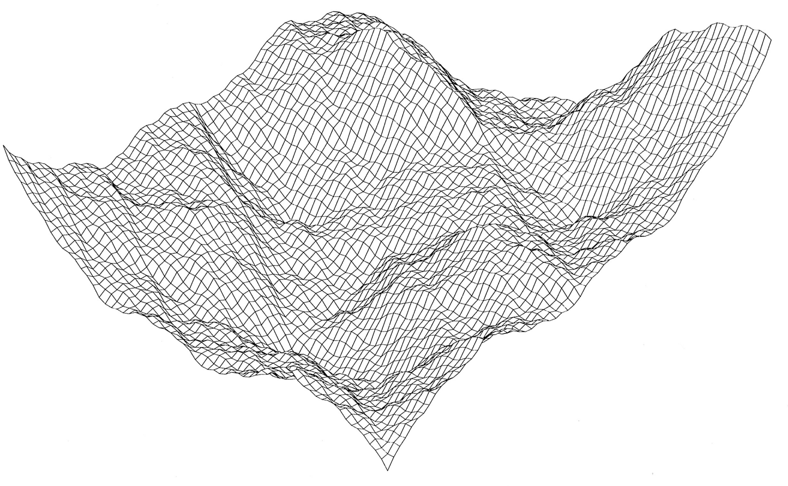
Hilbert-Kurve



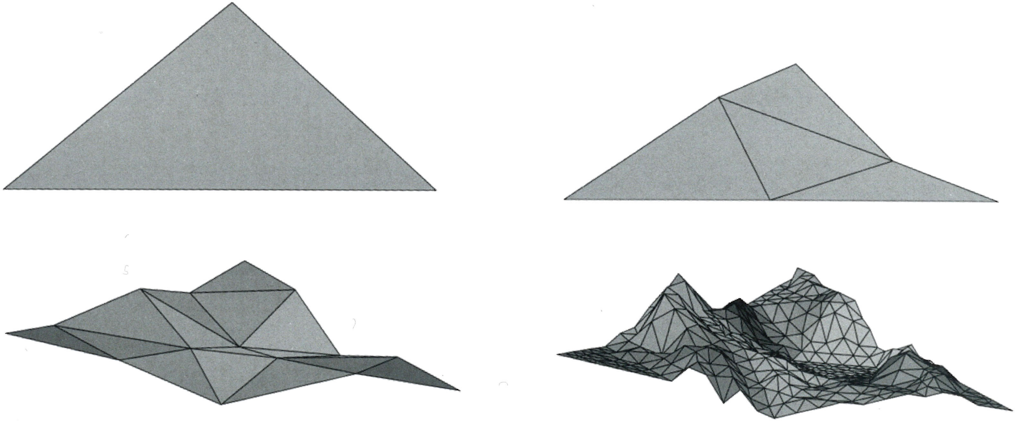
Sirpinsky-Kurve



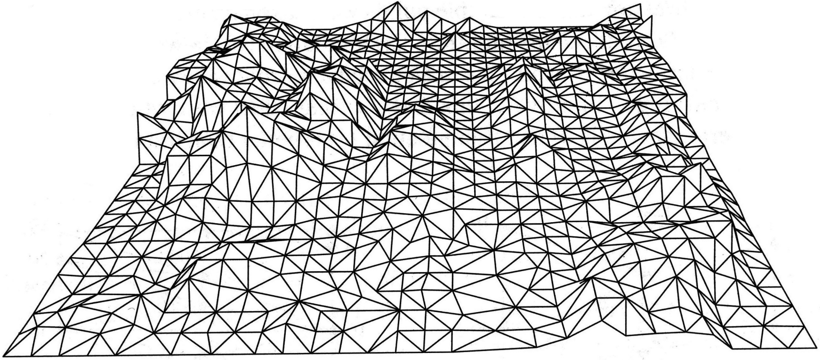
Vegetation, Shih 1990

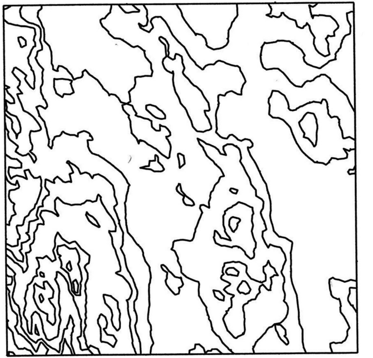


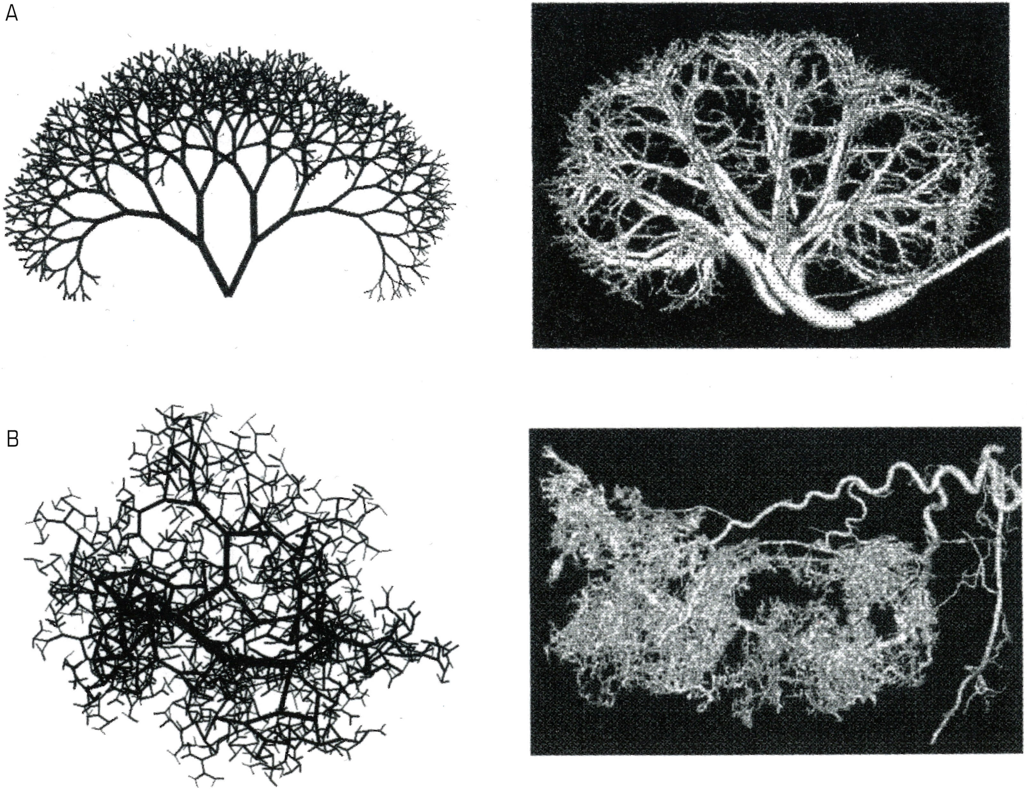
Fraktale Landschaft, Shih 1990



12-56. Equipped with a computer, an animator can model a mountain such as this in seconds by repeatedly dividing the sides of a large triangle (conceived as a pyramid on a three-dimensional grid) into smaller triangles, using a program that introduces random changes at each iteration. This process produces a realistic mountain by essentially mimicking the simple, repetitive processes (sedimentation, crystallization) that nature uses to make a mountain. Earlier hand-drawn cartoons simulated depth by overlapping flat planes, and motion by moving left and right on a two-dimensional grid. This computer simulation of a mountain was created in three dimensions, so the animator can show the mountain from the viewpoint of someone moving *through* the space.



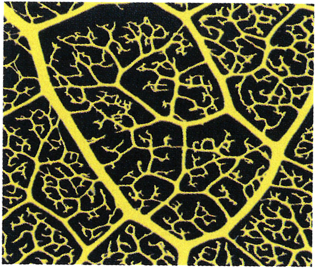


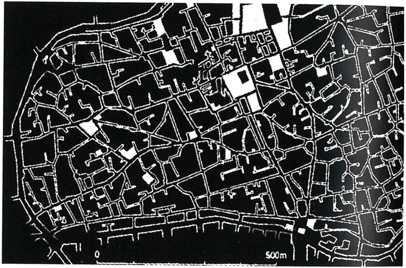


12-54. Fractal blood-flow patterns in healthy and pathological tissue, in Raffi Karshafian, Peter N. Burns, and Mark R. Henkelman, "Transit Time Kinetics in Ordered and Disordered Vascular Trees," *Physics in Medicine and Biology* 48 (2003): 3225–37; images are on 3231–2. Used with permission.

A Computer-generated kidney vascular tree model (left) and the kidney of a healthy rabbit.

B Computer-generated tumor vascular tree model (left) and a cancerous tumor (a neuroblastoma) in a mouse.





Leaf veins and urban cities. It is known that there are patterns which exist beyond genre, dimensions, and scale. Is there a reason for their similarity? If so, what is it? Induction Cities *wants to discover this.*

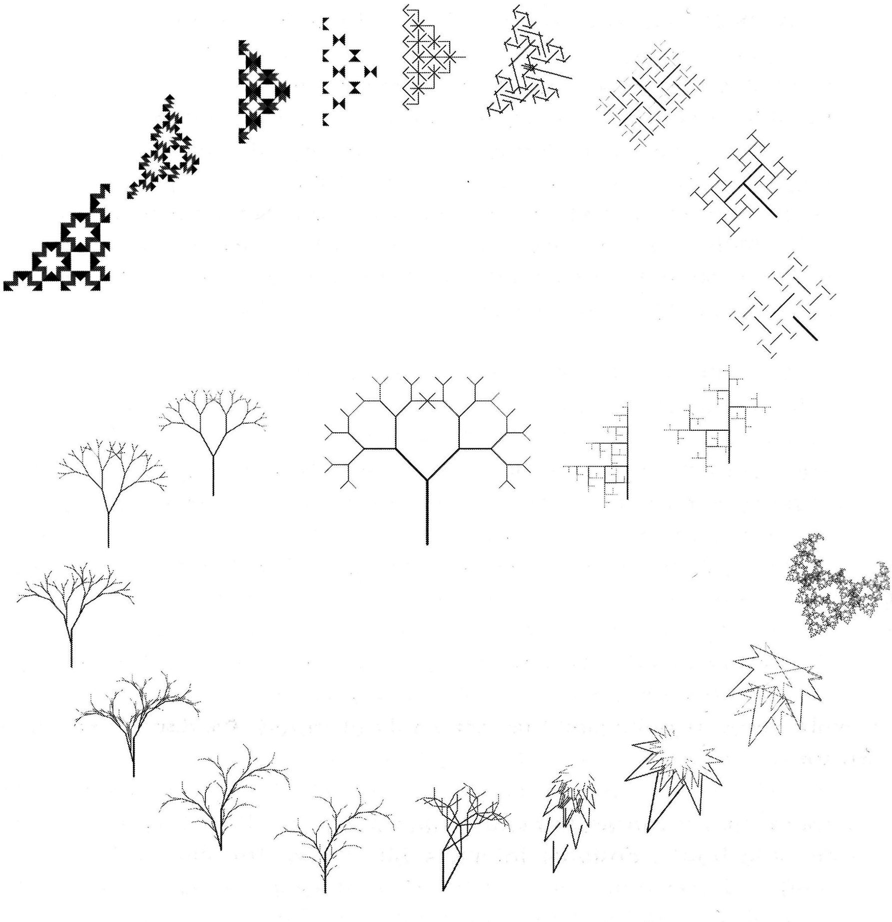
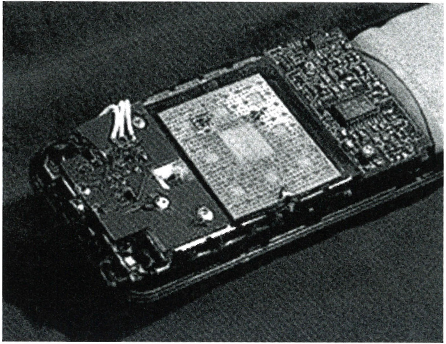
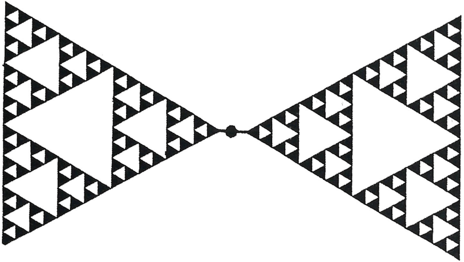


Figure 10.1: A single recursive structure with minor variations produces a wide range of designs. Image credit: Drawings courtesy Robert Woodbury.

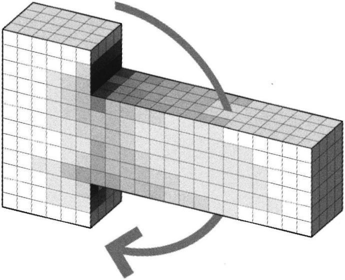




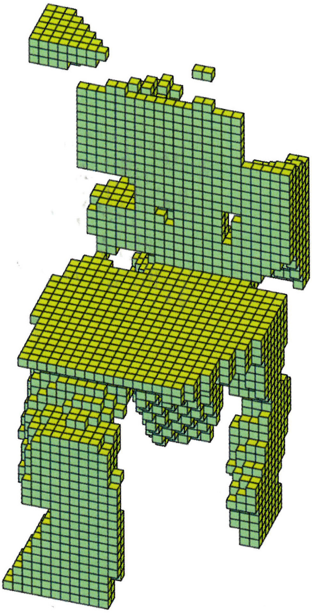
12-55. (Left) Fractal antenna in a cell phone in the form of a square Sierpiński carpet (see plate 12-33). Courtesy Fractal Antenna Systems, Bedford, Massachusetts.

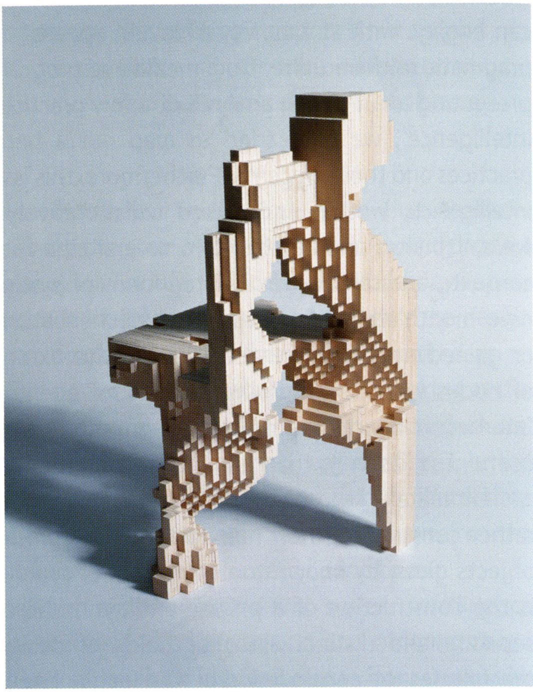
(Right) Fractal antenna in the form of a triangular Sierpiński carpet, in Nathan Cohen and Robert G. Hohlfeld, "Self-Similarity and the Geometric Requirements for Frequency Independence in Antennae," *Fractals* 7, no.1 (1999): 79–84. © 2011 World Scientific Publishing Company. Used with permission.

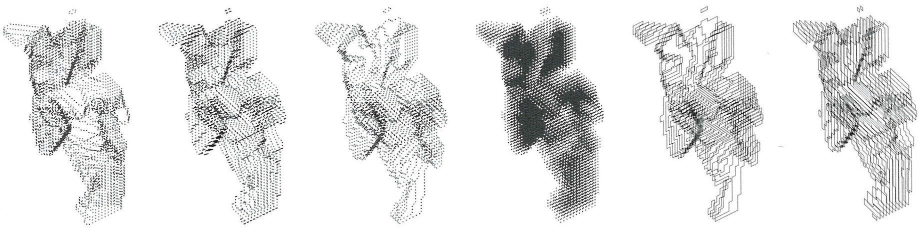
Finite-element analysis



Finite elements are like tiny cubic blocks that make up the whole. They can be very small, their size a balance between the grainyness or pixellation of the form at low resolution and the computing time, which increases very steeply with the reduction of element size. Each element is impacted by the forces transferred from its immediate neighbours, and this type of analysis uses these forces.



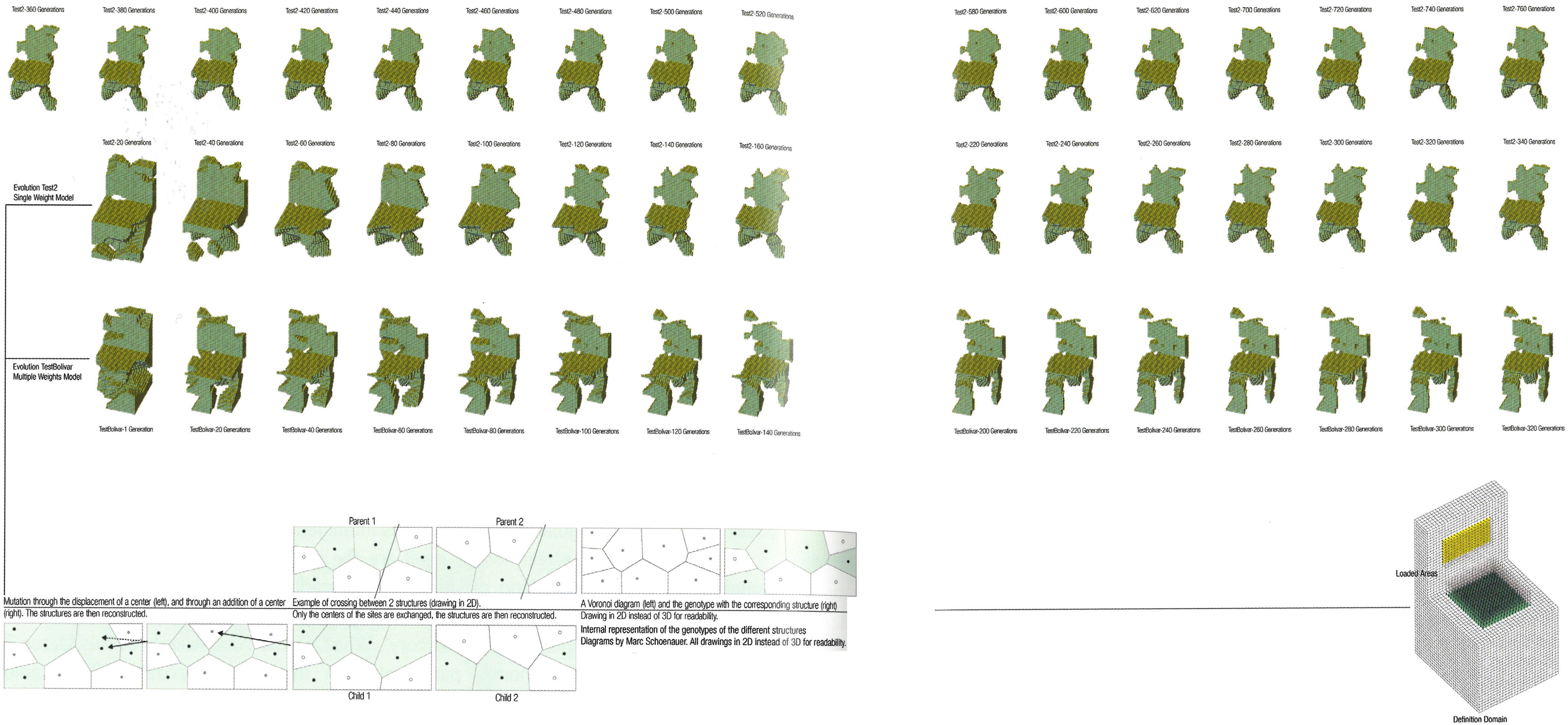




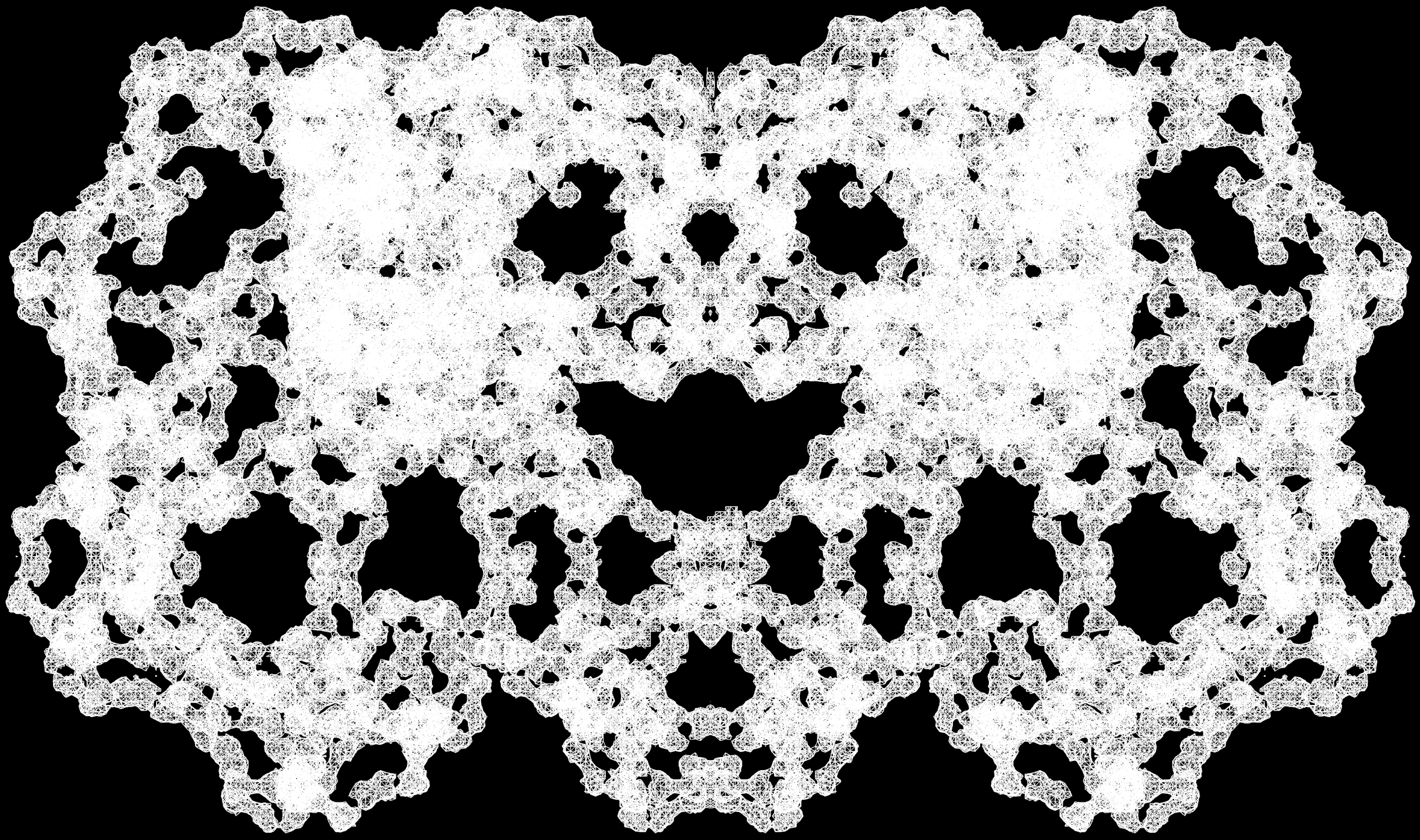
top left: EZCT Architecture & Design Research with Hatem Hamda and Marc Schoenauer, studies on optimisation: computational chair design using genetic algorithms, 2004. The 'Bolivar' model is evaluated for a multiple load strategy (it is always stable, whatever way the seat is positioned). This model (prototype and drawings) is part of the Centre Pompidou Architecture Collection. © Philippe Morel (original drawings © Centre Pompidou).

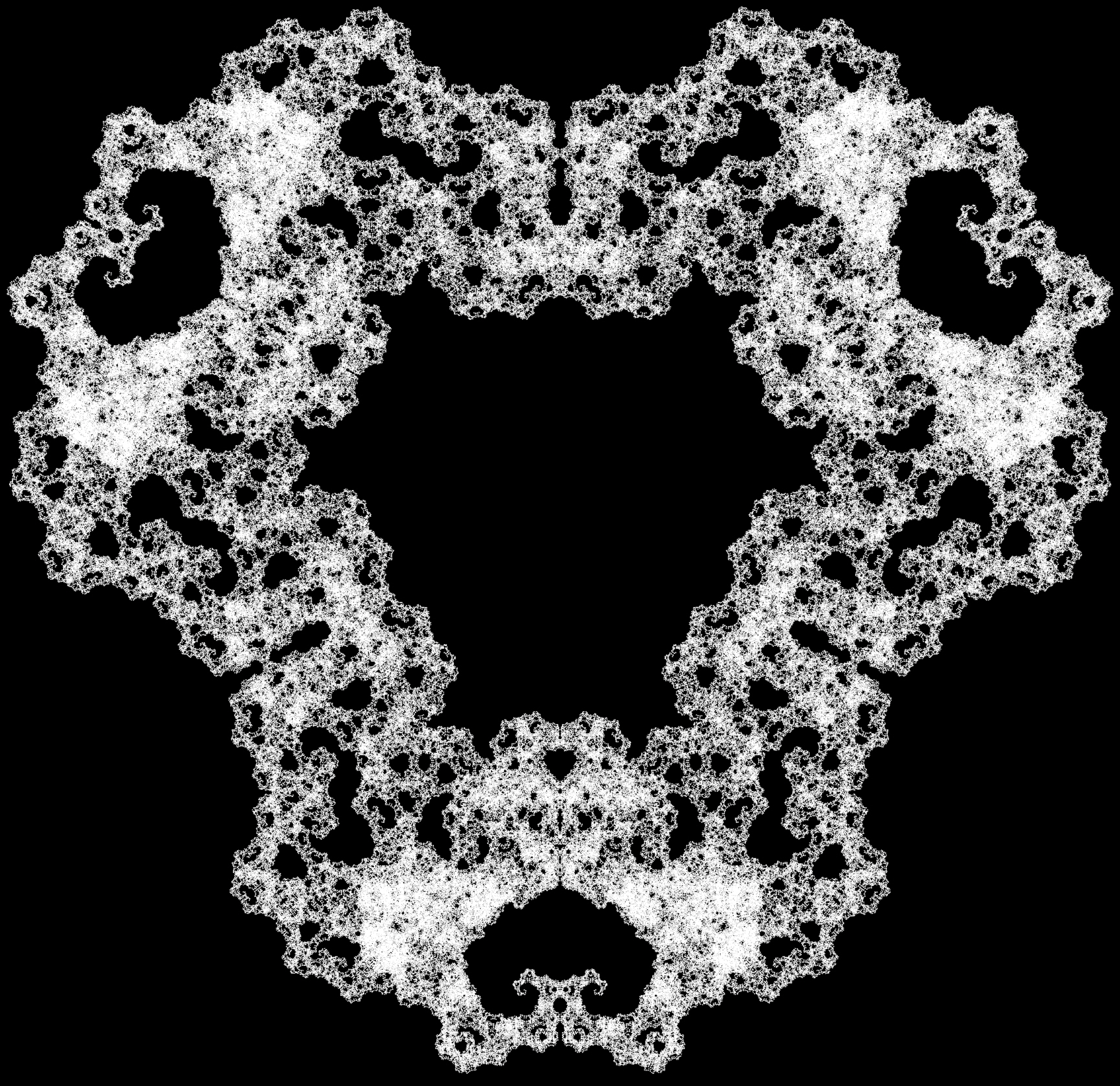
top right: Philippe Morel/EZCT Architecture & Design Research, chair 'Model T1-M', after 860 generations (86,000 structural evaluations). Courtesy Philippe Morel © Ilse Leenders.

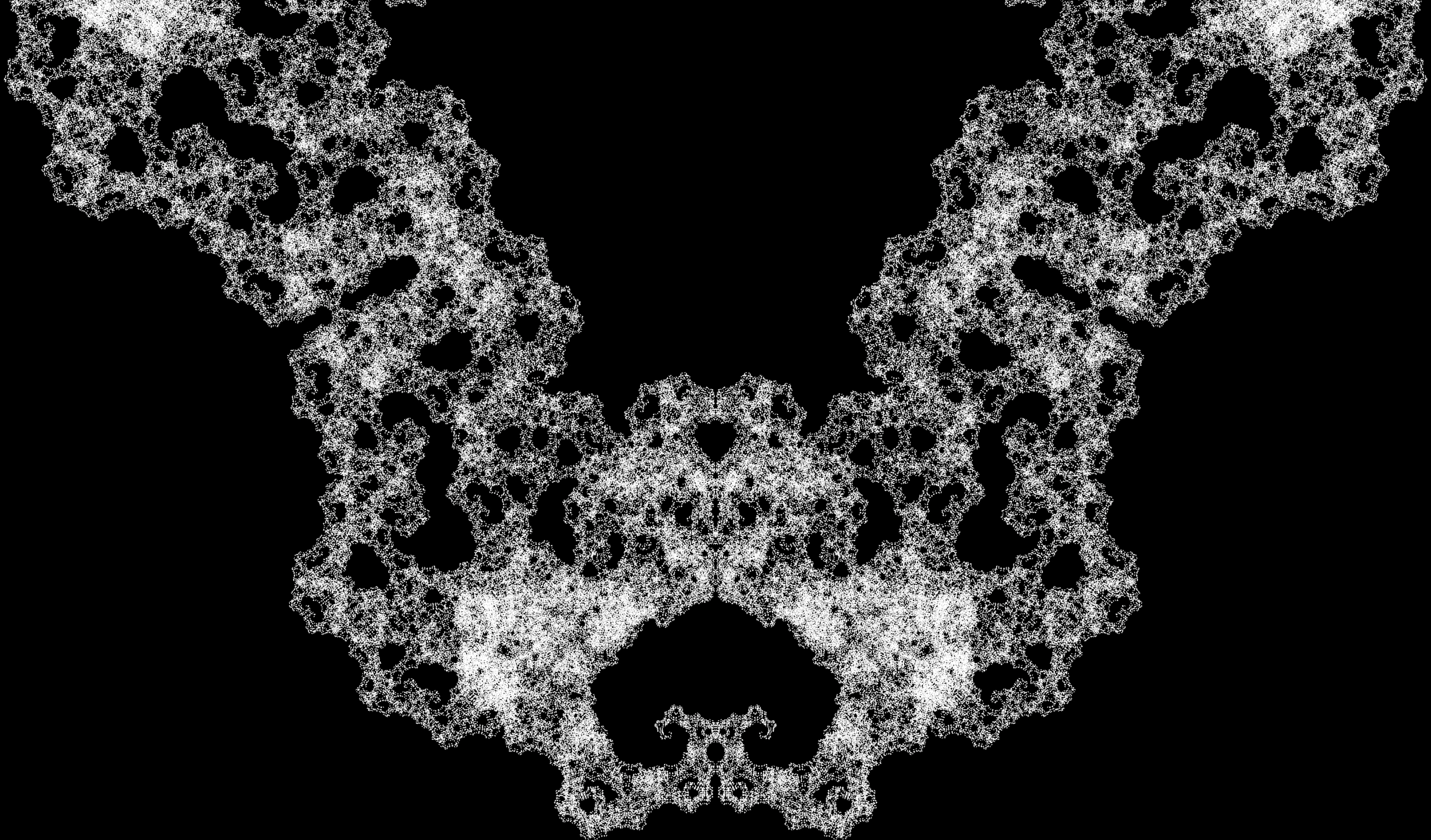
above: EZCT Architecture & Design Research with Hatem Hamda and Marc Schoenauer, Studies on optimisation: computational chair design using genetic algorithms, 2004. Data analysis, 'Bolivar' model, Mathematica drawings. Because the data was structured for mutations and evaluation via finite element methods, it needed to be rearranged for fabrication. Mathematica was therefore used for writing different algorithms in order to ease pricing, cutting and assembling. The drawings are part of the Centre Pompidou Architecture Collection. © Philippe Morel (original drawings © Centre Pompidou).

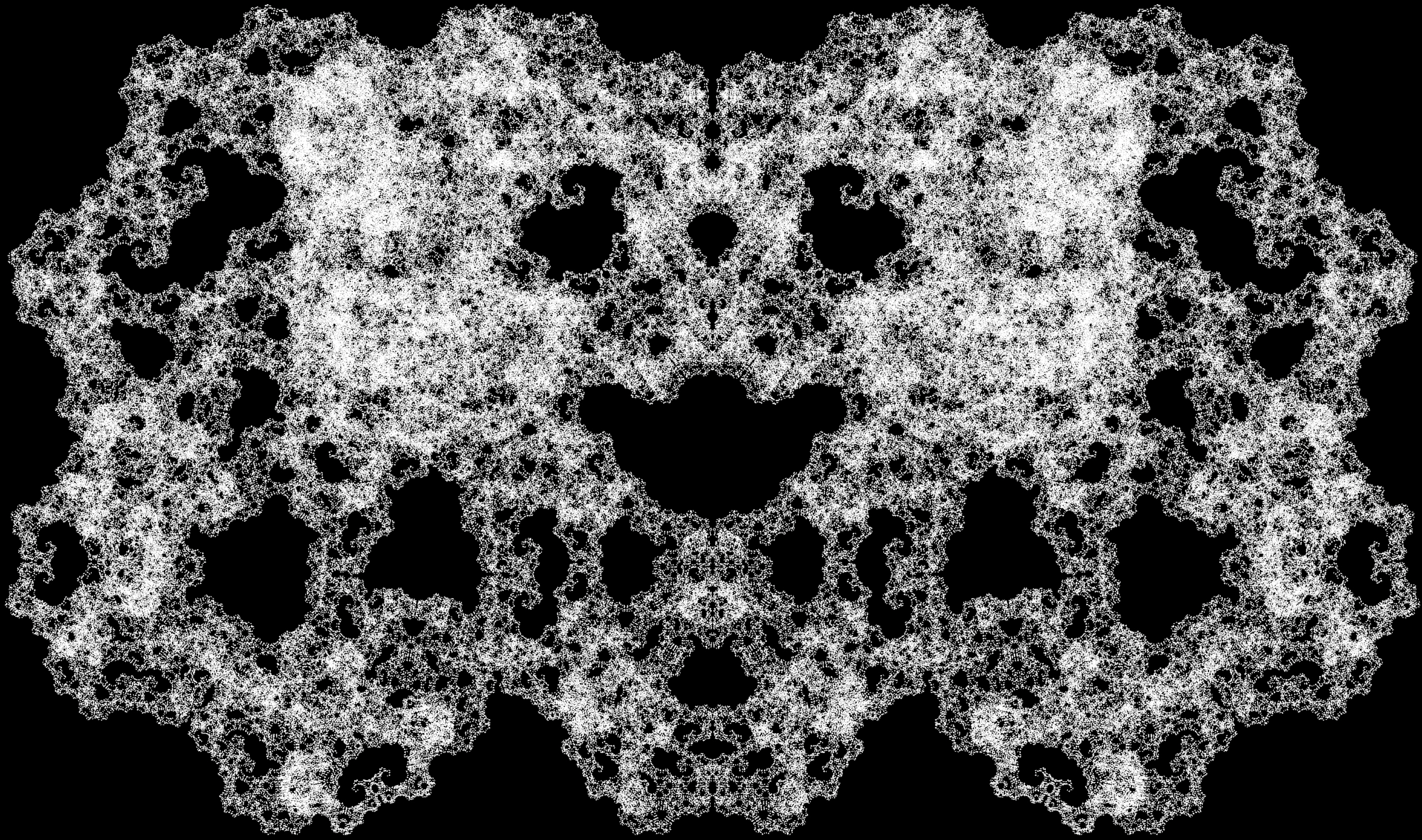


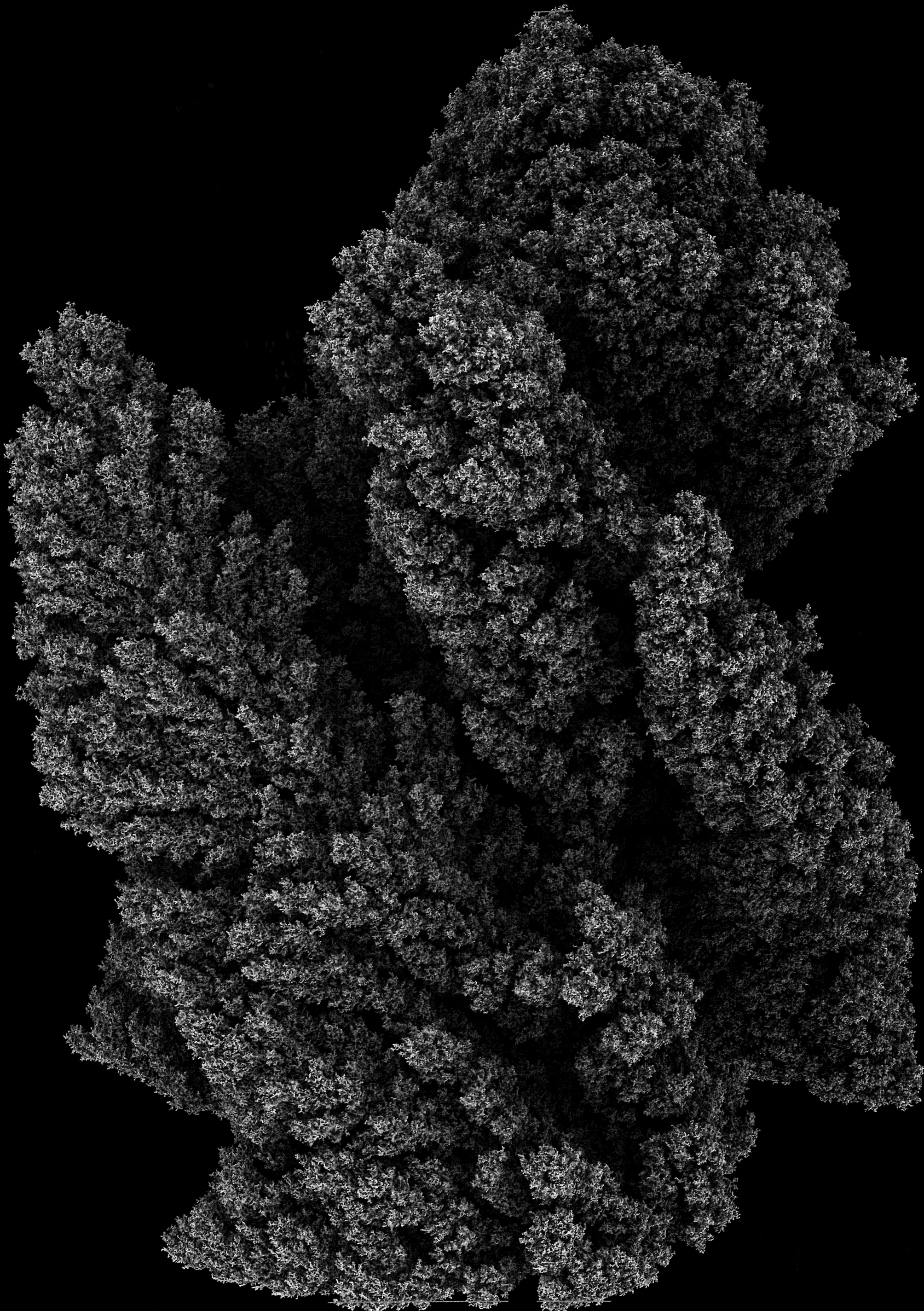
above: EZCT Architecture & Design Research with Hatem Hamda and Marc Schoenauer, studies on optimisation: computational chair design using genetic algorithms, 2004. The process sheet shows seven chairs optimised through a mono-objective optimisation strategy, two chairs optimised through a multi-objectives strategy, and the optimisation process for Model 'Test2'. The sheet shows the crossing-over internal representation based on Voronoi diagrams. This high-level representation strategy, developed by Marc Schoenauer, allows for a better correspondence between the genotype representation and the phenotype of the real chairs. © Philippe Morel.











Aggregation 4, by Andy Lomas, 2005
This form was built from a gradual accumulation of particles on top of an initial surface. In the simulation, millions of particles flow freely until they hit either the initial seed surface or other particles that have been previously deposited.