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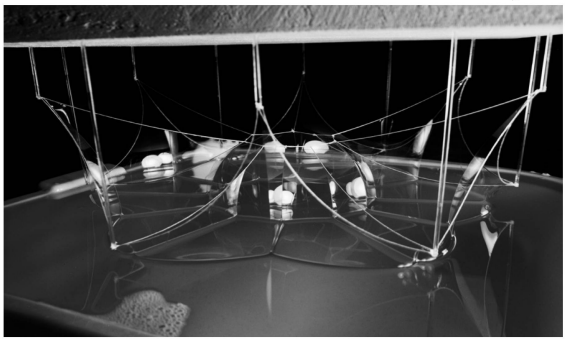
The Model as a Machine: Frei Otto's Architectonic Experimental Systems

Georg Vrachliotis

"People say that machines, the tools of development, kill fantasy. That's not the fault of machines, however, but of man himself, who builds machines that are neither adaptable nor rational: machines that are lacking in fantasy." [1] Thus wrote the young German architect, Frei Otto, in his concise, manifesto-style essay "Imagination et architecture: essai d'une vision d'avenir," which was published in the French journal *L'Architecture d'Aujourd'hui* in 1962. Otto illustrated his essay not with photos of realized projects but with watercolor drawings and sketches in Indian ink, in which intriguing membrane roofs and tent-like structures could be seen to span residential developments, landscapes, or even entire self-contained cities. In juxtaposing factors ostensibly worlds apart—the unfettered imagination; constructive or machinic potential—Otto put his finger on what would prove to be a core tenet of his architectural practice: the abiding aspiration to strike an effective and fertile balance between creative vision on the one hand, and the rationale of technological constraints on the other. f.1 a–c/f.2



In the early 1960s Otto was still at the start of his career. Yet already he had laid the theoretical and practical groundwork for a modern minimalist reading of the tent. [2] His early dynamic tensile structures, seemingly suspended in mid-air, epitomized the longing of his generation for an open, enlightened society, and lent a new face to the young German Federal Republic. The ideal of eternal, monumental, and prestigious architecture was swept aside by a striving both to perfect construction by minimalist means and to inscribe mutability and ephemerality in the interface of architecture and engineering—artistically, technically, and socially. Otto's reflections on the relationship between machines and fantasy, cited above, were first and foremost a critique of the architectural concepts prevailing still in the immediate postwar period. The "fantastical line" had run dry, he noted, owing to the intently rational formal idiom of classical modernism. [3] Invoking fantasy, by contrast, would call to mind the experimental architecture and optimistic narratives of Expressionist movements of the 1920s, the poetic force and literary ingenuity of Paul Scheerbart and Bruno Taut, in short, the Expressionists' celebration of the spiritual dimension of worldly experience.

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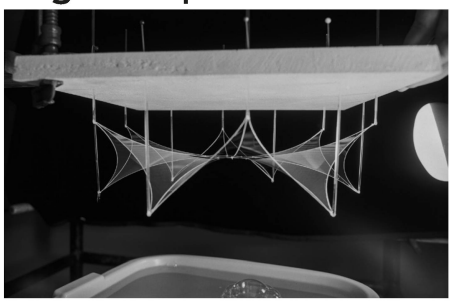
1 Frei Otto, "Phantasie und Architektur," *db deutsche bauzeitung*, 69 (1964), pp. 543–4; here p. 543; (French original: "Imagination et architecture: essai d'une vision d'avenir," *L'Architecture d'Aujourd'hui*, 102 (1962), pp. 89–93. This and all further translations by Jill Denton.

f.1 a–c Soap-film model of the dance pavilion, Federal Horticultural Show, Cologne, 1957.

2 To name but a few examples, Otto's modern tent-like constructions included a four-point tent for the Federal Horticultural Show in Kassel (1955), a star-shaped four-point tent for the dance pavilion and entrance arch at the Federal Horticultural Show in Cologne (1957), the so-called humped pavilion for the International Architecture Exhibition (IBA) in Berlin (1957), and the pointed tent for the Swiss cantonal exhibition in Lausanne (1964). Cf. Conrad Roland, *Frei Otto—Spannweiten: Ideen und Versuche zum Leichtbau* (Berlin: Ullstein, 1965).

3 Otto, "Phantasie und Architektur" (see note 1), p. 543.

It was therefore no accident that Heinrich Klotz — shortly after founding the German Museum of Architecture in Frankfurt in the mid-1980s — gave center-stage in one of the first exhibitions there to Otto's lightweight structures. This was prompted by nothing less than Klotz's own injunction to once again expose "modernism's other root" given that the "reductive geometry of the Bauhaus," which had long reigned supreme as "modernism's normative benchmark," had patently had its day. [4] Otto had made his mark, Klotz felt, by confidently exploring and exploiting "a promising aspect of modernism that *Neues Bauen*, Le Corbusier, and Gropius had overlooked: the art of engineering." [5] Yet, although Klotz paid a great deal of attention to Otto's architectural projects, he neglected one crucial point: the originality of Otto's design lies in the originality of his design process. Impossible, therefore, to adequately demonstrate the presumed development of modernism's other root by recourse to built projects alone. Far more pertinent, in this regard, is an investigation of the intricate workings of tools and apparatuses and their specific operative coupling as an ensemble of things, which is to say, of the technical procedures and medial and social practices that underpin any order of knowledge and without which no building as outcome can ever be envisaged. [6]



4 Heinrich Klotz, "Vision der Moderne," in Klotz (ed.), *Vision der Moderne: Das Prinzip Konstruktion* (Munich: Prestel, 1986), pp. 9–26; here p. 10.

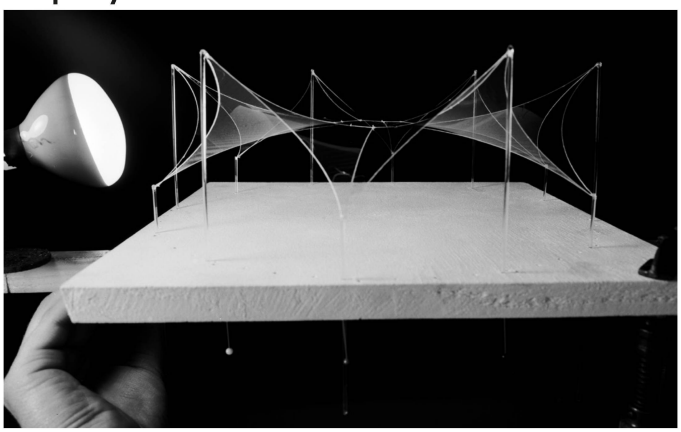
5 Ibid.

6 Cf. Gilbert Simondon, *Du mode d'existence des objets techniques* (Paris: Aubier, 1958), here in particular the chapter "L'invention technique: fond et forme chez le vivant et dans la pensée inventive," pp. 56–60.

Otto wrote his aforementioned essay two years after leaving the Ulm School of Design, where he had held the position of visiting lecturer for industrial construction from 1959 to 1960. Founded in 1953, the Ulm School of Design represented not only the perpetuation but also the institutionalization of the interwar Bauhaus tradition. However, the unity of art and technology propagated at the Bauhaus, above all by Walter Gropius, ceded there to a more analytical and methodological scientific concept of art and architecture, the visual expression of which took an abstract, namely diagrammatic, form. Implicit in this shift was a radical rethink of what exactly a machine might be. In publishing *Cybernetics; or, Control and Communication in the Animal and the Machine* in 1948, the mathematician Norbert Wiener had laid the foundations of a novel machinic realm in which the characteristics of a machine were taken to be not so much the mechanics of material itself (objects), as the mathematical control and, above all, the auto-control of abstract input and target variables. Wiener's book was quickly acclaimed in Ulm as the go-to work of reference, and it also proved pivotal to the School's theoretical articulation of its institutional role, in

particular thanks to the philosopher Max Bense and the design theoretician Tomás Maldonado. [7] In consequence, the importance of creativity and the social imagination became subordinate to the artificial intelligence of electronic brains and thinking machines. Design processes were reduced to scientific procedures for problem resolution, which were calculated using a methodology comprised of circuit diagrams and feedback loops. Aesthetics too was stripped of sensibilities and personal expression, and read instead as a communications technology issue. The rigor of this approach rested in many respects on cybernetics' claim to be a universal science and hence on the supposition that the borders between object and subject, nature and culture could be overcome in order to arrive at a novel way of "thinking by modeling" and a superordinate method of scientific global analysis. [8]

Young Otto did not join Ulm in singing the praises of techno-intellectualism, however understandable this would have been in light of general euphoria about progress at the time, particularly in postwar Germany. Instead, he pursued a line of inquiry that was not so much concerned with the imponderable nature of a universal science as with tackling the axiomatic terms of architectural practice. Likewise Ulm's highly theoretical claims and strictly scientific notion of design must have struck Otto as strange. [9] His endeavor to clarify the relationship between architecture, fantasy, and the machine must therefore be taken not only as a homage to the experimental architecture of Expressionism but also, so the hypothesis of the present essay, as a subtle critique both of the machine theory propagated at the Ulm School of Design and the cybernation of architectonic discourse therein implicit.



In 1964, Frei Otto was appointed to an institution founded in his behalf—the Institute for Lightweight Structures at the University of Stuttgart—where, in collaboration with architects, engineers, biologists, physicists, and artists, he quickly forged a world-class hub of interdisciplinary research. [10] It was in this period too that he won the competition for the design of the German Pavilion at EXPO 67 in Montreal. Together with the architect Rolf Gutbrod, Otto conceived an open exhibition landscape composed of spacious visitor terraces beneath a seemingly

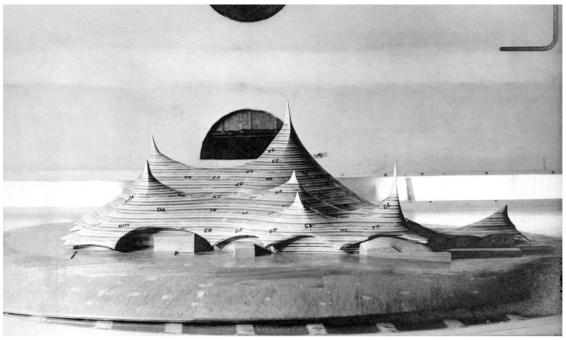
7 Cf. Max Bense, "Kybernetik oder Die Metatechnik einer Maschine" [1952], in Bense: *Ausgewählte Schriften*, vol. 2: *Philosophie der Mathematik, Naturwissenschaft und Technik* (Stuttgart: Metzler, 1998), pp. 429–46.

8 Cf. Michael Hagner, "Vom Aufstieg und Fall der Kybernetik als Universalwissenschaft," in Hagner and Erich Hörl (eds.), *Die Transformation des Humanen: Beiträge zur Kulturgeschichte der Kybernetik* (Frankfurt/Main: Suhrkamp, 2008), pp. 38–71. See also: Georg Vrachliotis, *Geregelte Verhältnisse: Architektur und technisches Denken in der Epoche der Kybernetik* (Vienna: Springer, 2012).

9 "The technical and philosophical realms and ever greater challenges are so extensive now that the work of the architect is becoming increasingly cerebral. He thus easily becomes distanced from his work and loses the capacity to tackle it himself, single-handedly, as the sculptor does who carves stone, forms clay, cuts wood, or bends steel, and who by the labor of his own hands is able to give himself completely to his craft. … If one senses that something is missing, one hides the fact in academic exchanges. The urge to explain is a fashion born of the misapprehension of science." Frei Otto, "Anmerkungen," *Baukunst und Werkform*, 8 (1955), pp. 721–2; here p. 721.

10 Cf. Daniela Fabricius, "The Spinner Experiment: Frei Otto and the Institute for Lightweight Structures," European Architectural History Network Meeting, Brussels, May 31 to June 3, 2012.

f.2 Nighttime view of the dance pavilion, Federal Horticultural Show, Cologne, 1957. → 170/171



f.3 a – b Wooden model in the wind tunnel, German Pavilion for the EXPO 1967 in Montreal, 1967.

free-floating yet meticulously structured tent-like roof. Once again, the Federal Republic of Germany had chosen to showcase its engineering skills in the form of an experimental lightweight structure, the acclaimed debonair flair of which made it a media darling the minute it opened. Soon, the term "Swinging Germany" was on everyone's lips. [11] Yet the apparent instantaneity of this fascinating structure belied its long and complex history: Gutbrod and Otto had designed not only the pavilion, but also all the requisite models, tools, measuring instruments, and visualization equipment for its design, planning, and implementation. Their venture was therefore nothing less than an apparatus-led rewrite of the cultural technics of design, the will to build revealed in an inventor's guise. And that, in a sense, is what made it a star attraction. **f.3 a – b**

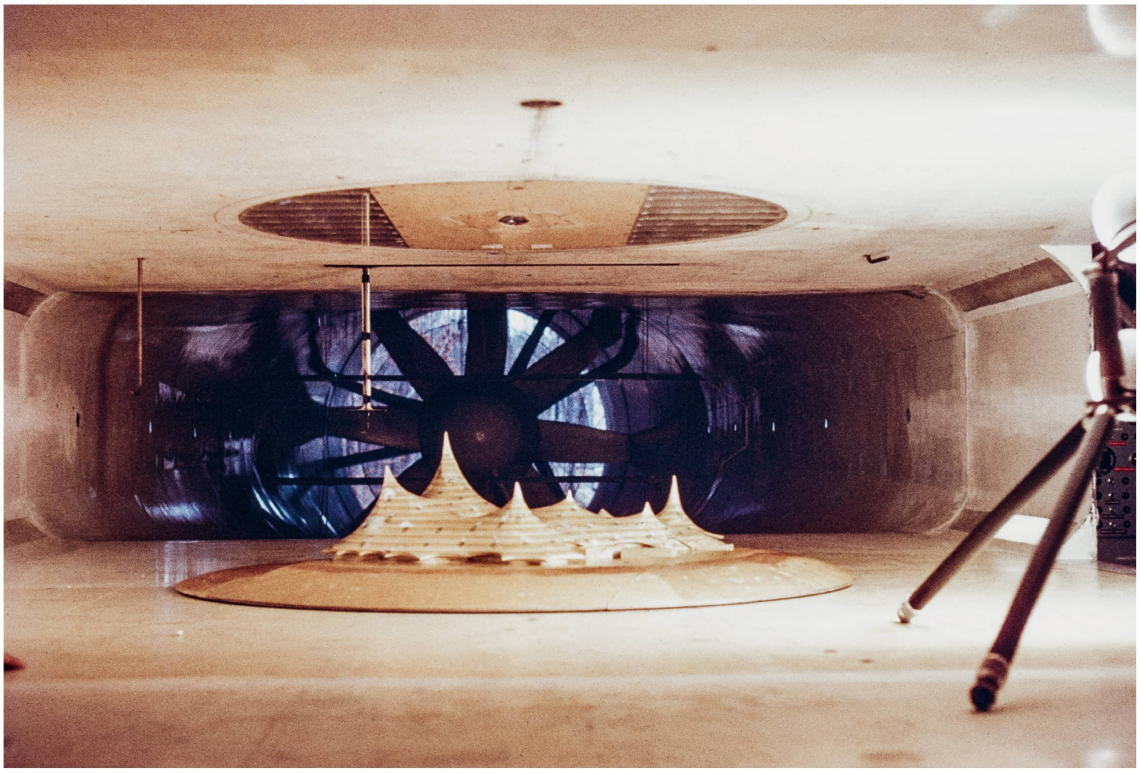
11 Rudolf Leonhardt, "Swinging Germany," *Die Zeit*, May 12, 1967.

To calculate the enormous roof span Otto had turned to what is known as model statics, an empirical method commonly used in engineering to examine the interplay of external boundary conditions and internal force distribution by direct reference to scale models. To simulate the German pavilion's exposure to wind-power, for example, he used a simple wooden scale model and a wind tunnel. Small holes drilled in the model's surface and equipped with thin plastic tubing enabled variations in its resistance to air velocity and pressure to be precisely ascertained. Meticulous documentation of the results clearly demonstrated how wind-power would affect the pavilion's complex tensile roof. Models thus served Otto as a means not only to elaborate form but also to measure and chart the balance of forces engineered by variable configurations of material, load-bearing system, and construction method. As he wrote of one of his later inventions:

"the measuring table is a machine in which a test point can be moved in the coordinates x, y, z. A threaded spindle powered by an electric motor traces the trajectory of each coordinate. Rotations of the spindles are measured. The measured data are shown on an LCD monitor and can be printed in plain text or as punched tape. The punched tape can be fed into computers and automatic drafting machines. On the measuring table's drawing board, while coordinates are being measured, the ground plan of the model can be punched in card with the aid of an automatic needle." [12]

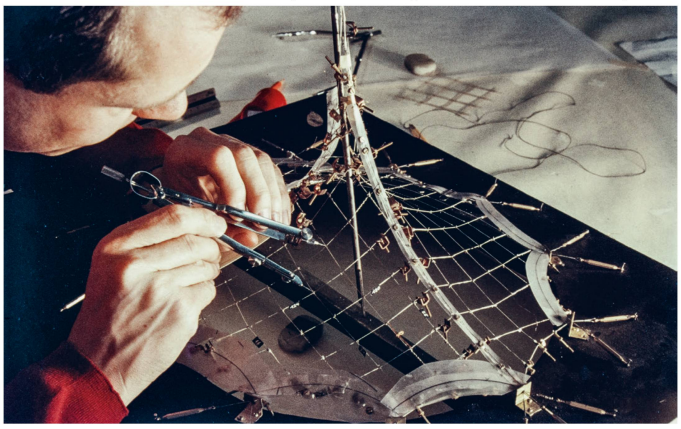
12 Frei Otto, "Protokoll: Über die Arbeiten des Instituts für Leichte Flächentragwerke an den Modellversuchen und Auswertungen am Projekt Deutscher Pavillon, 1967, Weltausstellung, Montreal," mimeographed manuscript issued by the Institute for Lightweight Structures, March, 1967, n.p.

Frei Otto used such pioneering experiments in CAD (computer-assisted design) in particular for the construction of the



timber gridshell of the Multihalle in Mannheim. One might join Gilbert Simondon in simultaneously describing this apparatus-based extrapolation process as "concretization" and "differentiation." [13] The technical object is embedded in a technical ensemble that is essential to its deployment and without which it would be incomplete. In building physics, then, models and machines become equal players in the same experimental system. **f.4/f.5**

How radically the interaction of model, machine, and materiality was explored here is clear from the broad range of materials brought into play. By the late 1950s, Otto had established that mixing distilled water with a few drops of dish soap suffices to create extremely thin yet relatively stable soap films and that (as with a child's bubble wand) such soap films take the shape of any closed, bent-wire form briefly dipped into then removed from them. [14] If the bent-wire form describes a so-called space curve then the soap film likewise constitutes a three-dimensional arcuate surface. In the course of countless experiments, Otto observed that a membrane of this sort is primarily defined by its contours, which is to say, its highest and lowest points; and also that it has specific geometric and physical properties. The surface tension in a soap film is identical at all



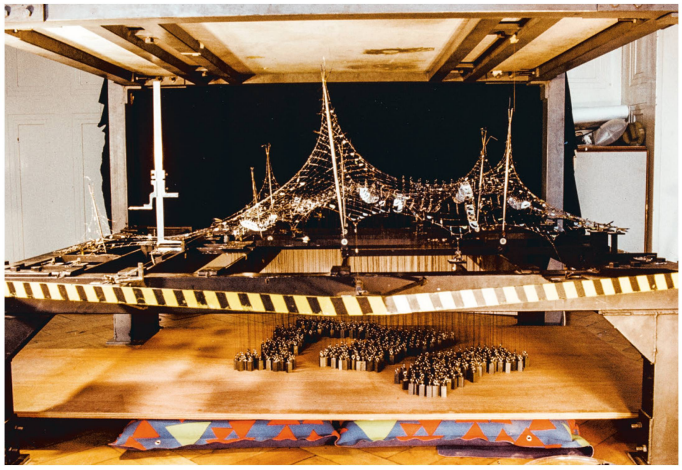
13 Simondon, *Du mode d'existence* (see note 6), pp. 34–5.

f.4 Net model and overall model on the measuring table, German Pavilion for the EXPO 1967 in Montreal, 1965.

14 Cf. Daniela Fabricius, "Capturing the Incalculable: Frei Otto's Experimental Models," in Sonja Hildebrand and Elisabeth Bergmann (eds.), *Form-Finding, Form-Shaping, Designing Architecture: Experimental, Aesthetical, and Ethical Approaches to Form in Recent and Postwar Architecture* (Mendrisio: Mendrisio Academy Press, 2015), pp. 49–63.

its points and in all directions, and this assures particular stability and efficiency, since the soap film takes the most economical form possible: the so-called minimal surface. [15] "It was fascinating to see, when developing these ... taut skins, how the endeavor to build forms with a minimum of material gave rise to forms of great clarity and captivating beauty—forms no one would ever have dreamed of designing." [16]

It was during preparations for the German pavilion at EXPO 67 that Otto and his colleague Larry Medlin developed a string of experiments in regard to geometric analysis of the potential forms of minimal surfaces. In the first experiments Otto opted for simple open frames. If the forms of minimal surfaces were to be geometrically analyzed using soap bubble models then the soap films would have to be more durable. The model would also need to be protected from drafts. A low-temperature, dust-free, and very humid environment would be required to prevent the soap films from rapidly drying out. The most important components of the minimal surface apparatus are: a chamber, air conditioning and humidity control, parallel light, a measurement grid, a projection umbrella, and a camera. Over the next circa fifteen years, the apparatus was further developed, in design terms and technically, and its functional range extended. [f.6] At the latest here, it is clear that Otto's predilection for experiment was based not on a systematization of architecture in the narrow, natural scientific sense, but rather on the artistic interpretation of forms experimentally induced with the aid of architectonic parameters. The machinic experiment served not only the investigation of cause and effect but also, to an equal or even greater extent, to generate form as part of the design process. This dual objective was feasible only because Otto (the designer) consistently bowed (as an engineer) to the physical properties of tensile membrane surfaces, systematically researched their geometric properties, and used apparatus-based techniques to precisely fathom the potential of the construction method in hand. Here, techniques assume the role of "processing" and "making real" ideas. [17] Modeling techniques, drawing techniques, measurement techniques, and evaluation methods must accordingly be read as constituents of Frei Otto's innovative experimentation culture, which was rooted



f.5 Net model and overall model on the measuring table, German Pavilion for the EXPO 1967 in Montreal, 1965.

15 Cf. Frei Otto et al., "Forming Bubbles: A research project of the Institute for Lightweight Structures on minimal surfaces under the direction of Frei Otto," *Mitteilungen des Instituts für Leichte Flächentragwerke der Univesität Stuttgart (IL)*, 18 (Stuttgart: Krämer, 1988).

16 Frei Otto and Peter Strohmeyer, "Zelte: Leichtbauweisen," *db deutsche bauzeitung*, 65 (1960), pp. 351–66; here p. 352.

17 Friedrich Dessauer, *Der Streit um die Technik* (Frankfurt/Main: Knecht 1956), pp. 225ff.

in the steady calibration of eye and hand, scientific observation, and mechanical dexterity—in short, in the self-assured fine-tuning of practical and intellectual capacities, whereby the act of architectural design propelled both individual knowledge production and collective debate of the discipline's future. For all their poetic fragility, the models in Frei Otto's work can certainly be described as exacting, for each reveals the tried and tested or as yet barely intuited insights of its maker. The most lasting impression on the mind's eye, however, is of an operative aesthetic that fuses the precision of scientific instruments with the allure of artistic intelligence.

f.6 Minimal surface apparatus with built-in wind tunnel, soap-film model in parallel light and camera.
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