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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 fan- Georg Vrachliotis tasy. That's not the fault of machines, however, but of man him- is Professor for the Theory of Architecture self, who builds machines that are neither adaptable nor rational: at Karlsruhe Institute of Technology (KIT). machines that are lacking in fantasy." 1 Thus wrote the young 1 Frei Otto, "Phantasie German architect, Frei Otto, in his concise, manifesto-style essay "Imagination et architecture: essai d'une vision d'avenir," which <sup>69</sup> (1964), pp. 543-4 here p. 543; (French was published in the French journal L'Architecture d'Aujourd'hui et architecture: essai



in 1962. Otto illustrated his essay L'Architecture d'Aujo not with photos of realized pro- urd'hui, 102 (1962), pp. 89–93. This and jects but with watercolor drawings and sketches in Indian ink, fila-c Soap-film in which intriguing membrane roofs and tent-like structures Cologne, 1957. 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 = -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 aroundwork for a modern minimalist reading of the tent. 2 His early dynamic ten- 2 To name but a sile 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 Lausanne (1964). Cf. Conrad Roland, Frei intently rational formal idiom of classical modernism. 3 Invoking Offo-Spannweiten: fantasy, by contrast, would call to mind the experimental architecture and optimistic narratives of Expressionist movements of the 3 Otto, "Phantasie 1920s, the poetic force and literary ingenuity of Paul Scheerbart (see note 1), p. 543. and Bruno Taut, in short, the Expressionists' celebration of the spiritual dimension of worldly experience.

is Professor for the

und Architektur," db deutsche bauzeitung, 69 (1964), pp. 543-4; d'une vision d'avenir, urd'hui, 102 (1962),

model of the dance pavilion, Federal Horticultural Show.

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 Otto – Spannweiten:

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 "modern-

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. ism'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." <sup>5</sup> 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. <sup>6</sup>

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 guickly 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 impor- 7 Cf. Max Bense, tance 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 *Naturwissenschaft* und Technik (Stuttgart: methodology comprised of circuit diagrams and feedback loops. <sup>Metzler, 1998</sup>, pp. 429–46. 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 "Vom Aufstieg und and culture could be overcome in order to arrive at a novel way Universal Wissenschaft, of "thinking by modeling" and a superordinate method of scientific global analysis.

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 <sup>9</sup> In technical and philosophical axiomatic terms of architectural practice. Likewise are so extensive now that the work of the Ulm's highly theoretical claims and strictly scientific notion of design to tackle it himself, must have struck Otto as the sculptor does who strange. , His endeavor to clarify the relationship by the labor of his own

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 the fact in academic essay, as a subtle critique both of the machine theory propagated at the UIm School of Design and the cybernation of architectonic discourse therein implicit.

In 1964, Frei Otto was appointed to an institution founded <sup>Werktorm, 8</sup> (1955), pp. 721–2; here p. 721. 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 European Architectural History Network period too that he won the competition for the design of the May 31 to June 3, 2012. German Pavilion at EXPO 67 in Montreal. Together with the f.2 Nighttime view architect Rolf Gutbrod, Otto conceived an open exhibition landscape composed of spacious visitor terraces beneath a seemingly  $\rightarrow 170/171$  show, Cologne, 1957.

Maschine" [1952], in Bense: Ausgewählte Schriften, vol. 2: Philo sophie der Mathematik, Naturwissenschaft Metzler, 1998),

8 Cf. Michael Hagner, Fall der Kybernetik als in Hagner and Erich Hörl (eds.), Die Transformation des Humanen: Beiträge zur Kulturaeschichte 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 realms and ever greater challenges architect is becoming increasingly cerebral. He thus easily becomes and loses the capacity single-handedly, as carves stone. forms clay, cuts wood, or bends steel, and who hands is able to give himself completely to his craft. ... If one senses that something exchanges. The urge to explain is a fashion born of the misappre-Frei Otto, "Anmerkungen," Baukunst und Werkform, 8 (1955),

10 Cf. Daniela Fabricius, "The Spinner Experiment: Frei Otto and the Institute for Lightweight Structures,"

of the dance pavilion, Federal Horticultural



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

11 Rudolf Leonhardt, "Swinging Germany," Die Zeit, May 12, 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. <sup>11</sup> 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. <sup>f3a-b</sup>

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

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

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.



timber gridshell of the Multihalle in Mannheim. One might join Gilbert Simondon in simultaneously describing this apparatusbased extrapolation process as "concretization" and "differentiation." 13 The technical object is embedded in a technical ensem- 13 Simondon, Du ble that is essential to its deployment and without which it would note 6), pp. 34-5. 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 f.4 Net model and wand) such soap films overall model on the measuring table, German Pavilion for take the shape of any the EXPO 1967 in closed, bent-wire form briefly dipped into then removed from them. 14 If 14 Cf. Daniela Fabricius, the bent-wire form describes a so-called space Experimental Model in Sonja Hildebrand 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 Architecture (Mendrisio Academy lowest points; and also that it has specific geometric and physical properties. The surface tension in a soap film is identical at all

Montreal, 1965.

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

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.

**f.5** Net model and overall model on the measuring table, German Pavilion for the EXPO 1967 in Montreal, 1965. 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. <sup>15</sup> "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." <sup>16</sup>

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 fif-

teen years, the apparatus was further developed, in design terms and technically, and its functional range extended. 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. <sup>17</sup> 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

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.  $\rightarrow 176/177$

