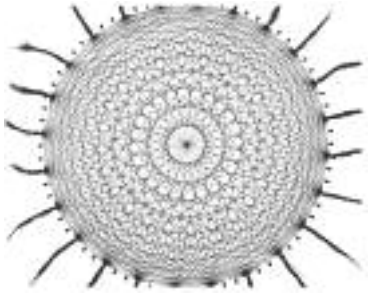


figure a

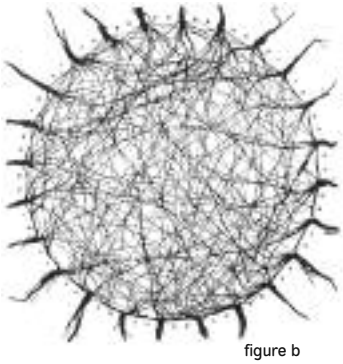


figure b

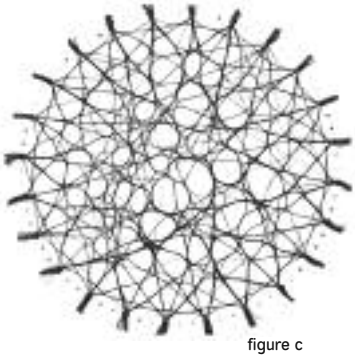
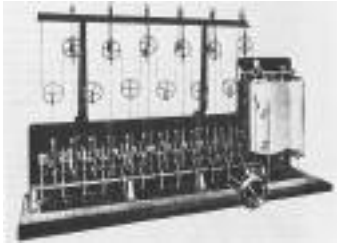


figure c

Frei Otto and Bodo Rasch,
*Finding Form*, p. 69 (1995)

## The Structure of Vagueness

Lars Spuybroek



Lord Kelvin, tide predictor from the early 1870s. It was one of the first large-scale analog computers.

Around the beginning of the 1990s, Frei Otto and his team at the Institute for Lightweight Structures in Stuttgart studied what they called "optimized path systems." Previously, similar to the chain modeling technique Gaudí used for the Sagrada Familia, they had experimented with material systems for calculating form. Each of these material machines was devised so that, through numerous interactions among its elements over a certain time span, the machine restructures, or as Frei Otto says, "finds (a) form." Most of them consist of materials that process forces by transformation, which is a special form of *analog computing*. Since the materials function as "agents," it is essential that they have a certain flexibility, a certain amount of freedom to act. It is also essential however, that this freedom is limited to a certain degree set by the structure of the machine itself. In classic analog computing most of the movement is contained in gears, pistons or slots, or often in liquids held by rigid containers, but in the case of Frei Otto's machines mostly all materials are mixtures of liquids and solids, or start out as liquid and end up as rigid. The material interactions frequently result in a geometry that is based on complex material behaviour of elasticity and variability. Sand, balloons, paper, soap film (including the famous minimal surfaces for the Munich Olympic Stadium), soap bubbles, glue, varnish, and the ones I will be referring to here: the wool-thread machines. This last technique was used to calculate the shape of two-dimensional city patterns, but also of three-dimensional cancellous bone structure or branching column systems. They are all similar vectorized systems that economize on the number of paths, meaning they share a geometry of merging and bifurcating.

For our purposes, we shall take a closer look at the wool-water technique, which follows an algorithmic three-step procedure:

STEP 1 (figure a): Map all the targets of the system (in this case, houses) on a board. For the sake of simplicity these are arranged here in the shape of a circle, which could be on a supporting surface, or on an open ring. Connect each point to every other using a wool thread. This ensures the basic connectivity of the system: each house is connected to another house by a road. This stage of

the system consists only of crossings; it is a typical surface model, a wire frame of lines that neatly make up a surface.

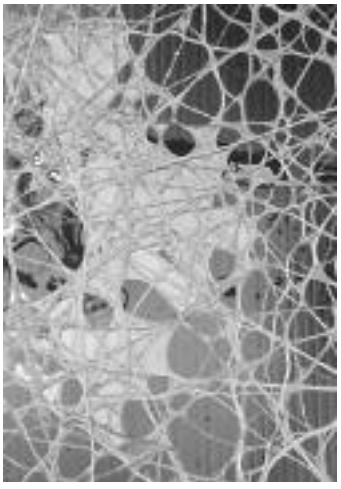
STEP 2 (figure b): Give each of the wool threads an overlength of 8%. Since we are always forced to take detours in cities because no single road ever leads straight to a single house this is necessity. The figure of 8% is a generalized figure, of course, this amount of detouring need not be averaged down to a single 8% for the whole and can be differentiated throughout the system.

STEP 3 (figure c): Dip the whole system under water, shake it carefully and take it out again while passing the surface slowly. The wet threads will have a tendency to stick together, and as threads start to merge they lose this capacity at other positions, since merging means elimination of available overlength. All overlength is processed out of the system by a surplus of stickiness. Since the paths are coming from all directions, the mergings also come from all directions, which results in a system organized by gaps, by rounded holes, surrounded by thick mergings of threads, sometimes more than eight, and smaller fields of crossings.

The first step contains only geometry, no materiality, then materiality takes over during a stage of reshifting and the procedure comes to a halt in a state of full geometry again, but a geometry that is now not imposed on a material, but is the result of material interactions. It starts out explicitly Euclidean, but it doesn't finish as such, because at the end there is no clear segmentation of dimensions anymore. While we could call the first step of the system a geometrical surface, a system where all directions are equally present, the final stage of the model is much more complex, because it consists of patches of crossings, mergings and holes. The crossing-patches consist of two dimensions, which means in these areas many directions are still available in the system – many lines keep on criss-crossing each other similar to the initial state. The merging-patches consist only of one dimension, where the system takes on one single direction – many lines stick together to form a main artery. And the holes of course are areas where we lose all dimensions and no directions are available anymore. While the first stage consists of homogeneous tiling, the last stage consists of heterogeneously nested patching. The end result (figure c) is based on looseness, but is itself not loose, not weak, but rigid and completely tight (when attached on an open ring it comes out of the water straight and horizontal!). It is a strategy of flexible, individually weak elements cooperating to form strong collective configurations. What emerges is a complex or *soft rigidity,* which is very different from the top-down, simple and *frozen rigidity* of the first stage. We should therefore resist the idea that the first stage is a rigid order and the end result is just a romantic labyrinth or park. Actually the arabesque order of the end result is as rigid as the first stage of the grid, but much more intelligent because it optimizes between individual necessities and collective economy. Yet it is not an easily readable and clear form of order, but a *vague order;* it is hardly possible to distinguish between surface areas, linear elements and holes. Surfaces can function as linearities and lines can cooperate in surfaces, and

holes can exist at all scales. Everything between the dimensions is materialized. And though the dimensions are clearly singularities arranging the system (the mergings into thick lines are like the ridges of dunes, which orient the sand surface to the wind forces), it is continuity that makes them emerge. And though the order is vague, it should nonetheless be considered very precise, because nothing is left out. There is no randomness; there is only variation.

The truly amazing feature of this system is that it is in fact structured by holes; the nesting of holes is the driving force behind its formation, while architects are always trained to think that holes are, in the end, subtracted from a system. This machine does not operate on subtraction or addition, but on multiplication, in the classic sense of early systems theory, which states that a whole is always larger than the sum of its parts. Here porosity is an emergent property. The first stage (figure a) is basically *drawn*, contrary to the end stage (figure c), which is processed by a machine, *calculated*. All effects that co-exist in the final result, all the curves, all the mergings, all the holes are interrelated, nothing can be changed without affecting the arrangement of the whole. All lines are mobilized simultaneously, in parallel, while drawing is serial, one line is drawn after the other. A drawing is always created in the visual field, while the analog machine follows a partly blind and informational logic where the image is the end product of the process. And though this technique should be considered as a hybrid of the top-down and the bottom-up, the drawn and the generated, its intelligence lies in the fact that nothing is "translated"; the drawn is not "translated" into the real. In itself it works 1:1. In that sense it is not even a model. This *direct proportion* is one of the main features of analog computing, which doesn't simulate by numbers, but by an empirical rescaling of the real. In our case of the optimized path system it is the materialization of the ink as wool *beforehand* that makes it work. The organizational and informational stage is material, not immaterial, as is so often put forth. It is the material *potential*, the material, distributed intelligence which sets the machine in motion, a transfer of water-turbulence to wool-curvature. Then it is the stickiness, the hairiness, and the curvability of the wool thread together with the cohesive forces on the water surface which bring it to a halt again and inform the end result. It is simply impossible to do this in ink. It is an intensive technique within an extensive system, and though the quantities (surface area, number of houses, etc.) are given beforehand, the quality emerges through the interaction and multiplication of different parameters. Generally, the intensive is a deformational property (like heating), but here it also becomes a transformational property (like boiling): the threads restructure and reorganize to "find form." The system as a whole passes a critical threshold. The degrees of freedom of deformation, which are more like extensive movements within an internal structure, become intensive, qualitative changes of "that" structure.



Experimental model produced in our office based on Frei Otto's two dimensional optimized path system. For *Soft Office*, 2001

## Wet Grid vs. Dry Grid

The classic regular, Greek, grid is a system that separates infrastructural movement from material structure. Simply put: the structure is of a solid, while the movement is of a liquid. We must consider the orthogonal grid as a frozen con-

dition, because its *geometrical* state of homogeneity relates directly to a *material*, crystallized state of frozenness. Frozen states are simple states and of course these have been the first to be mastered by the *geometers*, but to understand complex states we need to develop complex geometries. Generally we are taught to think geometry is the higher, the more abstract and pure form of materiality, which is a misconception because though geometry urges for the necessary exactitude it is totally imprecise. Any geometer comes after the event, when everything has dried up, and therefore he can only be dealing with the extensive state of the material, taking up length, width and height. The wet grid, Frei Otto's grid, is one in which movement is structurally absorbed by the system; it is a combination of intensive and extensive movement, of flexibility and motion. The geometry does not follow the event, geometry co-evolves with materiality, it is generated through analog, wet computing. One could call the organisation of the final stage wet, and its structure dry. While it itself is not moving anymore it has attained an architecture of movement. In this sense movement must be viewed as information, as pure difference because we all know when 'information' does not cause any change it is superfluous. It simply did not in-form, it did not enter the form. This means movement in itself is not enough to be called information, it must be internally processed as a (temporary or permanent) transformation. The physical displacement of movement must be processed as a structural change. Basically my case is here that all emphasis on movement as deformation are merely indexical and are meaningless when not resulting in structural transformation. Freezings of movement are merely *traces*, momentary stoppages of a bygone present, but they are not structured through time, they are not *paths* which allow for movement to be rerun over and over again and slowly consolidate and evolve. On the other hand they are not *roads* either, which with their exact distinction between surface and line prevent the system from reconfiguration and adaptation. Each state of pathforming should function as the analog computer of the next one. There should be enough solidifying for registering and there should be enough plasticity to enable changes. This brings the optimized path systems of Frei Otto close to contemporary multi-agent computing devices based on ant colonies with their pheromone distribution.


Plan of Milete, fifth century B.C.

For a real-time, analog computing model we need two things: first a system that is internally structured (or else it cannot process information), and second, external flows of information. This simply means there are always double states co-existing, simple states and complex states, in gradation. Higher states of information can only happen in lower states of information, they co-exist hierarchically but within a continuum. They do not exist next to each other, no, the generic and the specific share the same continuous, topological space as do the standard and the non-standard. One is always engulfing the other, we need to start from a state of equilibrium that already contains information through its structure, then we need disequilibrium to increase the amount of information, then we need equilibrium again to memorize it.

Ethiopian village demonstrating an energy-optimized network with minimal detours. Frei Otto and Bodo Rasch, *Finding Form*, p. 36 (1995)

The brilliance of the Frei Otto model is that the flexibility is taken literally and materially, that real movement of water-flow becomes abstract movement of wool-structure, which results in a coherent language of "bending," "splitting,"

Curved wooden spline held in place by five weights.

"curving," "nesting," "aligning," "merging" and the like. All arabesque figures in the final state of the model immediately relate to complex configurations. To understand that complexity however it is necessary to understand the nature of a curve. For Aristotle any curve could be described as a mixture of straight lines and circle segments, arranged in different orders. The later curve of differential calculus virtualizes both the straight line and the circle respectively as the *tangent* and the *approximative circle* that today is still an important indication for curvature. In seventeenth-century shipbuilding the control of curvature was however fully based on material intelligence and not on geometry. The needed curves for the ship's hull were 'lofted'1:1 with so-called 'splines', thin slats of wood that were bend in shape by heavy leaden weights. The spline is still present in all 3D-modeling software and though it now exists in many different forms (Bezier spline, B-spline, NURBS) it is always based on that very important notion of materiality. A digital spline starts out as straight and becomes curved by feeding information to it. The at-start straight spline has an internal structure of 'control vertices' or cv's and by moving these sideways it takes on curvature. Therefore the number of cv's on the line is the indication for the type of curvature: how far it is off from straightness or how close it is to circularity. In short, a *geometrical* straight line going from A to B doesn't have enough structure to be moved into a state of higher complexity: moving either A or B only results in a rotation of the same straight line. The spline's prestructuring through the range of control vertices makes it *parametrical*. The only difference between a material and a digital spline is that with the material version the 'overlength' is external, and with the computerized version it is internal. In the Frei Otto model the wool thread going straight from A to B in the initial state (figure a) is in its final state (figure c) charged by a whole field of other influences and directions, from C to D and from F to G, etc; the line is taken up in a field of potentials which make it an intensive line, which is simply a curve. *A curve is an intelligent, better-informed straight line*. Remembering that Frei Otto's model is a path system that curve should be read as a road with variable openness, on which one can partly return to one's footsteps, change one's mind, where one can hesitate or forget. It is not labyrinthine, causing you to lose your way completely; no, it complicates your way, makes it multiple and negotiable. A curve is a complicated straight line, it still goes from A to B, it still has overall direction, it still brings you somewhere, but it manages other many other subdirections (tangents) underway. It negotiates difference; it is differential precisely through connecting, through continuity. The dry grid is always segmented and Euclidean, while the wet grid is always a continuous network, topological and curved.

In architecture flexibility has always been associated with the engagement of the building with events that are unforeseen, with an unpredictable or at least variable usage of space. During modernism that flexibility often resulted in an undetermined architecture, in an averaging of program and an equalization, even neutralization, of space. A generalized openness, we must keep in mind, always has the effect of neutralizing events and being unproductive, because the type of space is not engaged in the emergence of events themselves. General, Miesian, openness is only suitable when all desired events are fully

programmed in advance, by strictly organized bodies, as in the case of a convention center, a fair, or a barracks. It is flexible, of course; it is open, yes; but it is totally passive. All activity is assigned to the institutional body. The architecture itself however does not engage into the way events and situations emerge; it is indifferent to that, so to speak. It states that life is merely the effect of decisions that have already been taken behind the scenes, of acts that are repetitions of previous acts, in which intentions are completely transparent. The Cartesianism of the grid doesn't just apply to its geometry but even more to the neuropsychology of the homunculus. The dry grid is not very different in its ambitions than, say, that Miesian box or hall in architecture: finding a structure, a tectonics that can absorb life, chance and change, while the structure itself must last and persist over time, to span the unforeseen with the foreseeable. The strategy of the grid and the box have always been to average out all possible events, to be general enough for anything. Now, surely a lot of what we do is planned, and a lot of what we intend is transparent; we script and schedule ourselves; but to engage in the unforeseen does not mean these are just accidents happening to our agendas.

Our whole question here becomes a study of the relationship between flexibility and movement: how does the body's flexibility relate to architecture's flexibility. I want to argue here that extensive, bodily locomotion is only possible when it is intensive first, both in the body and in the system. There is always a direct relationship between the system of motion and the internal mapping of movements in the body. That subsequently means that in the dry grid the body must be acting as if it is in an archive, constantly picking movements of the shelf, every act a reenaction – the body itself is a dry grid. The wet grid views the body as a complex landscape of tendencies and habit-chreodes that form grooves (lines) in less defined areas that are surfaces. All modern neurology describes the body as a wet computer, constantly evolving, adapting, practicing, managing, coping and scripting. So, the problem of flexibility is not so much "to open up space to more possibilities," but the concept of the *possible* itself. An event is only ever categorized as possible afterwards. The possible as category lacks the internal structure to relate the variations; it does not produce variation by itself – it is without *potential*. The choice has always been between determined functionalism and undetermined multifunctionalism, between Early and Late Modernism. Between the filled-in grid and the not-fully-filled-in grid. But potential is something else: "Potential means indeterminate yet capable of determination … The *vague* always tends to become determinate, simply because its vagueness does not determine it to be vague … It is not determinately nothing" (C.S. Peirce).[1] Vagueness comes before the situation; neutrality comes afterward. If it comes before, it will neutralize the forces making up the situation. *We must replace the passive flexibility of neutrality with an active flexibility of vagueness.* In opposition to neutrality, vagueness operates within a differentiated field of vectors, of tendencies, that both allow for clearly defined goals and habits for as-yet undetermined actions. It allows for both formal and informal conduct. But more important, it also relates them through continuity, it puts them in a tense situation of elasticity. The informal doesn't come out of the blue, it exactly emerges from the planned, but only because of intensive elastic

1. C.S Peirce, *The Essential Peirce: Selected Philosophical Writings*, vol. 1, ed. Nathan Houser and Christian Kloesel (Bloomington: University of Indiana Press, 1992)

planning. It is a structural Situationism. It allows for *dérives* and *detournements* as structural properties: the transparent intentionality of planning and habit is stretched by the sideways steps of opaque intentionality. It does not mean the unforeseen is now successfully tamed and reckoned with: it is precisely unplanned, but the structuring of the foreseen is now such that it can produce the unforeseen and the new. Why? Simply because all linearity is embedded within fields of non-linearity there is an enormous surplus of information in the system, a *redundancy* that allows behaviour to develop in multiple ways. This redundancy is opportunistic and pragmatic, offering multiple ways toward a goal, but it doesn't afford anything to happen at any place. Non-linearity doesn't mean a breaking of the line, nor does it even mean a relaxation which can stretch infinitely, it means an fundamental bendability, a looping, a feed-backing of the line.

## A Soft Constructivism

The techniques invented and suggested by Frei Otto have been very diverse, varying between the application of already invented techniques to ongoing projects and more fundamental research into material form finding. Not suprisingly his optimized path system machine is quite unique within the whole of his research because he hardly ever had to deal with horizontal structures. Essentially his research was in the complexity of the elevation, the structure, not the plan. He was always invited to cooperate with architects that had already developed the plan, and his contribution was subsequently in the typical engineering stages, afterward. Our agenda should be different. Patterning effects, configurational emergent effects happen on all stages, both in the plan and in the elevation. In stead of following the plan-floor/extrusion-wall method we should opt for a method where elevation and plan become more intertwined and co-evolve into structure. For centuries the order within the design process has been: first the plan (action), then structure at the corners (construction) which at the end is filled in with walls (perception), where the latter two have been part of the splendid Semperian distinction between tectonics and textile. Our agenda should be to short-circuit action, perception and construction. Having weak textile threads teaming up into rigid collective configurations is a direct upgrade or inversion of the Semperian paradigm. But they should be three-dimensional from the start, plan-threads can twist and become wall-threads. All these techniques already exist in textile art where complex interlacings occur in crochet, weaving and knitting. The art of the arabesque is as old as architecture, it has just never been conceived at the scale of the building. And that is certainly because of technological reasons – the arabesque has always been accomodated by manual labor while the straight extrusion was necessarily associated with standardization and industrialism. Clearly that is changing with non-standard architecture. We should be careful though not to mistake the non-standard for 'free-form architecture', for the amorphous or even the streamlined, we should strive for a rigorous non-standardization, rethinking repetition within sets of variability, rethinking structures within ranges of flexibility. The more we will move towards the non-standard the more articulation

must become an issue. If there is no technology of design a technology of manufacture becomes non-sensical, with machines under numerical control we need the design process itself also as an informational procedure, it needs clear stated rules and scripts to generate a structure of vagueness.
We have argued here and before that starting with the soft and ending with the rigid will offer us much more complexity in architecture. And here we are not referring to Venturi's linguistic complexity (of ambiguity) but to a material complexity (of vagueness). Obviously, the science of complexity has produced many diagrams of the soft, and these have often been dropped onto rigid architectural structures or typologies. That is not the way to go, though *deconstructivism* proved to be succesful in breaking down most of the top-down ordering tools we were used to in architecture (contour-tracing, proportion, axiality, etc.), it proved to be totally incapable of instrumentalizing complexity itself as a tool to produce architectural form. It understood every act of building as an implicit counter-act, as a negation – meanwhile the engineers silently repaired it. We should however understand all objects as being part of a process of emergence, *the made as being part of the making, not the unmade*. Our goal must be *constructivism*, or emergence, and anything that emerges should co-emerge, the way we see is emergent, the way we move around, the way we act in relation to others, to our habits, to our memories, all these emergent patterns should co-emerge with its material structure. This makes our agenda one of a post-industrial constructivism, a non-standard constructivism. All behaviour is material, all structure is material. "How do we orient, how do we feel, how do we group or ungroup", all these questions should be posed simultaneously, together with "how does it stand up". There have been many attempts to borrow 'images of complexity' that were fed into either circulational, formal or structural diagrams; Klein bottles, weather maps and the like - interesting but not enough. We should create complexity by feeding them into each other. We should feed circulation into structure, feed structure into perception, and feed perception into circulation. It doesn't matter where we start as long as we are looping a flexibility of action (affordances) into a flexibility of structure (vagueness) into a flexibility of perception (atmosphere), looping non-standard behaviour into non-standard structure into non-standard architecture.