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Form–Finding, Form–Shaping, Designing Architecture

a cura di / edited by
Sonja Hildebrand, Elisabeth Bergmann

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Form-Finding, Form-Shaping, Designing Architecture

Experimental, Aesthetical, and Ethical Approaches to Form in Recent and Postwar Architecture
Approcci sperimentali, estetici ed etici alla forma in architettura, dal dopoguerra ad oggi

a cura di / edited by
Sonja Hildebrand, Elisabeth Bergmann

Mendrisio Academy Press / Silvana Editoriale

Quando Elisabeth Bergmann e Sonja Hildebrand ci hanno comunicato l'idea di promuovere in Accademia un seminario internazionale sul tema delle relazioni tra questioni estetiche ed etiche in architettura, un progetto maturato grazie anche a un loro lavoro di ricerca sulle visioni di Frei Otto del periodo postbellico, siamo stati immediatamente catturati dalle loro intenzioni e abbiamo dunque incoraggiato l'iniziativa.

Nel 1996, proprio agli inizi delle attività della nostra giovanissima facoltà, nel vecchio mercato coperto, progettato a suo tempo dall'architetto futurista Mario Chiattone, la nostra scuola organizzò una bella mostra dedicata al lavoro di due grandi architetti: Eladio Dieste e Frei Otto. Quell'evento fu il primo di una lunga stagione di importanti esposizioni promosse dall'Accademia di architettura, Università della Svizzera italiana, che allora pubblicò, in occasione della mostra, il primo catalogo di Mendrisio Academy Press.

Molti di noi hanno senz'altro ancora impresse nella memoria le immagini delle Olimpiadi di Monaco del 1972, che avevano per sfondo quelle incredibili strutture progettate da Frei Otto e Günter Behnisch per l'Olympiastadion. Alcuni anni più tardi la lettura del volume *Natürliche Konstruktionen. Formen und Konstruktionen in Natur und Technik und Prozesse ihrer Entstehung*, pubblicato nel 1982, permise a un pubblico attento di avvicinarsi con maggior consapevolezza al lavoro dell'architetto di Stoccarda.

Che a diciassette anni dalla sua fondazione l'Accademia di architettura abbia ospitato un simposio sull'idea di *Form-Finding* sviluppata da Frei Otto, di cui questo volume rappresenta un esito duraturo, è per noi un segnale sicuramente positivo per la continuità nella ricerca dei valori in cui la nostra scuola vuole continuare a credere. Scorrendo la lista degli eminenti professori che sono stati coinvolti a Mendrisio durante le due giornate del seminario, e che qui pubblicano le loro riflessioni, siamo certi che per la nostra comunità questo evento abbia rappresentato di nuovo una buona occasione per incontrare personalità di differenti culture, provenienti da contesti diversi e dunque un'opportunità per scambiare opinioni differenti all'interno di uno spazio di dialogo.

Vogliamo esprimere dunque la nostra gratitudine a Sonja Hildebrand e a Elisabeth Bergmann dell'Istituto di storia e teoria dell'arte e dell'architettura della nostra facoltà e alla cattedra di Strutture del professor Joseph Schwartz e di Toni Kotnik dell'ETH di Zurigo, per i loro sforzi e per aver donato alla nostra scuola, ai nostri studenti e ai nostri professori questa grande opportunità d'incontro grazie anche al sostegno finanziario del Fondo Nazionale Svizzero per la Ricerca Scientifica.

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Pathways to Form

Frei Otto and Beyond

During the last 20 years, the topic of architectural form has become one of the most controversial problem areas in public and professional discussions about architecture. Initially, the topic was closely linked to debates about architectural "icons" – the "Bilbao effect" and its consequences. Following the Digital Turn,[1] the issue became exacerbated and at the same time generalized, since with the computer-aided design and production processes that are customary today it is possible to create "extraordinary", emblematic buildings with apparently ever-greater rapidity and effortlessness.[2] Existing material conditions and technical requirements appear to be acting less and less as restrictive factors. But there are also severe problems associated with the feasibility and ubiquity of icons. These affect the cultural embeddedness of buildings and the associated semantic potential they hold. Icons are now so frequent that they are threatening to become banal; and the formally extremely complex products of computational design in particular often "speak" mainly about their own form.[3] However, the problems also affect aspects of authorship and the way in which architecture is embedded in the sphere of human production.

This problem area is reflected in architectural practice from various points of view. In his concept for the 14th Venice Architecture Biennial (7 June-23 November 2014), Rem Koolhaas chose an approach aimed at the "fundamentals" of architecture. In the face of a phenomenon described by Oliver Domeisen as "endless circularity and stasis of insular parametric iterations", Koolhaas has undertaken to provide a basis for an alternative discourse, favouring "a more pluralistic, evolutionary and historically aware understanding of contemporary architecture".[4] In preparing for the exhibition, Koolhaas has been conducting a research project focused on "histories – on the inevitable elements of all architecture used by any architect, anytime (the door, the floor, the ceiling, etc.)".[5] Koolhaas's argumentation is based on the enduring recognizability of essential components of buildings, which are inscribed in collective awareness through the everyday usage of architecture. These offer a generally applicable interpretative pattern that can also be applied to formally extravagant buildings. In order to examine the tools and methods used in design and the products of computational design, a conference organized at RWTH Aachen University in April 2014 inquired into the epistemic objects that are involved in the design process. The conference was based on the diagnosis that "in the world designed by architects, designers and engineers … the protracted process of planning and production often remains barely visible. It disappears behind the usually perfect-looking surfaces of the objects, which suggest that the way they actually exist is the only way they could possibly exist".[6] Still more far-reaching is the hypothesis proposed by a conference announced for July 2014 at the University of Innsbruck on *The Disappearance of Architects. Architectural Practice in Precarious Design Conditions*:

> A drawing still allowed design steps to be examined and checked so that they could be further developed or abandoned – and it was thus [since the time of Alberti] constitutive for the idea of the author, for the idea of the architect as an autonomous creator of designs; by contrast, algorithmic, rule-based or self-generating production procedures of the sort that are now increasingly being used have proved to be indifferent to the concept of authorship.[7]

Jörg H. Gleiter, Professor of Architectural Theory at the Technical University of Berlin, has discussed this problem area in relation to perception. A large number of the products of computational design, he argues, are today characterized by an "overwhelming effect". According to Gleiter, this effect is closely linked to the hypercomplexity of the rational basis for the buildings – i.e., computational mathematics. Because of their high degree of mathematical complexity, the buildings tend to be inaccessible to any form of rational analysis, or even to appear irrational – and this is what makes them overwhelming. Whereas architectural language is traditionally based on constructional logic, the amorphous forms that result from computational design elude this type of articulation. They tend to remain silent about the way in which they are made and the structural scheme underlying them. Material constraints have apparently been overcome. Buildings such as Zaha Hadid's Guangzhou Opera House and Frank Gehry's Disney Concert Hall in Los Angeles appear to have been built by mysterious agencies. To counter this diagnosis, Gleiter suggests that "digital-formal and analogue-constructive rationality" should be allowed to interpenetrate each other. In this way, the products of computational design could preserve a residue of constructional legibility and could be perceived positively, as "digitally sublime".[8] What for Koolhaas is achieved by the fundamental elements of architecture is carried out for Gleiter by architectural-structural form.

Hardly anyone has reflected on the problem area involving architectural– structural form as intensively as Frei Otto – an innovative explorer on the boundary between architecture and civil engineering. His concept of "form-finding" is aimed at preventing any processes of designing and shaping – which in his view represent "distortion". Instead, form has to be found, "peeled out" and optimized.[9] This view raises fundamental questions that go beyond Otto's own architectural practices and are related to current debates: how much freedom of design do architects have? Do they need to abandon their view of themselves as "masters of form"? What does this imply for the work of the engineer? The pathways to architectural form that were theoretically reflected on and experimentally investigated by Frei Otto in the field of lightweight construction touch not only on problems of interdisciplinary teamwork, but also on more abstract questions of the aesthetics and semantics of form.

The concept of form-finding is being used increasingly often today in connection with the new opportunities provided by computer science and construction technology. At the same time, architectural and civil-engineering buildings have shown an increasing number of apparently arbitrary structural systems in recent decades that often no longer have any connection with constructional or functional principles – a situation that demands a critical analysis of the dynamics, changes and possible prospects for the future for architectural structures. All the more so since similar discrepancies are also noticeable in the current theoretical discourse.

Theoretical studies on the topic of generating architectural form often focus on the concept of form-finding, not infrequently with direct reference to Frei Otto. This group includes Ralf Höller's principles of form-finding for membranes and cable mesh, as well as the anthology on form-finding in shell constructions and lattice shells edited by Sigrid Adriaenssens, Philippe Block, Diederik Veenendaal and Chris Williams.[10] This group of engineers – only Block is also an architect – focuses on the technical, mathematical and applied aspects of the topic. The prefaces by Jörg Schlaich and Shigeru Ban emphasize the rapprochement between the spheres of the engineer and the architect. In his summary, Patrik Schumacher even mentions the "congeniality of architecture and engineering" (but not the congeniality of the architect and the engineer).[11] Works by Frei Otto, which are investigated in this context, include above all the Mannheim Multihalle and its prototype: the wooden lattice shell in Essen. In their essay on *Computational Form-Finding and Optimization*, Kai-Uwe Bletzinger and Ekkehard Ramm point out the advantages of Otto's suspended models, which result in clearly defined doubly curved surfaces, whereas hanging cloths generate shapes with wrinkles and negative curves at the edges. The catalogue of works at the end of the book also includes the domes of St Paul's Cathedral, St Peter's in Rome, and the Temple of Mercury from the first century B.C. as well. They are listed in alphabetical order along with contemporary shells and compared using their numerical parameters (area, span, thickness).

However, the way in which the term form-finding is used is often arbitrary, with any type of approach to form being described as a form-finding process in a generalizing way. This is true, for example, of Kari Jormakka's 2008 book *Methoden der Formfindung*, which offers a sketch of a wide variety of approaches to design, starting with nature and geometry and passing via music and mathematics, chance and the subconscious to generative processes such as morphing, datascape and parametric design.[12]

In *The Autopoiesis of Architecture*, Patrik Schumacher claims to have developed a new theoretical approach in architecture,[13] which he has described as a "comprehensive discourse analysis and sociological justification for architecture".[14] According to Schumacher, a new and sustainable constructive trend has now emerged after a long period of arbitrariness, and it requires a different discursive culture. In order to find the anchorage in history that he nevertheless seeks for this, he turns to Frei Otto, whom he describes as "the only true precursor of Parametricism";[15] in another context, he also turns to engineers such as Heinz Isler. At the Architecture Biennial in Venice in 2012, Zaha Hadid and Patrik Schumacher exhibited shell models from Heinz Isler's estate that are held in the gta Archive at the Swiss Federal Institute of Technology (ETH) in Zurich, placed side by side with models from their own design courses – but without even starting to address the topic out of the fundamental differences between the paths to form taken in each case.

Appropriations such as this exemplify the need for a precise definition of the processes of form-finding and form-shaping in the intricate balance between constructional and technical parameters, design procedures, and architectural, aesthetic and semantic-cultural aspects. Beyond simplifications and misinterpretations, there is a need for careful analysis of the formal characteristics of architecture and its production in the computer-aided design processes that are practised throughout the world today. Because these are not only raising questions of the possible semantics and cultural identity of the resulting formal structures; they are also generally blurring the disciplinary boundaries established in the nineteenth century between architecture and civil engineering – but without at the same time overcoming the disciplinary barriers to mutual understanding.

These observations and considerations gave rise to the idea of re-examining the issue of form-shaping, or form-finding, in the tension between architecture and civil engineering on the basis of the outstanding example case of Frei Otto, by bringing together expertise on architectural history, architectural theory and technology and construction. For this purpose, the editors of the present volume organized an interdisciplinary workshop in October 2013 on *Form-Finding, Form-Shaping, Designing Architecture. Experimental, Aesthetical, and Ethical Approaches to Form in Recent and Postwar Architecture*, funded by the Swiss National Science Foundation (SNSF). This volume reflects on the workshop's findings and seeks to contextualize them.

In the discussions held during the meeting, Frei Otto was the most important reference point, and one on which critical reflection took place. He also continues to be an important point of anchorage in the essays presented here. However, the content also extends beyond the example of Frei Otto and his attempt to derive structural and architectural form from phenomena in nature. This opening up of the content also takes account of the continuing expansion of the range of technological and material options for form-generation in contemporary architecture, which can by no means be assessed solely by the standards of "natural design".[16]

No claim can be made, of course, that valid solutions are suggested here for the problems that have been outlined above. Instead, it was a matter of exploring the cultural and semantic potential of architectural form in the context of its material and technological production, in an exchange between the disciplinary fields of the history of art, history of architecture and history of technology and of architecture and civil engineering studies – in a dialogue between individuals working in the field of history and theory and those working on a practical basis. The boundaries of what is feasible here became clear in the process. The bridge that was built during the conference discussions between the different ways of thinking and communicating in the two disciplines remained a fragile, temporary structure that it

has also not been possible to fully consolidate during the process of recording it in writing. The different conventions and "styles of thought"[17] used in the disciplines are still recognizable in the essays. This starts with the way of working with groups of authors (or with a compilation by one main author of passages written by different authors) that is customary in the field of engineering; but it also particularly affects aspects of content and methodology. There is a very wide span between the assumption-rich mathematical form of argumentation used on the engineering side (Neuhäuser et al.) and the use of the term calculation in the sense of a philosophical concept in the field of art history (Fabricius). Despite this – and precisely because of the breadth of this span – interdisciplinary discussion is important, as it sharpens our critical awareness of disciplinary conventions and habits.

The essays presented in this book cover a period of a good 100 years, although most focus on the second half of the twentieth century. Those essays that range further back investigate fundamental questions of the origins of aesthetic patterns of experience on the basis of lightweight "mobility machines" such as the bicycle and small car around 1900 (Möser) and the potential range of form theories, based on the example of Gottfried Semper (Hildebrand). The subject of form-shaping or form-finding is also approached from varyingly wide perspectives, ranging from concrete pathways to form in engineering research (Neuhäuser et al., Bergmann on Weinand) and in (experimental) model-making (Neri, Fabricius) to the ideology-critical reflections on form by Oswald Mathias Ungers and Rem Koolhaas (Schrijver). In addition to the producer side, consideration is also given to the way in which (everyday) objects are perceived and to the emergence of aesthetic patterns that art and architecture can connect with (Möser).

The referential fields of architectural form that are investigated in the essays are not limited to the natural laws investigated by Frei Otto and adapted in his buildings, nor to the social and technological dynamics and momentum acting in this context (Fabricius, Keller). They also investigate influencing factors such as early regulations on the multilayered structure of facades in Swiss-German architecture during the 1970s and 1980s; architects responded to these by developing a strategy in which they interpreted the skin of the building not merely as an air-conditioning shell, but rather as a form-shaping element that was increasingly regarded as a tectonic structure (Grignolo).

However, the fundamental question is also addressed of whether form-finding and form-shaping do in fact need to be mutually exclusive approaches, or whether they can also be regarded as the two ends of a continuum of scholarly and artistic aspects that need to be balanced off against each other. The approach used in the *Stuttgart SmartShell* creates a continuing process of form-finding. This adaptive structural shell was developed at the Institute for Lightweight Structures and Conceptual Design (ILEK), the successor to Frei Otto's Institute for Lightweight Structures. With a thickness of only four centimetres, the shell would be far too thin over a span of more than ten metres to be able to absorb wind and snow loads. However, active and targeted shifting of three of its four points of support distorts the wooden shell when necessary in such a way that tensions and distortions can be sufficiently reduced (Neuhäuser et al.). The experimental finding of form is continually repeated, so to speak, in order to approach the optimal form in each case for various different load situations. At the same time, the active altering of the support points and the resulting continuous alteration in the shape of the *SmartShell* can also be interpreted as form-shaping. The *SmartShell* implicitly demonstrates that technological developments by no means necessarily lead to new architectural forms. Unusual new architectural forms in wood are now also being produced at the IBOIS Laboratory for Timber Construction at the Swiss Federal Institute of Technology (EPFL) in Lausanne (Bergmann on Weinand).

Frei Otto's philosophy of architecture revolves around the three key concepts of form(-finding), aesthetics and ethics (Bergmann on Otto). He regarded his lightweight constructions as counterexamples opposed to Nazi monumentalism. The architect's attempt to find an inherently democratic approach to form became problematic precisely when – as in the tent construction for the German Pavilion at Expo '67 in Montreal – the aim was to express weightiness in content and impressiveness in size, but without falling into nationalist rhetoric or oppressive monumentality (Keller). Oswald Mathias Ungers and Rem Koolhaas attempted to avoid the dangers of ideologically motivated shortcuts between form and content by denying the political semantics of form. On the basis of this critique, Ungers argued in favour of a form-shaping procedure based on morphological analogies that would link content to psychologically and culturally shaped visual habits, rather than ideologies (Schrijver).

The conference and subsequent discussions during work on the publication have shown how important it is to deploy larger-scale interpretative structures in the context of interdisciplinary dialogue – and also how important it is to have as precise as possible a definition of the specific subject concerned. The variety of disciplinary, methodological and theoretical approaches that were presented prompts reflection on one's own approach and leads to greater sharpness of focus in concepts and arguments. The present volume may thus be regarded as a model study, offering approaches that can be pursued further. It provides a set of tools – which should be further expanded – for considering the fundamental issues involved in architectural form and ways of creating it, along with the associated semantic, ethical and aesthetic aspects.

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(Translation by Michael Robertson).

Notes

_1. B. Junge et al. (eds.), *The Digital Turn. Design in the Era of Interactive Technologies*, Park Books, Zürich 2012; M. Carpo (ed.), *The Digital Turn in Architecture 1992-2010*, Wiley, Chichester 2013.

_2. A. LeCuyer, *Stahl & Co. Neue Strategien für Metalle in der Architektur*, Birkhäuser, Basel-Boston-Berlin 2003; and, more recently, F. Gramazio, M. Kohler, *The Robotic Touch – How Robots Change Architecture*, Park Books, Zürich 2014; F. Gramazio, M. Kohler, S. Langenberg (eds.), *Fabricate. Negotiating Design & Making*, gta Verlag, Zürich 2014.

_3. This risk has already been debated for several years, for example: *Urgency. Rem Koolhaas and Peter Eisenman in Conversation at the Canadian Centre for Architecture*, Montreal, 8 June 2007 (video, available at vimeo.com/2711744); B. Cache, *Projectiles*, AA Publications, London 2011.

_4. O. Domeisen, *Back to the Future. The Rewriting of History in Architecture*, "archithese", 43, 2013, n. 4, pp. 58-65, p. 58.

_5. R. Koolhaas, *La Biennale di Venezia. 14th International Architecture Exhibition/Fundamentals* (Statement) [press release], January 2013, cited after Domeisen 2013 (see footnote 4).

_6. Conference *Manifestationen im Entwurf* (Aachen, 10-12 April 2014), "H-ArtHist", 27 March 2014 (http://arthist.net/archive/7320, accessed 30 May 2014).

_7. Conference *Das Verschwinden der Architekten. Architektonische Praxis innerhalb prekärer Entwurfsverhältnisse* (Innsbruck, 3-4 July 2014), "H-ArtHist", 5 Feb 2014 (http://arthist.net/archive/6921, accessed 30 May 2014). A related approach with a positive evaluation is represented by G. Franck, D. Franck, *Architektonische Qualität*, Carl Hanser, Munich 2008, esp. chapter 6, pp. 169-196: *Kreativität: Fortsetzung der Evolution mit kulturellen Mitteln?* See also – following on from his studies of historical aspects of the graphic representation of architecture – M. Carpo, *The Alphabet and the Algorithm*, MIT Press, Cambridge MA-London 2011, esp. pp. 20-48.

_8. J.H. Gleiter, *Das Digital-Erhabene. Wie mit dem Computational Design eine vergessene ästhetische Kategorie in die Architektur zurückkehrt*, "Neue Zürcher Zeitung", 1 June 2013, p. 64.

_9. *Form. Form Kraft Masse 2 / Basics: Form Force Mass 2* (Mitteilungen des Instituts für Leichte Flächentragwerke, Universität Stuttgart / IL 22), Stuttgart 1988; F. Otto, B. Rasch, *Gestalt finden. Auf dem Weg zu einer Baukunst des Minimalen*, Edition Axel Menges, Fellbach 1995; F. Otto, *Architektur Natur*, Christian-Wagner-Gesellschaft, Warmbronn 1996, p. 3. On Frei Otto in general: W. Nerdinger (ed.), *Frei Otto. Das Gesamtwerk. Leicht bauen, natürlich gestalten*, Birkhäuser, Basel-Boston-Berlin 2005.

_10. R. Höller, *FormFindung. Architektonische Grundlagen für den Entwurf von mechanisch vorgespannten Membranen und Seilnetzen*, Balistier, Mähringen 1999; S. Adriaenssens et al. (eds.), *Shell Structures for Architecture – Form Finding and Optimization*, Routledge, Abingdon 2014.

_11. P. Schumacher, *The congeniality of architecture and engineering – the future potential and relevance of shell structures in architecture*, *ibidem*, pp. 271-273, p. 271.

_12. K. Jormakka, *Methoden der Formfindung*, Birkhäuser, Basel-Boston-Berlin 2008 (English edition: *Design Methods*, Birkhäuser, Basel-Boston-Berlin 2008).

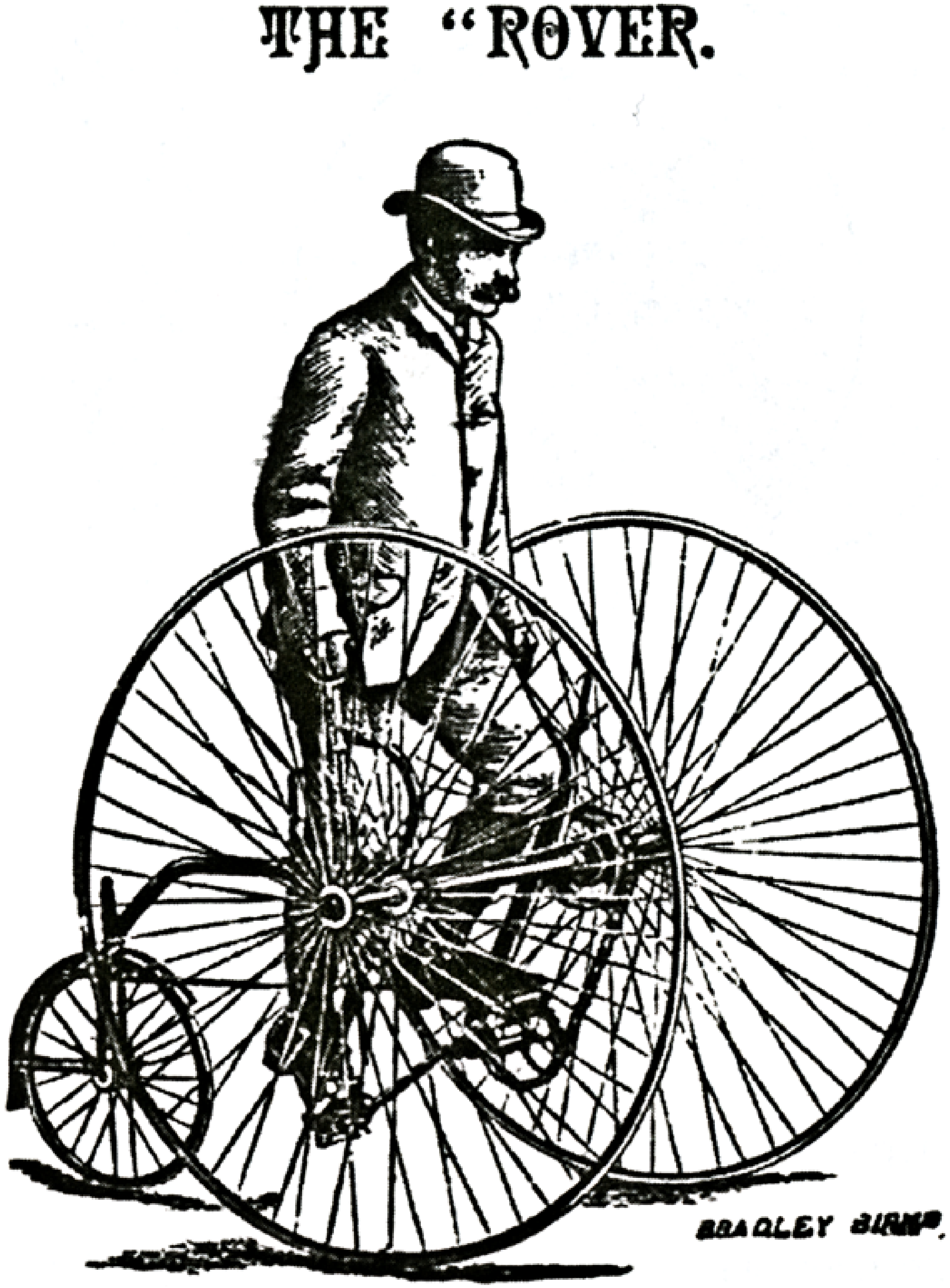
_13. P. Schumacher, *The Autopoiesis of Architecture*, 2 vols., John Wiley & Sons, Chichester 2011-2012.

_14. Interview *"The Autopoiesis of Architecture". Ralf Ferdinand Broekman und Olaf Winkler im Gespräch mit Patrik Schumacher*, "build. – Das Architekten-Magazin", 2, 2011 (available at: http://www.build-magazin.com/index.php/themenfull/items/the-autopoiesis-of-architecture.html, accessed 30 May 2014).

_15. Schumacher 2012 (see footnote 13), p. 680.

_16. F. Otto et al., *Natürliche Konstruktionen. Formen und Prozesse in Natur und Technik und Prozesse ihrer Entstehung*, Deutsche Verlags-Anstalt, Stuttgart 1982.

_17. Borrowing the concept formulated by Ludwik Fleck around 1930; cf. L. Fleck, *Denkstile und Tatsachen. Gesammelte Schriften und Zeugnisse*, ed. S. Werner, C. Zittel and F. Stahnisch, Suhrkamp, Frankfurt am Main 2011, pp. 41-259.



_ Figure 1.
The Rover: cycle technology as a paradigm of light construction, 1884 (T. Hadland, H.-E. Lessing, *Bicycle Design*, Cambridge MA 2014 p. 113).

Kurt Möser

«A man a-riding upon nawthin'»

Light Structures and New Mobility Cultures Around 1900

There were two trends that moved into the foreground around 1900 – trends that were technological and cultural as well as artistic. I will try to bring together these two simultaneous revolutions which, at first glance, do not appear connected, viz., a technological revolution, characterized by lightness of construction, speed and mobility; and a cultural revolution, characterized by transparency and de-materialization. These two techno-cultural revolutions encompass such different phenomena as steel tubing, kites and gliders, transparent clothing, futuristic speed cult, rays and emanations of newly researched elements, doubts about the stability of elements and atoms, blurred perception of speeding machines, rubber tyres, speedlines in art, just to name a few. These trends have to be anchored in objects and hardware rather than in concepts and programmatic prose. The “material turn” in revisionist cultural history[1] is an approach which research-orientated museums have been doing for a long time; thus, it can be put in perspective and may appear less innovative.

The Technical Basis: Light Structures around 1900

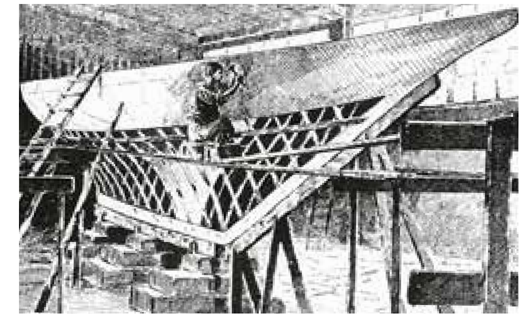
Around 1900, there was a significant and culturally stimulating transition from heavy engineering to light engineering. Before that period, heavy engineering was on the forefront not only of engineering but also on the prestige of structures. This changed: new light engineering came to the centre of interest. It manifested itself, for instance, in the gradual superseding of heavy steam engines with internal combustion engines (which tended to be much lighter for their power output), and, finally, in the development of electrical power technologies. Even more significant was the usage of new light materials: light seamless tubes, pressed sheet metal, roller bearings, or chains. Aluminium was a decidedly modern material for light construction, together with rather unusual or innovative materials which were previously not regarded as worthy of engineering at all: bamboo, light spruce spars, tin clasps, canvas fairings, or transparent cellon. On the construction side, a general principle was the emphasis on tension instead of compression. Typically, wires were used for certain applications, bringing down the weight to as much as one tenth of old compression-based constructions. The usage of piano wires was typical. Their near-invisibility contributed to the visual lightness of the new engineering style, as will be discussed later. Even in old technologies, there was a jump towards less weight and more "rational" and material-saving construction. Steam engines for special uses, for instance for planes or light vehicles, were transformed and lightened considerably, as seen in the *Clement Ader engine* in the Conservatoire des Arts et des Métiers in Paris, or Hiram Maxim's light engine for his experimental aircraft.[2]

Paradigmatic Light Structures: Mobility Machines

The new mobility machines appearing before 1900 were a paradigmatic species of light structures.[3] Among these was the bicycle with its significant technological as well as cultural impact. But there were also light boats, canoes, flying structures like kites, and of course the early flying machines. Most of them showed astonishing and nearly unbelievable capabilities for contemporary commentators. For instance, a *penny-farthing bicycle* of 1890 with tensioned wire wheels, weighing around 12 kilograms, was capable of carrying a five- to eightfold, or in some cases nearly tenfold load. Canoes or light racing dinghies had a similar crew-to-structure weight. These machines, made frequently from unusual materials, were seen at the cutting edge of technology and on the forefront of spectacular achievements. Without any efforts to "design" it in an intentional way, the bicycle created a new aesthetics of a light "personal machine", made of stable triangles of tubing and tensioned elements.[4] Fig. 1

On top came, of course, flying. The new aeroplanes were paradigmatic light structures, frequently making use of the light and innovative construction materials developed originally for bicycles, e.g. steel tubes, chains, ball bearings or wire-spoked wheels. Aeroplanes were not the only decidedly modern artefacts. Kites and gliders, light canoes, dinghies and racing boats attracted public attention for their light materials and construction. Landmarks in this respect were for instance the first sailing boat whose hull was made from aluminium, the *Vendenesse*, built in 1893,[5] or the first racing yacht without ballast, the *Alpha*, launched one year previously.[6] Very light yacht construction became a fad after the turn of the century, but, as the *Independence* from 1901 – whose nickname was *Rubber Boat* – showed, there were problems with the static stability of the construction.[7] For instance, all load-spreading tubes broke soon after serious testing. Typically, fast boats were not elongated any more in order to increase waterline length, which was (and is) the prerequisite for speed in a displacement hull. Instead, speed was attained by "planing" boats skimming the surface. Count Lambert is credited with building the first such vessel in 1897. A typical example is the *Ricochet-Antoinette* from 1907, of the type called *Ricocheteur*.[8] These boats had to be built extremely light in order to be lifted out of the water on the plane. Fig. 2

Especially in the early aeroplanes weight ranked first. Thus, not only the materials used, but also their construction had to be light. Calculated structural strength was often sacrificed, or even not calculated at all, but simply guessed. A typical con-



_ Figure 2.
Vendenesse, the first aluminium yacht, 1893 (D. Charles, *Die Geschichte des Yachtsports*, 2002, p. 136).

struction and a typical engineer in this line of thinking was Antony Fokker with his first successful model *Spin*, meaning "spider". Fokker's method was strictly empirical. He claimed that construction drawings were done at the end of the engineering process, not at the beginning.[9] The *Spin* had an extremely reduced structure without a fuselage in the common sense. This principle of shedding unnecessary elements is seen in many early planes, for instance in the *Farman 7*, a "pusher" with a rear engine, having just longerons and no fuselage at all. Fig. 3

In the First World War, similar planes were built and flown by the Germans, e.g. the Vickers *Gunbus*, called *Lattice Tail* (*Gitterschwanz*). Even when completely covered with canvas, the structure appeared to be transparent and the biomorphic "skeleton" of ribs and fuselage bulkheads was visible, especially when seen against the sun.[10] See-through cellon cladding was experimentally used by German planes as a form of camouflage; it was assumed that planes could be rendered invisible in the sky.[11]

Gabriele D'Annunzio described the strange and unprecedented structures of the planes of the first *annus mirabilis* of flight, 1909, in his novel *Forse che sì, forse che no* (1910), as follows:

> Le tettoie nuove, dalle fronti dipinte alla maniera degli antichi pavesi, custodivano i più diversi mostri artificiati con le materie più diverse, coi più diversi ingegni. Per mezzo alle ampie tende di tela agitate dal turbine delle eliche in prova, apparivano a quando a quando le strane forme delle chimere senza bellezza e senza virtù partorite dalla manìa pertinace o dalla presunzione ignara, condannate irremissibilmente a sollevare la polvere e ad arare il suolo: ali ricurve e aguzze costrette al remeggio con uno stridore di usci in càrdini rugginosi; adunazioni di celle quadrangolari, simili a mucchi di scatole senza fondo; lievi scafi oppressi da impalcature sovrapposte, simili a fragili canghe; alberi giranti forniti d'una sorta di cilindri cavi come i burattelli di stamigna nei frulloni dei fornai; lunghi fusi ferrei con un gran cerchio a ogni estremità, fatto di cotonina imbullettata su stecche, a simiglianza della ruota a pale nel mulino natante; congegnature di aste e di vèntole in guisa di quegli arnesi mobili che servono a ventilare le stanze nelle colonie torride; difficilissimi intrichi di sartie, di traverse, di longherine, di tubi, di stanghe, di spranghe; tutte le composizioni del legno, del metallo, del tessuto intese all'impossibile volo.[12]

Two Types of Transparency: Static and Dynamic

There were also new ways of perceiving light technology. Its main feature appeared to be transparency: one could look right through bicycles or early planes; there was no hard surface to hinder the eyes. Thus, mobility machines can have light skeleton structures or structures in tension which radiate lightness even when static, or they can acquire transparency when in motion. There are two ways of perceiving lightness and transparency. Most attractive to contemporary observers was the spectacle of speed and the specific distortion it was linked with.

_ Figure 3.
The first german glider. Like the airplane Farman *Longhorn*, 1914, without proper hull.
(P. Supf, *Das Buch der deutschen Fluggeschichte*, Vol. 2, 1958, p. 130).

The spoked wheels which appear to be completely immaterial when in motion are a case in point. Visually, a sort of "de-materializing" by blurring happened. This is true for fast-moving objects like bicycles, which seemed to lose their "objectness", so to speak. A caricature in the satirical paper "Punch" stated in the caption that a rider on a *penny-farthing bicycle* looked like "a man a-riding upon nawthin'".[13] Here, transparency was in the eye of the ironic beholder. The giant reflecting, flaring, moving, spoked wheels intrigued, but were a source of irritation and insecurity, too. The spokes reflecting the light became an opaque disk, and the rider seemed to roll on light through space: "... it was thrilling to see a man hurtling through space on one high wheel with another tiny wheel wobbling helplessly behind".[14]

The necessity of balancing, of maintaining a precarious and dangerous equilibrium, was recognized as a specific feature of light mobility machines. Thus, a fascination with near-artistic balance was a feature of the culture around 1900. Franz Kafka evidently was fascinated by the flyers in their open fuselages when describing the Blériot's flight at Brescia: "Blériot is in the air, one sees his straight upper body over the wings, his legs are buried deep as part of the machine. The sun has gone down and from under the canopy of the stands it shines on the soaring wings".[15]

Balancing and transparency were not the only source of irritation. Around 1900 there was a universal complaint that it was difficult to judge the speed of small fast-moving objects in everyday contexts – or even to see them properly. This had to be learnt slowly. The art of perceiving speed was part of the

_ Figure 4.
Picture postcard
(collection of the author).

_ Figure 5.
Robert Delaunay, *Hommage a Bleriot*, 1910
(G. Vriesen, M. Imdahl, *Robert Delaunay: Light and Colour*, New York, 1967, p. 67).

mobility revolution which affected not only the sense of velocity but also the sensory perception of 360-degree sight[16] and the shifting forward of focus, connected with high or different speeds. For the new class of mobility machines these difficulties and the necessary adaptation are comparable to the difficulty first-time users of railways had to adjust to the new "dromological" vision.[17] Coupled to this dematerializing perception revolution is the artistic problem of developing a depiction of lightness and speed. Blurring and dematerialization are features that were specifically employed by the Italian Futurism, but there is an older tradition of employing these specific artistic means. William Turner's *Rain, Steam, and Speed* is a case in point, but after 1900 new and revolutionary solutions were brought forward quite frequently. Robert Delaunay, for instance, chose the propeller as a paradigmatic object. It had attraction when static and dynamic: on the one hand, it was seen as a perfect sculpture, and on the other, when revolving, it became a perfect transparent circle in Delaunay's paintings of the 1910 period. Yet other elements of the iconography of lightness were speed lines and the employment of opaqueness, drawing lines instead of filling up colours, or intentional blurring. These can be found frequently in paintings by the Italian Futurists as well as specific artistic means of conveying transparency.

Fig. 5

Thus, a specific rhetoric and iconography of transparent, fast and light technologies developed. In addition to mobility being a prestigious principle and an epitome of modernity, the new means of conveying these qualities artistically spread into popular culture. Blurring, "speedlines" trailed by fast cars or planes, or distortions became common in advertising and popular graphics. The producers named their machines appropriately: *Dragonfly*, *Spider*, or *Ariel* hinted at lightness.

Two Types of Modern Lightness: Skeleton and Clad Body

Around 1900 an aesthetic of openness and unclad, visually cleared structures did develop. The "deconstructing" of cars and planes by removing cladding and paneling was typical. Especially when racing, everything deemed unnecessary was unscrewed and removed, leaving an open body which revealed its structure. This resulted in open constructions in which the distribution of forces was visible, for instance in the compression and tension elements of a biplane. Behind that physical lightness was the guiding idea. Probably there was the idea of a sort of technological *Ockham's Razor*, removing everything not required for the task in hand – speed. This is the heroic exposure of naked technology; the presentation and demonstration of mechanical innards, resulting in an aesthetic of angularity and openness. In addition, a structurally minimalistic approach held a specific attraction. Typical for this is the picture of a racing car competing with an early *Curtiss plane*. The plane has shed all traces of a covering, whereas the car retains a body but lacks wheel guards.

On the other hand, a contrary trend is recognizable: the idea of perfect covering in order to increase speed by streamlining. The use of scientific research to reduce drag by creating a perfect body for fast-moving vehicles was tested out at the same time. Despite adding weight to the pure skeleton, the gain in speed efficiency was noticeable. But still, lightness was in the focus: The panels for the electric racing car, which reached a record speed of 100 km per hour, were made of the paradigmatically light aluminium sheeting. In other cases, light fabric coverings were the standard, as seen in airships. A special feature to combine lightness and strength is the use of pre-stressed skins. This was used in airplane construction from the end of the First World War but had been employed before in the building of fishing dories, which relied on the strength of the body with only minimal internal framing.

Thus, there were two ideals, which were not necessarily in conflict, and which complemented each other and coexisted: the ideal skeleton cleared of all weight and cladding, versus the ideal convex body. The *tertium comparationis*, still, was lightness. Sometimes, both trends were united in one artefact, as seen in the famous Channel-crossing *Blériot XI* machine. Here, the rear part of the fuselage was left unclad; the front showed canvas sheeting. Around 1910, there was no clear-cut preference. Both paradigms coexisted in this period, even in racing cars. Thus, the record-breaking electrical vehicle *La Jamais Contente*, which exceeded 100 kph in 1899, subscribed to the aesthetic of streamlining, whereas the famous *Ford 999*, setting in 1902 a speed record at the *Grosse Pointe Racetrack*, was of the skeleton type.

Contextualizing Light Structures

Around 1900 the de-materialized view of the world was in the making. Primarily, the stability of beliefs in the nature of the material world was shattered by new revelations of science. A new culture centered on "streams and rays" emerged.[18] Beginning roughly with the discovery of x-rays by Wilhelm Conrad Röntgen in November 1895 and its immediate popular reception, there was growing scepticism regarding the former security of the solid material world. This changing view was reinforced by Maxwell's *field theory*, by instabilities of space and time, even by a seemingly fluidity of natural laws. More specifically, Heinrich Hertz's waves and, much more in the public eye, the application of radio waves by Marconi and others created new immaterial forms of communication. Especially in the two decades before the First World War, this trend towards dematerializing known, secure matter accelerated. Theories of radiation by atoms, which proved not to be stable building blocks as was earlier thought, and new types of rays not only shattered the Newtonian world-view but convinced (at least parts of) the intellectual elite in the Western world that they were living in a much less stable universe than they had previously thought.

Thus, secure and stable world-views were shattered in several areas. The high water-mark of certainty in the culture of knowledge was the *Encyclopaedia Britannica*, the 9th and 10th editions of which were still able to codify the complete knowledge of their time before the next edition had to admit in several articles (e.g. on atoms) that there was a new and disturbing insecurity that had to be digested scientifically. For intellectuals and artists, there was the necessity to cope with this new challenge of a seemingly unstable, insecure and de-materialized world. Instability became a new cultural feature.

Speed and acceleration moved into the centre of irritation. The "dromologic" revolution, as Paul Virilio postulated,[19] regarded the social obsession with speed as a cultural provocation. Painters, who had to live with a paradigmatically static medium, were especially challenged to find new ways of representing change, speed and the results on subjectivity. Grappling with speed representations was one of the big issues of the time. Futurism was at the forefront of this revolution, but French Expressionists also tried to incorporate dynamics in their paintings, inevitably somewhat neglecting the solid material world pre-modernism reveled in.

Attraction and Danger of Light Mobility Machines

The extra-light, even spidery or flimsy machines of the "new style" were often very demanding in use and even dangerous. Thus, they were regarded as "non-working artefacts" by more conservative users, characterized by insecurity and danger. Typically for this, a very light dinghy of the period was sometimes derided and feared since it was in some cases much lighter than the crew and would capsize easily. In contrast to the more cumbersome – and certainly heavier – boats, which were more forgiving, they demanded more alertness and more bodily activity from their crew, rewarding them with much better and more exciting performance. Likewise, some extreme yacht constructions were admired and feared at the same time. They were admired for their extraordinary performance, and ridiculed for their fragile and non-durable construction. Thus, critics revelled in negative comments when such yachts disintegrated, as they frequently did, while achieving spectacular victories in races when conditions were right.

The positions in this debate on the attractions and the danger of light mobility machines are not quite contradictory. The inherent dangers of cutting-edge light mobility machines, suspicion or doubts of their performance, and the problems of potentially dangerous collapses of structures built to the limits did not necessarily hinder their use. Quite to the contrary: these cutting-edge features added attraction by accepting risk and reveling in it. Early mobility machines were "adventure machines", ever unreliable and dangerous, but this made them highly attractive in a risk-dominated user culture that prized daring and dash.[20] Their very lightness, verging on collapse under stress, added to their fascination.

The concept of a social construction of technology – SCOT [21]– is concerned with the phenomenon of a "non-working artefact" that has many technological problems but nevertheless enjoys social acceptance. The dangerous and difficult -to-handle *penny-farthing bicycles* are cases in point, as well as canoes or daggerboard dinghies, which capsized easily, sometimes even when not in motion. It can be assumed that the danger and the complex, hard-to-acquire handling skills necessary to "dominate" these light mobility machines were part of their attraction, not arguments against their use.[22]

Lightness and Body

In parallel with the emerging paradigm of lightness, a culture of symbolic representation emerged. Typical for symbolizing lightness was the gesture of lifting: in order to demonstrate the manageable weight, frequently even heavy objects were depicted being lifted. This gesture was a common motif in bicycle advertisements. It was likewise used by Hiram Maxim, lifting seemingly effortlessly the machine gun he invented.

Figg. 6, 7

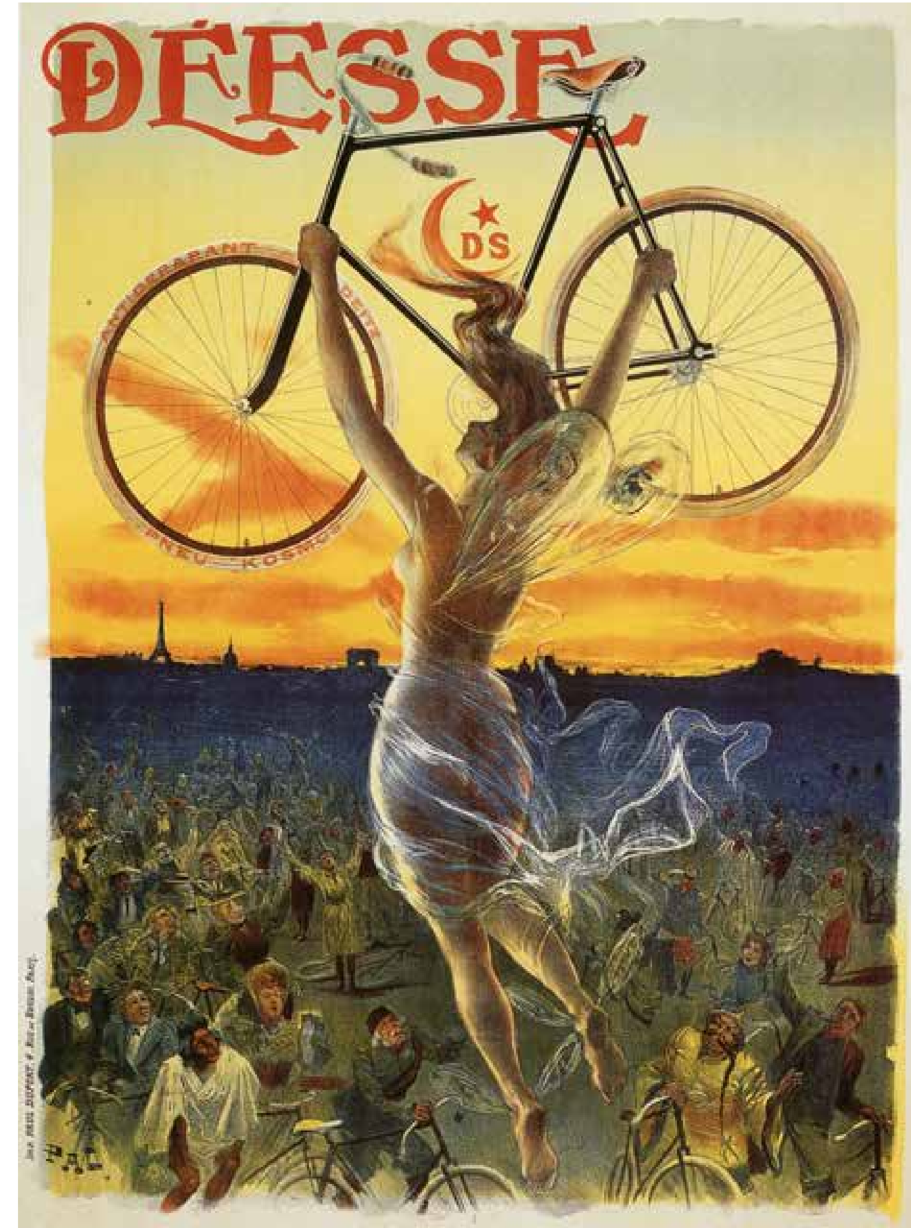
The connection of the lightness of technological artefacts with the human body is exemplified in the admiration for the French-Brazilian aviation pioneer Santos-Dumont. His mobility machines have a quality that makes them stand out: they are perfectly fitted to the body of the user. His small personal airships are geared to transport just him, and his light aeroplane, the *Demoiselle* of 1909, is regarded as the world's first light aircraft. These artefacts were seen in their time as examples of a type of highly personal and body-related mobility machine, adapted perfectly to the physique of the user. The Brazilian flight pioneer dreamt of and built the smallest possible "lighter than air" device, an airship capable of lifting and propelling his slight body. Santos-Dumont himself, the "flying dandy", was only 1.45 meters tall and weighed 45 kilograms (with his shoes), as he claimed.[23]

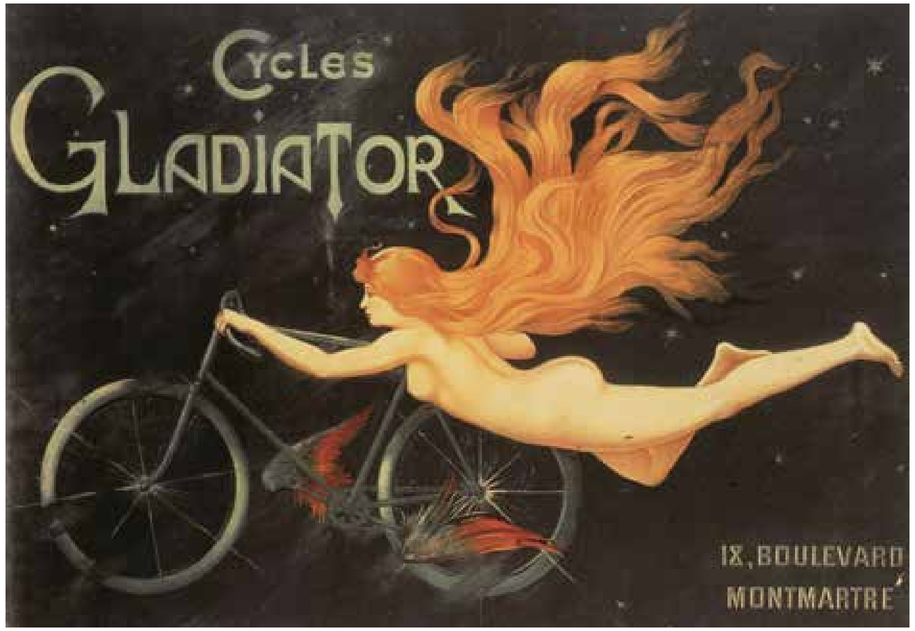
This emphasis on lightness was also politically charged. Santos-Dumont played off his light, smallish "personal airship" against the brute aerial monsters of Count Zeppelin. He ridiculed the clumsy and inelegant German approach to airships, while stressing his simpler and body-adapted solutions. Thus, he set the elegant Brazilian-French technology stereotypically against the heavy and clumsy German one. Creating an opposition between monumentality and elegance turned the aesthetics of lightness into politics. Moreover, to be slim and light was socially constructed as being specifically modern; and to "rule" sensitive, light and fast mobility machines was seen as an emphatically modern quality, too. Lightness appeared as a supreme aim, perfected for light bodies and linking aesthetics, body politics, user qualities and modernism.

_ Figure 6.
Hiram Maxim, c. 1890.

Added to this was another component: Santos-Dumont's small airships also had to be light on the controls and rudders. And this presented a new dilemma, since in the question of controlling the new mobility machines there was no mainstream at first. There were contradictory and conflicting perceptions and ideals: on the one hand, there are nimble and light bodies as a new ideal. On the other, there is the need for a hard rein on these objects: "the steely fist at the controls" was a phrase employed to describe the dominance of man over machines – even if they were light and seemingly nimble.

_ Figure 7.
Déesse, from PAL, Paul Dupont, c. 1898.
(P. Dodge, *Faszination Fahrrad*, Paris 1996, p. 123).





_ Figure 8.
Cycle Gladiator, from C.B., G. Massias, c. 1900. (P. Dodge, *Faszination Fahrrad*, Paris 1996, p. 117).

This ambivalence can be found in sources describing the forces that a pilot of the new aeroplanes required. It could be either the powerful (and aggressive) control mentioned above over a stubborn and "obstinate" machine. While in contrast, new planes were often praised as requiring only feathery touches, which were soft on the controls, which radiated lightness to their pilot – who himself had to have a "light touch". The controls, the man-machine interfaces, thus had to correspond, be it the "feather-like" control of an aeroplane's ailerons, or the light helm of a fast sailing dinghy. Bicycles were praised as "leicht und leicht zu fahren" (light and easy to ride).[24] Bertolt Brecht wrote these lines in his famous poem *Singende Steyrwägen* (Singing Steyr Automobiles): "und so leicht fahren wir dich, daß du meinst, du fährst deines Wagens Schatten" (and we drive you so lightly that you think you are driving the shadow of your car).[25] Here, the desired quality of lightness of touch in driving is poetically linked to the immaterial quality of a shadow. Shadow itself was a name of the probably most prestigious luxury car of the time, the Rolls-Royce *Silver Shadow*. There was also the necessity to coordinate the body and the light machine by balancing. This was a necessary body technology not only in cycling but also in using light dinghies, canoes or even planes. Otto Lilienthal claimed that his glider was simply not flyable without prior experience in balancing a bicycle.[26]

And this ideal of a sensitive, body-orientated collaboration between man and machine seems to be the more modern type of man-machine interaction.[27] It ties in with the new ideal of a perfect cooperation of mobility machine and person, forming a new techno-human recombination of mutual "understanding". A recurring dream of the technologically-minded avant-garde who relish mobility thus combines light structures, adapted to human bodies, with an ideal of effortless use. In short: the light man-machine combination became a paradigm around 1900. The

task of the engineer was to create exactly this ideal. This probably foreshadowed and pre-empted the new type of light building, which is perfectly adapted to man, being a new task of the architect.

Gendering: Women and Lightness

In the new culture of light technologies and the "light touch" in dealing with them, the feminine approach became enhanced. The hard grip on mobility machines mentioned before was heavily gendered, of course. Pointing to the need of physical force, this argument was often employed to keep women out of the new mobility machines – together with the accusation that women were not able to keep a cool head in crises. As soon as light structures required or were supposed to require a
Fig. 8 sensitive touch, this argument was no longer viable. On the contrary: women were now seen as better suited to the delicate, light new machines, while men apparently lacked the qualities of "feeling the needs" of, for instance, light aeroplanes.

Frequently the mobility machines themselves were symbolically linked with feminine qualities and with prototypical female figures, mostly taken from the vast reservoir of cultural and mythological characters. Names like *Ariel*, *Sylph*, or *Fairy* were typical for bicycles, aimed not only – but increasingly – at a female market. The culture of lightness is also contextualized by the iconography of transparency and diaphanous colours or clothing that characterized German Jugendstil and French Art Nouveau after 1900.

The Attraction of Lightness and Mobility: Fearing a Crisis of Traditional Art

The aesthetic attraction of the new mobility machines was a provocation to traditional art and literature and traditionally-minded artists, too. Around 1900 many members of the avant-garde movement in Europe were particularly attracted to and fascinated by the new dynamic devices. A case in point is the work of the Italian Futurists. Their leader, Filippo Tommaso Marinetti, famously proclaimed in his *Technical Manifesto of Futurist Literature*, published in 1912, that an automobile seemingly run on explosives is more beautiful than the Nike of Samothrace.[28] Another typical protagonist of this fascination is the Italian poet Gabriele D'Annunzio. During an aviation meeting in Brescia – the first one in Italy – he took his first flight with Curtis, regarding the American pilot as far superior to the poet's profession and to himself, as observed by Franz Kafka, who reported the event.[29]

This feeling of inferiority of art and the role of the artist was also common among painters and sculptors. In their case it was the appeal of the new light mobility machines that induced the feeling of inferiority. For instance, when visiting an aeroplane exhibition with Brancusi, Marcel Duchamp exclaimed to him: "Painting has come to an end. Who can do something better than this propeller? Can you?"[30]
Fig. 9 Duchamp followed this up: his ready-made entitled *Bicycle Wheel on a Chair* follows this trajectory.[31]

Likewise, flying was given the status of an art, and an emphatically modern

_ Figure 9.
Duchamp and his *Bicycle Wheel on a Chair*.
© Succession Marcel Duchamp / 2015, ProLitteris, Zurich.

one at that. An American journalist described the art of the pilot Lincoln Beachey in 1913: "There is music and most inspiring grace and prettiest poesy in flight by man in the heavens. And posterity will write the name of Lincoln Beachey as the greatest artist of the aeroplane. In his flying is the same delicacy of touch, the same inspirational finesse of movement, the same developed genius of Paderewski and Milton".[32]

Thus, the act of using avant-garde technology was often seen as a more revolutionary act than producing art. This was a typical feature of twentieth-century art and literature, and within this new and provoking hierarchy, light mobility machines became the focal point. There are many statements playing off technology against art, from the notion of the Expressionist author Franz Richard Behrens in 1915 that Sikorsky (the Russian engineer of huge planes) was more important to him than Kandinsky,[33] to Andy Warhol's statement that the car is better than art.[34]

In these (and many more statements that could be quoted), several trends are recognizable: a deep respect for the new mobility culture; an appreciation of its new aesthetic qualities, especially their lightness and transparency; and a sense of the inadequacy or insufficiency of traditional art. All three trends, surfacing between the 1890s and the First World War, had consequences in other cultural and technological fields. The new mobility machines became paragons for designers and architects, who came to see them as products to be admired and imitated. The aesthetics of lightness and the materials achieving this lightness influenced designers in several fields of work. Light wood, bent laminations, shells formed from thin plies became favourite construction elements – for example, for chair designers. And, of course, architects such as Le Corbusier propagated aeroplanes and aeroplane materials as supplying innovative ideas for architects and stimulating them to think about building along new lines, learning from the construction of mobility machines.

And, last but not least, the provocation of the aesthetics of light mobility machines disturbed notions of traditional art, and this had a lasting effect on transgressing the borders of art – including "found" objects, or only slightly transformed objects, or bringing "real" objects into the realm of art. Thus, the cultures of lightness and mobility, of speed, movement and transparency proved to be a significant area of provocation to which designers, architects and artists had to react during the rest of the twentieth century. Otherwise, they would prove themselves hopelessly "passéiste".

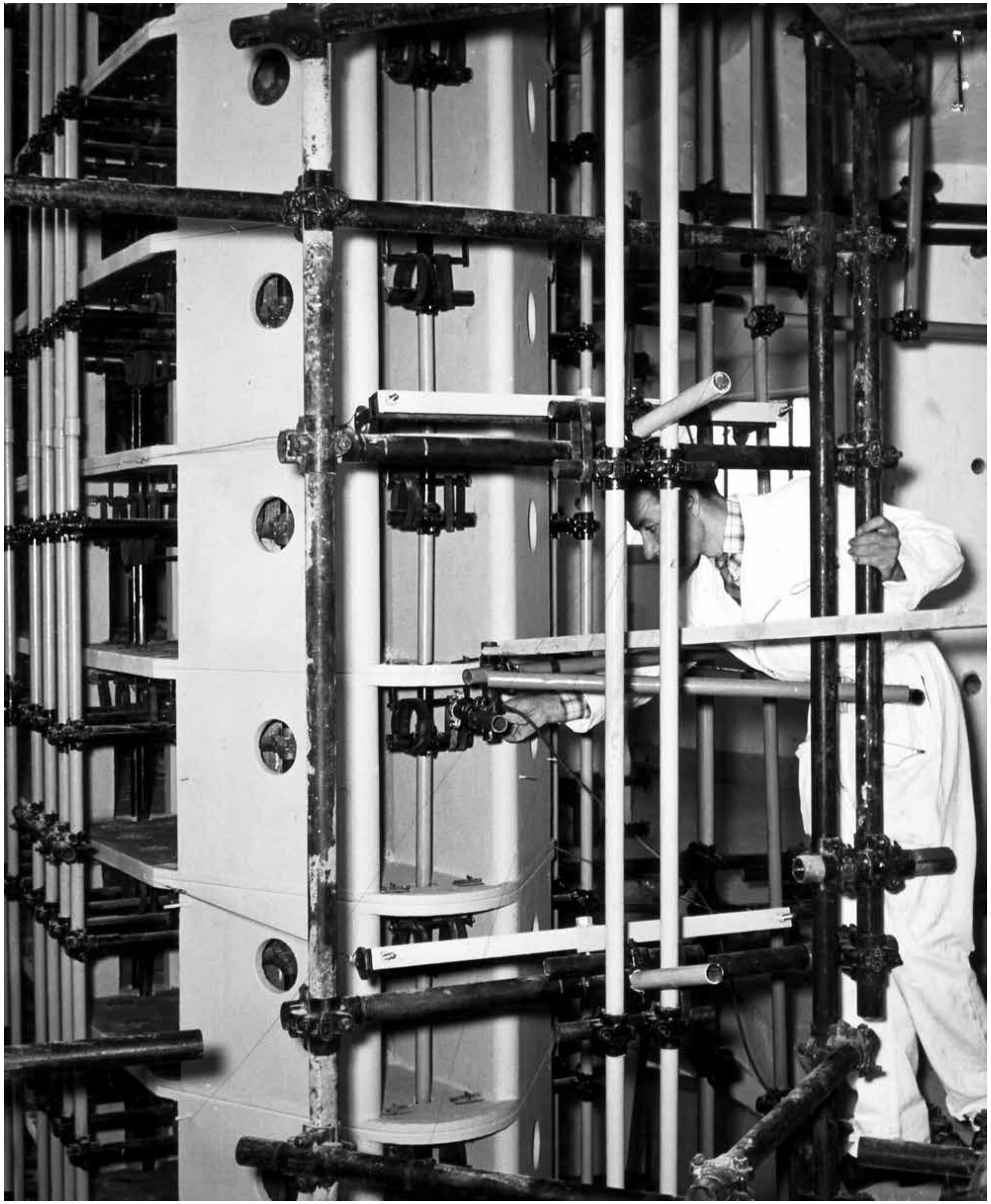
Abstract

«Un uomo a cavallo del nulla».
Strutture leggere e nuove culture della mobilità negli anni intorno al Novecento.

Intorno al 1900, con l'avvento di nuovi tipi di macchine per la mobilità – biciclette, piccole barche, automobili, aeroplani – si è evoluto un nuovo stile tecnologico. Divennero disponibili nuovi materiali e nuovi modi di costruire strutture leggere, trasparenti e innovative, che venivano fatte funzionare in modi anch'essi nuovi. Tutto questo suscitò l'opposizione degli ingegneri, mentre un'accoglienza culturale entusiastica proveniva da coloro che prendevano parte alla rivoluzione nelle arti. L'intervento intende esplorare lo stile ingegneristico delle nuove macchine per la mobilità, mettendone in luce l'aspetto e la loro ricezione culturale. Vengono presi in considerazione diversi ambiti: la storia dell'ingegneria strutturale; il contesto estetico di una cultura dematerializzata fatta di «raggi e correnti elettriche» (Asendorf); la ridefinizione del corpo quando si interfaccia con le macchine per la mobilità; il paradigma della trasparenza nel contesto artistico. Per concludere, il testo analizza come la tecnologia e la cultura leggere divennero, per l'arte tradizionale, una provocazione.

Notes

_ 1. Cf. D. Hicks, M.C. Beaudry, *The Oxford Handbook of Material Culture Studies*, Oxford University Press, Oxford 2010; S. Lubar, W.D. Kingery, *History from Things: Essays on Material Culture*, Smithsonian Institution Press, Washington DC 2007; J. Skibo, M.B. Schiffer, *People and Things: A Behavioral Approach to Material Culture*, Springer, Heidelberg 2008.
_ 2. Cf. R.P. Hallion, *Taking Flight: Inventing the Aerial Age from Antiquity through the First World War*, Oxford University Press, Oxford-New York 2003, pp. 138-145.
_ 3. K. Möser, *Fahren und Fliegen in Frieden und Krieg. Kulturen individueller Mobilitätsmaschinen 1880-1930*, Verlag Regionalkultur, Heidelberg 2009.
_ 4. Cf. J. Krausse, *Versuch, auf's Fahrrad zu kommen. Zur Technik und Ästhetik der Fahrrad-Evolution. Zwischen Fahrrad und Fließband, absolut modern sein,* in *Culture technique* in *Frankreich 1889-1937*, exhibition catalogue Neue Gesellschaft für bildende Kunst (Staatliche Kunsthalle Berlin, 20.3.-8.5.1986), Elefanten Press, Berlin 1986, pp. 59-74, pp. 64-67.
_ 5. D. Charles, *Die Geschichte des Yachtsports*, Delius & Klasing, Bielefeld 2002, p. 136.
_ 6. *Ibidem*, p. 132.
_ 7. *Ibidem*, p. 143.
_ 8. *Ibidem*, pp. 174-175.
_ 9. M. Dierikx, *Fokker: A Transatlantic Biography*, Smithsonian Institution Press, Washington DC-London 1997; A. Fokker, B. Gould, *Flying Dutchman: The Life of Anthony Fokker*, Routledge, London 1932.
_ 10. Fokker, Gould 1932 (see footnote 9), pp. 63, 77 et al.
_ 11. Editorial note, "Flugsport", 8, 1916, pp. 93-94.
_ 12. Quoted from http://www.gutenberg.org/files/42673/42673-h/42673-h.htm, p. 80 (accessed 8 May 2014).
_ 13. J. Woodforde, *The Story of the Bicycle*, Henley, London-Boston 1980, p. 50.
_ 14. *Ibidem.*, p. 39.
_ 15. "Bleriot ist in der Luft, man sieht seinen geraden Oberkörper über den Flügeln, seine Beine stecken tief als Teil der Maschinerie. Die Sonne hat sich geneigt und unter dem Baldachin der Tribünen durch beleuchtet sie die schwebenden Flügel". Quoted from P. Demetz, *Die Flugschau von Brescia. Kafka, D'Annunzio und die Männer, die vom Himmel fielen*, Zsolnay, Vienna 2002, p. 25.
_ 16. Möser 2009 (see footnote 3).
_ 17. W. Schivelbusch, *Geschichte der Eisenbahnreise. Zur Industrialisierung von Raum und Zeit im 19. Jahrhundert*, Hanser, Munich-Vienna 1977.
_ 18. C. Asendorf, *Ströme und Strahlen. Das langsame Verschwinden der Materie um 1900* (Werkbund-Archiv 18), Anabas Verlag, Giessen 1989.
_ 19. P. Virilio, *Geschwindigkeit und Politik. Ein Essay zur Dromologie*, Merve, Berlin 1980.
_ 20. Cf. K. Möser, *The Dark Side of Early "Automobilism", 1900-1930: Violence, War and the Motor Car*, "Journal of Transport History", 24, 2003, n. 2, pp. 238-258.
_ 21. Cf. W. Bijker, *Of Bicycles, Bakelite, and Bulbs: Towards a Theory of Sociotechnical Change*, MIT Press, Cambridge MA-London 1995.
_ 22. Cf. K. Möser, *Geschichte des Autos*, Campus Verlag, Frankfurt am Main-New York 2002.
_ 23. P. Hoffman, *Wings of Madness: Alberto Santos-Dumont and the Invention of Flight*, Hyperion, New York 2003.
_ 24. Krausse 1986 (see footnote 4), p. 72.
_ 25. B. Brecht, *Werke in 20 Bänden*, vol. 9, Suhrkamp, Frankfurt am Main 1967, p. 127.
_ 26. K. Möser, *Stabile und instabile Maschinen – Fliegen, Fahren und Gleichgewicht 1910-1918*, in R. Schönhammer (ed.), *Körper, Dinge und Bewegung. Der Gleichgewichtssinn in materieller Kultur und Ästhetik*, Facultas, Vienna 2009, pp. 109-122.
_ 27. K. Möser, *Automobil und Körper*, in G. Schmidt et. al. (eds.), *Und es fährt und fährt … Automobilindustrie und Automobilkultur am Beginn des 21. Jahrhunderts*, edition sigma, Berlin 2005, pp. 285-296.
_ 28. http://greeninteger.com/pdfs/marinetti-technical-manifesto-of-futurist-literature.pdf (accessed 4 May 2014).
_ 29. F. Kafka, *Die Aeroplane von Brescia*, in F. Kafka, *Drucke zu Lebzeiten*, W. Kittler, H.Koch, G. Neumann (eds.), Fischer, Frankfurt am Main 1996, pp. 401-412.
_ 30. "Die Malerei ist am Ende. Wer kann etwas Besseres machen als diesen Propeller!", quoted from J. Simmen, *Die Aufhebung der Erdgebundenheit in Kunst und Architektur*, in Deutsche Lufthansa AG (ed.), *Aviatik und Avantgarde. Fliegen und Schweben*, Lufthansa, Cologne 1988, pp. 55-65, p. 26 (my translation); cf. also Y. Rabinovich, http://www.invisiblebooks.com/Duchamp.htm (accessed 4 May 2014).
_ 31. For the "finding" of the bicycle wheel as a machine gun mount cf. http://www.invisiblebooks.com/ Duchamp.htm (accessed 4 May 2014).
_ 32. H.S. Villard, *Contact!: The Story of the Early Birds*, Bonanza Books, New York 1967, p. 196.
_ 33. Feldtagebuch, 14.5.1915, 126/1, p. 7, Deutsches Literaturarchiv Marbach.
_ 34. E. Mai, *Das Auto in Kunst und Kunstgeschichte*, in T. Buddensieg, H. Rogge (eds.), *Die Nützlichen Künste. Gestaltende Technik und Bildende Kunst seit der Industriellen Revolution*, exhibition catalogue (Messegelände am Funkturm, Berlin, 15.5.-21.6.1981), Quadriga, Berlin 1981, pp. 332-346, p. 344.



_ Figura 1.
Dettaglio del modello in scala 1:15 del grattacielo Pirelli (Archivio Storico ISMES).

Gabriele Neri

Pensare in piccolo per costruire in grande

Teoria, prassi e cultura del modello in scala ridotta nella ricerca della forma strutturale nel XX secolo

Durante il XX secolo il modello in scala ridotta ha rappresentato per molti progettisti un mezzo indispensabile per affrontare la definizione della forma strutturale.Infatti, se anche nei secoli precedenti il modello fu utilizzato non soltanto per definire questioni di tipo compositivo ed estetico ma anche di tipo tecnico e strutturale,[1]i progressi scientifico-tecnologici avvenuti tra Ottocento e Novecento (messa a punto di nuove teorie fisico-matematiche, di nuovi strumenti di misura, nuovi materiali eccetera) hanno reso possibile lo sviluppo di sofisticate procedure sperimentali di verifica e gestione delle variabili statiche di strutture complesse, spesso sopperendo ai limiti delle coeve formulazioni teoriche della scienza delle costruzioni. Tra i numerosi ingegneri e architetti che nel Novecento ricorsero con frequenza al modello in scala ridotta in funzione della progettazione strutturale si possono citare Pier Luigi Nervi, Eduardo Torroja, Yoshikatsu Tsuboi (per gli edifici di Kenzo Tange, ma non solo), Heinz Hossdorf, Ove Arup, Frei Otto, Kenzo Tange, Sergio Musmeci e molti altri.

Analizzando queste sperimentazioni da diversi punti di vista,[2] si comprende che dietro alle differenziazioni di tipo tecnico del singolo esperimento – legate al materiale utilizzato, alla scala del modello e al compito specifico – vi sono diversi tipi di approccio al problema della forma strutturale, aiutati o favoriti proprio dalla pratica sul modello. Nei limiti del presente contributo, è possibile far emergere almeno due diversi modi di concepire la genesi e lo sviluppo della forma strutturale, che si rendono evidenti incrociando l'analisi di casi-studio peculiari con brani della produzione teorica di alcuni degli autori citati. Da un lato, infatti, è possibile rintracciare una concezione del modello come strumento di verifica di una forma strutturale già in buona parte definita a priori da parte del progettista; dall'altro, invece, emerge la volontà di superare questo tipo di logica utilizzando il modello per trovare (e non solo verificare) una forma ottimale.

In questa duplice visione della ricerca sperimentale e del ruolo del modello come strumento di lavoro – due visioni che spesso tendono a contaminarsi, piuttosto che restare freddamente distinte – il modello diventa dunque il veicolo privilegiato nel passaggio dalla mente alla materia reale: uno strumento tecnico, certamente, ma anche un manufatto simbolico nel quale si concentra la forza potenziale del progetto.

Form-checking

Rispetto alla prima categoria individuata appare emblematico il notevole sviluppo della modellazione strutturale nel corso del Novecento, una tecnica sperimentale basata sull'utilizzo di speciali modelli in scala ridotta sui quali era possibile riprodurre le condizioni che una determinata struttura avrebbe dovuto sopportare una volta costruita (ad esempio, peso proprio, carico del vento, azioni sismiche eccetera). Questi modelli infatti corrispondono all'opera da realizzare non soltanto dal punto di vista geometrico ma anche in relazione ad altri tipi di grandezze influenti per l'analisi del loro comportamento statico,[3] secondo una precisa e complessa similitudine tra modello e prototipo.[4] Tralasciando in questa sede le pionieristiche esperienze condotte negli Stati Uniti negli anni Venti per i grandi impianti idroelettrici,[5] un contributo decisivo per lo sviluppo di questa tecnica fu dato da due dei maggiori protagonisti dell'ingegneria strutturale del Novecento: Eduardo Torroja e Pier Luigi Nervi. Entrambi, infatti, all'inizio degli anni Trenta, trovandosi in difficoltà nella verifica delle loro complesse strutture, individuarono nel modello in scala ridotta uno strumento capace di superare le limitazioni intrinseche nella teoria della scienza delle costruzioni, che a quei tempi sembrava inadeguata a restituire e governare in toto il comportamento di un materiale sorprendente ma anche complicato (in quanto non omogeneo) come il cemento armato.

Nel 1933 l'ingegnere spagnolo stava studiando la copertura del Gran mercado di Algeciras (progettato con l'architetto D. Manuel Sánchez Arcas), costituita da una calotta sferica di 47,6 m di luce in appoggio su otto supporti collegati da un anello poligonale post-teso. Come scritto nella relazione tecnica, oggi conservata al CEHOPU di Madrid (Centro de Estudios Históricos de Obras Públicas y Urbanismo), la complessità delle equazioni adatte a risolvere questo problema statico rendevano il processo di calcolo «practicamente casi inabordable» e comunque non esaustivo, dal momento che non sarebbe stato possibile tenere in considerazione le deformazioni non elastiche agenti nel cemento.[6] Torroja decise allora di affrontare il problema attraverso il metodo sperimentale, e lo stesso anno fondò a Madrid l'ICON (Investigaciones de la Construcción), un'impresa privata per ricerche sperimentali legate alle costruzioni. La copertura del mercato di Algeciras fu così riprodotta e verificata su un modello in scala 1:10, e negli anni successivi la stessa tecnica venne usata per verificare molti altri progetti, tra cui la copertura del Frontón Recoletos di Madrid (modello in microcalcestruzzo, scala 1:10, testato nel 1935), formata da una volta sottile cilindrica a due lobi disuguali con una luce di 55 m. Nel corso degli anni Torroja sarà sempre più coinvolto nel mondo della modellazione, e figurerà tra i fondatori di quello che oggi si chiama Instituto Eduardo Torroja de la Construcción y del Cemento.[7]

In Italia, nel 1935, Pier Luigi Nervi stava invece progettando la complessa struttura delle sue celebri aviorimesse in cemento armato, scontrandosi con la difficoltà di tradurre in formule una struttura che si allontanava dalle tipologie strutturali allora utilizzate. Come ribadì in più occasioni, l'ingegnere aveva infatti progettato l'ardi- Fig. 2

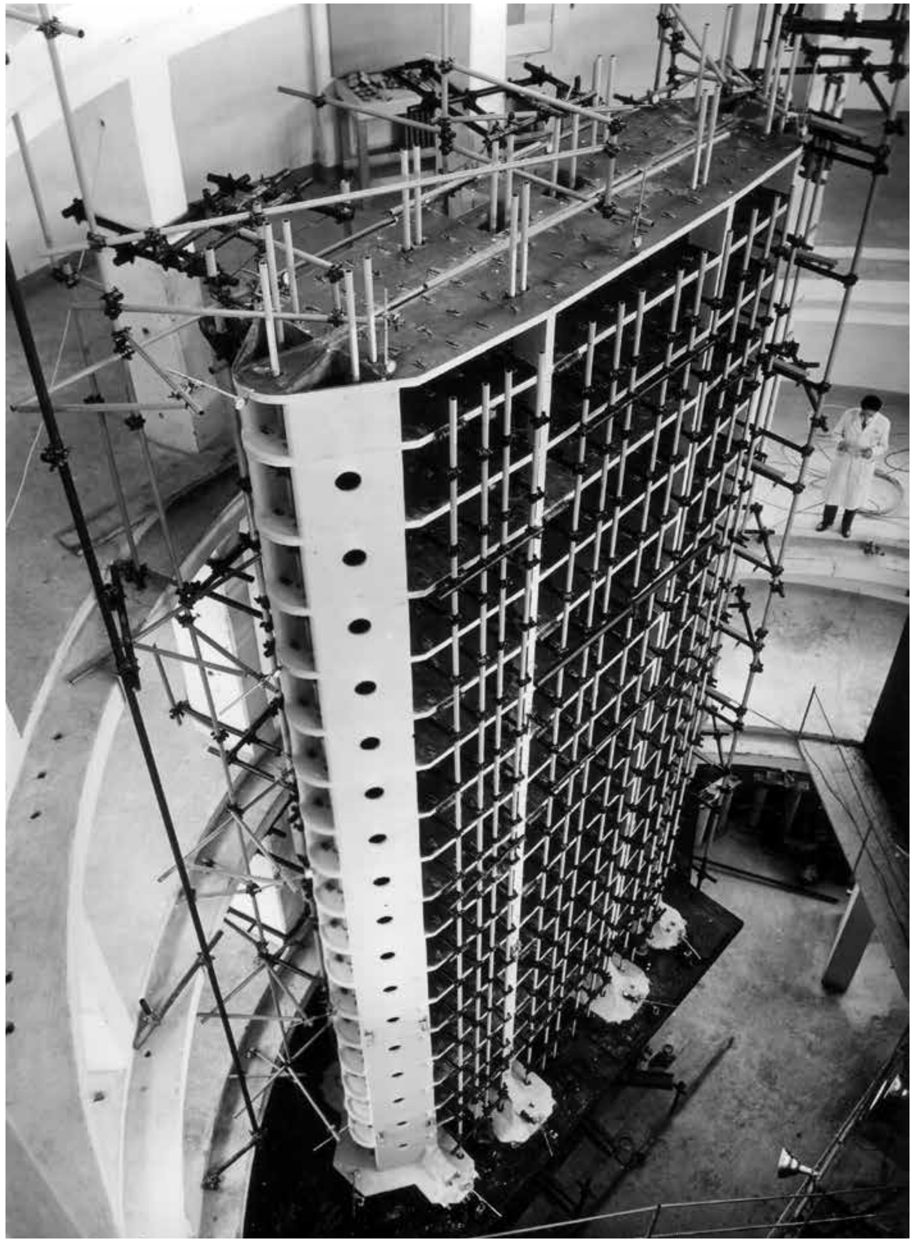
_ Figura 2.
Pier Luigi Nervi, modello in celluloide in scala 1:37,5 dell'Aviorimessa di Orvieto, 1935-1936 (P.L. Nervi, *Scienza o arte del costruire?*, Roma 1945, tav. III).

ta volta a padiglione – formata da una doppia orditura di travi ad arco in cemento armato (alte circa un metro per 10 cm di spessore), incrociate a 90 gradi, fortemente iperstatica – utilizzando soprattutto il proprio "intuito statico" e pochi calcoli orientativi dai quali sarebbe stato imprudente passare alla fase esecutiva.[8] La soluzione arrivò da Arturo Danusso, celebre ingegnere e professore che aveva da poco (1930-1931) inaugurato al Politecnico di Milano un piccolo laboratorio dedicato alla sperimentazione su modelli in scala ridotta, attraverso i quali era possibile analizzare geometrie difficilmente schematizzabili con la sola teoria, ad esempio quelle delle grandi dighe. Nel 1935-1936 fu così realizzato a Milano un modello in celluloide in scala 1:37,5 sul quale si esaminò il comportamento statico in regime elastico della struttura, sotto l'azione del peso proprio e dei sovraccarichi accidentali.[9] Come affermò Danusso: «Anche qui il calcolo – come la materia dantesca – era sordo a rispondere. Non fu sordo il modello, anzi fu prezioso consigliere di utili adattamenti».[10]

Assodata l'efficacia del modello strutturale, Nervi, come Torroja, non lo abbandonò più. Al primo modello delle aviorimesse seguì un secondo, e nel decennio successivo furono riprodotti e testati al Politecnico di Milano diversi altri suoi progetti. Il legame tra Nervi e la modellazione strutturale si intensificò poi a partire dal 1951, quando Arturo Danusso fondò a Bergamo l'ISMES (Istituto Sperimentale Modelli e Strutture), centro presto famoso in tutto il mondo in questo settore. Capendo le potenzialità delle moderne attrezzature dell'ISMES, Nervi intensificò i rapporti con Danusso e con i suoi allievi (in particolare con l'ingegnere Guido Oberti) e negli anni successivi fece testare su modello in scala ridotta il Grattacielo Pirelli, la Torre della Borsa di Montreal, l'Arena di Norfolk in Virginia, la Cattedrale di San Francisco e molte altre strutture.[11] Dal 1964 egli divenne addirittura presidente dell'Istituto.

Figg. 1, 3
Figg. 4-5

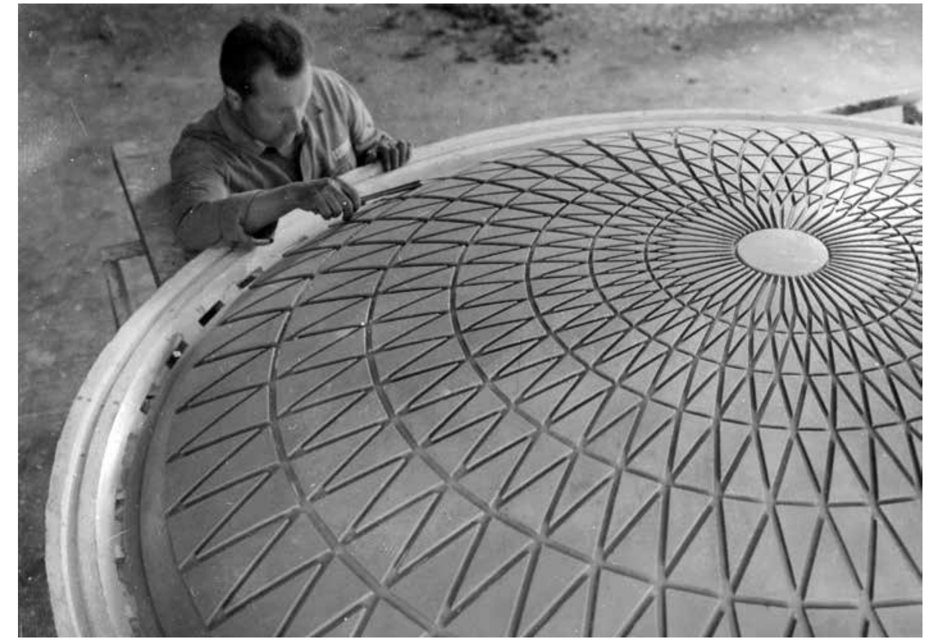
Analizzando il pensiero dei due ingegneri – entrambi ci hanno lasciato numerosi scritti da cui si evince la loro particolare "filosofia delle strutture"[12] – si comprende come dietro al favore per il modello in scala ridotta vi sia un preciso atteggiamento nei confronti del ruolo della teoria della scienza delle costruzioni all'interno del processo progettuale, dell'ingegneria in generale e di conseguenza nei confronti del peso che formule e calcoli matematici avrebbero dovuto avere nel processo di definizione di una forma strutturale. Ad esempio, già nel 1931, in un articolo dall'emblematico titolo interrogativo *Scienza o arte dell'ingegnere?*, Nervi ragionava sull'evidente distanza tra la realtà e la presunta esattezza delle teorie matematiche, insegnate nelle università come foriere di dati certi e inoppugnabili ma in realtà ben lontane dalla realtà dei fatti, specie in un settore così pieno di variabili come quello del cemento armato. Scriveva infatti: «E allora che valore possono avere quei numeri che si raggiungono dopo formule che trattano con esattezza cose inesatte, se non quello di indici di ordine di grandezza, di risultati di larga approssimazione da interpretarsi con un criterio tutto personale dove elementi di giudizio siano il sentimento e l'intuito, uniche facoltà capaci di valutare le cose non valutabili con metro e



_ Figura 3.
Pier Luigi Nervi, modello in scala 1:15 del grattacielo Pirelli, 1955-1956 (Archivio Storico ISMES).

bilancia?»[13] E in un altro scritto: «Non si possono fare regole se non di larghissima massima, e perciò l'opera dell'ingegnere ha sempre qualche cosa di assolutamente personale, frutto più dell'intuito che dell'anonimo ragionamento… Troppo spesso si confonde l'ingegneria con i procedimenti matematici di calcolo che le sono propri e la espressione buon calcolatore o buon matematico è molte volte, e non solo da profani, confusa con quella di buon ingegnere».[14]

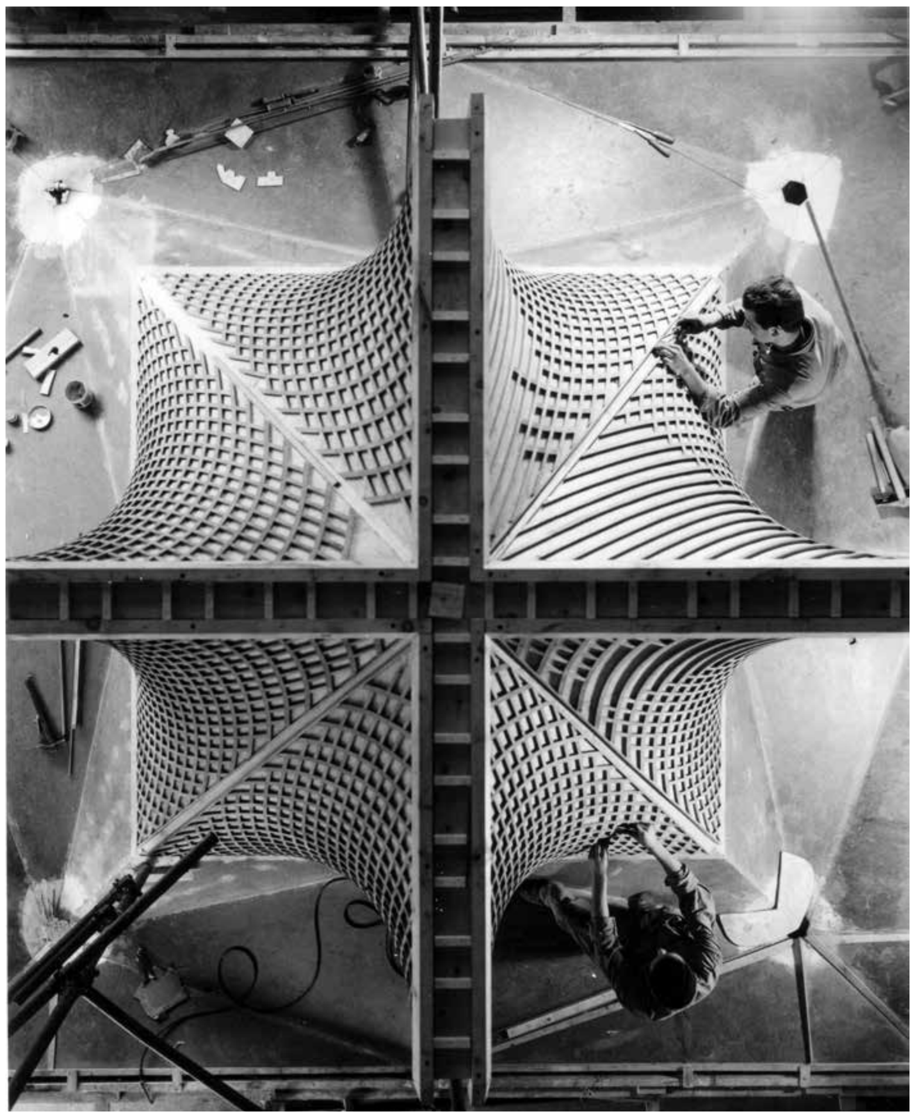
_ Figura 4.
Il confezionamento del modello della Norfolk Scope Arena all'ISMES, 1967 (Archivio Storico ISMES).



Tali riflessioni, frutto di anni di pratica nei cantieri, portarono Nervi all'elogio della sperimentazione – vista come strada maestra nella comprensione dei fenomeni statici e del comportamento dei materiali – e all'esaltazione dell'intuito, preziosa facoltà umana capace di individuare e definire una forma strutturale. Simile il pensiero di Torroja: «La mente che concepisce una struttura – scriveva nel 1957 –, o la mano che la traccia, non ricevono aiuto di sorta da sviluppi matematici astrusi e complessi».[15] E ancora: «L'atto di progettare, anche una struttura molto semplice, pur avendo molti rapporti con la scienza e con la tecnica, rimane sempre legato all'arte, al senso comune, all'inclinazione, alla predisposizione, alla soddisfazione professionale di realizzare un progetto adeguato; al quale, poi, il calcolo non apporterà che pochi ritocchi atti a garantire la capacità resistente dell'opera».[16]

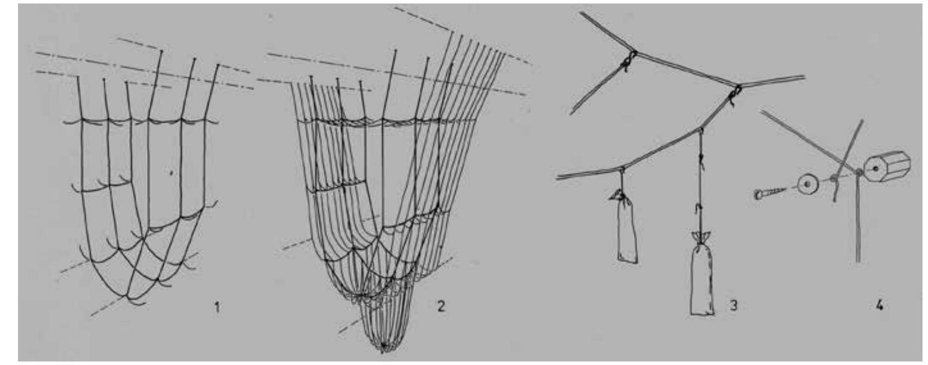
Partendo da questi presupposti, appare chiaro come la tecnica della modellazione strutturale fosse – almeno in linea di principio, dal momento che assumerà molteplici significati e valenze nelle carriere dei due ingegneri[17] – uno strumento particolarmente in sintonia con questa visione dell'ingegneria e della progettazione. Da un lato, infatti, costruire e testare un modello in scala ridotta significava operare sulla realtà concreta (seppur "in miniatura") e non su astratte teorie, in accordo con la convinzione di Nervi che ogni contatto con la realtà fisica portasse necessariamente «ad un atteggiamento mentale di modesta ammirazione di fronte alla misteriosa e complessa saggezza delle cose, ben più appropriato e proficuo che non la semplicistica sicurezza, cui può condurre l'assolutismo formale delle schematizzazioni matematiche».[18] Dall'altro lato, è necessario osservare come la costruzione e la verifica di un modello strutturale presupponesse la definizione, o "l'invenzione", a priori di una forma strutturale: una forma che nasce quindi nella mente del progettista grazie al suo "intuito" e viene poi, in un secondo tempo, passata al vaglio di un procedimento sperimentale che ne confermerà gli assunti di base e al massimo potrebbe suggerire qualche piccola modifica, come accadde per le aviorimesse di Nervi o per il mercato di Torroja. Questo processo è stato spiegato bene da Giulio Carlo Argan, che nei suoi fondamentali scritti sull'opera dell'ingegnere italiano diede parecchio rilievo proprio alla sperimentazione su modello e al ruolo dell'intuizione:

> Avendo constatato l'insufficienza del calcolo matematico, Nervi lo sostituisce e lo integra con la sperimentazione: costruisce il modello di una forma e lo sottopone a una serie di sollecitazioni fisiche che riproducono con la maggior fedeltà possibile quelle che la struttura dovrà, nella realtà, sostenere. Sulla base di queste prove di carico, procede alle necessarie modifiche e determina la forma finale della sua struttura di cemento. Ma perché una forma possa essere sperimentata,



_ Figura 5.
Fasi del confezionamento del grande modello cementizio della Cattedrale di San Francisco all'ISMES, 1964 (Archivio Storico ISMES).

_ Figura 6.
Fasi costruttive del modello funicolare di Gaudí: 1. Realizzazione della struttura primaria; 2. Aggiunta della struttura secondaria; 3. Dettaglio degli uncini utilizzati per collegare i fili e i sacchetti riempiti di pallini di piombo; 4. Dettaglio dei dischi in legno collegati ai fili (J. Tomlow, *Das Modell*, Stuttgart 1989, p. 55).



> è necessario averla "inventata"; … Così si comprende meglio perché il calcolo matematico raramente conduca alla determinazione di una giusta forma spaziale: infatti quel calcolo dà per postulata un'idea o una struttura geometrica dello spazio e in relazione ad essa computa le possibilità di resistenza e funzionali dei materiali e delle strutture.[19]

Queste considerazioni, scritte nel 1955, ribadivano la tesi di Argan già enunciata dieci anni prima secondo cui l'opera nerviana poteva essere inserita a pieno titolo all'interno di un "modo artistico" del costruire, e addirittura essere paragonata a quella dei grandi costruttori del Rinascimento. Questi infatti utilizzavano il modello allo stesso modo di Nervi, dimostrando una tesi di cruciale importanza: «La forma è la determinante della forza, e non l'inverso».[20]

Form-Finding

A partire dal secondo dopoguerra, punti di vista come quello di Argan – e di conseguenza anche il *modus operandi* seguito da Nervi nella sua attività – cominciarono a essere criticati da più parti. Se uno dei problemi fondamentali della scienza delle costruzioni era sempre stato, come si è visto, quello di poter verificare un elemento o un sistema di elementi strutturali dati a priori, selezionati a partire da un catalogo di forme codificate nel tempo oppure "intuiti" in base alla sensibilità e all'esperienza del singolo progettista, dagli anni Cinquanta in avanti si è invece potuto assistere alla definizione di un approccio al problema strutturale completamente opposto, in cui al centro non sta la verifica ma la ricerca della forma strutturale (*form-finding*), delegata molto spesso proprio al modello fisico, che entra dunque in campo fin dalle prime fasi della progettazione.

L'idea di poter determinare una forma strutturale deducendola (e non solo "intuendola") da procedimenti empirici trova diversi antecedenti nella storia delle costruzioni. Il caso più celebre è forse quello di Antoni Gaudí (1852-1926): il suo progetto per la Chiesa della Colonia Güell a Santa Coloma de Cervelló, nei pressi di Barcellona, commissionato da Eusebio Güell nel 1898, fu infatti portato avanti usando un particolarissimo *modelo colgante*: un modello composto da un sistema di fili ai quali erano appesi dei piccoli pesetti. Il principio è quello noto della catenaria invertita, già sfruttato ad esempio da Christopher Wren per definire il profilo del-

Fig. 6

la cupola della St. Paul's Cathedral a Londra alla fine del Seicento: se la catenaria è soggetta a sforzi a trazione, ribaltando di 180 gradi il sistema si ottiene una struttura soggetta a compressione. «Ut pendet continuum flexile, sic stabit contiguum rigidum inversum»,[21] aveva enunciato Robert Hooke.

Per Gaudí il ribaltamento del sistema veniva fatto ponendo uno specchio sotto il modello, così da visualizzare in anteprima il profilo delle volte da costruire. In qualche modo tale metodologia rappresentava un'evoluzione, o quantomeno una declinazione, della statica grafica, che l'architetto catalano conosceva bene e che aveva utilizzato nei suoi progetti precedenti. Fu un processo molto lungo e laborioso: la costruzione e gli esperimenti sul modello cominciarono nel 1898 e durarono dieci anni. Se esperimenti simili furono sviluppati anche in passato – sono conosciuti i modelli funicolari di Heinrich Hübsch e in particolare le prove effettuate da Giovanni Poleni sulla cupola di San Pietro –,[22] il modello di Gaudí li superava però per dimensione e complessità:[23] il modello della chiesa, allestito all'interno del cantiere, era infatti in scala 1:10, lungo circa 6 m e alto 4 m.

Nel campo del *form-finding* nel corso del Novecento è ben nota l'attività sperimentale di Frei Otto, svolta in proprio e dal 1964 presso l'Institut für leichte Flächentragwerke dell'Università di Stoccarda, al fine di studiare e governare membrane sottili, strutture pneumatiche e tensostrutture,[24] che ancora negli anni Sessanta e Settanta erano difficilmente gestibili dal computer. Si possono citare ad esempio gli studi di schemi strutturali in tensione che ribaltati di 180 gradi diventano soggetti a compressione pura, realizzati con sottili catene metalliche; modelli di gomma sottoposta a tensione uniforme; modelli di tessuto; reti di diverso tipo e modelli realizzati con bende di gesso, che indurendo, una volta bagnate, possono

_ Figura 7.
Heinz Isler, esperimenti con membrane appese e congelate (gta Archivio, ETH Zurigo, fondo Heinz Isler).

_ Figura 8.
Heinz Isler, modello pneumatico per la determinazione di forme strutturali (gta Archivio, ETH Zurigo, fondo Heinz Isler).

mantenere la forma assunta anche quando vengono invertite.[25] Celebri sono anche i suoi esperimenti sulle "superfici minimali" – cioè superfici che sviluppano l'area minima ottenibile per un contorno prefissato, con un minimo impiego di materiale – condotti ad esempio su modelli di pellicole di sapone, anche di dimensioni notevoli, realizzati con una speciale *soap film machine.*

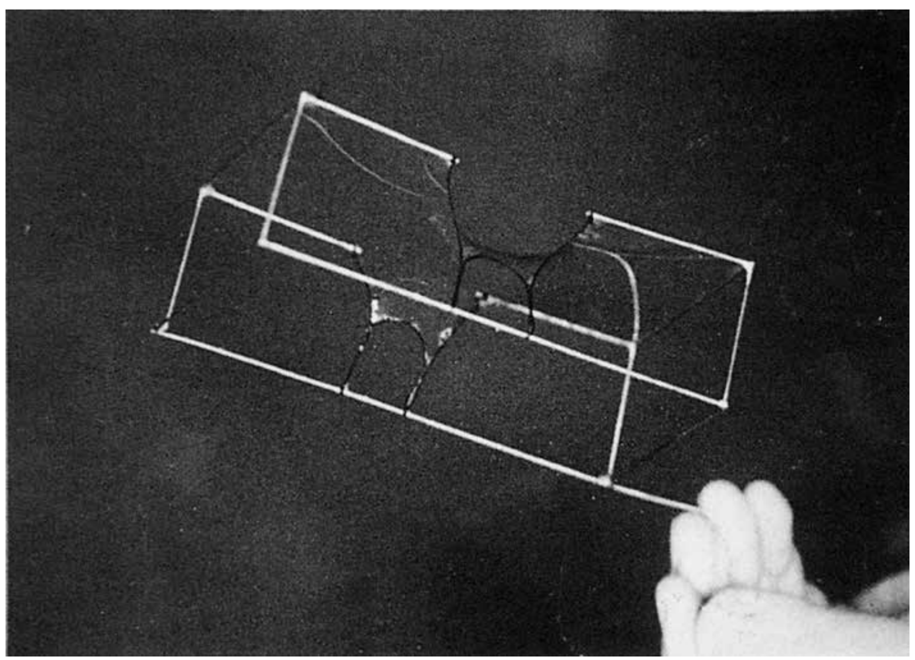
Di grande interesse sono anche gli esperimenti condotti tramite modelli in scala ridotta da Heinz Isler nel campo delle volte sottili in cemento armato,[26] con l'obiettivo di creare una genealogia di *ideal shells*. A partire dagli anni Cinquanta, Isler sondò numerose tecniche sperimentali: il primo metodo, definito "preistorico", consisteva nel dare forma a una piccola collina artificiale lasciando che la terra si disponesse liberamente secondo il proprio peso, fino a ottenere un profilo ottimale. Un secondo sistema prevedeva esperimenti fatti con membrane messe in tensione da un congegno pneumatico: fissando a un piccolo telaio a pianta rettangolare una membrana di gomma e insufflando aria dal basso, essa infatti diviene soggetta soltanto a sforzi di tensione. Una volta sottile della stessa forma sarà quindi soggetta solo a sforzi di compressione, relativi al peso proprio e all'eventuale carico della neve.[27] Le coordinate della forma ottenuta grazie alla pressione dell'aria venivano quindi misurate, e lo schema era pronto per essere rifinito in base agli altri dati del problema statico e funzionale.[28] Una terza tecnica si affidava al cosiddetto *flow method*, che consisteva nell'ottenere forme strutturali dall'espansione e dall'indurimento di una schiuma poliuretanica costretta in un contenitore cavo. Poiché la velocità di espansione della schiuma è variabile da un minimo in corrispondenza dei bordi a un massimo nel centro del contenitore, ciò che si ottiene è una cupola: «This natural function produces lovely shapes, as seen in the hill».[29]

Fig. 8

Il metodo preferito dall'ingegnere svizzero era tuttavia quello della *hanging reversed membrane*, accostabile agli esperimenti di Frei Otto con tessuti e reti. Isler era solito spiegare questa tecnica raccontando dell'esperimento da lui fatto nel gelido febbraio del 1957, quando appese in giardino un telo sottile a un incrocio di pali, lo spruzzò con acqua e ne attese l'indurimento causato dalla temperatura invernale. Una volta "congelata", la forma ottenuta fu ribaltata: «Thus I got a very elegant and light shell structure, resting on four points and being in equilibrium. It had obtained its perfect and natural shape by its own weight. In its final position the dome part had only compressional forces, as the cloth itself, when hanging, evidently had only tensional forces».[30]

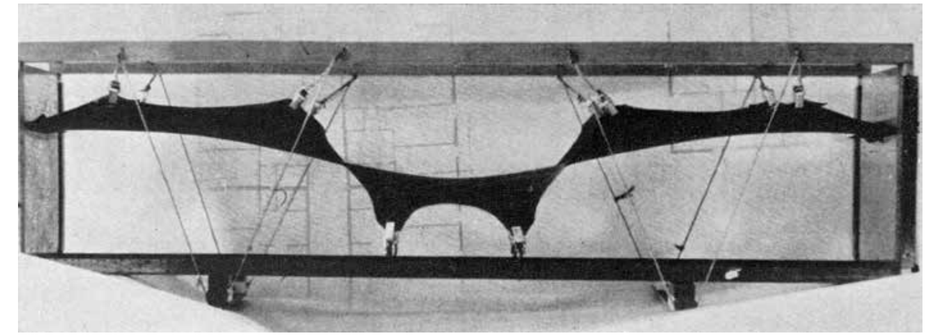
Fig. 7

All'interno di questo filone sperimentale si distinse in Italia la figura di Sergio Musmeci, autore di progetti singolari come il ponte sul Basento a Potenza (1967-1975). Molto vicine alle ricerche di Frei Otto sono le sue indagini sulla geometria del continuo e in particolare sulle superfici minimali, nelle quali i modelli non si limitano ad essere la visualizzazione tridimensionale di speculazioni teoriche, ma assumono un ruolo attivo determinante nella genesi della forma, complementare e a volte prioritario – data la complessità di descrivere analiticamente certe geometrie – rispetto all'analisi matematica. Nel modello di studio utilizzato per il ponte sull'Astico vicino a Vicenza (1956), costituito da fili a cui sono appesi semplici bulloni e poi capovolto in modo da ottenere il profilo corrispondente all'andamento dei carichi, troviamo una consapevole citazione di Gaudí; in altri casi invece è diretto il legame con quanto sarà sviluppato, poco più tardi, nei laboratori di Stoccarda con Otto. Per stabilire il profilo dei sostegni del ponte di Tor di Quinto a Roma (1959), pensati come volte a membrana a compressione uniforme e isotropa (il suo obiettivo era di far lavorare il calcestruzzo a compressione pura), Musmeci ricorre infatti a un modello di gomma fortemente tesa e ad esperimenti fatti con una pellicola di sapone.[31]



_ Figura 9.
Sergio Musmeci, modello di soluzione saponata e fili di cotone per una prima determinazione della forma del Ponte sul Basento ("L'industria italiana del Cemento", n. 2, febbraio 1977).

_ Figura 10.
Sergio Musmeci, modello in neoprene del Ponte sul Basento, messo in tensione con uno speciale dispositivo di prova ("L'industria italiana del Cemento", n. 2, febbraio 1977).



Degno di nota è il processo progettuale seguito per trovare e, successivamente, verificare la forma strutturale del ponte sul Basento. Per trovare la forma della "sottilissima" membrana in calcestruzzo armato (circa 30 cm), pensata come superficie a compressione uniforme ma non isotropa, egli fece innanzitutto esperimenti con soluzione saponata fatta formare tra fili di cotone e filo di ferro, elaborando poi i dati ottenuti con vari processi di calcolo.[32] Ottenuti i primi risultati, ancora approssimati, Musmeci fa realizzare un modello in neoprene, materiale che rispetto alla pellicola di sapone dava diversi vantaggi: oltre a essere più stabile e a consentire la formazione di tensioni differenziate in due direzioni perpendicolari (così come previsto per la volta del ponte), esso permetteva un rilievo preciso, attraverso una quadrettatura della sua superficie, della forma ottenuta in risposta alle forze applicate. Constatata la corrispondenza tra il rilievo della superficie di neoprene e la forma ottenuta con il calcolo,[33] Musmeci dispone finalmente di una prima vera superficie di progetto, dalla quale procedere per studi, calcoli e verifiche più specifiche. Pur trovandosi ancora in uno stato embrionale, la forma strutturale – una forma «ancora senza nome»[34] – era stata individuata, e la fase della creazione cede progressivamente il passo a quella della verifica, condotta utilizzando modelli simili a quelli usati da Pier Luigi Nervi: uno in metacrilato (scala 1:100) e uno in cemento armato (scala 1:10), lungo 14 m, realizzato all'ISMES nel 1970-1971.

Fig. 9

Fig. 10

Sarà proprio Musmeci a spiegare le ragioni alla base di questa ostinata ricerca della forma strutturale.[35] Scriveva infatti all'inizio degli anni Settanta:

> Il fatto che il calcolo sia in genere impiegato solo nella fase di verifica, fa sì che esso possa essere di aiuto solo quando le decisioni veramente importanti sono ormai prese. Quando le prende, il progettista è in realtà solo con la sua esperienza individuale, fondata su fatti non quantizzabili e che difficilmente possono essere posti fra loro in un rapporto dialettico. Ed è così che può succedere che tutte le nostre raffinate e approfondite conoscenze di scienza delle costruzioni non ci siano di alcuna utilità, se non indiretta, quando si tratta di dare una forma alle nostre strutture. … La materia viene formata con un atto che è, in ultima analisi, una versione superficiale di quello con cui agisce uno scultore, senza avere di questo né il programma né l'intenzione; che si usi o no la creta, l'atto mentale è sempre, più o meno, quello che corrisponde a dare forma a della creta. In tal modo i fatti più propriamente strutturali restano fuori dalle nostre possibilità, prima ancora che di controllo razionale, di immaginazione e di scelta inventiva.[36]

Per l'ingegnere romano, che all'inizio degli anni Cinquanta aveva lavorato proprio da Nervi[37], il diverso grado di "razionalità" tra la fase della creazione e quella della verifica era il risultato di un modo ormai anacronistico di pensare la scienza delle costruzioni, la quale era stata «essenzialmente concepita come l'insieme di tutte le teorie e metodi di calcolo che consentono la verifica di strutture già progettate»,[38] lasciando però fuori, "per definizione", la fase creativa della forma strutturale. «Bisogna pensare – precisava Musmeci – che la scienza delle costruzioni si era andata sviluppando, nei secoli XVIII e XIX, come figlia della fisica e della meccanica dell'epoca, strettamente deterministiche. Per i fisici la natura era data e il loro compito era quello di analizzarla, e in modo analogo, per la scienza delle costruzioni dell'Ottocento, la struttura doveva essere data, perché la si potesse "calcolare". Da allora molte cose sono cambiate».[39]

Dal modello fisico a quello virtuale

Nella pratica, la distinzione proposta è ovviamente molto più articolata e sfumata. La complessità del processo di creazione, gestione e verifica della forma strutturale non permette infatti di confinare in compartimenti stagni una fase analitica e una sintetica, il processo intuitivo e quello deduttivo, l'invenzione e la verifica; appare inoltre superfluo sottolineare come qualsiasi esperimento, di un tipo o di un altro, sia già in se stesso il frutto di una precisa progettualità che indirizza le premesse ancor prima dei risultati. Se tali questioni ci porterebbero nei meandri della storia della filosofia della scienza – dalla quale peraltro non si può prescindere nello studio di tali temi – richiedendo molto più spazio di quello qui concesso, l'analisi dei significati sottesi a questi modelli sembra poter essere un valido punto di partenza per interrogarsi su quanto è successo nel campo dell'ingegneria e dell'architettura strutturale dagli anni Sessanta a oggi. L'avvento di nuovi procedimenti di analisi strutturale, resi operativi dall'incredibile sviluppo degli strumenti informatici, ha infatti causato un profondo stravolgimento delle modalità operative all'interno degli studi di progettazione, non soltanto dal punto di vista pratico ma anche teorico, con notevoli conseguenze sulla produzione architettonica e ingegneristica contemporanea.

Rispetto alla categorizzazione avanzata in questo saggio, è possibile evidenziare due strade principali: da un lato, la modellazione strutturale, così come intesa da Arturo Danusso, è stata profondamente ridimensionata (in alcuni settori fatta addirittura sparire) dallo sviluppo di metodi di analisi come il *Finite Element Method* (FEM) e dal connesso ricorso a modelli virtuali generati da software nati nel mondo dell'industria aeronautica e adattati all'ingegneria strutturale; modelli che in breve si sono dimostrati più rapidi ed economici, sebbene non proprio equivalenti,[40] rispetto ai loro corrispettivi tridimensionali.[41] Dall'altro lato, come già intuito da Musmeci e da molti altri tra gli anni Sessanta e Settanta, il calcolo elettronico e in generale gli strumenti informatici si sono ben presto dimostrati straordinariamente efficaci per i processi di *form-finding* – come l'odierno ampio utilizzo di software parametrici in molteplici settori progettuali (tra cui ovviamente anche quello strutturale) dimostra con evidenza – andando prima a completare e poi a sostituire pratiche sperimentali "fisiche" come quelle condotte da Frei Otto e da Heinz Isler. Senza voler cadere in una sterile difesa dell'analogico sul digitale, c'è da chiedersi quali conseguenze abbia avuto un simile passaggio storico-tecnico sul processo di elaborazione della forma strutturale e sul concetto stesso di modello; quali nuovi nuovi orizzonti siano stati aperti e quali, eventualmente, siano stati chiusi. Queste domande, che oggi non trovano ancora risposte sufficienti, appaiono assolutamente decisive per poter valutare con cognizione di causa una rilevante parte della progettazione strutturale contemporanea, e soprattutto rendono evidente la necessità di procedere a uno studio consapevole e approfondito degli strumenti attraverso cui il processo progettuale è andato mutando negli ultimi decenni, sulla scia di ricerche come quella alla base della mostra *Archaeology of the Digital*, andata in scena al CCA di Montreal nel 2013.[42] Ciò non per portare a una sopravvalutazione dei mezzi rispetto ai fini cui il progetto tende, ma con la consapevolezza che le tecniche di rappresentazione, analisi, gestione, verifica eccetera, messe a disposizione dell'architetto e dell'ingegnere, o da lui create appositamente, siano foriere di significati e valori inscindibili dalla complessità del progetto, qualunque esso sia.

Abstract

Thinking small to build great

For many twentieth-century designers, the reduced-scale model represented an essential device for defining and controlling structural forms — one need only think of the work of Arturo Danusso, Pier Luigi Nervi and Sergio Musmeci in Italy; Eduardo Torroja in Spain; Heinz Isler and Heinz Hossdorf in Switzerland; and Frei Otto in Germany, etc. In addition to technical variations associated with the choice of material, scale and task, it is possible to identify two main approaches behind the experiments conducted with these models. On the one hand, the model was initially regarded as a device that was useful for checking the precision of a structural form that had already been conceptually defined; while on the other, many designers found that the modelling process was a perfect way of finding or determining the form of a structure. When these two different perspectives – which in fact include countless nuances and connections – are analysed, many questions emerge, especially in relation to the 'structural architecture' of the last 50 years, in which the physical model has gradually been replaced by new methods and new devices.

Note

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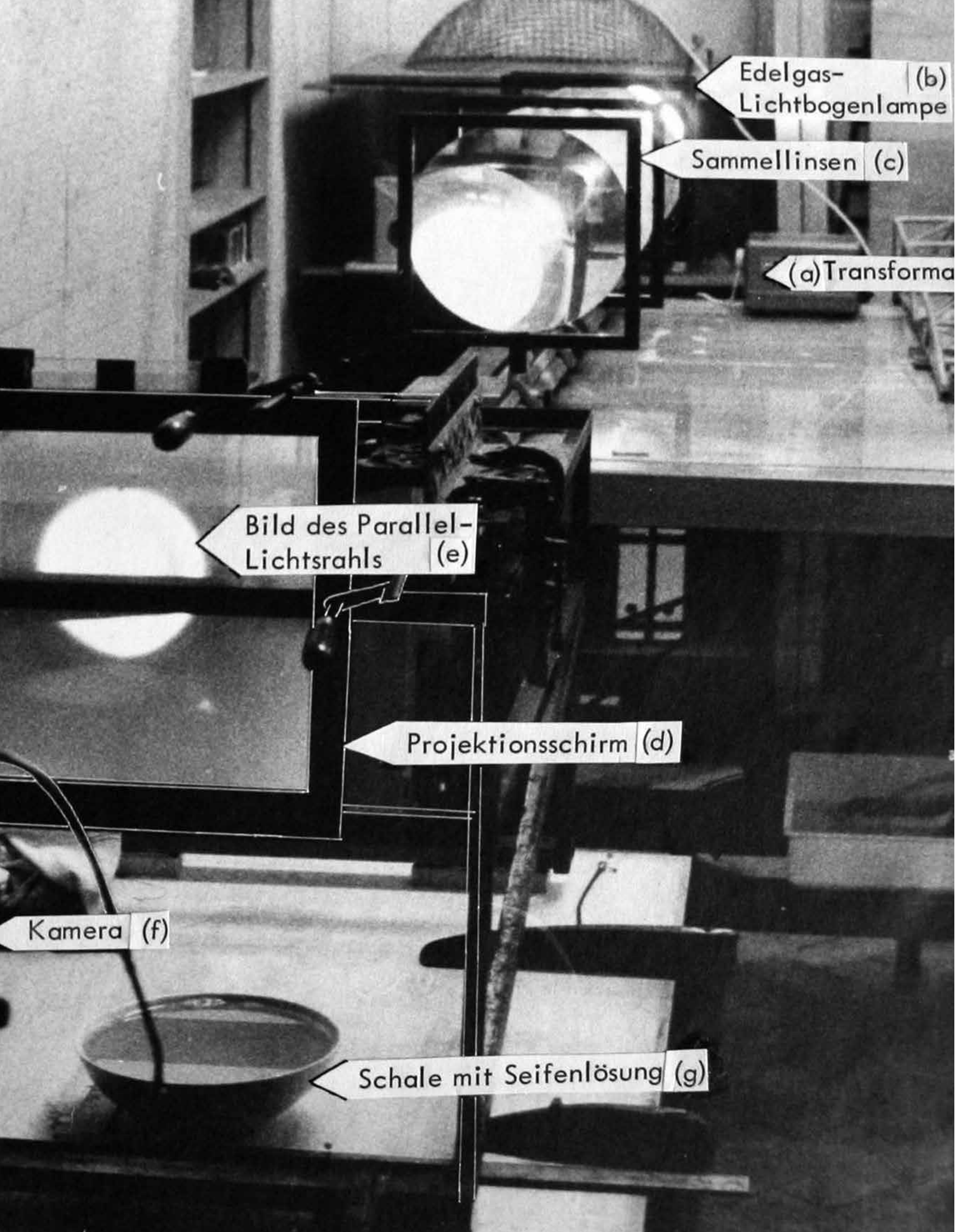


_Figure 1.
Soap film model measurement setup with optical bench (W. Reinhardt, S. Waldraff, *Bestimmung der Geometrie eines Minimalflächen-Seifenfilms zwischen Kreisring und schlaufenförmiger innerer Unterstützung*, IL student research project, 1967–1968).

Daniela Fabricius

Capturing the Incalculable

Frei Otto's Experimental Models

For the German architect Frei Otto, attempts to measure and calculate "incalculable" structures were central to his search for a "degree zero" of economy and lightness in architecture. "Lightness" is a complicated term in Otto's work, referring not only to the weight and efficiency of a structure, but also a moral and aesthetic principle in opposition to what he saw as the "brutality" and heaviness of both Fascist and concrete architecture. Otto discovered lightness primarily by observing and measuring the behaviour of physical models and objects, the most famous of which were made of soap film. Soap film forms a structure of almost perfect optimization, with a thickness of only a few molecules. These self-generated forms are highly ephemeral, and usually last only seconds or minutes. In his 1953 dissertation, *Das hängende Dach*, Otto had already suggested a relationship between self-formation, economy, and lightness:

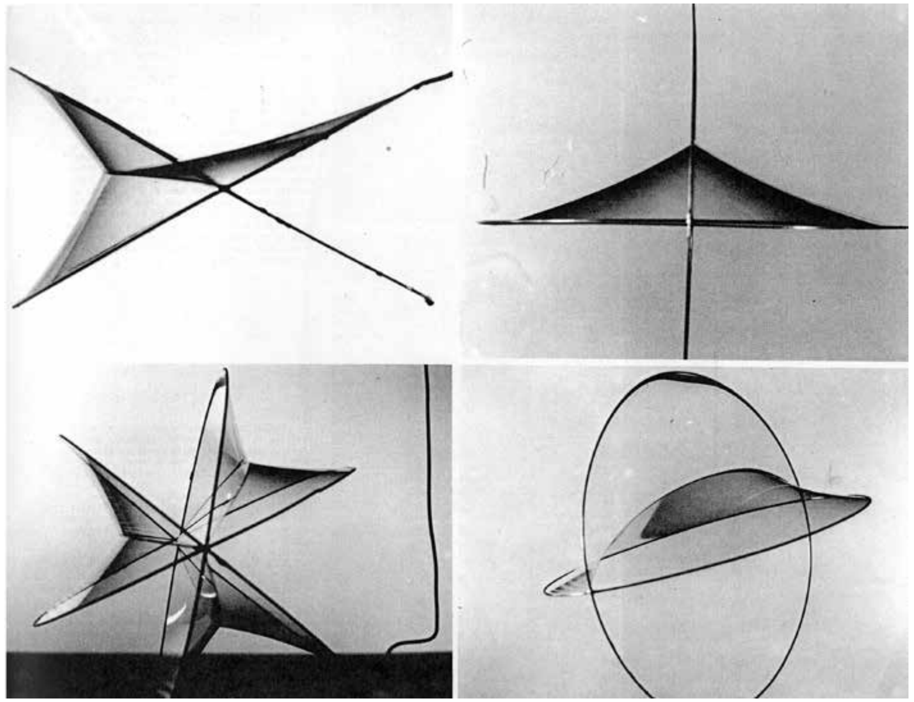
Fig. 2

> Hanging roofs cannot be designed. When every impure tone is avoided, one can help them unfold. They suggest a peculiar beauty that is perhaps closest to the plastic trace of the spider's web: an appearance that one cannot draw or explain, that will unobtrusively elude us.[1]

In these phrases Otto expresses concerns that he would investigate for the next decades. An ideal structure is one that unfolds by itself, and in a way that is judged as beautiful. The spider's web – which preoccupied him throughout his career – is the ultimate example, a structure so minimal and light that it is almost beyond representation or analysis.

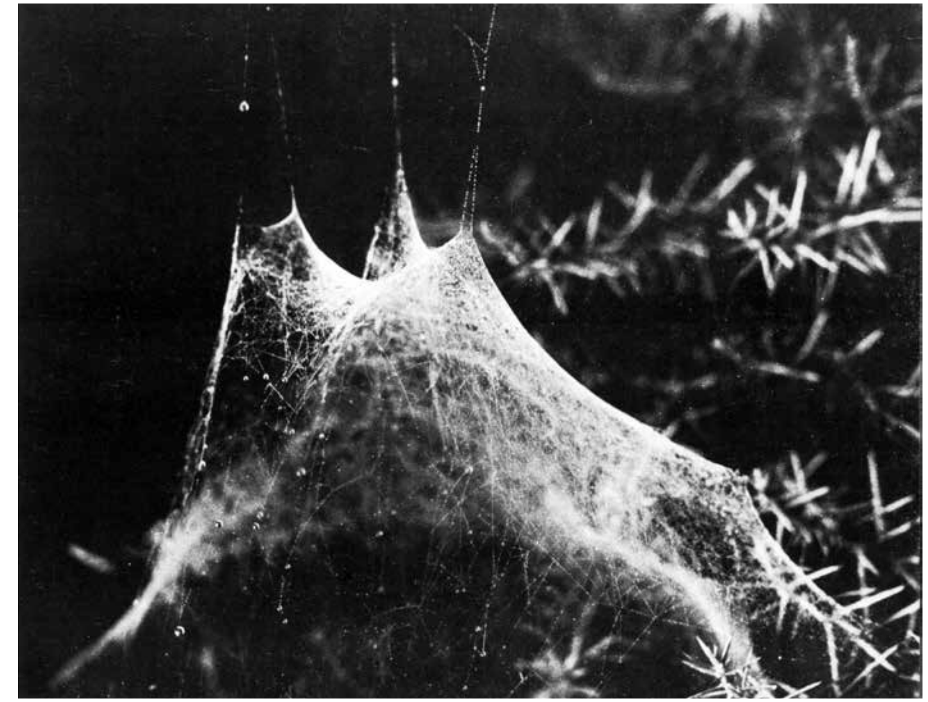
Fig. 3

Trying to precisely recreate and document such minimal forms, while at the same time insisting on their elusiveness, became a complicated ideal in Otto's practice. Otto pursued incalculable forms as part of an attempt to expand what he saw as the limited imagination of modernist architecture. He saw experimentation as a way of discovering as yet unrealized forms, and argued for a method of direct observation rather than "theoretical planning with drawings and calculations which can today be supported by extensive use of computers".[2] Yet the creation, representa-



_ Figure 2.
Frei Otto, experiments with soap film in wire frames, 1960 (*Seifenblasen*, IL 18, 1987).

_ Figure 3.
Spiderweb, shown in suite of images of German Pavilion for Expo "67 (*Nets in Nature and Technics*, IL 8, 1975).



tion and analysis of these forms took place primarily through highly mediated and calculated processes. Otto ascribed a sublime quality to incalculable natural forms; yet this is challenged when these forms are "captured" and calculated.[3]

In his experiments, Otto developed not only new forms but also a new language of architectural representation. The conventions of the architectural model in particular were challenged by the tiny, ephemeral bubbles that Otto began working with in the late 1950s. Photographic images played a primary role in the process of translation between model and calculation. Jürgen Hennicke, a long-time collaborator of Otto's, has confirmed that photography was the "central medium" of the work at the Institute for Lightweight Structures (IL), which was founded by Otto in 1964.[4] Because the model was ephemeral and mutable, the photograph was the only means of capturing its trace. Thousands of photographs and photographs of experiments were published in the IL's internal and external bulletins and reports; many more remained part of an improvised archive. In his efforts to avoid numbers Otto became a producer and collector of images.

Chasing Bubbles

Soap film structures were for the most part still mathematically incalculable at the time Otto began working with them in the 1950s. Otto came upon soap film after realizing that the fabric tensile structures he was designing were unequally stressed, leading to buckling and flapping. He began experimenting with soap film at the small research institute that he founded in Berlin in 1959 in his in-laws' back yard. An account by Ewald Bubner, a collaborator of Otto's, gives an impression of the provisional atmosphere in which these experiments began in the 1950s:

> One day I arrived at the studio fairly early. Frei Otto was alone, blowing soap bubbles through a wire loop and chasing them back and forth through the studio to catch them and stick two or three bubbles together at a time. I asked whether he was alright – and was reassured when he answered that he was conducting a scientific experiment.[5]

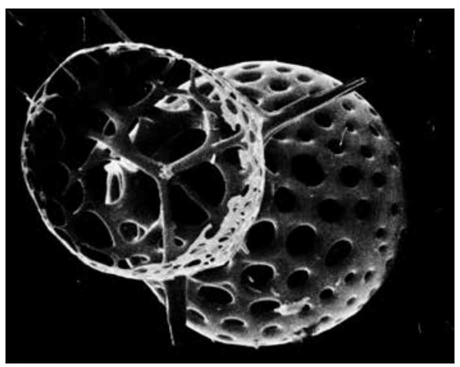
Photographs of these "experiments" would later be published in the book *Zugbeanspruchte Konstruktionen* (Tension Structures).[6] In this large publication Otto makes reference to only one source for his experiments: *Soap Bubbles, Their Colours and the Forces which Mould Them*, by the British physics professor C.V. Boys, which was first published in 1890.[7] Boys provided recipes and instructions for repeating his experiments, many of which Otto used in his work. The book is illustrated with images showing lanterns projecting light through bubbles, and playful but scientifically questionable experiments. Boys revealed the visual effects and mysteries of soap films, but not their mathematical properties or economy of material. It is in keeping with Otto's initial unfamiliarity with scientific methodology that he was willing to borrow from a set of experiments based more on the formal and visual aspects of soap films than their "hard" scientific properties.

An Expanded Vision

The scientific shift in Otto's working methods could be traced to his relationship with the biologist and anthropologist Johann-Gerhard Helmcke, whom he met at the Technical University of Berlin and began collaborating with in 1961.[8] It is without doubt this relationship that consolidated Otto's interest in natural and "self-forming" structures at every scale, especially the microscale. Helmcke, an expert in the field of microscopic photography of diatoms, probably also sparked Otto's interest in the possibilities of scientific images. In describing microstructures, Helmcke used stereoscopic images, but also more architectural conventions such as sections and renderings. For Otto, these images suggested the possibility of a universal structural principle that could be measured and applied at any scale:

Fig. 4

> Helmcke showed me his stereoscopic photographs of diatoms and radiolaria taken with an electron microscope. On these photos I saw shapes which had formed "of themselves" in my experiments with pneumatics, i.e. soap bubbles, soap films, rubber membranes and net structures. From then on I saw only such forms in all living organisms, not only in diatoms.[9]



_ Figure 4.
Radiolaria shells in an Electronmicrograph (*Biology and Building* I, IL 3, 1971).

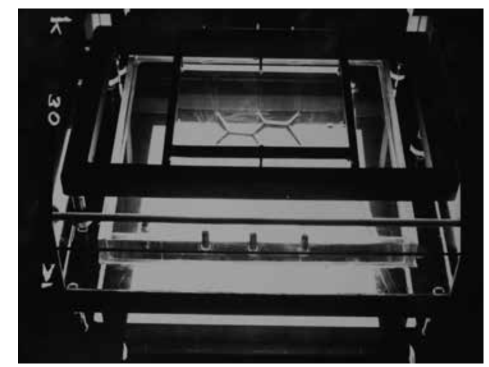
Otto insisted on physical models yet accepted optical instruments as an extension of the senses used to apprehend them. He predicted that the dominance of analytic engineering would wane thanks to these "newly developed, extremely sensitive instruments", which would usher in a renewed emphasis on observation and experience.[10] For Otto, direct observation was thus understood as already mediated and enhanced through instruments borrowed from the sciences to document and measure material forms that were either too small and ephemeral, or too large and complex, to be comprehended otherwise. When Otto moved to the Technical University in Stuttgart in 1964 and founded his institute, he continued his work with soap film. He also incorporated biological structures, and made the transition from provisional experimentation to large-scale government-funded scientific research.[11] Here he was supported by technical facilities, scientists, and student researchers who followed quasi-scientific protocols. While Otto's early years of free experimentation had yielded a collection of attractive photographs, these were more a documentation and classification of forms than data. For the soap film models to be measurable, they first had to be made more durable by manipulating their chemistry and atmospheric conditions. They also had to be placed within a framework in which space was already constructed as measurable, where a total and precise coordination between object, camera, lighting, and background was possible. Here I will argue that the devices developed for this increasingly came to take precedence over the models, becoming more sophisticated and eventually transforming into a category of space themselves.[12]

_ Figure 5.
Frei Otto (left) with Eberhard Haug. Pneumatic experiment with inflated animal intestines, 1973 (photo IL Archive).

Minimal Path Device

The first soap film device was constructed in 1965 to study minimal path systems. Otto had been interested in self-forming paths since his time in Berlin, citing failed experiments with viscous materials such as honey and soft cheese. Here Otto's methods show vastly greater sophistication. References now also include the work of the nineteenth-century Belgian physicist Joseph Plateau and the German-American mathematician Richard Courant, who in 1940 published his accounts of soap film experiments, many of which were repeated at the IL.[13] It was a diagram of one of Courant's experiments that led to this first apparatus for soap film structures.

_ Figure 6.
Minimal path device, 1965 (photo IL Archive).

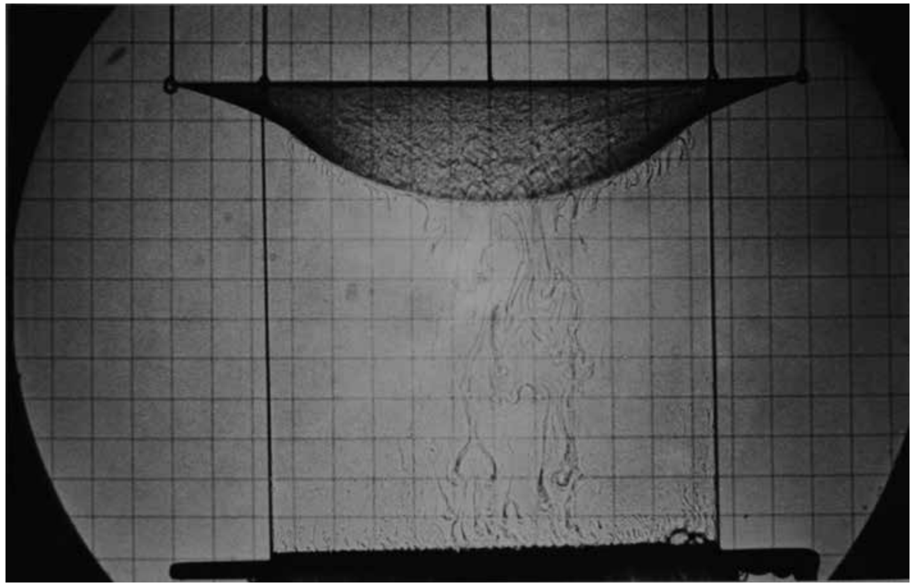


Featured in the first publication of the IL, this device consisted of a glass plate suspended over a soap tank. A matrix board holds pins that establish the points that are connected by the film. The entire device was installed on a concrete slab in order to avoid vibration, and featured a glass cover that "nearly" hermetically seals the environment. This protection from dust and evaporation apparently allowed for fragile soap membranes thinner than a micrometre to be kept stable for up to three weeks. A camera was not yet incorporated, but the series of glass plates and camera-ready lighting suggests that this would be an eventual development.

The multiple, detailed steps necessary for the photographs to reach this high level of accuracy are explained by the researchers with terms such as "exact", "precise", and "consistent".[14] Where chance had in the past served as an aid to design, here it is a distraction that must be eliminated.[15] A series of careful (and repeatable) protocols were carried out not so much for the creation of a model as for the creation of a perfect image of a model.

Between Image and Calculation

This first IL publication shows the formation of minimal nets between points, offering simple calculations of the angles of the soap film as it slowly deforms and



_ Figure 7.
Model in soap film machine (L. Beckmann, M. Gröne, *Untersuchung von aufeinanderstehenden Seifenhäuten über kreisformigem Grundriss*, IL student research project, 1978).

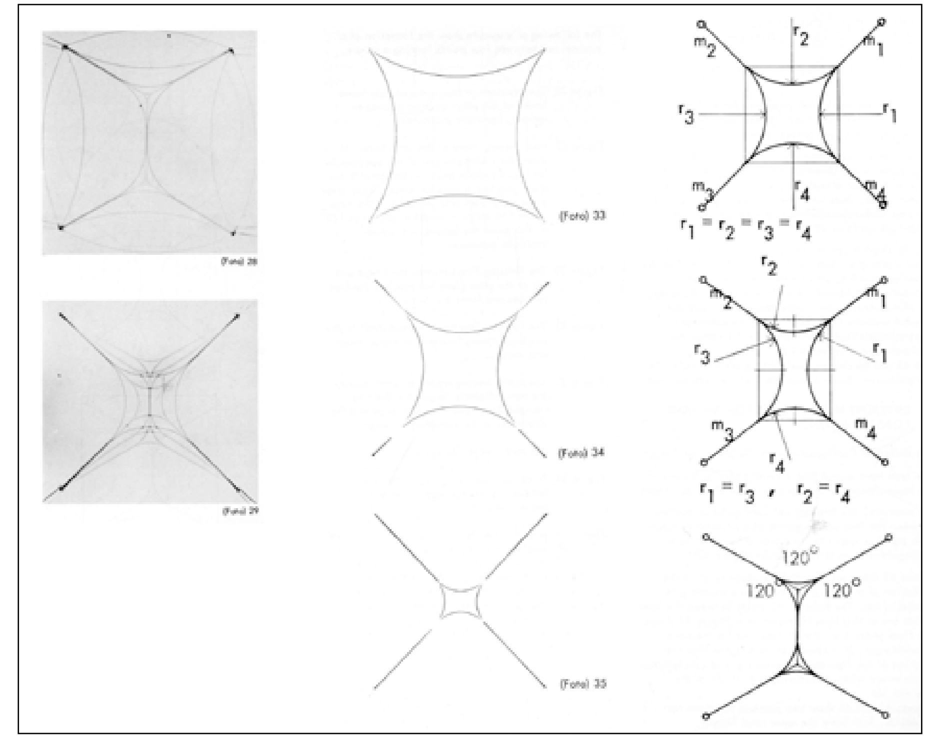
reaches a state of equilibrium.[16] When equilibrium is attained, the film forms a structure that apparently demonstrates optimal organization. The volume is illustrated throughout with high-contrast, graphic photographs of these network formations, used interchangeably with line drawings. Here, the model, and then the image, become data. The impression is that these photographs have the accuracy of a drawing.

Peter Galison identifies a shift in the history of scientific experimentation that serves as a relevant analogy. He describes two methods of producing information in microphysics: the indexical preservation of forms through photographic images, and a statistical mode of representation – "counting rather than picturing" – that he calls "logic".[17] According to Galison, the rise of the electronic image in the early 1980s marked the convergence of these two traditions. Otto's experiments – which were conducted at the cusp of an analogous convergence in digital architecture – often tried to account for, and translate between, these two types of information.[18] This is seen even in the simple example of translating photographs of soap film through analysis in drawings in order to finally arrive at mathematical calculation.

Fig. 7

Photogrammetry

Otto's team continued to develop a series of devices for creating soap film structures in ideal conditions. These contraptions became increasingly larger and more complex as they sought to eliminate environmental interference. Instruments were borrowed from other sciences that could measure the diameter and tension of the soap film. More significantly, these apparatuses integrated ways of capturing the models photographically, using special lights, plates, and lenses.



_ Figure 8.
Photographs, drawings, and calculations of minimal nets between four points reaching equilibrium, c. 1965 (*Minimal Nets*, IL 1, 1969).

Soap films are not only difficult to produce, but, because of their near immateriality, they are also especially difficult to photograph in a way that allows for accurate measurement. The method of photography itself had to change; images could no longer be distorted by the curvature of an amateur's 35-mm lens. Stereoscopic cameras and methods of flattening were thus used to produce a more measurable image. One of the most important tools was photogrammetry, which uses multiple photos as the basis for obtaining accurate dimensions. This technology was developed in the nineteenth century for measuring aerial photographs and buildings, and was thus already intrinsically linked to the architectural object.

The technique of photogrammetry from a distance was well established, but this was not the case for a 9-cm model at close range. Soap film is so thin – about the magnitude of a wave of light – that it is practically invisible (calling to mind again the ideal of the spider's web). In order for a photogrammetric image to be produced, the object needs to have a series of target points from which measurements can be taken. However, projection onto soap film is difficult because it is both transparent and reflective, and light particles literally move around on the liquid surface. The process became less about finding form than finding ways to make the incalculable calculable (or at least measurable); with the threshold of possible forms having almost been reached, attention had turned to creating data.

Developing the Soap Film Device

Between 1967 and 1968, two students of Frei Otto – Walter Reinhardt and Stefan Waldraff – dedicated themselves to developing a soap film device for three-dimensional forms.[19] The effort in these experiments was not to come up with a variety of forms – in fact, the form remained the same (it was essentially a model of the IL tent itself). The focus lay instead on improving the experimental set-up and its method of documentation, specifically the photograph. The students created a series of devices, one of which in effect turned the entire experimental set-up into a camera. Here, the soap film model was placed on an aluminium ring, below a turntable that was able to rotate and thus shift the shape of the model by means of an attached string. The introduction of this kinetic element – the movement and manipulation of the model in space – should be noted. From one side of the contraption, a light source was projected onto the model, located at a considerable distance of 15 m in order to approximate parallel light waves and reduce distortion. A sheet of photo paper was inserted behind the model and exposed to light, creating a photogram. Photos were taken with rotations of the model in increments of 10 degrees, allowing for a "scan" of the form. This measuring of an object in space in order to replicate it can be read as a crude version of 3-D scanning.

Subsequent experimental set-ups further eliminated imprecision to allow for more accurate measurement. In one set-up, the photo paper was replaced with a frosted plate that was etched with a millimetre grid. The image projected onto this screen was photographed with a large-format camera. The entire set-up, which appears to have been several metres long, was mounted on an optical bench with four convergent lenses in order to create parallel light projections. It is clear that another shift had taken place at this stage: the apparatus for creating and documenting the model had become larger and far more difficult to produce than the model itself. In the final set-up, the structure suspending the model was adjusted so that the model could be not only rotated but also inverted (to study the possible effects of gravity). The photographs that resulted from this experiment became the basis for plotted contour lines that could produce a "precise" drawing and even a plaster model, again calling to mind later 3-D scanning and plotting technologies. One composite drawing showed the result of the full range of photographs, although it did not convey a sense of the spatial qualities of the model. Here, as in the early experiments with minimal networks, there was a process of moving from model to photograph to drawing, or a transition from image to data.

Fig. 1

The final and most elaborate apparatus, which is still in use at the IL today, was first developed in 1973. The comical-looking machine is a large assemblage (about 2 m tall and 3 m deep) of acrylic basins, rubber and plastic tubes, dials, steel frame supports, a spindle, a light box, and a camera. One can hardly imagine a stranger device for creating or documenting architecture. Aesthetically, it calls to mind the air-based, apparatus-based and machine-based fantasies of the avant-garde of the 1960s. It similarly suggests the utopia of a device that harnesses technology to create instant, adaptable, and autonomous architecture. It is at the same time not unlike the self-contained world of the computer, in which model creation, measurement, calculation, and output are enclosed in one machine.

Fig. 9

The machine is also architectural in the sense that it provides a "well-tempered environment" for spawning form. In this machine, the model is housed in an air-

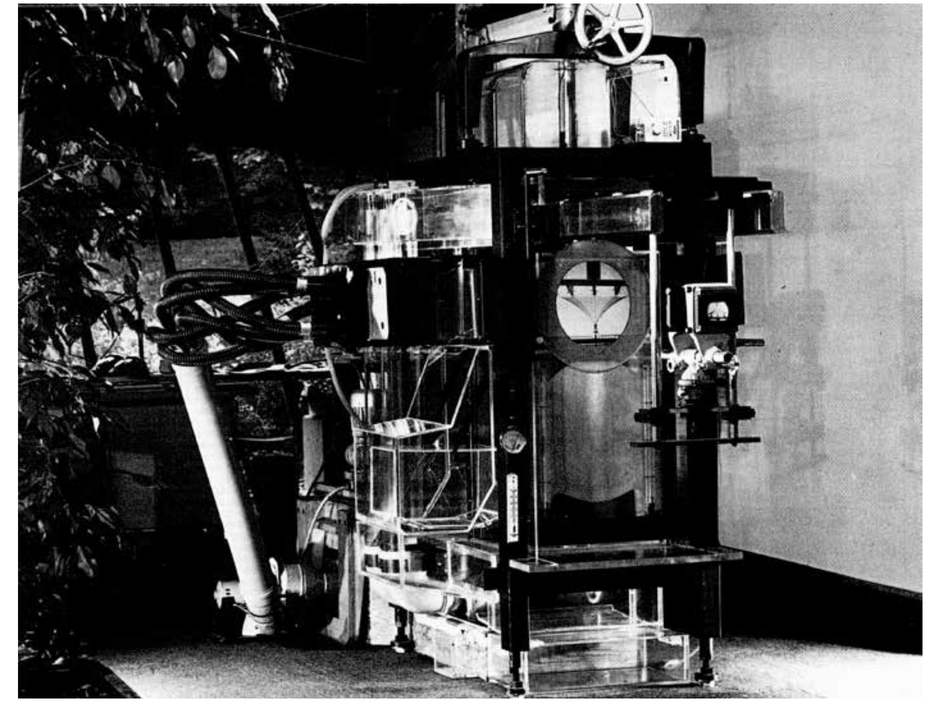


_Figure 9. *Seifenhautmaschine*, "soap film machine" (photo IL Archive).

conditioned chamber surrounded by glass and acrylic. The structure provides a container filled with soap solution and tracks for a parallel projector and optical bench. A camera is mounted on an adjustable support in front of the chamber. The support for the soap film model can be fully manipulated using a spindle and fork, which not only adjust the height but also allow it to be rotated 360 degrees and swiveled 180 degrees. This recalls the disorienting space of the digital model, in which it is no longer the viewer who moves around the model, but the model that is manipulated in space according to its axes.

One can make several observations about the evolution of these devices. The onus of representation is no longer placed on the model, but on the apparatus that documents it. Otto's ideal of the disappearing spider's web has been realized – in the sense that the object is overwhelmed, and eventually disappears, in the structure that measures it and converts it into data. Form-making and "scanning" are integrated into one machine. The question is no longer that of analogue representation but the extraction of numerical data that can be applied across scales.

Calculated Images

But is data ever pure? The move away from analogical models hardly suggests that problems of translation do not arise in the poverty or excess of the model and that which it seeks to represent. What is created in these model experiments is not only pure numerical data but also a proliferation of images, including photographs of the machines themselves. The materials published by the IL showed not only research, but also how research is made. Their ideological function was to give scientific validity to this nationally-funded project, achieved through photographs of complicated machines and beautiful bubbles.

As these devices became more sophisticated, it was clear that the image had gained prominence, perhaps even over form and its calculation. As a result, the experiential and phenomenological aspects of image-making and observation were also emphasized. For instance, a 1973 IL publication included a groovy pair of 3-D glasses for the reader to use in order to view a series of anaglyphic images printed in red and green at the center of the book.[20] This use of optical illusion is reminiscent of 1960s Op Art and psychedelic film, but also of the teachings of *Gestalt* theory-based optical tricks.[21] One can also look again at the influence of Helmcke, whose 1953 atlas of microscopic photos of diatoms had also included a pair of stereoscopic glasses, with the explanation that "only in this way is a spatially correct ("raumrichtig") impression of the framework of the structural elements possible".[22]

Fig. 10

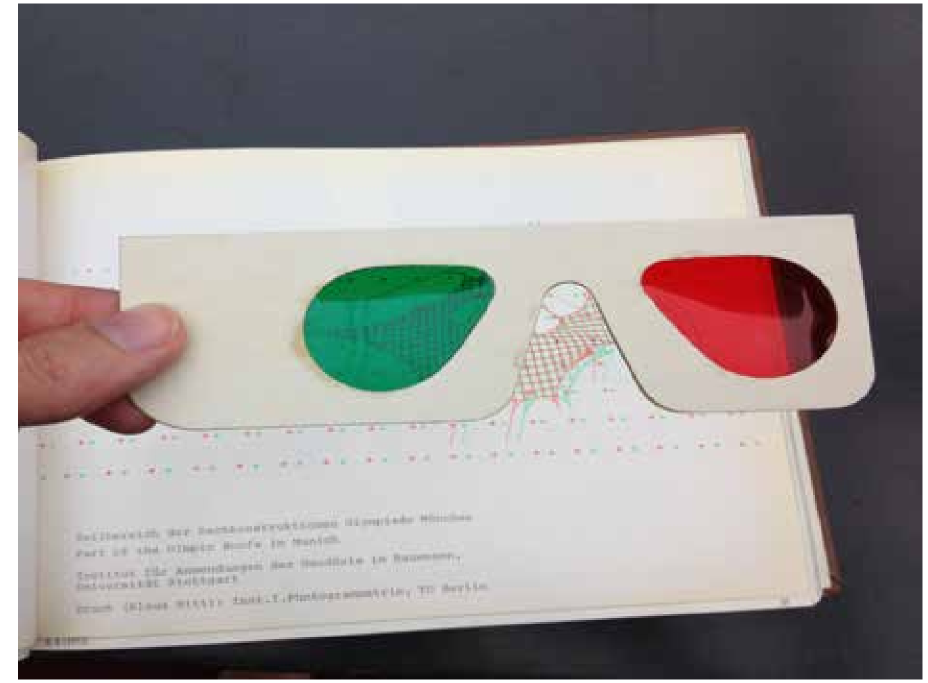
Similarly, the reason for using this technology at the IL was, surprisingly, not tied to questions of "perception", but to "precision": they argue that these images are more "realistic" spatial representations, without distortions, unlike two-dimensional drawings, which were viewed as inadequate for describing new forms that do not follow "simple geometric laws".[23] While the measuring photographs had attempted to capture an object in order to flatten it into data, here there is an effort to virtually maintain the object in three dimensions. This was done not only with cameras but also with the computer, as measurements taken from models were processed and plotted in red and green ink. In this reconstitution of the object, even the physiology of the human eye was calculated. One researcher includes a study in the same publication in which the distance between human eyes, the ability of the brain to perceive depth, and the desired focal distance and angle (so as not to create blind spots), were mathematically calculated to produce an ideal architectural representation in the mind.[24]

While Otto had placed much emphasis on the importance of image technologies as an expansion of human vision and thus the physical realm, here those technologies are also used to alter, enhance, and direct human vision – in other words to insert themselves into the process of perception itself. The "imperfect" eye, which for Otto was not entirely capable of objectivity, is helped along so that the brain can produce a more realistic image. This shows the importance of the eye for Otto – a form should not simply be calculated numerically but should also be comprehended visually. In a significant step towards simulation (and computer modelling), the traditional architectural drawing and its outdated technology of perspective are seen as no longer sufficient. In these images, Otto proposed something closer to a simulated image, and one that, unlike his fragile models, could be stored, reproduced, and transferred in the form of media.

The Melancholy of the Incalculable?

Antoine Picon has argued that modern architects generally understood the sciences through appropriated images. These are borrowed by architects not for their con-

_Figure 10.
Biology and Building (IL 6), 1973, with anaglyph images and 3-D glasses (photo Daniela Fabricius).



tent, but for their "imaginary social signification".[25] Otto takes the imaginary one step further by not only appropriating scientific images, but literally creating them. Photography plays a double role as a tool of both precision and architectural projection. The stunning soap film images created at the IL cannot maintain a purely objective innocence, considering the tradition of scientific photography as part of the aesthetic language of the avant-garde.[26] In the process of dematerializing the architectural object and reducing it first to form and then to data, Otto instrumentalizes this experimental tradition. Photography is used as a tool to document material experiments, not as an experimental medium in itself.

What then of the elusive object, as exemplified by the spider's web? Is the soap film model captured in the end, or does it disappear into immateriality as it is calculated? While the devices and methods shown here portray a process of increasing precision and seeming mastery over these fragile forms, they were in truth only one part of Otto's practice. By the 1970s Otto would increasingly return to forms that could only be observed, not calculated. Among the studies at the IL are photographs not only of soap bubbles but also more eccentric and tantalizing forms that remained impossible to translate into numbers. Where calculation is impossible, photography again becomes the primary medium of capture, in subjects that include the inside of the human body, mould, foam, wet hair, eggs, or an animal's intestines.

Fig. 11

We are left with several questions then, not only for architecture but also for the problem of calculability. Otto's contradictory relationship to calculation was symptomatic of larger cultural questions around the notion of progress that were taking place in West Germany during this period. While Otto is typical-

ly portrayed as a representative of the somewhat naïve postwar technological utopianism, I would like to suggest that the endeavours described here are more evocative of the conflicted figure of Melancholia in Dürer's famous etching of 1514: surrounded by the tools of measurement, having seemingly mastered complex geometries, and yet nevertheless resigned. In 1971, around the time of Otto's experiments, Günter Grass wrote of Dürer's etching as an example of "stasis in progress", comparing it to Germany's political and cultural state after 1968: caught between the lightness of utopia and the heaviness of melancholy. Grass described melancholy as the place where "everything is shallow, empty, calculable, mechanical".[27]

Erwin Panofsky read Dürer's melancholic figure as the result of the confinement of the mathematical mind, or an inability to move beyond the limits of space. However, this more heroic reading does not explain Otto's fascination with the incalculable as such. I would suggest instead that the melancholy of Otto's work is closer to the "wise melancholy" that Jean-François Lyotard associated with the "mourning of arrogance" after the eighteenth century's claims to Enlightenment and two centuries of war that followed.[28]

One can then read Otto's insistence on physical model testing as a reaction to what has been described as a culture of "dematerialization" that began in the 1960s. On the occasion of his 1985 exhibition *Les Immatériaux*, Lyotard described this new relationship between matter and information:

> Research and development in the techno-sciences, technology and the arts, and also in politics, give the impression that reality, whatever it may be, is becoming increasingly intangible, that it is never immediately mastered … Materials themselves never cease to become more complex … It is as if a filter has been dropped between things and us, a screen of numbers. A colour, a sound, a material, a pain, or a star return to us as very precise identification cards. These coders–decoders teach us realities that are otherwise unknowable. In the end the good and beautiful matter itself reaches us analysed and reconstituted into complex formulas. Reality is made of indiscernible elements organized by structural rules (matrices) in inhuman scales of space and time.[29]

Otto's experimental models predate this text by two decades, yet one can observe his engagement with the problem of "good old matter" as it is coded and decoded in moving between models, images, and numbers. Otto's eventual response is to grasp for matter. In Otto's neo-rationalism, calculation reappears in the guise of a material calculation, producing the reconfiguration of the material and the immaterial that Lyotard describes.

_Figure 11.
Photographic
studies of "pneumatic" forms at IL archive, taken by IL researchers:
animal innards at a slaughterhouse, mid-1970s (photo IL Archive).

Fig. 12

_Figure 12.
Albrecht Dürer,
Melancholia I, 1514.

Considering Otto's politics of lightness, one could go so far as to ascribe a moral imperative to his insistence on physical evidence. The use of calculation, especially with more sophisticated tools, may displace the arrogance of authorship, but it also displaces accountability and blame. While it is Otto's project to move beyond the confines of calculation, his melancholic limitation is to constantly return to it in the form of structures that become immaterial.

Abstract

Catturare l'incalcolabile.
I modelli sperimentali di Frei Otto

Nelle sue strutture Frei Otto ambiva alla dematerializzazione, secondo un ideale di leggerezza che viene al meglio rappresentato nei suoi famosi esperimenti con pellicole di sapone. Negli anni Cinquanta, quando Otto iniziò a lavorare con questi strumenti, le strutture in pellicola di sapone non erano calcolabili matematicamente. A partire dagli anni Sessanta, invece, la creazione, la misura e il calcolo di simili forme minimali era diventato uno dei punti principali della sua ricerca. Questo intervento esamina in dettaglio lo sviluppo dei dispositivi elaborati per creare e catturare i modelli in pellicola di sapone presso l'Institut für Leichte Flächentragwerke di Stoccarda a partire dal 1965, e dimostra come si sia venuta a creare una dialettica tra ciò che in questi esperimenti è calcolabile e ciò che invece non lo è. La fotografia scientifica giocò un ruolo decisivo nella precisa rilevazione di queste superfici effimere, che a causa della loro immaterialità erano particolarmente difficili da documentare e misurare accuratamente. Al fine di superare le imprecisioni, il modello doveva essere posto all'interno di un'area precisa, nella quale lo spazio e l'atmosfera venivano definiti a priori ed erano misurabili: uno spazio dove era possibile una coordinazione totale tra oggetto, camera, luce e sfondo. Gli strumenti per creare e misurare tali modelli presero sempre di più la precedenza sui modelli stessi, suggerendo talvolta un nuovo tipo di spazio: uno spazio di calcolo. Nel creare e catturare forme incalcolabili per l'architettura, Otto trasformò di fatto il materiale in un dato sensibile. Per Otto l'incalcolabile suggeriva un limite formale, un confine che egli provò a superare ed estendere continuamente attraverso esperimenti non solo con pellicole di sapone ma anche con sistemi statici ottimizzati, con strutture troppo piccole o grandi per essere misurate fisicamente, con le interiora di animali ed esseri umani. In questi esperimenti Otto sviluppò non solo nuove forme, ma anche un nuovo linguaggio e una nuova estetica della rappresentazione architettonica, sfidando in particolare le convenzioni e le possibilità del modello architettonico.

Notes

_1. F. Otto, *Das hängende Dach. Gestalt und Struktur*, Bauwelt Verlag, Berlin 1954, p. 158. My translation.
_2. *Grundlagen. Form Kraft Masse 1 / Basics: Form Force Mass 1* (Mitteilungen des Instituts für Leichte Flächentragwerke, Universität Stuttgart 21 / IL 21), Stuttgart 1979, p. 63.
_3. The idea of calculation is used here more generally as a quality of rationality, in the sense evoked by Max Weber: "In principle, then, we are not ruled by mysterious, unpredictable forces ... on the contrary, we can in principle *control everything by means of calculation*", in M. Weber, *The Vocation Lectures*, D. Owen, T.B. Strong (eds.), Hackett, Indianapolis 2004, pp. 12-13.
_4. J. Hennicke (Instructor, IL, now called IL-EK), in discussion with the author, February 2013.
_5. E. Bubner, *Institute for Development of Lightweight Construction and Atelier Warmbronn*, in W. Nerdinger (ed.), *Frei Otto: Complete Works: Lightweight Construction, Natural Design*, Birkhäuser, Basel-Berlin-Boston 2005, pp. 80-89, p. 83.
_6. F. Otto, *Zugbeanspruchte Konstruktionen*, Ullstein, Frankfurt am Main 1962.
_7. C.V. Boys, *Soap Bubbles, Their Colours and the Forces which Mould Them*, Society for promoting Christian knowledge, London 1890. A 1958 Dover edition of the book is at the IL library, and may have belonged to Otto. Otto's experiments with soap film began around 1958. Boys also shows a spiderweb, and explains the beading of fluids on the surface of the threads, pp. 84-86.
_8. In 1962 Otto co-published an article with Helmcke which outlines their early collaboration. F. Otto, J.G. Helmcke, *Lebende und Technische Konstruktionen – Bemerkungen zu Schalen und Raumtragwerken in Natur und Technik*, "deutsche bauzeitung", 67, 1962, n. 11, pp. 856-861. For a detailed account of their collaboration see *Diatomeen II - Schalen in Natur und Technik III / Diatoms II (Shells in Nature and Technics III)* (IL 38), Stuttgart 2004.
_9. IL 38, 2004 (see footnote 8), p. 141.
_10. IL 21, 1979 (see footnote 2), p. 63.
_11. The university was then still called the TH (Technische Hochschule) Stuttgart, until its name was changed to the TU Stuttgart after 1967.
_12. This is the case for soap film models but not for Otto's measuring models, where the model itself becomes a device.
_13. *Minimalnetze / Minimal Nets* (IL 1), Stuttgart 1969; R. Courant, *Soap Film Experiments with Minimal Surfaces*, "American Mathematical Monthly", 47, 1940, pp. 167-174.
_14. IL 1, 1969 (see footnote 13), p. 39.
_15. It is useful to pause here and consider the precision of these "scientific" protocols when compared to the comparative freedom of "experimentation" in the Bauhaus *Vorkurs*, or even in the pedagogy of the more scientifically oriented Ulm School of Design.
_16. IL 1, 1969 (see footnote 13), pp. 15-19.
_17. P. Galison, *Image and Logic: A Material Culture of Microphysics*, University of Chicago Press, Chicago 1997, pp. 19-21.
_18. This is especially true of Otto's measurement models, used for projects like the 1972 Munich Olympic stadium. Indeed the stadium was an early example of a building that was analyzed and optimized using a computer.
_19. W. Reinhardt, S. Waldraff, *Bestimmung der Geometrie eines Minimalflächen-Seifenfilms zwischen Kreisring und schlaufenförmiger innerer Unterstützung*, IL student research project, 1967-1968, archives Institut für Leichte Flächentragwerke, Universität Stuttgart.
_20. *Biologie und Bauen 3 / Biology and Building 3* (IL 6), Stuttgart 1973.
_21. Dieter Blümel, a researcher at the IL, compared the process of the experimental researcher who aims to see the "whole picture" to the principles of Gestalt psychology. D. Blümel, *IL-Archive: Interdisciplinary Information and Documentation*, in *Netze in Natur und Technik / Nets in Nature and Technics* (IL 8), Stuttgart 1975, p. 393.
_22. J.G. Helmcke, W. Krieger, *Diatomeenschalen im elektronenmikroskopischen Bild*, vol. 1, J. Cramer, Weinheim 1962[2] (1961), p. 3. My translation.
_23. B. Burckhardt, *The Problem of Form Presentation*, in IL 6, 1973 (see footnote 20), p. 55.
_24. D. Schwenkel, *Three-Dimensional Perspective Representation of Structures Using Automatically Drawn Anaglyphs*, in IL 6, 1973 (see footnote 20), pp. 82-86, p. 85.
_25. A. Picon, *Architecture and the Sciences: Scientific Accuracy or Productive Misunderstanding?*, in Á. Moravánszky, O.W. Fischer (eds.), *Precisions: Architektur zwischen Wissenschaft und Kunst*, Jovis Verlag, Berlin-New York 2008, pp. 48-81, p. 71.
_26. While they have the precisely descriptive nature of a Karl Blossfeldt photo for example, the images also participate in the "subjectless" and even objectless tradition of the photography of László Moholy-Nagy.
_27. G. Grass, *From the Diary of a Snail*, Harcourt Brace Jovanovich, New York 1973[2] (1972), p. 288.
_28. "Technology is not the cause of the decline of the modern figure, more one of its signs. Another symptom is our sorrow. At the end of the 18th century, Europe and America raised their claim to the enlightened, free, and virtuous mind, to spread light, the right, and the wealth over the human world. After two centuries of war – civil, international, and global, and massacres – the mourning of this arrogance begins. 'Les immatériaux' should, in some way, in its scenography at least, echo this wise melancholy". J.F. Lyotard, *Conception*, Exposition catalogue *Les Immatériaux* (Paris, Centre national d'art et de culture Georges Pompidou, 28 March – 15 July1985), Centre de Création Industrielle, Paris 1985, p. 4. My translation.
_29. Centre Georges Pompidou Archives, dossier de presse de l'exposition 'Les immatériaux' (Paris, Centre national d'art et de culture Georges Pompidou, 28 March - 15 July 1985), www.centrepompidou.fr/media/imgcoll/Collection/DOC/M5050/M5050_A/M5050_ARCV001_DP-2007011.pdf; accessed 28 May 2014). My translation.

_ Figure 1.
Behnisch with Frei Otto, roof of the Olympic, Munich, 1972 (photo Sean Keller).

Sean Keller

Anti-Monumental Anti-Nationalist National Monumentality

The Postwar Politics of Form-Finding

The World of the Tent

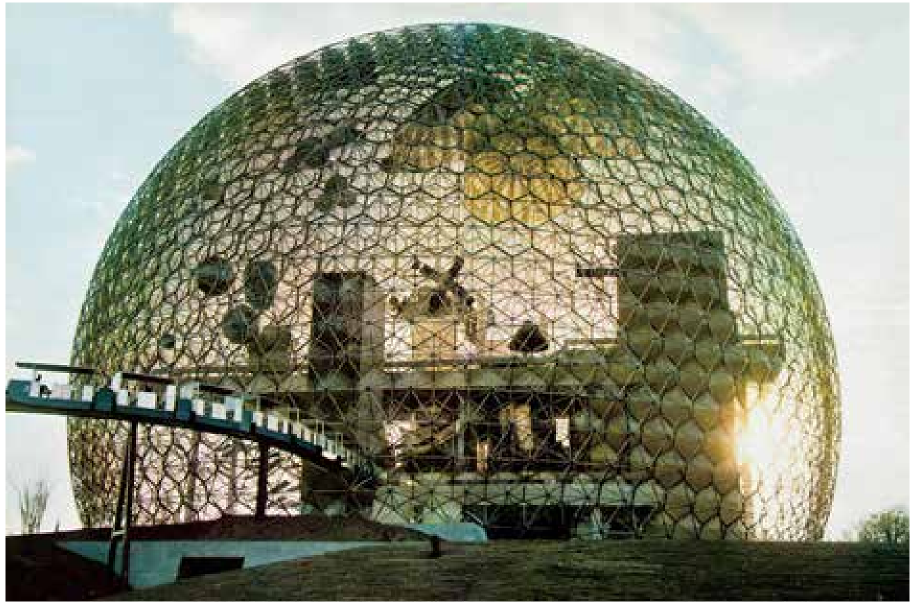
Of the more than thirty national pavilions at the Expo '67 world's fair in Montreal, two stood out then, and stand out still, as signal examples of mid-century architecture: the U.S. Pavilion with its large geodesic hemisphere designed by Buckminster Fuller, and the wide-splaying tent-like pavilion of West Germany designed by Rolf Gutbrod and Frei Otto.[1] While Otto held Fuller in high regard and had often invited him to speak in Germany, he also drew a consequential, if casually put, distinction between their two Montreal structures: "Obviously the American pavilion was entirely different from what we did. ... by chance we had learned of his project in advance, and then I said to him: 'Oh Bucky, you're making a dome'".[2]

Fig. 2
Fig. 3

Underlying Otto's disappointment in Fuller's "dome" were deep convictions about the appropriate forms and meanings of postwar architecture, the relationship of buildings to nature, and the role of semi-automatic form generation as the method of correctly establishing this relationship.

Although the Expo '67 Pavilion was in many ways the single fullest expression of Otto's world view, all of the major contours and tensions of that view were already apparent in his 1954 doctoral dissertation. There Otto suggests the extent to which his concerns for natural forms and processes of formation were, from the start, entangled with the technologies and political valences of the war:

> The tent is fundamentally a biological, non-technical or ur-technical type. (In contrast, the stonework dome is surely a technical type, invented by an individual, that became a model, and was taken up by everyone and used everywhere.) ...
> Here two different worlds meet with their aspirations and their desires: In the relationship of stone and tent, in the relationship of rest and restlessness, transience and duration, an involuntary expression of human existence – as also with the modern suspended roof.
> Through the upheaval of our time we have become nomads and strive for the sake of a lasting peace. The mobile seems to assert itself and gives us the support for new urges.[3]



_ Figure 2.
Buckminster Fuller, Shoji Sadao, Geometrics Inc., and Cambridge Seven Associates, United States Pavilion, Expo '67, Montreal, 1967 ("Paris Match", 20 April 1967).

The choice that Otto poses between the world of stone and that of the tent takes on a deep poignancy when one recalls that as he wrote, he was surrounded by the still-unrepaired expanses of blasted stone in Berlin in the early 1950s. More than a decade later Otto would help realize a project that embodied this dichotomy: a retractable membrane roof for the open-air theatre of the monastery ruins in Bad Hersfeld, Germany. Fig. 4

Suggested here is the sometimes difficult conflation of biological and technological processes that would become a mainstay of Otto's career. The ambiguity in Otto's description of tent-making as both instinctive and technological (the unresolved choice between *untechnisch* and *urtechnisch*) anticipates the continual ambiguity in his works between their supposed harmony with nature and their highly sophisticated artificiality – between their rhetorical minimalism and their maximal realization.

Model-Based Form-Finding

For while the surfaces of the Expo '67 Pavilion may have been minimal, their realization was entirely maximal. Given the ubiquity of complex digital models today, it may be difficult to appreciate the challenge that the roof geometry presented: its form was incalculable, yet needed to be absolutely precise in order to avoid irregular stresses that could result in failure. The coordinates defining the minimal surface had to be located literally "in thin air." In order to meet the challenge presented by the complex three-dimensional form that exceeded drawing, Otto and the newly established Institute for Lightweight Structures (IL) relied on a large series

_ Figure 3.
Rolf Gutbrod and Frei Otto, West German Pavilion, Expo '67, Montreal, 1967 (Atelier Frei Otto Warmbronn).

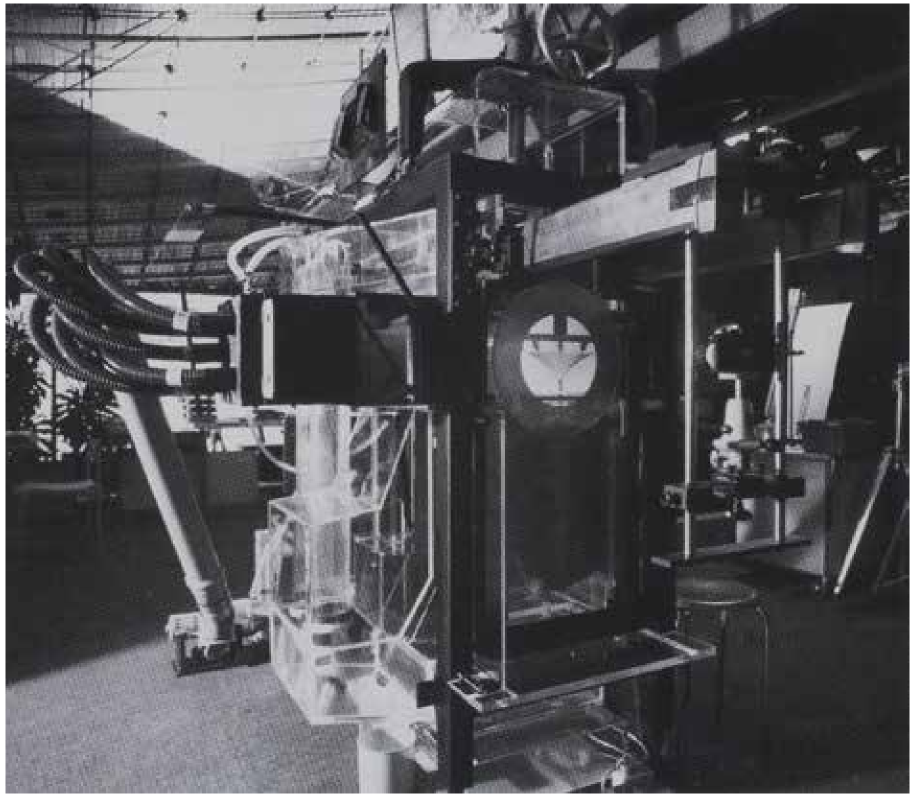
of complex and novel models to drive the design process and to generate construction drawings.

Of course, first the geometry of the tensile surface had to be determined, which is where, prior to electronic computation, Otto's form-finding soap film models came to play their indispensible role. Fig. 5 At a time when others were celebrating the anti-formal properties of pneumatics, Otto was using his soap films as a step toward precise, mathematical, forms, emphasizing the idealized geometry of the bubbles rather than their adaptability or impermanence.

Yet, despite Otto's continual instance on the spontaneous form-finding aspect of his work, this spontaneity was always conditioned, on the one hand, by the highly artificial laboratory conditions that allowed it to occur, and on the other by the concrete architectural contexts to which it was be applied.

Granting the inevitability of these tensions – that is to say, the impossibility of an absolutely automatic design process – brings the character of Otto's process into sharper outline. Admitting the "personal style in problem solving" and the "complexity of a building task", Otto's model-based form-finding techniques can be understood as distancing devices, limiting and shifting his role within the design process. Shaping a minimal sur-

_ Figure 4.
Frei Otto with Romberg & Bubner, Open Air Theatre, Bad Hersfeld, 1968 (Bad Hersfelder Festspiele).



_ Figure 5.
Frei Otto and the Institute for Lightweight Structures, University of Stuttgart, "soap film machine", climatic chamber and photographic apparatus (F. Otto and B. Rasch, *Finding Form: Toward an Architecture of the Minimal*, 1996).

face structure through manipulation of its edge condition, or assembling an ensemble of minimal surfaces, allows Otto to achieve compositional action at a distance.

Paradoxically, then, despite the enormous technical complexity involved in designing and constructing a project such as the Expo '67 Pavilion, the unusual characteristics of minimal surfaces, and their quasi-spontaneous generation, allowed Otto to claim that his schemes were, in fact, manifestations of fundamental physical laws and, in some sense, not designed by the architects but by nature directly.

The Expo '67 models also became the subject of an even more radical representational experiment as a "digital model of the irregular structure was recorded and stored; any desired cross-section could then be calculated and plotted automatically".[4]

Reinforcing the association of the pavilion with a landscape, the experiment with computational modelling was conducted by a team from the Institute for the Application of Geodesy in Construction at the University of Stuttgart, headed by Klaus Linkwitz. Otto says:

> I worked with the geodesic expert Klaus Linkwitz, and we used the stereoscopic method that is used for measuring the surface of the earth ... We used this method on models for the German Pavilion in Montreal. We also put Konrad Zuse's computer in the World Exposition, together with a computer-controlled drawing machine, plotting the sections of our building.[5]

_ Figure 6.
Rolf Gutbrod and Frei Otto, West German Pavilion, Expo '67, Montreal, 1967.

Figg. 6-8

Appreciated fully, this scene, is one of the richest moments in the history of postwar architecture: on display in the West German Pavilion was the replica of Zuse's Z3 computer, which had been created to conduct research for the Luftwaffe that itself had been destroyed by Allied bombing, plotting sections of the complex doubly-curved roof above it, which was itself an expression of Otto's response to the rupture of the war generally and to his personal experience as a fighter pilot.

Here also, as Otto's physical modelling techniques had been stretched to the limits of their accuracy, and despite his own skepticism, was a poetic sign of the transition to a new paradigm in which computation would be the primary driver of advanced architectural form-making and analysis, especially for the multitude of complexly-curved surfaces that were to come decades later.

Anti-Monumental Anti-Nationalist National Monumentality

The importance of Otto's work from this period goes beyond contributions to technical advances. In an interview with Paul Sigel, he described the qualities that he believed led to the selection of the Expo '67 scheme:

> F.O. The main aspect was, of course, that we offered no firmly tied down monumental pavilion, but instead a landscape; that we also said we are planting the site, the garden runs through, we have this amazing situation on a lagoon and we are making only a very light roof. A further criterion was that we did not want to put on a German drama, but instead an unconventional Germany. Practically a little in the line of Egon Eiermann in Brussels.
> P.S. It worked also as proof of national self-representation.
> F.O. But of course. All world exposition pavilions have not only the function of just exhibiting something, but specifically they are representations of a country.[6]

_ Figure 7.
Zuse Z3.

Here, Otto presents a rapid sketch of the complex and nearly contradictory symbolic role that the West German Pavilion – and, for Otto, all postwar architecture – needed to perform. It must avoid monumentality and any dramatic nationalism. The way to avoid architectural monumentality was by conceiving of the pavilion as a landscape project, with a garden running through it and only a "very light roof" overhead. Yet, while the project must avoid national dramatics by becoming part of nature, it must also, by definition, be an instance of national self-presentation. Given the burden of Germany's history, the "unconventional Germany" that the pavilion represented was precisely a nation trying to move beyond nationalist representations of itself.

Otto's approach to this projection of self-effacement relied on semi-automatic methods of form generation to embody a rhetoric of transparency, lightness, naturalness, and the minimal use of materials in projects of great technical novelty and complexity. The results, notably the Expo '67 Pavilion, were both symbols of a new Germany and, paradoxically, of an approach to design and building that struggled to move beyond symbolic representation, or perhaps beyond architecture itself.

Another aspect of this complex relation of national and natural representations is hinted at by Otto's suggestion that the Expo '67 Pavilion was "a bit in the line of Egon Eiermann in Brussels". The reference here of course is to the German Pavilion at the 1958 Brussels World's Fair, designed by Eiermann and Sep Ruf. Despite the obvious differences, Otto was nevertheless acknowledging an important continuity between the projects as examples in a West German lineage of symbolic understatement (*Tiefstapeln*).

Thus the "Minimal Principle", which was the guiding idea of Otto's career and which he invariably described as a principle of nature, can also be interpreted as a historically specific national tendency to use understatement to create beautiful and elegant national symbols – an approach, Detlef Mertins has argued, crystallized in Mies van der Rohe's Pavilion in Barcelona, which, in the context of Germany's interwar economic crisis, made a virtue of restraint.[7]

Yet, while perhaps geometrically minimal, the formal complexity and technological exuberance of Otto and Gutbrod's roofs obviously departed from Eiermann's variety of "understatement". Most explicitly, Otto's roofs recalled Hans Scharoun's Berlin Philharmonie (1960-1963), which had already used a similar "anti-dome" roofscape as a solution to the problem of representing West Germany on the highly charged political site of Berlin's Kulturforum.

Fig. 9

This echo of Scharoun, and thus of German Expressionism, was not accidental. Otto has described how his father, a sculptor, had "a very active role in the Deutsche Werkbund and personally knew Erich Mendelsohn"; and how, after the

_ Figure 8.
Zuse Graphomat 64 plotter on display at Expo '67, Montreal, 1967 (Horst Zuse).

Second World War, Otto took part in Werkbund and CIAM discussions, where he learned:

> in detail about the fights and arguments arising in Germany about two opposing trends – one of them linked to the imaginary and to the current Green movement. The roots of Wassili and Hans Luckhardt, Hans Poelzig, and Erich Mendelsohn went beyond the limits of the classical modern movement; this has interested me a lot: why and how at the end of the 1920s one of the two trends continued to exist while this fantasy architecture, which I have called 'proto-Green', suffered a set-back.[8]

Otto's turn to nature as a reaction to the Second World War was, then, also a conscious historical revival of the reaction that Expressionists such as Scharoun, Mendelsohn, Poelzig, and the Luckhardts had had to the First World War. Indeed, formally, Otto's work can be described as a successful combination of two strains of earlier Expressionism: the technologically-enabled "light" architecture of Bruno Taut and the spatially complex compositions of Mendelsohn. Correspondingly, the success of Otto's vocabulary for high-profile national commissions was part of a general revival of interest in Expressionism in West Germany, where Expressionist architects such as Scharoun were seen to have had a "good war," and where the movement stood for a rejection of both Fascist historicism and the post-humanism of *Neue Sachlichkeit* (and its postwar bureaucratic counterparts). Indeed, with the Philharmonie as a recent precedent, and Munich '72 as a close successor, one begins to suspect that the tented roofs of the Expo '67 Pavilion were instances in an emerging typology for anti-nationalist, anti-monumental national monuments in West Germany.

Fig. 1

_ Figure 9.
Hans Scharoun,
Philharmonie, Berlin, 1963.

The Vaulting Problem

Yet, looking further, this was not an exclusively West German development. The anti-dome appeared as a general postwar solution to the dilemma of modernist monumentality. A cluster of projects, some tensile, others not, suggest the widespread use of the doubly-curved roof from the mid-1950s to the mid-1960s.

The cultural significance of these works had already been described by Sigfried Giedion in 1954 – the same year that Otto's dissertation was completed – in an essay entitled *The Need for Imagination*. Giedion begins by describing what he sees as the two principal difficulties facing postwar architects: the speed of purely technical advances and the challenge of creating a vibrant community in a population numbed by the habits of watching "a ball game or a television screen".[9] Arguing that meeting these difficulties would require both "social" and "spatial" imagination, Giedion shifted his discussion in a somewhat unexpected direction:

Fig. 10

> The area where the spatial imagination has always had the greatest freedom – where it could unfold with the least interference – has been the area that lies above normal utilitarian requirements. This is the space that floats over our heads, lying beyond the reach of our hands. It is here that the fullest freedom is granted to the imagination of the architect. In two words, we are talking of the vaulting problem. At a certain stage of its development, each civilization has solved the vaulting problem in a way that has expressed its own emotional ideas ... What will be our answer to the vaulting problem?[10]

Seeing the possibility for the vaulting problem to offer an integrated solution to the difficulties of technology and community, Giedion's suggestion was that the answer would emerge from new approaches to long-span structures, specifically space frames and doubly-curved shells. Crucially, it is precisely because they rise

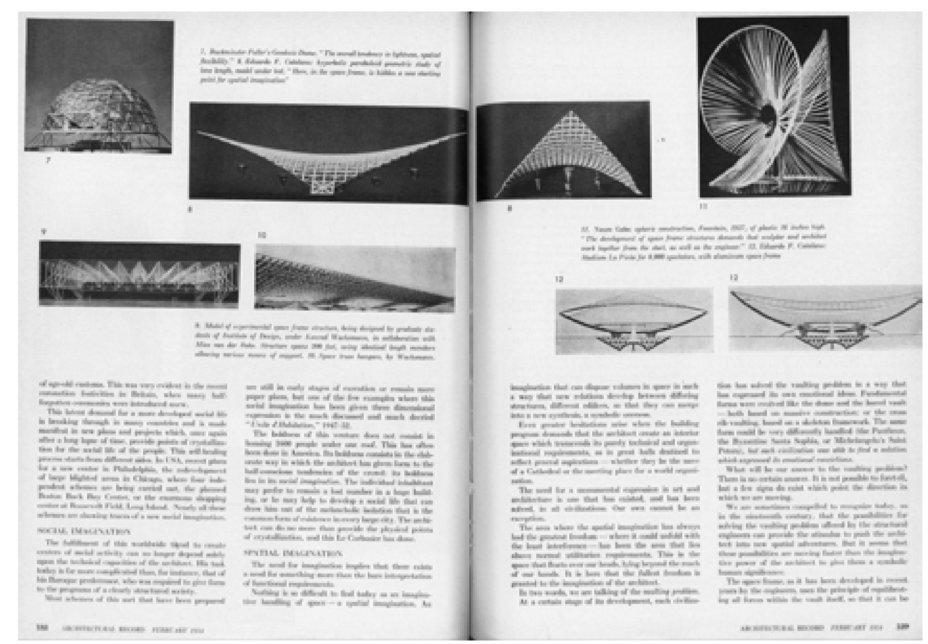
"above normal utilitarian requirements" that these forms offer hope: "the moulded sphere above the head always gives a decisive stimulus to the places where the community gathers ... It is not the creation of an all-embracing sphere which immediately changes a chaotic crowd into an integrated community, but it is its foremost symbol".[11]

Yet, where Giedion's condensed history of "the vaulting problem" emphasizes the historical continuity of the vaulting problem as a means of dealing with symmetrical centralized spaces, Otto, as we have seen, reads two distinct building lineages – one of stone and one of the tent – and a development away from centralized solutions toward naturalistic compositions.

Moreover, where Scharoun's roof was entirely compositional, Otto's tensile structures represented a rejection of the dome that was technically and geometrically precise. In order to succeed, the geometry of their membranes or nets needed to take the special form of an "anticlastic" surface, which is characterized by opposing double curvature. In contrast, a dome is a surface with allied double curvature – which we can term "synclastic".

Here we come to see all that was implied in Otto's sighing disappointment with Fuller's vast geodesic dome at Expo '67. More important than any positive associations Otto's tensile surfaces may have had with landscapes, or tents, or bubbles was their negative significance: their ability to avoid the most traditional method of spanning a monumental space – the dome – any echo of which was foreclosed by its associations with the pompous neo-classical schemes of Nazism. Otto's roofs were important not just technically, but because they advanced a new and acceptable formal vocabulary for large-scale national structures, designed through form-finding processes which are themselves not an escape from representation but the

_ Figure 10.
Sigfried Giedion, lineage of the "vaulting problem" as illustrated in *The State of Contemporary Architecture II: The Need for Imagination*, "Architectural Record", 115, February 1954.



sign of an attitude toward design, toward representation, and toward power. Finally, the circumstances of postwar West Germany meant that, although stimulated by a condition of material limitation, Otto's works, such as the Expo '67 Pavilion, actually came to represent the opposite – they tacitly, but forcefully, embodied the technical and material wealth of the West German *Wirtschaftwunder* (as indicated above). This conflation of the organic and the technological, the flexible and the rigid, the minimal and the elaborate, endowed Otto's projects with symbolic stresses that redoubled that of their structural tensions, and were the key to their success as representations of postwar West Germany.

The anticlastic vocabulary developed by Otto and others after 1945 reflects a fundamental distinction between prewar and postwar architecture, one specifically shaped by the issue of monumentality. The horrific abuses of power leading up to, and during, the Second World War produced a fundamental shift in architecture, at least in the West, such that straightforward monumentality became a near-impossibility. If Nietzsche famously claimed that "Architecture is a kind of eloquence of power in forms", the war, with its Nietzsche-dazzled ideologues, forced that age-old equation to be rethought.[12] Prewar architecture – what we might call the long synclastic age of architecture – could create monumentality by aligning technical achievement with monovocal assertions of power. Postwar architecture – apart from obviously regressive exceptions – had to find a new way to express power, whether national or institutional. We continue live in this anticlastic era, in which technical, economic, or political power cannot be celebrated directly but must be put under erasure so that it both is and is not expressed.

Abstract

Monumentalità nazionale, antimonumentale, antinazionalista.
La politica postbellica del *form-finding*

Per quanto famoso soprattutto per le sue innovazioni strutturali, il lavoro postbellico di Frei Otto possiede una valenza storica che va ben al di là delle sue innovazioni tecniche. Il suo approccio alla costruzione – in particolare per quanto riguarda i progetti per l'Expo '67 di Montreal e le Olimpiadi di Monaco del 1972 – si intrecciò in modo complesso con il contesto politicamente teso della Germania postbellica. Fin dalla dissertazione di laurea, Otto ha spiegato il suo interesse per il *form-finding* come una reazione all'architettura oppressivamente grandiosa del nazionalsocialismo e come un tentativo di scoprire un approccio alla progettazione che fosse intimamente democratico. I suoi metodi di lavoro e le forme che ne derivano illustrano i dilemmi impliciti nella realizzazione di questa visione attraverso progetti che cercano di incarnare il compimento della ricostruzione postbellica della Germania.
Questo intervento situa il *form-finding* di Otto all'interno dei contesti storici sia dell'architettura tedesca sia dei dibattiti internazionali sulla monumentalità dopo la seconda guerra mondiale. Il vocabolario anticlastico sviluppato da Otto dopo il 1945 riflette una fondamentale distinzione tra architettura prebellica e postbellica, in particolare riguardo alla questione della monumentalità. I tremendi abusi di potere della seconda guerra mondiale produssero un cambiamento fondamentale nell'architettura, al punto che la monumentalità pura e semplice venne quasi bandita. Se Nietzsche aveva notoriamente affermato che «l'Architettura è una specie di oratoria della potenza per mezzo della forma», la guerra, con i suoi ideologi abbagliati dal pensiero nietzschiano, costrinse al ripensamento di quella secolare equazione. L'architettura prebellica, che potremmo chiamare la lunga era sinclastica dell'architettura, riusciva a creare monumentalità combinando la competenza tecnica con asserzioni monovocali di potere. L'architettura postbellica, a parte le sue eccezioni apertamente regressive, ha dovuto trovare un nuovo modo di esprimere il potere, nazionale o aziendale che fosse.
Oggi continuiamo a vivere in questo periodo anticlastico, nel quale ogni manifestazione architettonica di potenza tecnica, economica o politica deve essere al contempo addolcita, temperata e diffusa – un obiettivo spesso raggiunto ricorrendo alla natura in quanto generatrice di forme.

Notes

_ 1. While Jonathan Massey has drawn attention to the rivalry between the U.S. Pavilion and that of the Soviet Union, it was the contrasting architectural approaches of the U.S. and West German pavilions that received special note in the official album of the exhibition (which also noted the advantages of Otto's strategy). Cf. J. Massey, *Buckminster Fuller's Cybernetic Pastoral: The United States Pavilion at Expo '67*, "The Journal of Architecture", 11, 2006, n. 4, pp. 463-483; C. Beaulieu, *Architecture*, in P. Dupuy, J.L. de Lorimier, Canadian Corporation for the 1967 World Exhibition, *Expo '67: The Memorial Album of the First Category Universal and International Exhibition Held In Montreal from the Twenty-Seventh of April to the Twenty-Ninth of October Nineteen Hundred and Sixty-Seven*, Thomas Nelson & Sons, Montreal 1968, pp. 325-340, p. 328.

_ 2. P. Sigel, *Interview mit Frei Otto*, in P. Sigel (ed.), *Exponiert: Deutsche Pavillions auf Weltausstellungen*, Verlag Bauwesen, Berlin 2000, pp. 300-304, p. 303.

_ 3. F. Otto, *Das Hängende Dach*, Ullstein, Berlin 1954, pp. 9-10. My translation.

_ 4. K. Linkwitz, *Application of Photogrammetry and Electronic Data Processing to the Model of the Pavilion*, in F.M. Sitte, G. Eisenberg (eds.), *Expo '67 Montreal – German Pavilion: Documentation on the Structure*, Werner-Verlag, Düsseldorf 1967, p. 18; cf. also M. Eekhout, *Frei Otto and the Munich Olympic Games: From the Measuring Experimental Models to the Computer Determination of the Pattern*, "Zodiac", 21, 1972, pp. 12-74, p. 38; and Frei Otto as quoted in J.M. Songel, *A Conversation with Frei Otto*, Princeton Architectural Press, New York 2010, pp. 76-77.

_ 5. Frei Otto, quoted in *Frei Otto in Conversation with the Emergence and Design Group*, "Architectural Design", 74, 2004, n. 3, pp. 18-25, p. 23. Evidence of the collaboration between the research groups of Otto and Linkwitz on the Montreal pavilion is also given in Eekhout 1972 (see footnote 4), p. 38; W. Faig, *Vermessung dünner Seifenlamellen mit Hilfe der Nahbereichsphotogrammetrie*, Verlag der Bayerischen Akademie der Wissenschaften, München 1969.

_ 6. Sigel 2000 (see footnote 2), p. 300.

_ 7. D. Mertins, lecture at Illinois Institute of Technology College of Architecture, 12 March 2008.

_ 8. Songel 2010 (see footnote 4), pp. 25-27.

_ 9. S. Giedion, *The State of Contemporary Architecture II: The Need for Imagination*, "Architectural Record", 115, 1954, pp. 186-191, p. 186.

_ 10. *Ibid.*, p. 189.

_ 11. *Ibid.*, p. 191.

_ 12. F.W. Nietzsche, *Twilight of the Idols, or How One Philosophizes with a Hammer* (1889), in W. Kaufmann (ed. and trans.), *The Portable Nietzsche*, Penguin, New York 1954, pp. 463-563, p. 521.

_ Figura. 1
Voliera per lo zoo di Monaco di Baviera, 1980 (Archivio fotografico Institut für Leichte Flächentragwerke, Universität Stuttgart).

Elisabeth Bergmann

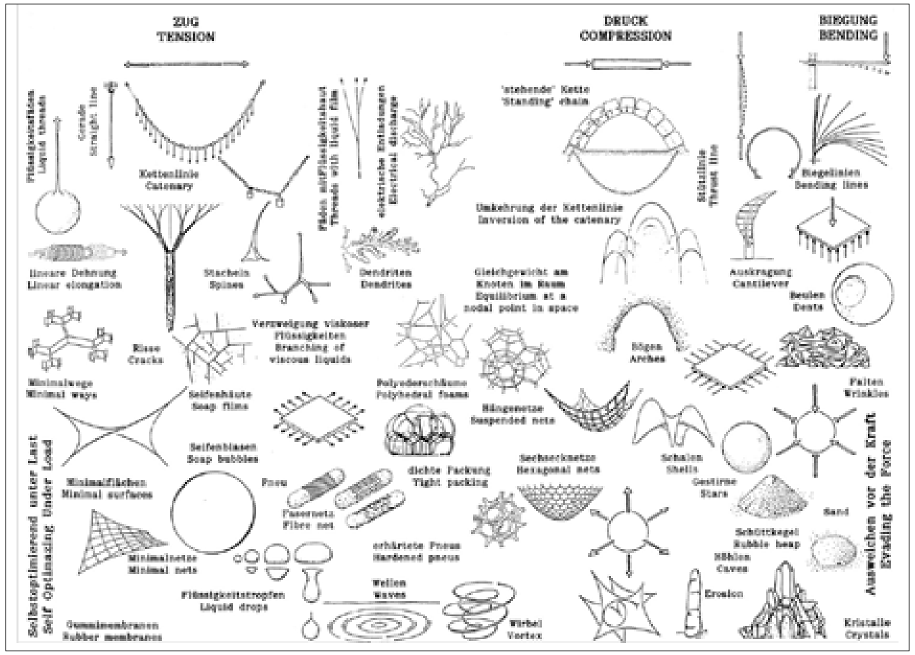
La “filosofia architettonica” di Frei Otto

I concetti di forma, estetica ed etica e la loro ricezione

Gli spettacolari progetti di Frei Otto, le sue strutture pneumatiche, autoportanti leggere e le tensostrutture, hanno fino ad ora offuscato la ricezione del suo contributo teorico all’architettura. Nelle numerose pubblicazioni relative al suo lavoro, infatti, il punto focale è il tema della costruzione leggera, mentre le ulteriori implicazioni teoriche non vengono approfondite o vengono analizzate in maniera insufficiente.

Il catalogo di Winfried Nerdinger, ad esempio, contiene un elenco di lavori sviluppati nel periodo 1951-2005 e l’analisi di aspetti tecnici della costruzione leggera.[1] L’unico saggio che indica qualche traccia relativa alla *Gestaltwerdung*, alle “costruzioni naturali” e agli impulsi sociologici è quello di Nerdinger stesso, dal titolo *Frei Otto. Arbeit für eine bessere “Menschenerde”* (Lavoro per una “Terra degli uomini” migliore).[2] Nel testo di Irene Meissner si descrive invece come Otto abbia sempre avuto l’ambizione di lavorare «in armonia con la natura e la tecnica».[3] Anche in un’altra monografia, quella di Karin Wilhelm,[4] il contributo teorico di Frei Otto non viene approfondito.

A partire da tali considerazioni, in questo saggio viene esaminato un altro aspetto, finora poco trattato, del lavoro di Frei Otto: la sua teoria dell’architettura, che egli stesso a partire dagli anni Settanta descrive come una «filosofia architettonica».[5] La rilevanza di questa teoria viene accennata nella pubblicazione di Hanno-Walter Kruft *Storia delle teorie architettoniche. Dall’ottocento ad oggi*: «Un’attenzione particolare può meritare l’impostazione teorica di Frei Otto … che considera le sue costruzioni pneumatiche, le tensostrutture e le sue ricerche sulle strutture leggere a superfici autoportanti come riflessioni fondamentali per un nuovo concetto di architettura … ».[6] Anche Kruft accenna soltanto ai concetti di *form-finding* e costruzione biologica e naturale, nonostante ammetta come il lavoro dell’architetto tedesco vada oltre le prime impostazioni biologistiche con una sua particolare “bionica”, traducendo la legge della forza della natura direttamente nella costruzione.[7]



_ Figura 2.
«Übersicht der aus Selbstbildungsprozessen hervorgehenden Konstruktionen geordnet nach den sie erzeugenden Kräften / Overview of the structures which develop from self-forming processes, classified according to the generating forces» (*Experimente/Experiments*, IL 25, 1990, p. 2.17).

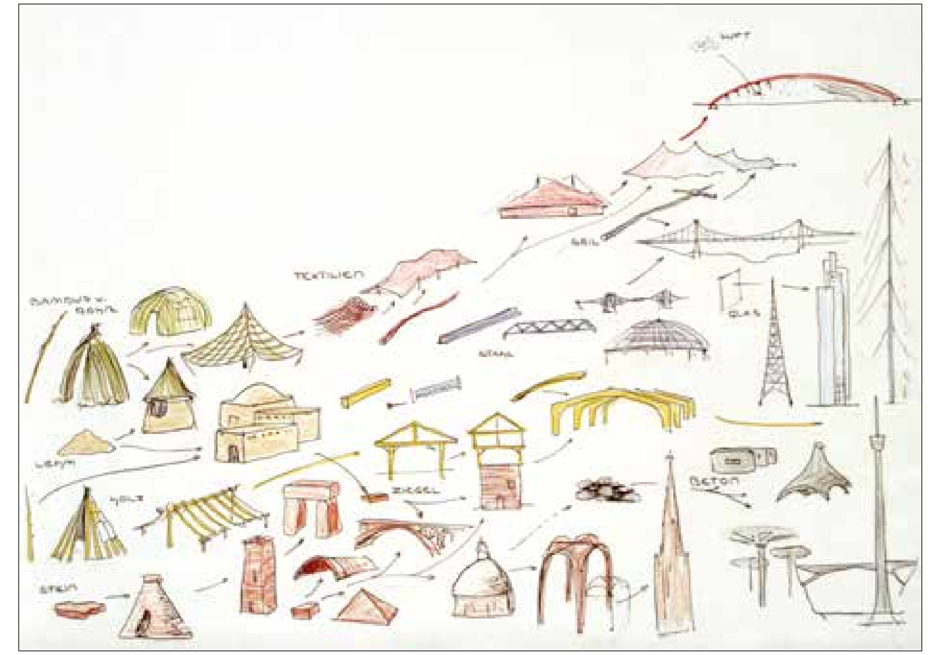
Fig. 1

Come è emerso durante la presente ricerca, la scelta di Otto di utilizzare la costruzione leggera non è dovuta né a motivi formali né a ragioni materiali. Più che altro, è il fondamento etico a motivarla. Con il principio della costruzione leggera egli prova anche a spiegare la ripercussione che essa ha sull'estetica degli oggetti. Per questo motivo, al centro della ricerca sono posti i concetti chiave di forma, estetica ed etica. Importanti in questo contesto sono anche le connotazioni politiche, ma dal momento che esse sono state trattate da Sean Keller,[8] non verranno qui approfondite.

Le reazioni dei contemporanei ai progetti di Otto rivelano come i suoi pensieri siano stati fonte di ispirazione tanto in patria quanto all'estero. Ciò è dimostrato in maniera paradigmatica da due esempi: i lavori e le pubblicazioni dell'architetto zurighese Lisbeth Sachs negli anni Settanta e, più di recente, le costruzioni e i progetti urbanistici di Zaha Hadid, effettuati con il supporto teorico di Patrik Schumacher.

Il percorso verso la forma

Frei Otto sviluppa il suo pensiero sulla base del binomio forma e *Gestalt*, definendo la *Gestalt* come la «tipica forma di oggetti percepibili in maniera sensibile» (*Unter dem Begriff Gestalt versteht man die typische Form von sinnlich wahrnehmbaren Gegenständen*) e sottolineando, dal punto di vista storico, come la parola "forma" provenga da *Gestalt* (intesa nel senso di "configurazione"). Secondo l'architetto, questa parola deriverebbe da «il messo lì, il collocato, il posato, l'essere divenuto».[9] In questo modo si fa cenno a uno dei suoi approcci preferiti nei confronti della ricerca



_ Figura 3.
«Geschichte der Baukontruktion» (W. Nerdinger, *Frei Otto*, Basel 2005, p. 165).

della forma, ovvero il cosiddetto *form-finding*, processo attraverso il quale la forma viene "trovata", o per meglio dire viene "lasciata divenire".

Frei Otto manifesta il suo concetto teorico di *form-finding*, nel quale si sottolinea il primato della ricerca scientifica della forma, rifiutando la realizzazione artistica come pure la manipolazione della forma. Questo aspetto è stato messo in evidenza, in particolare, nella polemica con Günter Behnisch a proposito della copertura dello stadio olimpico di Monaco: «La volontà di una configurazione forzata – scriveva Otto – risulta in contrasto con la ricerca della forma ancora sconosciuta, ma sottomessa alle leggi della natura».[10] Convinto che la forma non debba mai essere trascurata, ma anzi ricercata e trovata con coscienza, e non debba comunque essere creata, Frei Otto criticava la situazione a lui contemporanea affermando:

> Conosciamo quasi solo chi crea o chi evita la forma. Coloro che invece la cercano sono davvero rari. ... Alcuni la creano e basta, altri la dimenticano. Non è giusto prendere una forma in mano per deformarla. Noi invece proviamo a toglierla dal guscio, a farla migliore, e per questo abbiamo anche ideato il processo del *form-finding*. Noi non creiamo una forma dal contesto, ma piuttosto la sviluppiamo.[11]

Come funzioni questo processo di trovare la forma viene spiegato in un'illustrazione, in cui Otto differenzia tre gruppi di costruzioni a seconda delle loro sollecitazioni.[12] Sin dall'inizio della sua attività come architetto, ma già prima dell'inizio degli studi, egli abbozzava e disegnava seguendo il principio della curva catenaria;[13] questo lo portò a utilizzare dei modelli composti da reti appese, che saranno fondamentali per i suoi studi sulla forma della Multihalle di Mannheim.

Fig. 2

Figg. 5, 6,11

Forma ottimale, forma minima e il "principio costruzione leggera"

Durante il processo del *form-finding* Frei Otto cerca di avvicinarsi a una forma ottimale, definita come la forma che abbia «una buona divisione delle tensioni», una configurazione statica «in cui forma e forza siano in sintonia».[14]

Questo concetto implica un punto di vista estremo, secondo il quale per ogni problema esiste esattamente una soluzione ottimale. Frei Otto ragiona in questa maniera già nella sua tesi di dottorato, la sua prima pubblicazione sulle strutture leggere, e a proposito di questa convinzione, che più tardi verrà relativizzata, afferma che anche nell'ambito della forma classica, definita storicamente come una forma a cui non si può aggiungere né togliere alcunché, raramente vi è una unica soluzione.[15] Ottimizzare una forma significa per lui, anche dal punto di vista costruttivo, «trovare una forma con un minimo di materiale».[16] Fin dall'inizio della sua ricerca formale troviamo dunque l'ideale della forma minima, vale a dire della costruzione leggera.

_ Figura 4.
Voliera per lo zoo di Monaco di Baviera, 1980 (Archivio fotografico Institut für Leichte Flächentragwerke, Universität Stuttgart).

Dietro il principio della costruzione leggera sta un'etica filosofica ma anche un postulato estetico, secondo il quale «la ricerca della forma minima in architettura» è «allo stesso tempo una ricerca dell'essenza della *Gestalt*, della configurazione materiale». Frei Otto spiega in seguito: «Si pensa di averla trovata [la forma minima, cioè l'essenza della *Gestalt*] quando nulla, ma davvero nulla può essere rimosso da una costruzione senza svalutarla».[17]

Le sue esperienze durante la seconda guerra mondiale, unite all'avversione per l'architettura megalomane e anti-umana dei nazionalsocialisti, portarono inevitabilmente Otto a formulare il «principio della costruzione leggera»: «Dopo l'ossessione nazista per l'eternità, il nulla mi è servito come possibilità di una nuova strada. Il semplice e l'effimero sono allora diventati il mio filo conduttore».[18]

Figg. 3, 4

L'estetica particolare del minimale

Secondo Frei Otto, per produrre architettura di alta qualità con una certa rilevanza estetica è indispensabile che l'architetto e l'ingegnere lavorino a stretto contatto.[19] Il processo dello sviluppo della forma in alternanza con la natura è stato chiamato da Frei Otto «il percorso inverso» (*der "umgekehrte Weg"*).[20] Da questo concetto risulta che per poter sviluppare una nuova estetica, adeguata ai tempi, gli architetti – e vorrei aggiungere: anche gli ingegneri – dovrebbero occuparsi di come l'architettura ottiene la propria forma, di quali percorsi e quali metodi esistono per inventare la forma o, appunto, per trovarla.

Frei Otto definisce l'estetica in questo modo: «In generale viene visto come *estetico* ciò che tocca i nostri sensi, ciò che si riconosce come bello, che sembra superiore, senza suscitare paura o invidia».[21] Una definizione poco abituale, a mio avviso, perché infatti riunisce in sé anche l'aspetto della *superiorità*: una superiorità che viene avvertita solo in senso estetico, qualora non contenga aspetti in qualche modo aggressivi verso lo spettatore. In contrasto con il concetto comunemente inteso nella filosofia della *Gestaltqualität* (qualità della forma), secondo l'opinione di Frei Otto architetti e designer valutano questa *Gestaltqualität* dal fatto che la funzione sia leggibile in maniera chiara, e che l'essenza sia percepibile. In questo modo, essa diviene strettamente collegata al percorso verso il tipico, verso la "forma classica", la forma ideale, ma anche verso la "giusta" forma funzionale.[22]

Fig. 5

Quando parla di "forma funzionale", Frei Otto dà soprattutto importanza a una chiara differenziazione tra "funzionalismo" e "costruzione funzionalmente giusta": «Ogni enfatizzazione è un "fare di più" e quindi un evitare la vera forma di sviluppo ... In questo senso, non è importante la costruzione, ma piuttosto *das Gestaltbare im Konstruktiven*»,[23] cioè "il configurabile nel costruttivo". Tale aspetto è di rilevanza centrale. Potrebbe essere questo uno dei motivi dell'attuale crisi di creatività nel campo dell'ingegneria? È questa la radice del conflitto tra architetti e ingegneri? È questo il motivo dell'apparente o effettiva arbitrarietà del corpo costruttivo dell'architettura contemporanea? Otto attacca in modo diretto anche quelle tendenze che considerano il funzionale apparente o effettivo come elemento alla base della creazione. Un simile approccio, infatti, porterebbe unicamente a un gioco espressionistico e non avrebbe niente a che vedere con la costruzione funzionalmente giusta.[24] La funzione, da sola, non può portare alla forma né determinare la forma; essa potrebbe tuttavia essere la causa dello sviluppo di oggetti estetici:

> Di certo non si può tracciare un confine chiaro tra funzionale e non-funzionale. Nonostante tutte le riserve che potrebbero sorgere contro questa tesi, suppongo che l'estetico nella forma pura stia già fuori dal funzionale. Ma spesso il funzionale è la ragione per la … formazione di un oggetto estetico. … L'estetica … aiuta (o dovrebbe aiutare) … a riconoscere il "particolare" e lo "straordinario". All'estetica appartiene anche la teoria che aiuta a riconoscere determinati fenomeni descritti come non-estetici, anti-estetici, come bluff, o addirittura inganno o kitsch.[25]

Anche in questo caso Otto enfatizza il particolare, l'eccezionale, il prevalente: ciò che rappresenta un importante elemento della sua teoria sull'estetica particolare della costruzione leggera.

Frei Otto ha cercato per molto tempo una spiegazione del fascino emanato dalle costruzioni leggere. Il "principio della costruzione leggera" in generale, e in particolare le costruzioni pneumatiche (*Pneu*), sembra essere per lui la chiave per la comprensione della speciale estetica degli oggetti.[26] Egli fa risalire a questo principio anche il corpo umano: «Molto, molto lentamente abbiamo capito che la cosiddetta bellezza dei corpi umani non è altro che una membrana riempita d'acqua».[27] A riguardo della costruzione leggera scrive:

> Gli oggetti che rispondono al principio delle costruzioni leggere possono diventare estetici unicamente quando non solo sembrano economici fisicamente, leggeri e forti; non solo quando sembrano adeguati, ma quando – senza diventare allo stesso tempo non funzionali – sono formati in maniera ideale, sono perfetti, "mostrano" la loro vera "forma" …, quando essi non solo rispecchiano la forma tipica di tutti gli oggetti ottimizzati in maniera compiuta, … ma anche quando rispecchiano sia il generale sia l'individuale, con le deviazioni (imperfezioni) tipiche di quest'ultimo.[28]

Oltre a questa spiegazione materialistica, Otto azzarda anche una giustificazione psicologica:

> Piuttosto, è da supporre che proprio la capacità degli uomini di individuare oggetti di costruzione estremamente leggera – capacità che origina dal suo passato animale – sia con buona probabilità la più importante radice per essere sensibili verso particolari oggetti. … in particolare, quando la forma dell'oggetto segnala superiorità senza essere aggressiva. … Il pericoloso funzionale allarma. Anche l'inconsueto crea allarme – perché potrebbe essere pericoloso. Il "particolare", il "superiore", crea ammirazione nel momento in cui non è pericoloso. … Superiori fisicamente sono tutti gli oggetti che si sviluppano dal principio della costruzione leggera.[29]

Ma tutti questi tentativi, fatti per decodificare il mistero di un'estetica tanto particolare, non riescono a convincere. Interrogato su come definisse oggi l'estetica peculiare delle costruzioni leggere, e su dove nascesse il loro fascino particolare, nel 2013 Frei Otto rispondeva: «È il "leggero"? Tutto quello che è più leggero dell'ambiente. La nebbia, i banchi di nebbia, la luce. Cos'è questo, in realtà? Semplicissimo, non lo so. E ci stiamo ancora pensando sopra. Dunque, a questo non ho una risposta».[30]

Etica del minimale

Più importante dell'effetto estetico è per Frei Otto una buona architettura in senso etico: «Più che bella, è importante che l'architettura sia buona, buona per tutti gli uomini. … Buona architettura … non è solo tecnica ma anche sensuale».[31] E a questa asserzione

_ Figura 5. Multihalle, Mannheim, 1975 (Südwestdeutsches Archiv für Architektur und Ingenieurbau, Karlsruher Institut für Technologie, fondo Carlfried Mutschler, foto Ingrid Weiland-Autenrieth, Freiburg-Zähringen).

_ Figura 6. Multihalle, Mannheim, 1975, modello sospeso (Deutsches Architekturmuseum, Frankfurt am Main, foto Uwe Dettmar).

aggiunge: «L'ideale è un'architettura eticamente buona che sia anche estetica».[32] Otto ha questa pretesa etica non solo verso l'architettura, ma anche verso l'architetto: «Gli architetti aiutano gli uomini a vivere, abitare, sentirsi a casa sulla terra. … con i loro lavori potrebbero danneggiare gli uomini nel corpo e nell'anima, o addirittura ucciderli».[33]

Frei Otto è convinto che l'architettura minimale della costruzione leggera non abbia soltanto una particolare estetica, ma che necessiti anche di un particolare fondamento etico, che egli deduce da forme architettoniche arcaiche: «L'architettura dell'origine (*Urarchitektur*) è un'architettura della necessità. Non ha niente di superfluo … È minimale. Può essere bella nella povertà e buona in senso etico».[34] Idealmente, l'architettura dovrebbe soddisfare delle richieste estetiche ed etiche. Per Otto questo accade nelle costruzioni vernacolari, naturali: «Una nuova comprensione della natura si crea sotto un aspetto, quello della forma ad alto rendimento (chiamata anche "forma classica"), che riunisce in sé elementi estetici ed etici. In questo momento riconosciamo anche la qualità degli edifici e delle abitazioni più vernacolari».[35]

Nel 2002, durante il Congresso mondiale di architettura a Berlino, Frei Otto tenne un discorso che intitolò *Etica, estetica, innovazione*, nel quale, per prima cosa, cercò di definire i termini etica ed estetica:

> Etica è la base per la sopravvivenza dell'umanità; estetica è l'oggetto dell'educazione. … Ciò che è bello, non deve allo stesso tempo essere etico. Il bello non è allo stesso tempo buono. Il bello può anche essere terribile, e il brutto buono. Talvolta il bello diventa orribile con il tempo e l'orribile bello. Il bello nell'arte è sempre originale, nuovo, è invenzione, innovazione.

Ancora una volta, Otto sottolinea la prevalenza dell'etica sull'estetica: «Credo che noi oggi non abbiamo bisogno di una teoria del bello nell'architettura. Quello di cui sicuramente abbiamo bisogno è invece una ferma identificazione con un'etica del costruire, senza la quale una casa può essere sì bella, ma non ancora umana».[36]

Con leggerezza contro la brutalità è il titolo di un intervento di Frei Otto del 1976, apparso in "Allgemeine Bauzeitung", nel quale egli definisce ogni costruzione "inumana" come brutalità: «Costruire in maniera non ragionata, avida di potere, incompetente, senza arte è, in maniera maggiore o minore, costruire in modo disumano, quindi brutale, come per esempio nel caso della cosiddetta costruzione "sociale" di case popolari (*"sozialer" Wohnungsbau*)».[37] Rispetto al costruire in maniera umana Otto avanza delle elevate pretese etico-sociali: «Costruire in maniera umana non aiuta solamente a sopravvivere, ma, idealmente, favorisce un pieno sviluppo delle facoltà dell'individuo e il suo ingresso in gruppi sociali definiti o in continuo cambiamento».[38]

Oltre a questo, il costruire deve fare fronte alle necessità pratiche in modo flessibile. Otto ammette che una totale adattabilità sia tecnicamente irrealizzabile, ma rivendica in modo ironico che l'uomo dovrebbe almeno costruire in maniera duttile, come faceva tre millenni fa. Egli critica la diffusa opinione che un materiale come il calcestruzzo sia facilmente modellabile e quindi anche adattabile, dal momento che l'ideale, irraggiungibile, dell'adattabilità sta nel costruire senza materiale, e la realizzazione ottimale nel campo del costruire si ottiene con meno materiale possibile: «La capacità di adattamento è un segno di riconoscimento fondamentale del costruire umano. Non s'infilano gli uomini, come oggi spesso accade, in gabbie immutabili o in brutali montagne di scatole già pronte, perché ciò non serve a loro per sentirsi a casa. Edifici che possono adattarsi completamente sono un ideale indubbiamente irraggiungibile, potrebbero mutare all'interno come all'esterno e sarebbero mobili. Sarebbero in ogni momento moderni, non invecchierebbero mai».[39] «È però di certo possibile – con l'adeguata tecnica moderna – costruire in maniera adattabile come si faceva 3000 anni fa, quando crebbero le prime città fatte di argilla, che oggi, profondamente mutate, in parte esistono ancora. Costruzioni di argilla, paglia e tende sono adattabili, variabili o mobili. Il materiale da costruzione di oggi si chiama calcestruzzo. Il calcestruzzo non è solo un materiale da costruzione, ma un concetto che fa l'architettura. Il calcestruzzo è facilmente modellabile una volta sola, poi non lo è più».[40] Almeno fino ad oggi, sottolinea Otto.[41]

La ricezione della "filosofia architettonica" di Frei Otto: L'interpretazione di Lisbeth Sachs

Una personalità che già dai primi anni Cinquanta ha seguito in maniera interessata il lavoro di Frei Otto è l'architetto zurighese Lisbeth Sachs. Particolarmente impressionante è la sua comprensione del potenziale etico della costruzione leggera, e la sua interpretazione sensibile e significativa dei lavori di Otto.

In una bozza di testo per una pubblicazione su Frei Otto, Lisbeth Sachs descrive il carattere delle costruzioni leggere come «gioia nell'invenzione della pelle», e riconosce il loro stretto intrecciarsi di costruzione e forma, tetto e parete, peso e sospensione:

> Con le costruzioni leggere si dispiega il nuovo nella forma e nello spazio, apparentemente da solo. L'impulso viene dalla gioia della scoperta della pelle. La forma segue la costruzione. … Sono spesso tetto e parete allo stesso momento. … Raggiungono il loro obiettivo con un basso utilizzo di materiale e in gesti abbozzati e allegri. È come se con le loro forme fermino il momento del passaggio da una condizione pesante a una sospesa. Hanno qualcosa di danzante, dinamico, entusiasmante. Tutto questo è frutto del fascino, del cavarsela con poca materia, del ridurre il mezzo attraverso una continua ottimizzazione ingegnosa della costruzione e della forma.[42]

Nel 1985, in occasione del sessantesimo compleanno dell'architetto, Lisbeth Sachs ha pubblicato, insieme a Karin Wilhelm, un libro sull'opera di Frei Otto. Nell'introduzione Sachs racconta il suo primo incontro con Otto, e seguendo i parametri "forma", "estetica" ed "etica" ne caratterizza il linguaggio architettonico. Descrive come la forma si componga di "superfici autoportanti" e cerca di spiegare l'estetica particolare delle costruzioni leggere: «… un nuovo linguaggio della forma che avviene in maniera apparentemente casuale, come un'estetica particolare».[43] Le sue riflessioni poetiche culminano nella domanda: «Sono edifici che respirano?»[44] Soprattutto le considerazioni sull'etica del costruire in maniera leggera dimostrano come lei abbia compreso profondamente anche la loro base umanistica: «Queste forme oscillanti … creano gesti che fanno sentire protetti e sollevati allo stesso momento. … spazi come laboratori del vivere. Provocano il nostro lato creativo, un inizio sempre nuovo, il cambiamento. Un impulso naturale a non rimanere fermi».[45]

Uno dei progetti di Lisbeth Sachs sembra collegarsi in maniera molto stretta all'opera di Frei Otto. Dall'inizio degli anni Settanta, e con instancabile perseveranza fino agli anni Ottanta, ella provò a convincere il Consiglio della città di Zurigo a costruire una Casa della gioventù, cosa che però non le riuscì mai. Il suo progetto prevedeva infatti non semplicemente un edificio per giovani, bensì una struttura galleggiante amorfa sul lago di Zurigo! Come una zattera, essa avrebbe dovuto lasciarsi trascinare dall'acqua. Nella baia del lago, alla fine di Tiefbrunnen, oppure una struttura su pali nel Limmat (uno dei due corsi d'acqua di Zurigo).[46] Il 15 febbraio 1971, Lisbeth Sachs aveva già ampiamente parlato con Frei Otto di questa idea per la Casa della gioventù.[47] Quanto fosse importante per lei questo progetto è dimostrato dal fatto che il giorno dopo il colloquio con Frei Otto scrisse al consigliere Erwin Frech, che lavorava presso l'Ufficio tecnico comunale di Zurigo:

Figg. 7-9

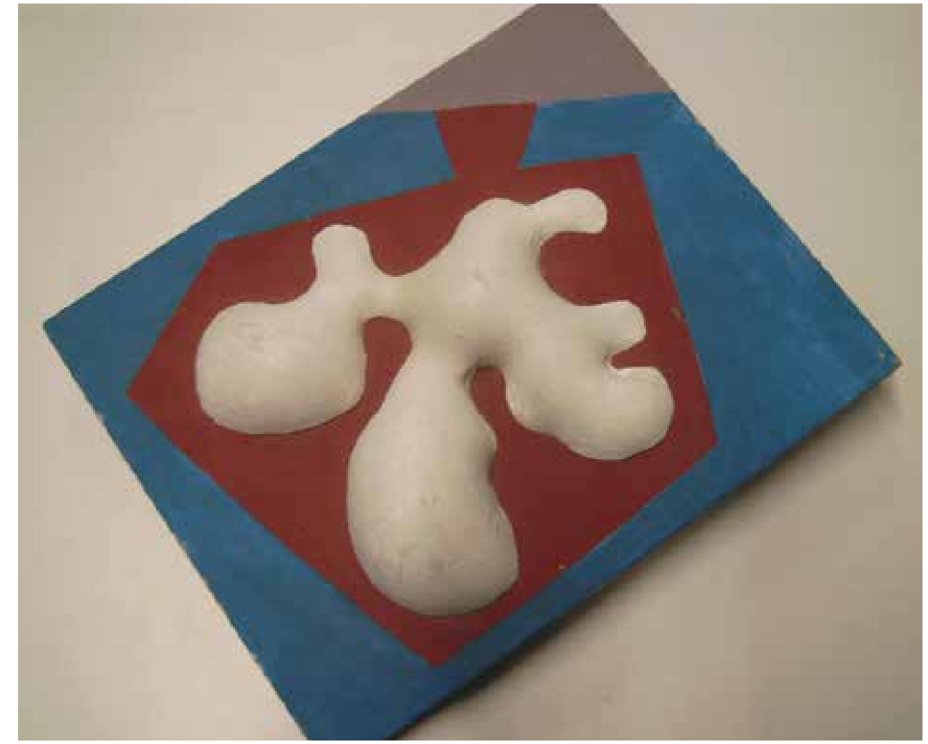
> Di mia iniziativa, questo scrivo in maniera confidenziale, sto studiando in questo momento una Casa della gioventù attraverso l'invito di diversi giovani alla discussione. … L'area coperta è di 1.000-1.400 m² … Ampliabile, demolibile e spostabile. Realizzabile in tempi brevi. All'interno e all'esterno ha un aspetto allegro e leggero, facilmente in grado di liberare, certo più di qualche muro, i pensieri degli utenti da idee aggressive.[48]

Tuttavia, presto dovette riconoscere di aver scelto un momento sfavorevole per l'invio della sua lettera; scrisse infatti con ironia a Frei Otto: «Visto che il weekend prossimo ci sono le votazioni del Parlamento cantonale, nessun partito, davanti ai cittadini, vuole scottarsi le dita con i capelloni».[49]

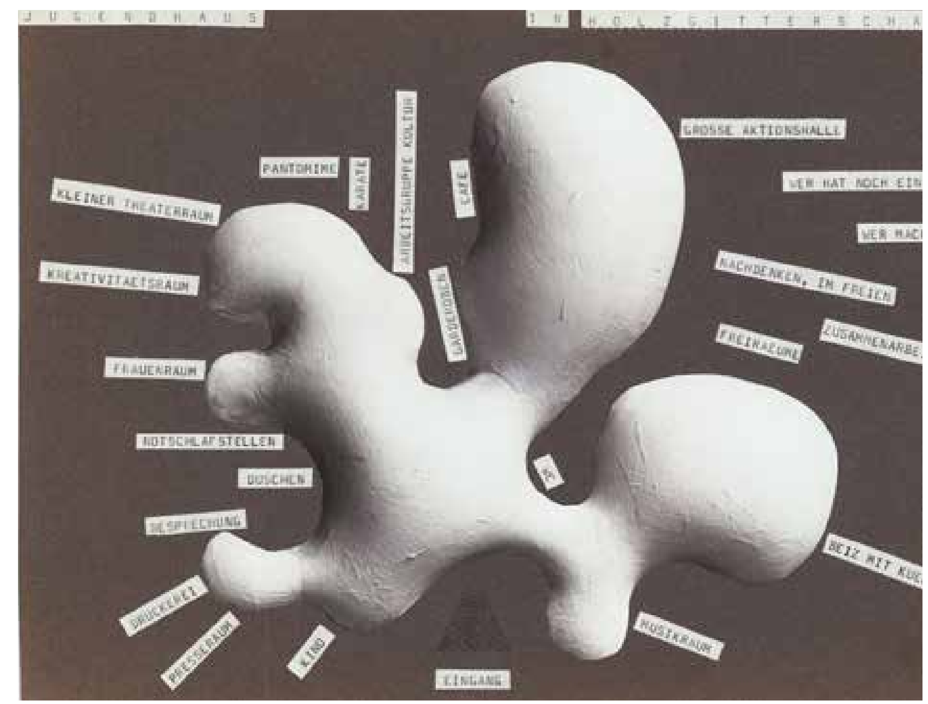
L'idea di Lisbeth Sachs per una Casa della gioventù galleggiante e la sua propo-

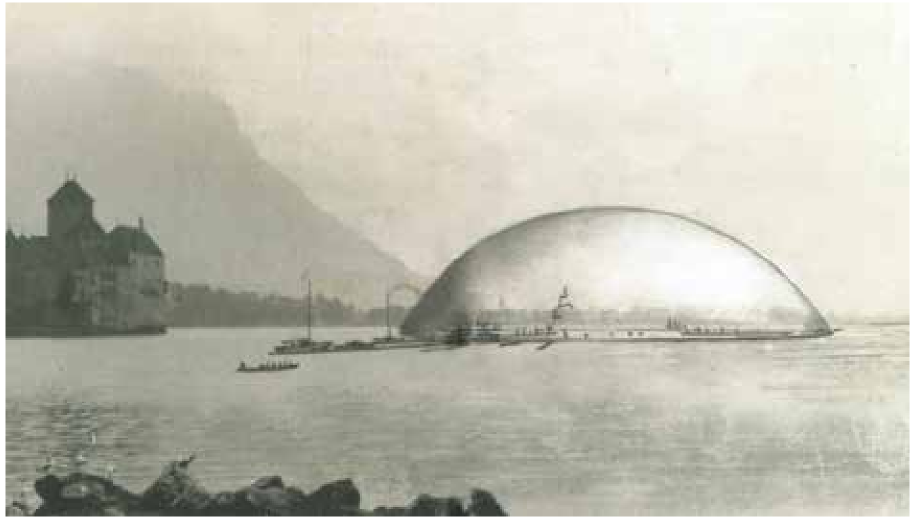
_ Figura 7.
Lisbeth Sachs, progetto per la Casa della gioventù galleggiante, 1971, schizzo (gta Archivio, ETH Zurigo, fondo Lisbeth Sachs).

_ Figura 8.
Lisbeth Sachs, progetto per la Casa della gioventù galleggiante, 1971, modello (gta Archivio, ETH Zurigo, fondo Lisbeth Sachs, foto Elisabeth Bergmann).



_ Figura 9.
Lisbeth Sachs, progetto per la Casa della gioventù galleggiante, 1971, fotomontaggio (gta Archivio, ETH Zurigo, fondo Lisbeth Sachs).





_ Figura 10.
Piscina sul lago di Ginevra, progetto, 1960
(W. Nerdinger, *Frei Otto*, Basel 2005, pp. 190, 191).

_ Figura 11.
Multihalle, Mannheim, 1975, interno
(Südwestdeutsches Archiv für Architektur und Ingenieurbau, Karlsruher Institut für Technologie, fondo Carlfried Mutschler).

sta suggestiva di collocarla sul lago ricordano molto il progetto di Otto per una piscina sul lago di Ginevra. La forma della Casa deriva direttamente dalla Multihalle di Mannheim di Frei Otto. Il 5 giugno 1975 Lisbeth Sachs scrive infatti a Frei Otto di come fu impressionata dal suo progetto:

Figg. 5, 6, 10, 11

> Egregio professore, le devo confessare che sono stata di recente a Mannheim, per poter vedere i gusci a graticcio in legno. Il contrasto tra la corpulenta pelle di elefante esterna e il suo gracile scheletro, che forma lo spazio interno, è una sorpresa che lascia a bocca aperta, necessaria, ancora una volta, allo sviluppo dell'architettura. I passaggi tra gli spazi interni sembrano da una parte volgersi al barocco e dall'altra guardare al futuro. – E questo perché l'uomo qui si sente in maniera nuova e diversa, come mai prima. Si sente sotto il cielo, sotto la grandezza, e allo stesso tempo protetto. E in contatto con il proprio simile, in una naturale convivenza nello scorrere della vita. Lei ha creato un'opera davvero ragguardevole![50]

In che cosa consista per Lisbeth Sachs il fascino particolare delle superfici autoportanti e l'effetto psicologico dello spazio che creano, lo spiega lei stessa in un testo scritto in collaborazione con Karin Wilhelm: «Perché gli spazi sono anche luoghi di pensiero. Sono capaci di mettere in movimento il pensiero. Le superfici autoportanti leggere sono quelle che riflettono un suono nuovo dello spazio … Nonostante le dimensioni talvolta immense, non risultano autoritarie e soffocanti, ma trasmettono leggerezza, stimolano l'utilizzatore. Questa è la loro caratteristica, questo è il futuro».[51]

Patrik Schumacher, *The Autopoiesis of Architecture*

Patrik Schumacher ha dedicato a Frei Otto la penultima delle sessanta tesi della sua pubblicazione *The Autopoiesis of Architecture*: "THESIS 59. The work of Frei Otto is the only true precursor of Parametricism".[52] Si riferisce però soltanto ai modelli per la distribuzione di zone di insediamento e sistemi di percorsi. A proposito del *form-finding*, scrive che i modelli auto-organizzanti metterebbero insieme una grande varietà di componenti in un campo di forze simultaneo. Variando anche solo un unico elemento, reagirebbero tutti gli altri elementi. Questo potrebbe costituire un parallelo con la sua idea di *parametricismo*. Tralasciando i punti essenziali dell'approccio di Frei Otto, Schumacher non coglie tuttavia il pieno significato del processo del *form-finding*. Egli prova anche a spiegare l'effetto estetico del parametricismo, definito da lui stesso come «lo stile del XXI secolo»: «Elegance is here promoter as the general watchword of Parametricism's aesthetics».[53] Solo il termine "eleganza", che egli promuove come motto per l'estetica del parametricismo, e che per lui contiene soprattutto raffinatezza e perfezionamento, mostra come egli provi a spiegare il fenomeno guardando in particolare l'aspetto esteriore. Inoltre, Schumacher sostiene che l'eleganza è espressione di complessità, sottolineando come il suo concetto estetico sia in contrasto con l'eleganza del minimalismo, poiché questa si basa sulla semplicità mentre egli (seguendo in maniera abbastanza libera la tesi di Robert Venturi) rivendica complessità e varietà,[54] anche se la complessità non dovrebbe degenerare nel disordine e l'eleganza mai potrebbe risultare da un'unione puramente additiva. Secondo Schumacher gli strumenti della progettazione digitale inibiscono tutto ciò, dal momento che essi sostengono l'integrazione. A proposito dell'aspetto di forma e funzione, scrive: «An elegant, legible scene should deliver what it promises, i.e., an efficient, physical organization of the vital life-processes must be assumed».[55] Egli spiega anche la pretesa sociologica della sua teoria in una sola frase: «Architecture's societal function is the innovative ordering of social communication via spatial frames, on an ever more complex, more productive level».[56] Schumacher si appella così al concetto di bellezza di Leon Battista Alberti, secondo il quale niente potrebbe essere aggiunto o tolto senza distruggere l'armonia, ma lo limita: «Except, in the case of contemporary elegance, the overall composition lacks the sense of perfect closure that is implied in Alberti's conception».[57] I progetti contemporanei sarebbero piuttosto composizioni incomplete nel senso dell'assemblaggio "deleuziano" che non organico nel senso della concezione classica.[58]

Infine, Schumacher arriva a parlare del sistema portante sotto l'elegante superficie, senza tuttavia avvicinare o addirittura collegare tra loro forma e struttura. La composizione della superficie sarebbe solo il primo passo abbozzato del progetto di una architettura elegante,[59] assicura, senza però andare più nel dettaglio. Egli scrive che il parametricismo offre linee guida e addirittura «many concrete recipes».[60] Come unico esempio viene citato «the employment of global distortions to cohere a field of fragments», ma di nuovo pone anche qui dei limiti: «the elegant result cannot be guaranteed as the complexity of the problem increases. With increasing complexity the maintenance of elegance becomes increasingly demanding».[61] Tuttavia, non viene fatto emergere nessun tipo di dubbio sulla valenza della sua teoria «fino alla rivoluzione»:

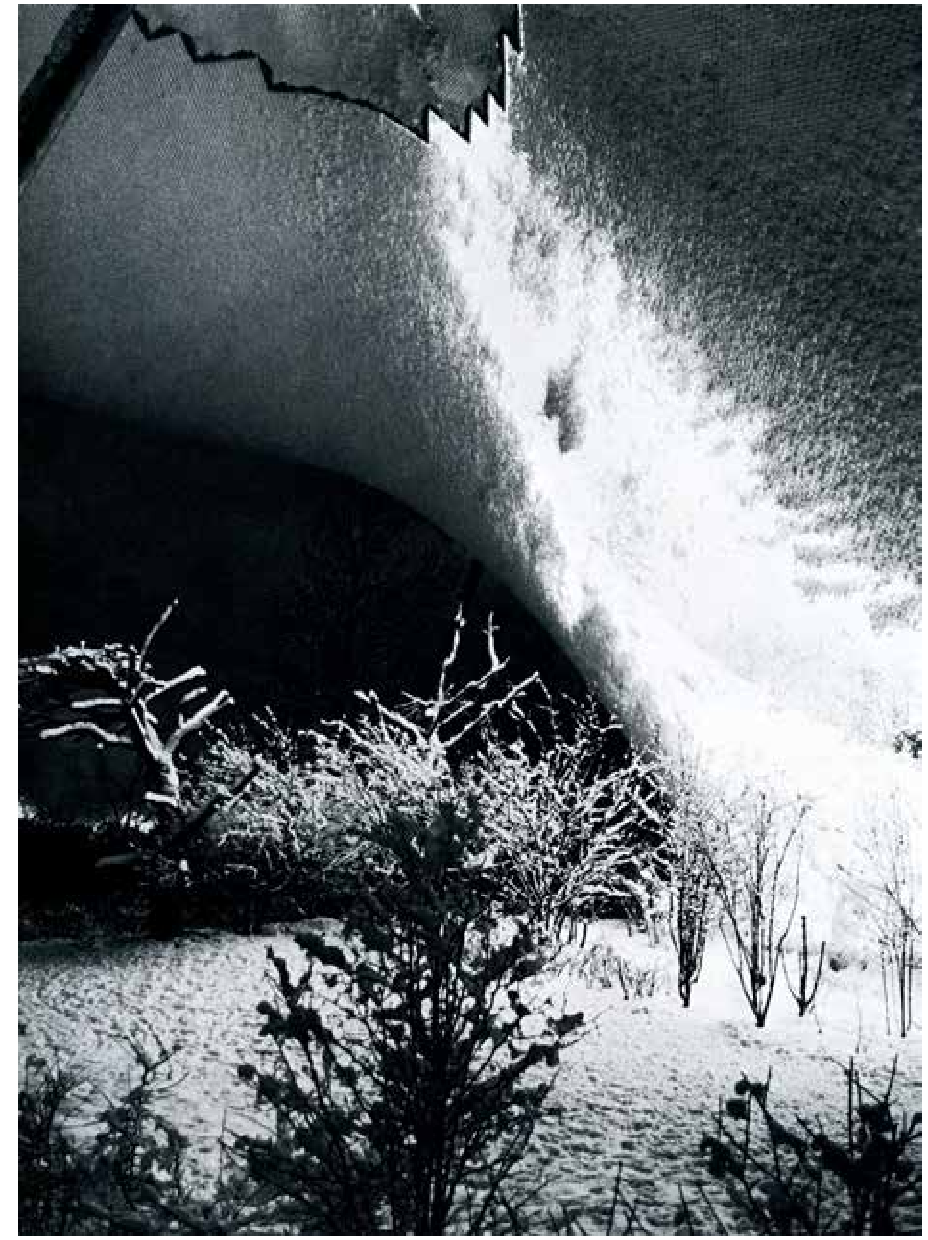
> The revolution, when it comes, will surprise us all, including artists and the most radical of radicals. Revolutionary periods – inherently – arrive unannounced. The theory of architectural autopoiesis thus suggests that – until then – cumulative design research within the broad framework of Parametricism is the most sensible "order of the day" for the architectural avant-garde.[62]

Conclusione

Questa rassegna di concezioni sulla forma, l'estetica e l'etica nella "filosofia architettonica" di Frei Otto intende offrire una panoramica delle sue idee, a dimostrazione della loro costante e inseparabile presenza nel suo modo di pensare e progettare. Alcune delle sue riflessioni sembrano trovare una nuova eco al giorno d'oggi.[63] In particolare, nel dibattito architettonico contemporaneo, il concetto di *form-finding* sembra essere quasi inflazionato,[64] ma con due possibili declinazioni errate: nella prima, questo termine diventa vuota espressione per ogni approccio arbitrario alla forma in sé; nell'altra, il concetto di *form-finding* viene spesso ridotto alla sola genesi sperimentale della forma, tralasciando così ogni riflessione teorica. Due casi esemplari e opposti rappresentano la ricezione del suo approccio dagli anni Settanta fino ad oggi: l'interpretazione sensibile dell'architetto zurighese Lisbeth Sachs e l'appropriazione inadeguata nelle dubbie riflessioni teoriche di Patrik Schumacher.

Frei Otto descrive il suo metodo del *form-finding*, la scoperta della forma, come un «percorso inverso», e cerca di dare così una spiegazione della bellezza:

> L'intero mondo vivente (piante e animali) altro non è che liquido racchiuso in membrane. Ho impiegato moltissimo tempo prima di realizzare che fosse necessario capire queste costruzioni e le loro strutture. … E solo con il passare del tempo si è arrivati a capire che anche questo è un cammino di comprensione della vita. Questo è un percorso praticamente inverso – non copiare le strutture viventi ma sviluppare delle strutture tecniche affinché si giunga a una comprensione. E così … si è arrivati a comprendere che effettivamente tutti gli oggetti viventi sulla terra sono costituiti da membrane che contengono acqua. Ogni goccia ma anche ogni bruco o ogni bocciolo, ogni fiore. Così come anche il mondo intero, e questo ha qualcosa di speciale: un tendere a ciò che l'uomo considera "bello". E qui ci si avvicina, che lo si voglia o meno, anche se ci si oppone – e io mi ci sono opposto già abbastanza – alla parola "estetica".[65]



_ Figura 12.
Voliera per lo zoo di Monaco di Baviera coperto di neve, 1980 (Archivio fotografico Institut für Leichte Flächentragwerke, Universität Stuttgart).

Il punto centrale dell'approccio di Frei Otto alla forma è proprio il "trovare" una forma, non l'invenzione o la copia dalla natura:

> Non ho inventato, in senso stretto, nessuna nuova forma. Proprio nessuna. Le abbiamo studiate. Si sono sviluppate. Ci siamo sempre sorpresi, quando abbiamo fatto modelli di studio, che improvvisamente avevamo forme completamente nuove, che qualche volta abbiamo ritrovato – soprattutto nella natura vivente.[66]

Il suo obiettivo primario è di ridurre il consumo di materiale e ottimizzare la forma, per avvicinarsi a una “forma classica” che dev’essere corretta anche sotto il profilo funzionale. Egli è convinto che la funzionalità sia già la base da cui si sviluppano oggetti che hanno valore estetico, e crede che la particolare estetica delle costruzioni leggere derivi dal fatto che tutti gli oggetti sviluppatisi dal principio della costruzione leggera siano “superiori” anche sotto il profilo della fisica e che il “superiore” crei ammirazione nel momento in cui non è pericoloso. Ma assai più che bella, per Frei Otto, è importante che l’architettura sia “buona” e “umana” sotto il profilo etico. È per questo che i suoi progetti appaiono così convincenti? Proprio perché la forma non nasce automaticamente o autonomamente, ma rispecchia invece la misteriosa bellezza di ciò che è leggero, il fascino che esercita il minimo e la ricerca, infinita, del meglio possibile? Perché il *form-finding* non si sviluppa in modo inconsapevole, ma origina piuttosto da riflessioni di carattere etico?

Fig. 12

(Traduzione di Matteo Trentini, Elisabeth Bergmann e Gabriele Neri).

Abstract

The “architectural philosophy” of Frei Otto. Concepts of form, esthetics, ethics and their dissemination

Form(-finding), aesthetics and ethics are key concepts in the philosophy of architect Frei Otto. Several of his ideas currently appear to be experiencing a renaissance (Schumacher 2012; Finsterwalder 2011). This is especially true for his concept of “form-finding” which frequently features in contemporary architectural discourse – albeit often with one of two common misconceptions: in the first, the term is used, or misused, as a catch-all for every imaginable approach to form, while in the second misconception “form-finding” is often presented simply as the genesis of form in a process of experimentation overlooking its inseparably intertwined theoretical background.
For these reasons, this paper comprehensively examines Frei Otto’s own position on the meaning of these key concepts. Two cases demonstrate exemplarily the wider dissemination of his ideas: in the work and writings of Swiss architect Lisbeth Sachs from the 1970s, and, more currently, in the buildings and urban planning of Zaha Hadid with the theoretical underpinning of her professional partner, Patrick Schumacher.

Note

_1. W. Nerdinger (a cura di), *Frei Otto. Das Gesamtwerk. Leicht Bauen, natürlich gestalten*, Birkhäuser, Basel-Boston-Berlin 2005.
_2. W. Nerdinger, *Frei Otto. Arbeit für eine bessere ‘Menschenerde’*, *ibidem*, pp. 9-15.
_3. I. Meissner, *Im Gleichklang mit Natur und Technik. Zur Architektur und Arbeitsweise von Frei Otto*, *ibidem*, pp. 57-63, p. 57.
_4. K. Wilhelm, *Portrait Frei Otto*, Severin, Berlin 1985.
_5. F. Otto, *Stuttgarter Architektur – gestern, heute und morgen. Einige subjektive Anmerkungen über die drei bisherigen Stuttgarter Schulen, über die “Neue Sachlichkeit” der zwanziger Jahre, über das Bauen im “Dritten Reich” und über das natürliche Bauen* (1978), in B. Burkhardt (a cura di), *Frei Otto. Schriften und Reden 1951-1983*, Vieweg, Braunschweig-Wiesbaden 1984, pp. 154-168, p. 160.
_6. H.-W. Kruft, *Storia delle teorie architettoniche. Dall’ottocento a oggi*, Laterza, Roma-Bari 1987, pp. 260-261. Siccome la traduzione in italiano non è precisa, aggiungo la citazione originale: «Besondere Aufmerksamkeit darf der theoretische Ansatz von Frei Otto ... beanspruchen, der seinen pneumatischen und Zelt-Konstruktionen sowie seinen Untersuchungen zu leichten Flächentragwerken grundsätzliche Überlegungen an die Seite stellt, die sich um einen neuen Architekturbegriff bemühen», in H.-W. Kruft, *Geschichte der Architekturtheorie von der Antike bis zur Gegenwart*, Beck, München 1985, pp. 506-507.
_7. *Ibidem*.
_8. Cfr. il saggio di Sean Keller in questo volume.
_9. F. Otto, *Gestaltwerdung. Zur Formentstehung in Natur, Technik und Baukunst*, R. Müller, Köln 1988, p. 5: «Das Wort ‘Gestalt’ ist, historisch gesehen, das Gestellte, Hingestellte, Gestandene, Entstandene. Natürliche Gestalten sind nach meinem Verständnis solche, die “von selbst” entstanden sind; künstliche Gestalten sind solche, die vom Menschen gemacht sind».
_10. F. Otto, *Das Zeltdach. Subjektive Anmerkungen zum Olympiadach* (1972), in Burkhardt 1984 (vedi nota 5), pp. 98-105, p. 101.
_11. H. Klotz, *Architektur in der Bundesrepublik*, Ullstein, Frankfurt am Main 1977, p. 227.
_12. *Experimente. Form Kraft Masse 5 / Experiments: Form Force Mass 5* (Mitteilungen des Instituts für Leichte Flächentragwerke, Universität Stuttgart 25 / IL 25), Stuttgart 1990, p. 2.17.
_13. Klotz 1977 (vedi nota 11), p. 233.
_14. *Ibidem*, pp. 212-213.
_15. *Konstruktion. Form Kraft Masse 3 / Construction. Form Force Mass 3* (IL 23), Stuttgart 1992, p. 16.
_16. Klotz 1977 (vedi nota 11), pp. 212-213.
_17. Otto 1988 (vedi nota 9), p. 70.
_18. Intervista *Der Herr des Augenblicks. Seine Liebe gilt dem Leichten und Beweglichen. Ein ZEIT-Gespräch mit dem Architekten Frei Otto von Hanno Rauterberg*, “Die Zeit”, 2 gennaio 2003.
_19. Nerdinger 2005 (vedi nota 1), p. 127.
_20. F. Otto, B. Rasch, *Gestalt finden. Auf dem Weg zu einer Baukunst des Minimalen*, Edition Axel Menges, Stuttgart 1995, p. 45.
_21. F. Otto, R. Barthel, *Natürliche Konstruktionen. Formen und Strukturen in Natur und Technik und Prozesse ihrer Entstehung*, Deutsche Verlags-Anstalt, Stuttgart 1982, p. 110.
_22. Otto 1988 (vedi nota 9), p. 5.
_23. *Ibidem*, p. 61.
_24. F. Otto, *Mit Leichtigkeit gegen Brutalität* (1976), in Burkhardt 1984 (vedi nota 5), pp. 128-132, p. 128.
_25. Otto, Barthel 1982 (vedi nota 21), p. 109: «Sicher gibt es keine klar zu ziehende Grenze zwischen Funktionellem und Nicht-Funktionellem. Mit allen Vorbehalten sei hier angenommen, dass das Ästhetische in reiner Form bereits außerhalb des Funktionellen steht, dass aber das Funktionelle häufig Grund ist für das ... Entstehen von ästhetischen Objekten. ... Die Ästhetik ... hilft (oder soll helfen) auf der Basis von Erfahrung und Wissen aus der Fülle des Üblichen (des “Gewöhnlichen“ und “Gemeinen“) das “Besondere“ und “Herausragende“ zu erkennen. Zur Ästhetik gehört auch die Lehre, die hilft, jene Phänomene zu erkennen, die als nicht-ästhetisch, als anästhetisch, als Bluff, ja als Täuschung oder Kitsch bezeichnet werden».

_26. *Prinzip Leichtbau. Form Kraft Masse 4 / Lightweight Principles. Form Force Mass 4* (IL 24), Stuttgart 1996, p. 11.
_27. Frei Otto in un'intervista con l'autore, Warmbronn, 17 maggio 2013.
_28. Otto, Barthel 1982 (vedi nota 21), p. 110.
_29. *Ibidem*, pp. 109-110: «Es ist sogar eher zu vermuten, dass gerade die Fähigkeit des Menschen, extreme Leichtbauobjekte zu erkennen, vermutlich die wichtigste – von seinen tierischen Vorfahren herrührende – Wurzel für das Aufmerksamwerden auf besondere Objekte ist. ... besonders dann, wenn die Form des Objektes jene Steigerung des Überlegenseins ohne Aggressivität signalisiert. Gegen die Annahme, dass es beim Menschen ein angeborenes Empfinden von Ästhetischem gibt, spricht scheinbar die Tatsache der großen Unsicherheit bei der Beurteilung des ästhetischen Gehalts. ... Das funktionell Gefährliche alarmiert. Das Ungewohnte alarmiert auch – denn es könnte ja gefährlich sein. Das "Besondere", das "Überlegene", löst Bewunderung aus, wenn es ungefährlich ist. ... Physisch überlegen sind alle Objekte, die sich nach dem Prinzip Leichtbau entwickeln».
_30. Otto 2013 (vedi nota 27).
_31. Otto, Barthel 1982 (vedi nota 21), p. 126.
_32. Otto, Rasch 1995 (vedi nota 20), p. 13.
_33. Nerdinger 2005 (vedi nota 1), p. 125.
_34. Otto, Rasch 1995 (vedi nota 20), p. 13.
_35. *Ibidem*.
_36. Nerdinger 2005 (vedi nota 1), pp. 126-127.
_37. Otto 1976 (vedi nota 24), p. 129.
_38. *Ibidem*, pp. 128-129.
_39. Burkhardt 1984 (vedi nota 5), p. 131.
_40. *Ibidem*.
_41. «Zweifellos kann man aber – mit entsprechender moderner Technik – ebenso anpassungsfähig bauen wie vor 3000 Jahren, als die ersten mit Lehm gebauten Städte entstanden, die zum Teil heute, vielfach verändert, noch existieren. Bauten aus Lehm, Stroh und Zelte sind anpassungsfähig, wandelbar oder mobil. Der Baustoff von heute heißt Beton. Beton ist nicht nur Baustoff, sondern ein Begriff, der Architektur macht. Beton ist nur einmal leicht formbar, dann nie wieder. Beton ist – bisher wenigstens – fast "unerweichlich"».
_42. gta Archivio, ETH Zurigo (Fondo Lisbeth Sachs), 114-S-9, Otto FREI [sic], Gesammeltes, testo con correzioni a mano: «Hier, mit den leichten Konstruktionen, entfaltet sich Neues an Formen und Räumen scheinbar von selbst. Der Impuls kommt aus der Freude an der Erfindung der Haut. Die Form folgt der Konstruktion. ... Sie sind oft Dach und Wand zugleich. ... Sie genügen ihrem inhaltlichen Zweck unter knapper Verwendung von Material in ausholender, beschwingter Geste. Es ist, als ob sie mit ihren Formen den Augenblick des Übergangs vom Zustand der Schwere in den des Schwebens festhielten. Sie haben etwa Tänzerisches, Dynamisches, Mitreißendes. Das Ereignis ist Frucht der Faszination, mit wenig Materie auszukommen, die Mittel zu reduzieren unter fortwährender ingeniöser Optimierung von Machart und Gestalt».
_43. Wilhelm 1985 (vedi nota 4), p. 11.
_44. *Ibidem*.
_45. *Ibidem*.
_46. gta Archivio, ETH Zurigo (Fondo Lisbeth Sachs), 114-073-M (F), *Vorschläge für ein neues und billiges Jugendhaus in Zürich und für Künstlerateliers*.
_47. gta Archivio, ETH Zurigo (Fondo Lisbeth Sachs), 114-S-9, *Materialien zu Frei Otto / Lisbeth Sachs*, estratto da una lettera di Lisbeth Sachs a Frei Otto del 9 marzo1971, nella quale ringrazia per il colloquio dettagliato inerente un'ipotesi di Casa per giovani a Zurigo del 15 febbraio a Vaihingen.
_48. *Ibidem*, estratto da una lettera di Lisbeth Sachs all'assessore Erwin Frech dell'8 giugno 1971: «Aus eigener Initiative – dies vertraulich – studiere ich im Moment ein Jugendhaus unter Diskussionszuzug von ein paar verschiedenen jungen Leuten. Kosten unter 1 Million. Ueberdeckte [sic] Fläche 1000-1400m². Winterfest. Erweiter- abbrech- und verschiebbar. Relativ kurzfristig. Innen und außen von beschwingter, leichter Form und Ausstrahlung, welche die Gedanken der Besucher von Aggressionen eher zu befreien vermöchte als manche Mauern».
_49. *Ibidem*, estratto da una lettera di Lisbeth Sachs a Frei Otto del 9 marzo 1971: «Weil am kommenden Wochenende hier Kantonsratswahlen sind, will sich keine Partei die Finger mit den "Langhaarigen" verbrennen – vor dem Bürger».
_50. *Ibidem*, estratto da una lettera di Lisbeth Sachs a Frei Otto del 5 giugno 1975: «Sehr geehrter Herr Professor, ich muss Ihnen doch schnell gestehen, dass ich kürzlich in Mannheim war, um die ineinandergreifenden Gitterschalen zu sehen. Der Kontrast zwischen der behäbigen Elefantenhaut aussen und deren grazilem, raumbildenden Skelett innen ist eine ungeheure Überraschung, wie sie die Entfaltung von Architektur wohl wieder einmal brauchte. Die Raumübergänge innen scheinen einerseits auf den Barock zurückzuweisen und greifen andererseits weit in die Zukunft. – Deshalb, weil sich der Mensch hier neu und anders empfindet als wie je zuvor. Er empfindet sich unter dem Himmel, unter der Weite, und doch behütet. Und – hingewiesen und [auf?] den andern, auf ein natürliches Miteinander im Flusse des Lebens. Sie haben Bedeutendes hingestellt!»
_51. *Ibidem*, *Otto FREI* [sic], *Gesammeltes*, testo di Lisbeth Sachs con correzioni a mano.
_52. P. Schumacher, *The Autopoiesis of Architecture*, vol. 2, John Wiley & Son, Chichester 2012, p. 680.
_53. *Ibidem*, p. 700.
_53. *Ibidem*.
_55. *Ibidem*, p. 707.
_56. *Ibidem*, p. 708.
_57. *Ibidem*, p. 704.
_58. *Ibidem*.
_59. *Ibidem*, p. 703.
_60. *Ibidem*, p. 706.
_61. *Ibidem*.
_62. *Ibidem*, p. 709.
_63. R. Finsterwalder (ed.), *Form follows nature. Eine Geschichte der Natur als Modell für Formfindung in Ingenieurbau, Architektur und Kunst / A history of nature as model for design in engineering, architecture and art*, Springer, Wien 2011; Schumacher 2012 (vedi nota 52).
_64. K. Jormakka, *Methoden der Formfindung*, Birkhäuser, Basel-Boston-Berlin 2008.
_65. Otto 2013 (vedi nota 27).
_66. *Ibidem*.
_67. Qui divergo dall'interpretazione che Sean Keller propone nel suo saggio in questo volume.

_Figure 1.
The *Stuttgart SmartShell*, spanning 10 m x 10 m with a thickness of only 4 cm. Active hydraulic support shown in foreground (photo Bosch Rexroth).

Stefan Neuhäuser, Martin Weickgenannt, Christoph Witte, Walter Haase, Oliver Sawodny, Werner Sobek[1]

Stuttgart SmartShell

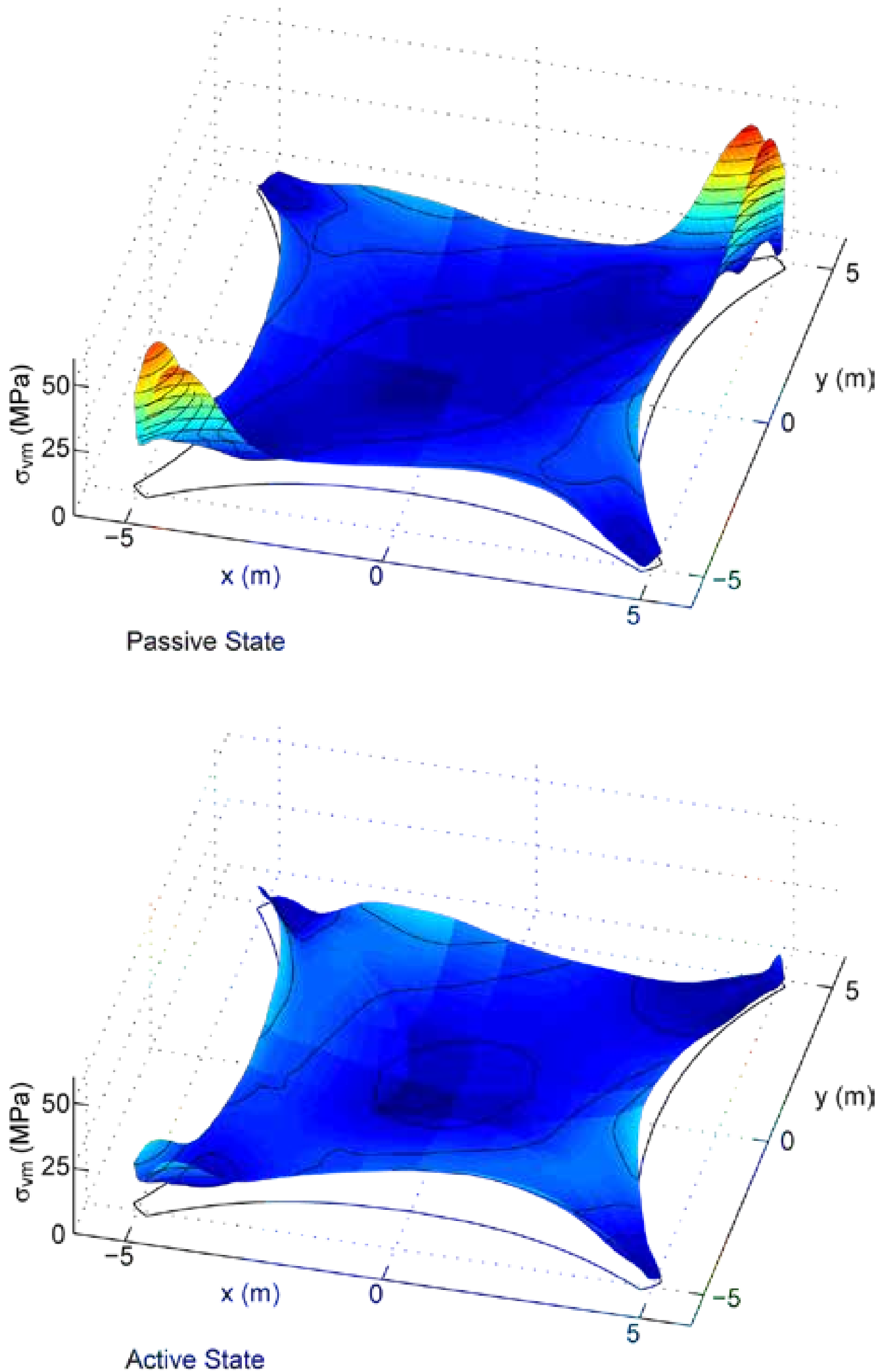
A Full-Scale Adaptive Shell Structure

Introduction

Shell structures in the built environment, both as a form of architectural expression and as one of the classic typologies of lightweight structures, have a long history going back to the very earliest construction methods. Shells are favoured for their efficient load-bearing behaviour, which is facilitated by their structural form – the double-curved geometry – along with appropriate loading and support conditions. If the relationship between the form, the load distribution and the supports is appropriately taken into account during the design process, a shell structure can transmit loads via a so-called "membrane state of stress", developing a uniform stress distribution within the cross-section. This allows a properly-designed shell structure to carry loads efficiently over large distances with minimal weight.

Single-curved arches and double-curved dome-type structures have been constructed for centuries. Largely guided by intuition, early builders arrived at such curved geometries in order to transmit structural forces using predominantly compression-only construction materials, such as stone and masonry. Although investigations seem to indicate that the connection between the geometry of the hanging chain – the catenary – and that of an arch thrust line may have been recognized as early as the sixth century,[2] this relationship is first documented by Robert Hooke in 1675, with a mathematical description of the catenary formulated by David Gregory in 1697.[3]

In the twentieth century, the extension of the two-dimensional analogy between the catenary and the thrust line of an arch to three dimensions led to important developments of experimental methods to determine ideal shapes for shell structures, most notably by architects and engineers such as Antoni Gaudí, Heinz Isler and Frei Otto.[4] The vertical inversion of hanging chain meshes or hanging cloths, subject only to tension by the virtue of their physical nature, ideally produced compression-only structures. Heinz Isler, in particular, constructed a number of relatively



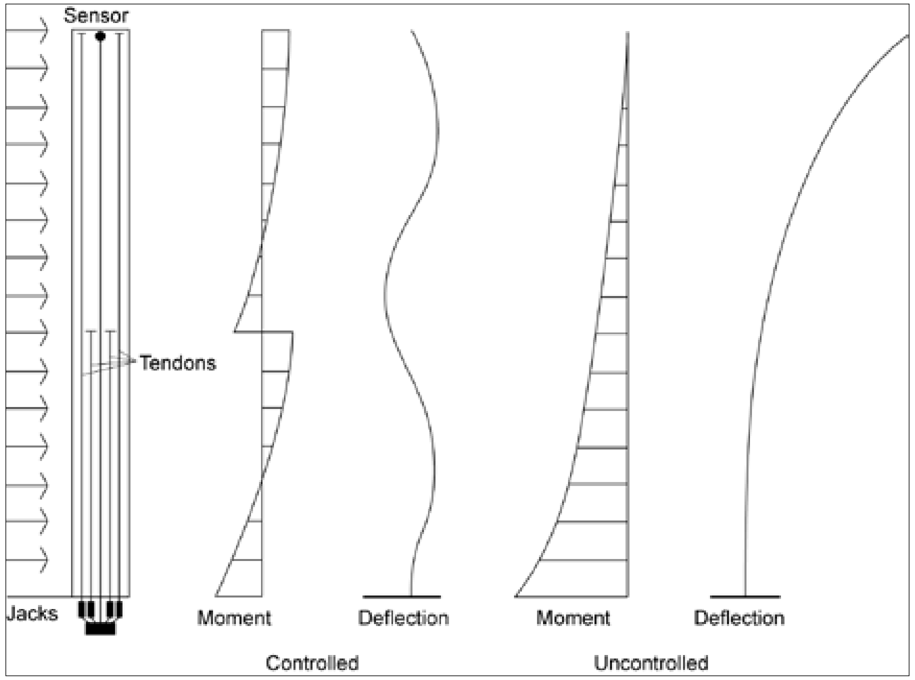
_ Figure 2.
Von Mises stresses in the passive state and in the active state on bottom surface of the shell due to a load of 2000 N/m^2 on quarter section as shown in figure 8. The stress values are plotted on the vertical axis over the projected area of the shell
(figure Stefan Neuhäuser).

_ Figure 3.
Heinz Isler, Service station Deitingen-Süd, a thin concrete shell with a geometry based on the inversion of a hanging cloth (ILEK archive).

Fig. 3 thin concrete shells based on this concept. With the advancement of computational methods, numerical techniques for form-finding were developed in the latter half of the century. These proceeded either by simulation of the earlier physical form-finding methods (indirect methods) or by solving the system of equations of the structural behaviour directly (direct methods).[5]

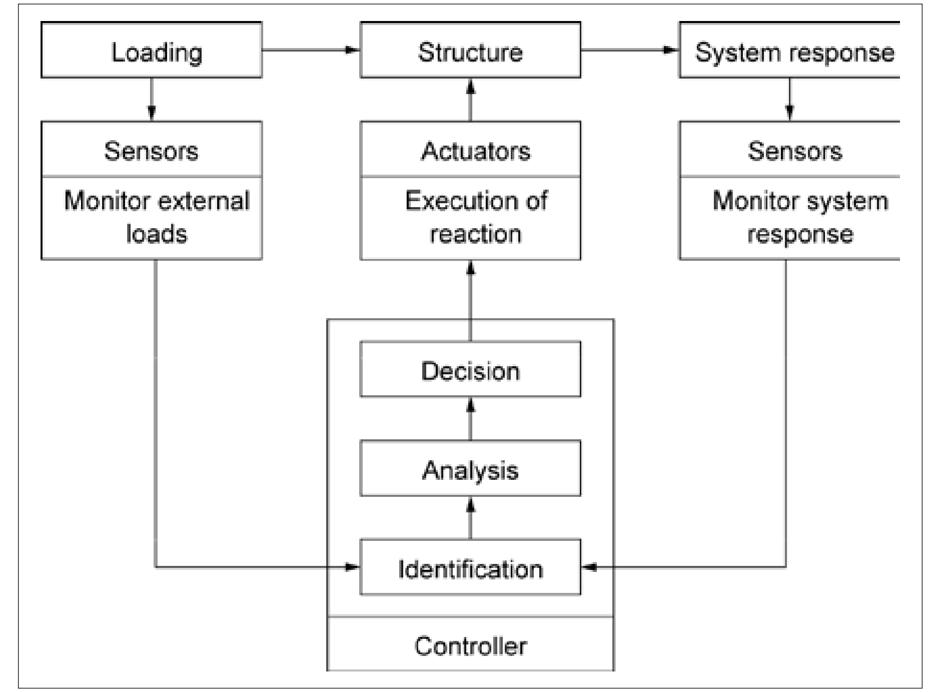
Computational methods, while more complicated to implement, allow the (virtual) representation of the actual, full-size structure. They are therefore not subject to the structural scaling problems incurred with physical models. In particular, the magnification of very small measurement errors on small-scale physical models, highly critical for form-sensitive lightweight structures, is avoided using a computational implementation of the form-finding process. Therefore, such methods typically lead to significantly more precise results with respect to geometry and greater control over the stress distribution within the shell.

An inherent shortcoming of all form-finding methods for shell structures is the strong correlation between form and load case. During form-finding, an ideal geometry is determined for exactly one load case, the so-called "form-defining" one. Even in ideal conditions, the desired state of stress is therefore achieved only when the distribution of applied loads matches the form-defining load case. For fairly heavy structures, the premise of the existence of one constant, dominating load case is fulfilled by the self-weight of the structure. Thus, the dead load can be applied as the form-defining load case. Nowadays, however, in the context of resource efficiency, methods and technologies for optimizing materials and structural analysis have advanced to reduce the weight of structures to the point that it is no longer feasible to consider self-weight as the dominant load case. Live loads and environmental factors (such as wind and snow), with spatially and temporally variable distributions, control the design.



_ Figure 4.
Concept for structural control of a high-rise structure using active tendons (W. Zuk, R.H. Clark, *Kinetic Architecture*, New York 1970, p. 37).

_ Figure 5.
Components of an adaptive system (P. Teuffel, *Entwerfen adaptiver Strukturen*, Stuttgart 2004, p. 12).



By definition, determining a structural geometry based on multiple load cases will yield non-optimal load-carrying conditions for any single load case. Furthermore, design standards require the assumption of peak loads which, in reality, occur very rarely. This leads to structures that are over-designed for a large proportion of their life span. Along with vibration and stability concerns, this hinders further advancement of lightweight structures based on the classical approach: to find one suitable geometry to accommodate all load cases as efficiently as possible.

A radically different approach to achieve optimal performance for lightweight structures subject to various load cases is the concept of adaptivity. Given the ability to actively adapt to variable loading scenarios in such a way as to optimize structural behaviour, mitigate vibrations and reduce deformations in real time, such structures are called ultra-lightweight structures.[6]

Concept of Adaptivity

The concept of active control of structures dates back to approximately 1960,[7] with initial ideas for the damping of seismic vibrations in buildings. Concepts for the active manipulation of forces and deformations were presented approximately ten years later.[8] Figure 4 shows these concepts as applied to a high-rise structure. Internal tendons are proposed to be activated and cause a counter-deformation in response to applied transient loads (wind). Thus, the moment distribution, as well as the deflection behaviour of the structure, are manipulated to minimize the peak values of either, and thus improve the structural performance without providing additional structural mass.

Fig. 4

According to a formal definition of structural control, adaptive structures contain three additional components in comparison with passive (conventional) structures: sensors to monitor the system state, controllers to evaluate the sensor information and determine an appropriate system response, and actuators to execute the response determined.[9]

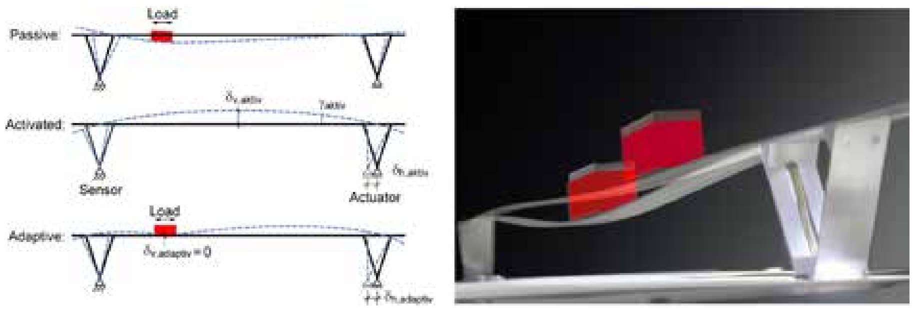
Fig. 5

The purpose of these additional components is to improve structural behaviour with respect to forces, displacements and vibrations. Research has therefore primarily targeted the active control of vibrations.[10] Since the initial proposal of these concepts in the context of building structures, there has been some progress in research with respect to the manipulation of forces and deformations.[11] A more comprehensive approach towards the implementation of adaptive structures, considering both static and dynamic concerns, has been a focus of research during the last fifteen years.[12]

A particularly illustrative example of the potential of adaptivity is presented by the scale model of the *Stuttgarter Träger* (Stuttgart Beam). As shown in figure 6, the activation of a single degree of freedom at one support achieves a structure with virtually infinite stiffness: the train moving across the bridge experiences zero deflection.[13]

Fig. 6

The *Stuttgart SmartShell*, as presented in this contribution, seeks to expand the experimental validation with respect to the reduction of peak stresses as well as active control of vibrations using a full-scale prototype.



_ Figure 6.
Left: *Stuttgarter Träger* principle
(C. Lemaitre, W. Sobek, *Design Principles of Adaptive Truss Structures*, Venice 2007, [p. 3]).
Right: Superposition of passive and adaptive state
(ILEK archive).

Manipulation of Stress Fields in Point-Supported Shell Structures

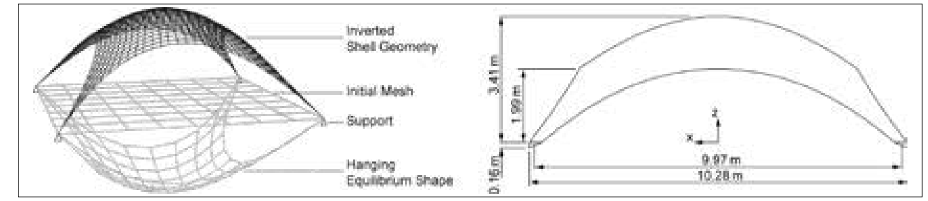
As described above, determining appropriate structural forms for shells to exhibit efficient load-bearing behaviour for multiple and variable states of loading is difficult, if not impossible. Form-finding methods assume one governing load case; the lack of a dominant loading scenario leads to inhomogeneous stress distributions and stress concentrations. In the case of point-supported shells, such stress concentrations occur predominantly near the free edges and near the supports. As the design must accommodate these stress peaks, shell thickness and material usage increase unnecessarily.

To investigate the potential of adaptivity with respect to the homogenization of the stress distribution, a shell with near-ideal geometry for the load case self-weight is considered. The form-finding method implemented in the case presented simulates a hanging net under equal nodal forces. The form-finding model and the resulting surface shell with four support points are shown in figure 7. Fig. 7

As a means of manipulating the structural behaviour in response to applied loads, translational displacement of the supports is considered. For this purpose, three of the four support points can be positioned freely in space. All four supports are pinned with no rotational restraint. The active displacement of the supports causes a manipulation of the form of the structure. The distinction from classical methods such as those employed by Isler and Otto becomes apparent here: the structural response of the system is no longer dependent on the determination of a single, most suitable geometry using a form-finding process. Rather, the manipulation of the form enables a continuous optimization of the load-carrying behaviour and thus mitigates the adverse effects stemming from the lack of dominance of the form-defining load case described above.

In the context of the current work, structural analysis is performed using the finite element method in the software package *Ansys*.[14] Deformations of the structure during the application of loads and displacement of the support points may be large in comparison with the shell thickness. Thus, geometric non-linearity is considered in the analysis. A parametric approach using the *Ansys Parametric Design Language* (APDL) provides an efficient method of varying the modelling and design parameters. Moreover, this approach allows the effective integration of the analysis with optimization algorithms, in this case implemented in *Matlab*.[15]

_ Figure 7.
Form-finding simulating a hanging mesh (left) and (right) final dimension for shell structure under investigation
(figure Stefan Neuhäuser).



To determine the optimal positioning of the supports for any given loading state, an optimization problem is formulated using:

Eq. 1: $$\min_{\boldsymbol{x}} f(\boldsymbol{x}) \,,$$

Eq. 2: $$f(\boldsymbol{x}) = \max \begin{pmatrix} \sigma_1 \\ \vdots \\ \sigma_{n_s} \end{pmatrix}.$$

The objective function f($\boldsymbol{x}$) constitutes the maximum value of all n_s nodal stresses on the shell top and bottom surfaces. The stress values result directly from the structural analysis in *Ansys*. This so-called minimax formulation of the optimization problem causes the objective function to be non-continuously differentiable, as well as potentially non-convex. Since multiple local minima may exist, a global search method based on the *Simulated Annealing* algorithm[16] is implemented. For comparison, a gradient-based algorithm can be implemented using a smoothing function, showing similar results in the case presented.[17]

As an example, the structure shown in figure 7 is modelled with a thickness of 25 mm and an isotropic material with the properties summarized in table 1. A partially distributed load of 2000 N/m² is applied to one quarter of the surface, as depicted in figure 8. Also as shown in figure 8, due to the symmetry of the structure and the loading conditions, four independent degrees of freedom can be activated to manipulate the structure. Degrees of freedom for statically determinate support conditions are passive, as their activation would result in rigid-body motions only, without manipulation of the structural behaviour.[18] These four displacement values at the active supports constitute the solution vector $\boldsymbol{x}$ in Eqs. 1 and 2. Fig. 8

Table 1. Isotropic material properties for the example investigation

Property	Value
Elastic modulus, E (GPa)	50.0
Shear modulus, G (GPa)	19.2
Poisson's ratio, ν	0.3
Density, ρ (kg/m³)	2500

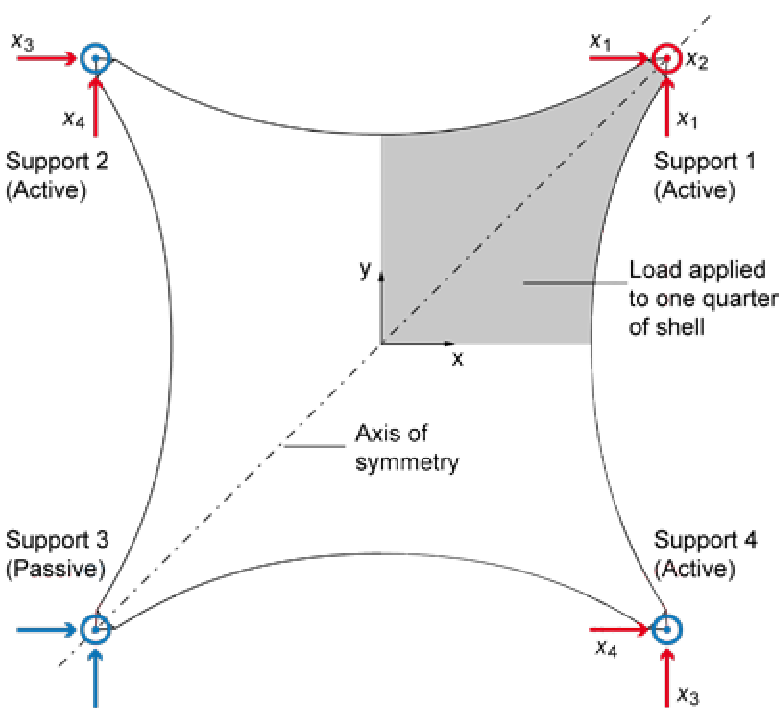
In the case presented, the critical stress being considered (forming the objective function in Eq. 2), is the maximum von Mises stress. The proposed analysis and optimization methods, however, can easily accommodate different types of stresses as available from the finite element analysis.

The results of the structural analysis in the passive state show a peak value for the stress of $f(\boldsymbol{x}) = \sigma_{max} = 57.3$ MPa. After the application of the optimisation algorithm, the maximum stress is reduced to $\sigma_{max} = 19.8$ MPa, with the solution vector

$$\boldsymbol{x} = \begin{pmatrix} 13.4 \\ 25.9 \\ 56.9 \\ 59.0 \end{pmatrix} \text{mm.}$$

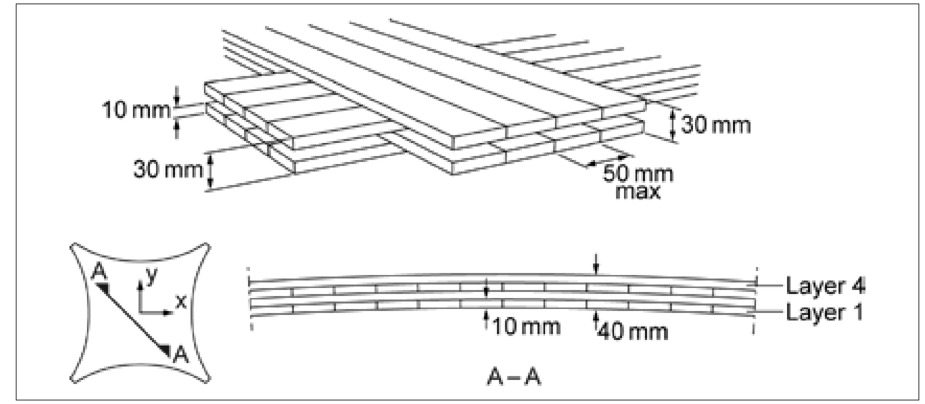
The entries in the solution vector $\boldsymbol{x}$ ($x_1 \ldots x_4$) correspond to the displacements of the supports as shown in figure 8. These displacements result in a manipulation of the structural geometry, and in this particular case in a reduction of the peak stresses of 65.4 %. Figure 2 shows the distribution of the von Mises stresses on the bottom surface of the shell in the passive state and in the active state. A homogenization of the stress field can clearly be observed, as the stress concentrations near the supports are reduced, with a slight increase in stresses in other regions of the shell surface, in particular along the free edges.

Fig. 2



_ Figure 8.
Area of load application (2000 N/m²), active degrees of freedom (red) and passive degrees of freedom (blue). Three of the four supports are active. Degrees of freedom resulting in rigid-body motions are passive. Active degrees of freedom symmetrical about the axis of symmetry as shown are assigned identical values. The four active degrees of freedom constitute the solution vector *x* (figure Stefan Neuhäuser).

_ Figure 9.
Wooden section composition of the *Stuttgart SmartShell* (figure Christoph Witte).



Active Vibration Control

Being highly flexible with a low degree of internal damping, ultra-lightweight structures are highly susceptible to prolonged vibration due to excitation by dynamic loads (wind, seismic activity). This can potentially lead to fatigue effects as well as serviceability concerns. The activation of the supports not only reduces stresses due to static loads as discussed above, but can also be used for active vibration control.

For the purpose of active vibration damping, the static finite element model of the structure is supplemented using dynamic properties to simulate the vibration behaviour. The resulting dynamic model is described as

Eq. 3: $$\boldsymbol{M}\ddot{\boldsymbol{q}} + \boldsymbol{D}\dot{\boldsymbol{q}} + \boldsymbol{K}\boldsymbol{q} = \boldsymbol{B}\boldsymbol{u}$$

with $\boldsymbol{q}$ being a vector containing all translational and rotational degrees of freedom of the finite element model. The matrices $\boldsymbol{M}$, $\boldsymbol{D}$ and $\boldsymbol{K}$ describe the mass, damping and stiffness matrix of the model respectively; $\boldsymbol{B}$ describes the influence of the applied forces u at the active degrees of freedom at the supports.
Modal transformation and reduction of the model yields:[19]

Eq. 4: $$\ddot{\boldsymbol{q}}_M + \boldsymbol{D}_M\dot{\boldsymbol{q}}_M + \boldsymbol{K}_M\boldsymbol{q}_M = \boldsymbol{B}_M\boldsymbol{u}_P$$

with $\boldsymbol{q}_M$ the amplitudes of the eigenmodes and $\boldsymbol{D}_M$, $\boldsymbol{K}_M$ and $\boldsymbol{B}_M$ the modal damping, stiffness and input matrix, respectively. The system input $\boldsymbol{u}_p$ is the displacement input at the active supports. The modal description of the model is used to implement a model-based controller using a linear-quadratic control algorithm. As shown, a reduction of 80% of oscillation duration and amplitude can be achieved, mitigating the adverse effects of the structural vibration.

The Stuttgart SmartShell

To validate the results and investigate the actual implementation of the adaptive processes described, the *Stuttgart SmartShell* was constructed as a full-scale prototype of an adaptive shell structure. Matching the overall dimensions shown in figure 7, the prototype comprises a four-layer timber system with a thickness of only 40 mm. The structure was constructed on site on a grid-type formwork, each of the four layers consisting of CNC-fabricated slat segments of varying widths to facilitate the double curvature of the structure.[20] The completed structure is depicted in figure 10.

Fig. 7

Fig. 10

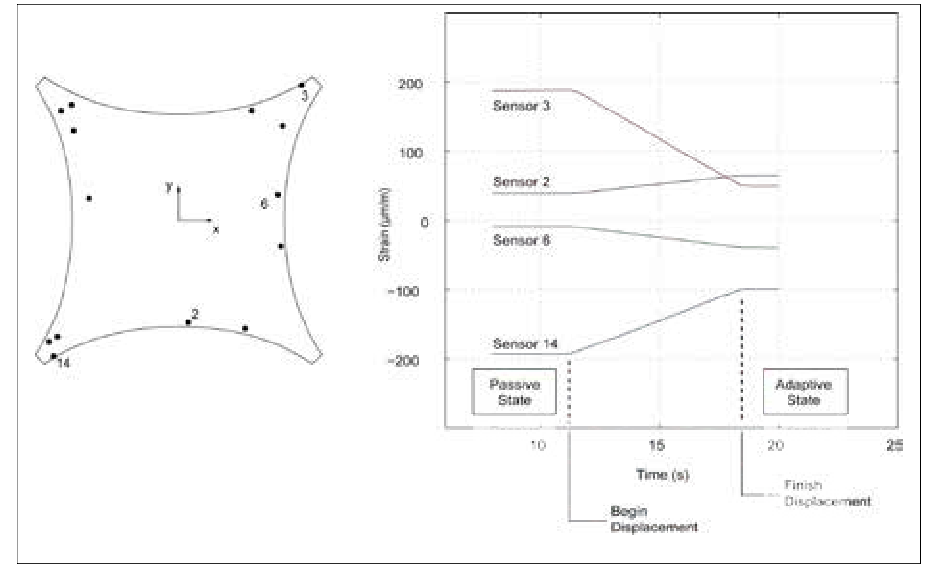
The activation of the structure occurs at three of the four supports using hydraulic actuators in a tripod configuration. Each of the cylinders is capable of applying 50 kN of compressive force and 35 kN of tension, with a maximum stroke of ± 150 mm. Information on the state of loading and vibration is provided by 14 strain gauge sensors applied to the bottom surface of the shell. Experimental investigations have shown that a long gauge length is preferable, due to the heterogeneity of the wood material, and only strains in the fibre direction can be measured with acceptable accuracy.[21] The strain gauges are used with strain gauge amplifiers that deliver the sensory information via a digital CAN-Bus signal for integration into the control system. The placement of the sensors was determined using optimization algorithms to provide accurate information on the system state while simultaneously reducing the number of sensors required.[22]

Fig. 1

The material properties of the wood used in the construction of the prototype (spruce/fir) are shown in table 2. The orthotropic material behaviour and the multilayer composition are considered accordingly in the finite element model. In the adoption of the optimization algorithms, the critical stress in the formation of the objective function is the normal stress in the direction of the fibres. Applying the optimization algorithm, for a load of 400 kg over one quarter of the shell surface, the optimal support displacements are determined. Figure 11 shows the strain data measured for four selected sensors for the passive and active states. As predicted by the simulation models, peak stresses at the supports are reduced with slight increases in stress along the edges, achieving an overall homogenization of the stress field.

Fig. 11

_ Figure 10.
Stuttgart SmartShell with one of the three active supports (support 1 from figure 8) in foreground (photo Bosch Rexroth).



_ Figure 11.
Sensor locations for the *Stuttgart SmartShell* and strain measurements for selected sensors in the passive and the active state. In the experiment, a load of 400 kg is applied over one quarter of the shell surface – matching the area shown in figure 7 (figure Stefan Neuhäuser).

Table 2. Orthotropic material properties for wood (spruce/fir)[23]

Property	Value
Elastic modulus parallel to fibre, E_x (GPa)	13.0
Elastic modulus perpendicular to fibre, E_y, E_z (GPa)	0.43
Shear modulus, G_{xy}, G_{xz} (GPa)	0.81
Shear modulus, rolling shear, G_{yz} (GPa)	0.081
Poisson's ratio, ν_{xy}, ν_{xz}	0.45
Poisson's ratio, ν_{yz}	0.50
Density, ρ (kg/m³)	440

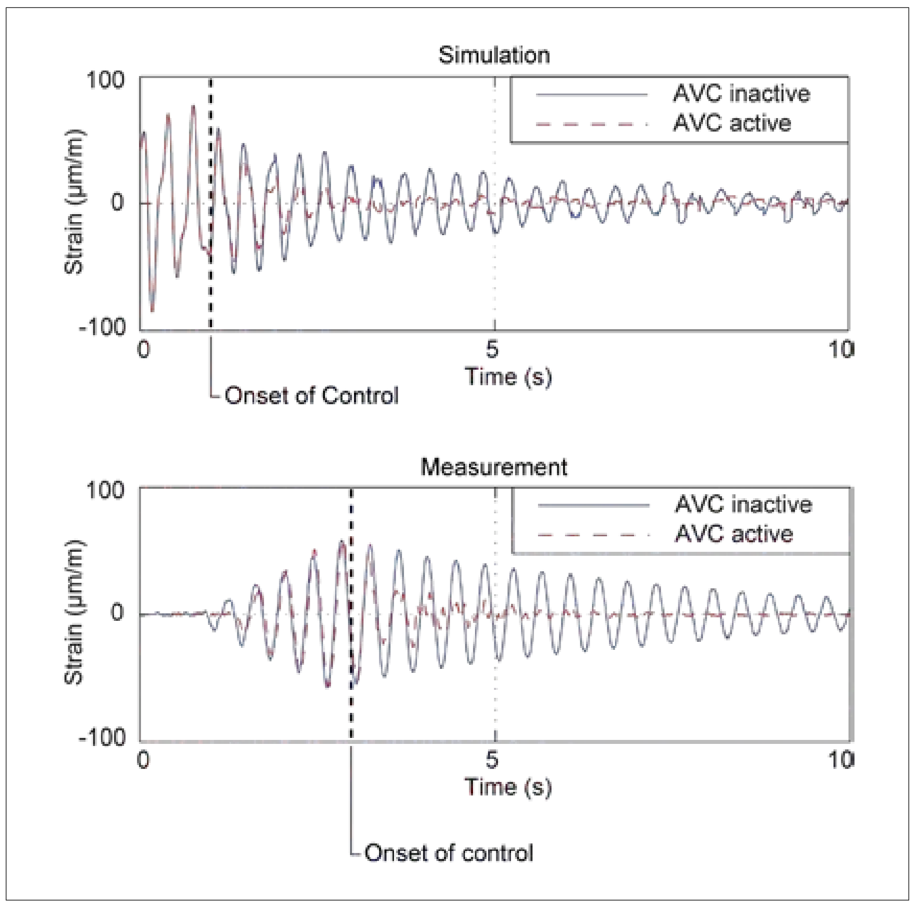
Fig. 12

Results for the active vibration damping are shown in figure 12, along with a comparison with simulation results as described. After excitation of the first eigenfrequency, the active vibration damping is engaged. The experimental data closely matches the simulation results and a significant reduction of the oscillation duration of the damped system is visible compared to the passive state.

Summary

The research work outlined in this paper has shown the potential of ultra-lightweight, adaptive structures. The ability to react to variable loading conditions, demonstrated in theoretical considerations as well as in experimental studies, achieves significant gains in structural performance in comparison with an optimized passive structure. Using the example of the *Stuttgart SmartShell*, a point-supported continuous shell structure with a nearly ideal geometry for self-weight based on form-finding methods, both peak stresses due to unevenly distributed surcharge loads as well as structural vibrations can effectively be reduced. To bring adaptive structures into reality, an interdisciplinary approach including architects, structural engineers, mechanical engineers, control systems specialists and electrical engineers is required, and has been shown to be successful in the context of the implementation of the prototype discussed.

The methodologies proposed are the result of a continuous evolution of research and have been derived with future applications and practical implementation in mind.



_ Figure 12.
Simulation and experimental results of the active vibration damping at the *Stuttgart SmartShell* in the uncontrolled state (blue) and the controlled state (red) (figure M.artin Weickgenannt).

Although many topics – such as the integration of safety aspects of adaptive structures into the appropriate design standards and a comprehensive consideration of energy balance – remain subject to future research, it is the hope of the authors that such research will continue to advance adaptive systems into practical reality.

The research focuses on shell structures as one classical example of lightweight structures, with the goal of reducing vibrations as well as bending-induced peak stresses. The effects of adaptive processes in the context of other types of lightweight structure – e.g., active and localized manipulation of pre-stress in tension-only structures – need to be investigated in future research.

The concept of adaptive structures dispenses with the assumption that structural forms are permanent and thus never ideally suited to provide the most efficient structural system for any given situation. Rather, based on a real-time modification of geometry, the most appropriate form can be continuously achieved via active manipulation of the system. In an architectural context, the concept of adaptivity may therefore offer the potential to overcome some of the limitations with respect to form that are inherent in classical lightweight structures.

Abstract

Stuttgart SmartShell.
Una struttura adattiva a guscio su larga scala

Per riuscire a sviluppare delle forme per strutture a guscio che diano prova di un comportamento strutturale ideale, sono stati approntati diversi metodi di *form-finding*. Mentre tali metodi riescono ad approssimare le geometrie che sostengono le forze solo attraverso la compressione di membrane, i campi di tensione desiderati si sviluppano, se si sviluppano, unicamente sotto il modello di carico che definisce la forma. Per le strutture pesanti, il peso stesso della struttura può essere considerato come il modello di carico principale. Tuttavia, per le strutture ultraleggere il peso della struttura è trascurabile in paragone ai carichi ambientali. Nel caso delle strutture a guscio, le concentrazioni di tensione e flessione si sviluppano come risultato di una distribuzione ineguale dei carichi. Piuttosto che rivolgere l'attenzione alla fornitura di massa addizionale, necessaria solo durante i momenti di maggiore carico, presso l'Università di Stoccarda la ricerca si è concentrata sul concetto di struttura adattiva. Permettendo ai sistemi di rispondere attivamente alle variazioni di carico, è infatti possibile ridurre le deformazioni e le tensioni di picco, come anche le vibrazioni. Questa ricerca ha condotto di recente alla costruzione di un prototipo di struttura adattiva in guscio, la *Stuttgart SmartShell*. Esso si estende su un'area di 10 x 10 m, con uno spessore di soli 40 mm, ed è dotato di supporti attivi che manipolano il comportamento di sostegno del carico.
Il presente contributo fornisce una presentazione sintetica del concetto di struttura adattiva: soffermandosi in particolare sugli effetti dell'adattività in relazione alle strutture a guscio, vengono valutati i risultati di un'indagine sulle strutture a guscio con supporti puntuali e dotate di sostegni attivi, comprendendo anche la descrizione del prototipo, le procedure di modellazione e ottimizzazione, come anche i risultati teorici e sperimentali.

Notes

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Elisabeth Bergmann

Le costruzioni in legno dell'IBOIS

Forme curvate, intessute, intrecciate: una conversazione con Yves Weinand

_ Figura 1
Prototipo del "Modulo tessile" per la mostra *Timber Project* (foto Markus Hudert).

Yves Weinand, architetto e ingegnere edile, dirige uno studio in Belgio e dal 2004 è direttore dell'IBOIS, il Laboratorio per le costruzioni in legno del Politecnico di Losanna (EPFL), dove è a capo di un gruppo di ricerca interdisciplinare in cui collaborano architetti, ingegneri, matematici e informatici. Attualmente sta progettando uno stadio del ghiaccio a Lüttich e l'edificio del Parlamento a Losanna con inserti strutturali in legno. A metà settembre 2013, poco prima del convegno *Form-Finding, Form-Shaping, Designing Architecture. Experimental, Aesthetical, and Ethical Approaches to Form in Recent and Postwar Architecture*, nel Campus di Mendrisio è stato montato un padiglione dell'IBOIS ed è stata inaugurata la mostra *Timber Project: Innovative Timber Construction*.

Figg. 2-5

Poiché Yves Weinand non ha potuto prendere parte al convegno, qui di seguito si riporta la rielaborazione di un'intervista da lui concessa in un incontro all'IBOIS, nella quale si approfondiscono alcune delle sue idee e diversi progetti.[1]

Percorsi innovativi verso la forma

Com'è possibile costruire in maniera innovativa in legno oggi? Com'è possibile impiegare questo materiale in maniera piacevole dal profilo estetico, convincente e corretta sotto il profilo costruttivo? A queste domande risponde l'attività dell'IBOIS: infatti l'obiettivo di questo Istituto è di sviluppare strutture in legno nuove e realizzabili in economia.

Importanti campi d'innovazione riguardano i pannelli portanti in legno (*tragende Holzvolumina*), i sistemi di pareti prefabbricate in legno, le tecniche di piegatura, lo studio di giunti innovativi e di strutture lignee simili a tessuti.

_ Figura 2.
Padiglione per Mendrisio (foto Enrico Cano).

Curvare e portare

Il percorso che conduce alla forma a partire dalle strutture a superfici autoportanti di Yves Weinand si sviluppa in maniera analoga a quello di Frei Otto, come si ricava dalle sue stesse parole: «Credo fermamente nelle strutture a superfici autoportanti, esse sono allo stesso tempo involucro e struttura. Struttura e superficie sono un tutt'uno; struttura portante e forma coincidono perfettamente».[2] Weinand, non a caso, ha analizzato in profondità la Multihalle di Mannheim, e negli spazi dell'IBOIS si trova un grande modello di lavoro del guscio a graticcio in legno sviluppato da Frei Otto, Carlfried Mutschler e Winfried Langner, che ha visibilmente influenzato il modello di studio del guscio dell'IBOIS per la definizione di reti geodetiche su forme libere, usato oggi come gioco per bambini nel parco Vallée de la Jeunesse a Losanna. Fig. 6

La ricezione delle idee di Otto è però libera, quasi ludica e del tutto critica; per Weinand, il nocciolo della questione è la logica strutturale. Nelle strutture reticolari la forma nasce dal movimento e dalla deformazione degli elementi,[3] per questo devono essere previsti nodi che permettano tale deformazione e che poi possano essere fissati. Weinand, analizzando la Multihalle, nota come vi siano zone che, dal punto di vista strutturale, «sono molto logiche e altre completamente illogiche». Queste debolezze del sistema costruttivo vengono tenute in conto per creare un'immagine architettonica adeguata al gusto del proprio tempo:

> Nella Multihalle ci sono zone che funzionano molto bene, mentre altre non funzionano per niente, nonostante la struttura portante o il sistema costruttivo siano gli stessi. Questo significa che l'immagine di un'architettura pop anni Settanta, voluta in realtà da Mutschler, sia stata la cosa più importante. Questa fu la motivazione. Ma ci furono problemi con gli sforzi in tensione in certi punti che poi fu necessario rinforzare. Questo sistema costruttivo consentì una forma libera, ma la forma nella analisi strutturale non è logica allo stesso modo in tutti i punti.

Premesso ciò, Weinand ammira la straordinaria coerenza tra sistema costruttivo e forma nella Multihalle.

Gusci a graticcio in legno, composti da una griglia di nervature di lamelle avvitate, sfruttano l'elasticità di questo materiale, che si lascia facilmente piegare grazie a una naturale costruzione a fibre. Yves Weinand utilizza questa caratteristica, finalizzandola sia alla costruzione sia alla generazione di forme, lavorando per questo con linee geodetiche. La definizione di reti geodetiche a forme libere mediante un programma di calcolo (GEOS), appositamente sviluppato, serve a miglio-

_ Figura 3.
Padiglione per Mendrisio, trasferimento delle due parti con struttura di supporto (foto Team Timber).

_ Figura 4.
Padiglione per Mendrisio, particolare della giunzione a coda di rondine (IBOIS).

_ Figura 5.
Padiglione per Mendrisio, fase di assemblaggio dei due elementi prefabbricati (foto Team Timber).

rare la progettazione e la costruzione di strutture a superfici autoportanti a nervature in legno. Weinand sottolinea come un punto critico dei gusci a graticcio in legno riguardi la necessità di avere una membrana che faccia da involucro. Vengono così calcolate solo le nervature; successivamente però queste sono coperte con il legno e la costruzione si irrigidisce. Per compensare la perdita costruttiva, Weinand ha iniziato a sviluppare esperimenti con grossi pannelli e volumi in legno, che presentano una maggiore stabilità di forma rispetto al legno massiccio. Da questi materiali, con le loro complesse costruzioni spesse fino a 50 cm e utilizzate come sistemi di parete con funzione portante, sono state create nuovi costruzioni a guscio la cui forma deriva direttamente dalla struttura. Le costruzioni lignee a guscio sono state fino ad ora piuttosto rare, pur possedendo un potenziale tale da ampliare il classico repertorio formale dei gusci in cemento armato, come in Heinz Isler.

Weinand è convinto che l'utilizzo di pannelli lignei portanti possa rovesciare completamente le metodologie precedenti, basate, nelle costruzioni tradizionali in legno, su sistemi di travi a sezione prismatica. Le superfici portanti giocano quindi un ruolo sempre più importante: se finora sono stati utilizzati pannelli in legno di piccole dimensioni come rivestimento e irrigidimento, i pannelli di grosse dimensioni vanno a rovesciare il rapporto tra asta e pannello: quest'ultimo viene ora impiegato per portare i carichi, mentre le aste sono usate come irrigidimento. Un simile procedimento, spiega Weinand, apre nuove possibilità per la creazione di spazi architettonici e per lo studio delle facciate. Cambiando, in questo modo, la tipologia stessa degli elementi strutturali, per il direttore dell'IBOIS è dunque necessario che venga sviluppata una nuova tettonica per i panelli in legno.

All'IBOIS la tettonica viene concepita come combinazione tra espressione architettonica, efficienza ed esecuzione della struttura portante. «Gli edifici buoni, convincenti al primo sguardo, confortevoli, che sorprendono e stupiscono, hanno un denominatore comune: una sintesi ben riuscita di tecnica e concezione spaziale»,[4] questa è la convinzione di Yves Weinand e del suo collaboratore Hans Ulrich Buri. In accordo con la definizione di tettonica di Kenneth Frampton,[5] essi intendono utilizzare la tecnica di costruzione in modo che sia parte fondamentale della concezione e che la influenzi attivamente.

La differenziazione operata da Karl Bötticher tra forma sostanziale e forma artistica, tra la struttura staticamente necessaria e la concezione eccessivamente artistica degli elementi costruttivi, che può dare un significato simbolico all'architettura,[6] viene ampliata da Buri e Weinand nel momento in cui la tettonica viene definita come il «poetico potenziale espressivo della tecnica costruttiva».[7] Condizione necessaria per una qualità tettonica è, secondo loro, il dialogo costruttivo tra definizione spaziale e tecnica. Con l'avvertenza che la parola greca *tekton* significa anche "carpentiere" e con una spiegazione etimologica che riporta a Gottfried Semper, i due intendono ancorare il pensiero della tettonica innanzitutto al costruire con il legno.

_ Figura 6.
Rete geodetica su guscio a forma libera (foto Alain Herzog).

Nell'era digitale, grazie anche a nuovi strumenti progettuali parametrizzabili e a modelli parametrici specifici, il legno può essere utilizzato come un materiale *high-tech*. Secondo questo tipo di approccio, la forma non viene più "disegnata" ma generata mediante un processo, governato da complessi algoritmi, che ne definisce l'ossatura e gli elementi costruttivi.[8]

Intessere e intrecciare

Dall'osservazione che le strutture tessili hanno buone qualità statiche e che il legno e i materiali tessili sono sorprendentemente simili, è nata all'IBOIS l'idea non soltanto di flettere ma anche di intessere e intrecciare il legno.[9] Yves Weinand crede che questo tipo di approccio sia adatto al materiale; così facendo si è infatti riusciti a sfruttare e trasformare in un vantaggio costruttivo la caratteristica a fibre del legno, che negli ultimi due secoli era invece stata vista come un limite. Ad esempio, Weinand ipotizza che le strutture portanti lignee intrecciate e curvate sopportino in maniera eccezionale i terremoti, il vento e il carico da neve. Poiché il potenziale delle costruzioni in legno con strutture a tessuto non è stato al momento ancora sistematicamente analizzato con riferimento alla riduzione dei rischi di crollo,[10] all'IBOIS Yves Weinand e Markus Hudert hanno iniziato un progetto di ricerca dal titolo *Tessuti lignei portanti. L'utilizzo di principi tessili nella dimensione costruttiva.*

Le tecniche di tessitura sono considerate tra le prime conquiste artigianali dell'uomo: si pensi agli scritti di teorici dell'architettura come Rondelet o Viollet-le-Duc, che ipotizzarono un utilizzo delle tecniche dell'intreccio nella costruzione dei primi insediamenti umani fatti di rami e frasche; così come all'opera di Semper, il quale sottolineò la possibile origine dell'architettura nell'arte tessile.[11] Tuttora gli indigeni costruiscono i propri insediamenti grazie all'intreccio di strutture in bambù o materiali simili.

Per il progetto di ricerca all'IBOIS si è cercato per prima cosa il minimo comune denominatore di tutte le strutture tessili. Come modulo base di materiali a maglia e a tessuto sono stati individuati due elementi che si incrociano. Markus Hudert ha trasferito questo principio al legno, e ha così sviluppato il "modulo tessile": due strisce incrociate di compensato che creano una forma spaziale simile a un arco o a un guscio con una superficie a doppia curvatura. Le caratteristiche portanti di questo modulo sono vantaggiose: con un carico verticale sul punto centrale dell'arco si rinforza il profilo della sezione trasversale, il modulo si stabilizza e guadagna in comportamento statico. L'intreccio dell'elemento modulare, inoltre, produce un effetto a catena che rende la struttura più robusta: il collasso di un singolo elemento non comporta il collasso dell'intero sistema. Il modulo base viene utilizzato come trave o in combinazione con strutture maggiori. Per la mostra *Timber Project* è stato costruito il modulo come prototipo in grande scala.

Fig. 1

In alternativa, possono essere intrecciati ad arco anche tre moduli tessili. Nel caso questi vengano disposti in fila e collegati l'uno con l'altro trasversalmente, è possibile creare una struttura leggera e trasparente di slanciata eleganza[12] che può essere rinforzata e ricoperta da una membrana translucida impermeabile. Purtroppo l'effetto spaziale così creato e il relativo gioco di luci e ombre non sono ancora direttamente apprezzabili. Hudert e Weinand sono convinti che simili strutture intrecciate siano realizzabili alla grande scala, ma oggi mancano ancora sia dei concorsi di architettura dedicati a questo tipo di costruzioni, sia degli incarichi diretti.

Il programma con cui le strutture intrecciate possono essere generate virtualmente e adattate grazie alla definizione dei parametri geometrici esiste già: si tratta di uno strumento parametrico che rende possibile differenti applicazioni. Ci si chiede, allora, se si viene così a creare una costruzione che si adatta in maniera autonoma alle variazioni di carico, anche improvvise, simile allo *SmartShell* di Stoccarda che Stefan Neuhäuser et al. descrivono in questo volume.[13]

Piegare

All'IBOIS il legno viene anche piegato, traendo ispirazione dall'origami, l'arte giapponese del piegare la carta.[14] Prima, la maggior parte delle strutture piegate erano in cemento armato, e sono state poi sostituite da quelle in materiali plastici rinforzati con fibra di vetro. Le strutture piegate in legno di solito sono più piccole e più semplici, costituite da pieghe parallele o concentriche. Anche in questo caso Yves Weinand, in collaborazione con Hans Ulrich Buri, si concentra su pannelli di legno compensato di grosse dimensioni e sulla possibilità di tagliarli grazie a una macchina computerizzata per la prefabbricazione di travi.

Determinante è stato osservare come l'origami unisca in sé caratteristiche quali semplicità, omogeneità materica, pieghevolezza, potenziale ricchezza di forme e un economico impiego di materiale, oltre a una semplice tecnica di base che consente, attraverso delle variazioni geometriche, una sorprendente ricchezza di geometrie complesse. Weinand e Buri si sono interessati al trasferimento di questa capacità di creare forme complesse con mezzi semplici alla costruzione di strutture piegate in pannelli lignei. Hanno così sperimentato la procedura intuitiva del piegare la carta, con la convinzione che un lavoro manuale e spontaneo potesse portare a scoperte scientificamente valide. In seguito, i due hanno messo a punto uno strumento digitale in grado di rappresentare nello spazio le strutture piegate e di poterle modificare velocemente. Dato che la profondità e l'inclinazione delle pieghe determinano la capacità di carico, la forma può così essere definita per passaggi successivi. Come dimostrano i prototipi realizzati e le analisi statiche, le geometrie delle strutture piegate presentano interessanti valori di resistenza grazie all'azione contemporanea delle piegature: possono venire collegate facilmente ed economicamente, come possono essere facilmente montate. Forma e resistenza sono facilmente adattabili e anche le piegature complesse si lasciano modellare.

La prima struttura piegata, progettata e realizzata con questo metodo è la Cappella di St. Loup a Pompaples, nel Cantone di Vaud.[15] Il gruppo di architetti Localarchitecture e il Bureau d'architecture di Danilo Mondadas vinsero il concorso per il restauro della casa madre della comunità delle diaconesse di St. Loup. Dato che durante la fase dei lavori si rendeva necessaria una cappella provvisoria per le messe giornaliere, venne proposta una collaborazione con l'IBOIS. Fu così possibile testare, per la prima volta in maniera concreta, lo strumento di modellazione digitale come supporto per la collaborazione tra architetti e ingegneri già dalla fase di progettazione.

Due linee soltanto generarono la forma: il rettangolo della sezione trasversale e la linea a zig-zag della scanalatura della piega in pianta. Si creò così una forma architettonica nuova e autonoma, che sarebbe stata difficilmente realizzabile senza la strumentazione digitale. Ciò ha inoltre contribuito a razionalizzare il processo di produzione, dal momento che le linee di taglio dei pannelli sono state disegnate direttamente nello strumento di modellazione per poi venire consegnate al produttore. Un disegno esecutivo, pertanto, non fu necessario. Poiché le pieghe aumentano la resistenza delle superfici sottili, le strutture piegate potrebbero non solo coprire degli spazi ma anche funzionare come sistemi portanti e formare direttamente degli spazi. «La geometria … integra involucro spaziale, struttura portante, costruzione, acustica e illuminazione in una forma omogenea che è chiaramente dettata dagli strumenti progettuali»,[16] dichiarano Buri e Weinand. Involucro, struttura e rivestimento interno derivano infatti da un unico strato di pannelli in legno. Nella prima fase progettuale, le pieghe parallele articolano lo spazio come fanno le colonne in una navata di una chiesa tradizionale. Nel progetto definitivo una piegatura ogni due è stata disposta diagonalmente, in modo da creare un sistema di piccole e grandi pieghe a direzione alternata che ravvivano lo spazio interno, migliorandone l'acustica e l'illuminazione e creando un'adeguata pendenza del tetto per favorire lo scolo delle acque. Come in Frei Otto, l'idea della riduzione al minimo necessario e l'ispirazione della natura hanno avuto un ruolo fondamentale. Anche la natura si serve del principio della piega nelle foglie delle piante e nelle ali degli insetti, per poter così creare superfici, grandi e stabili, con il minor dispendio possibile di materiale.

Comporre e saldare

Per poter disporre e congiungere i pannelli delle strutture piegate, delle strutture a tessuto o delle strutture disposte liberamente nello spazio, devono essere sviluppati dei giunti adatti. Tali giunti costituiscono per Yves Weinand uno dei campi di ricerca in assoluto più interessanti. Altre invenzioni, trasferite dall'industria delle lavorazioni delle materie plastiche e dei metalli alle costruzioni in legno – come la saldatura a frizione, che consente di connettere tra loro gli elementi in legno senza l'utilizzo di colle nocive per l'ambiente – sono per Yves Weinand meno significativi: «Adesso siamo finalmente arrivati ai giunti!»

Anche per questo i giunti sono un campo di ricerca particolarmente importante all'IBOIS, poiché costituiscono la metà dei costi di una costruzione in legno. Sono state sviluppate delle nuove connessioni dentellate di legno con legno per strutture spaziali come *dovetail joints* o *parametric woodworking joints*, che non necessitano di colle né di saldatura a frizione. Il ricercatore dell'IBOIS Christopher Robeller, ad esempio, indaga all'interno del suo dottorato lo sviluppo dei giunti in legno. Prima del suo impiego all'IBOIS collaborò, tra il 2008 e il 2010, col professor Achim Menges all'Istituto di progettazione digitale dell'Università di Stoccarda (Institut für Computerbasiertes Entwerfen/Computational Design, ICD) dove ha preso parte alla realizzazione del padiglione di ricerca temporaneo in legno.[17] Padiglione che, realizzato in collaborazione con l'Istituto di strutture e progettazione costruttiva (Institut für Tragkonstruktionen und Konstruktives Entwerfen/ITKE), anch'esso dell'Università di Stoccarda, impressionò per la dimostrazione pratica dello sviluppo delle nuove tecniche digitali di progettazione, visualizzazione e produzione grazie alla complessa struttura portante di oltre 500 fasce sottili di compensato. Le fasce di legno di betulla, della lunghezza di 10 m e dello spessore di solo 6,5 mm, vengono flesse in maniera tale da sviluppare una struttura che si stabilizza da sé sotto deformazione e che si irrigidisce. Ottanta di queste fasce vengono assemblate a formare un anello di 10 m di circonferenza e una campata di 3,50 m.

Anche questo padiglione mostra l'influenza dell'idea di *form-finding* di Frei Otto. Achim Menges definisce Otto un importante precursore del concetto di *Computational Design*,[18] che al contrario dell'ordinaria restituzione digitale di un progetto (CAD) non serve soltanto alla descrizione della forma ma anche alla sua generazione. Per Menges, il contributo fondamentale di Otto consiste nell'aver portato la metodologia di progetto a un gradino superiore: non più definizione della forma, bensì *form-finding*. Questo significa che, dopo la scelta dei materiali e la definizione dei parametri di partenza, si crea uno stato di equilibrio e nasce la forma.

Otto ha usato il materiale come fosse un computer analogico. Menges definisce questo processo *Computational Design*, sebbene esso sia stato portato avanti quasi

_ Figura 7.
Cappella St. Loup, vista esterna (foto Fred Hatt).

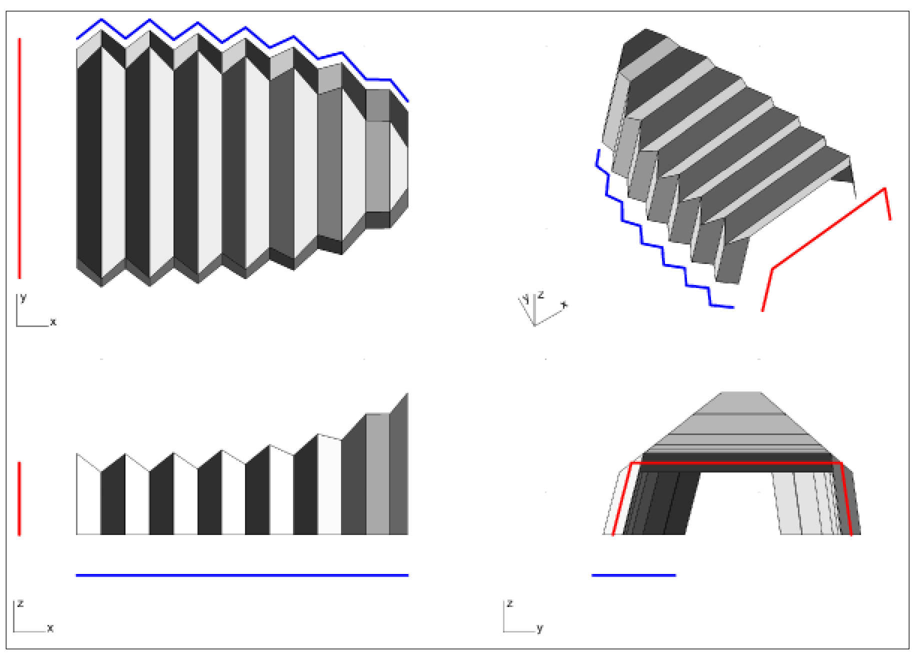
_ Figura 8.
Cappella St. Loup, vista interna (foto Fred Hatt).

senza l'impiego del computer stesso. Un aspetto non secondario di questo approccio consiste nel parametrizzare: operazione che, per Menges, consiste nell'utilizzare un modello matematico per scomporre digitalmente un sistema complesso secondo specifici criteri in un numero definito di elementi. In questo processo il cambiamento di ciascun parametro comporta una modifica di tutti gli elementi del sistema. A differenza della modellazione parametrica, nella progettazione parametrica (come nel caso dei padiglioni per Stoccarda e per Mendrisio) non variano solo i parametri ma anche l'elaborazione del codice informatico, definito e programmato appositamente.

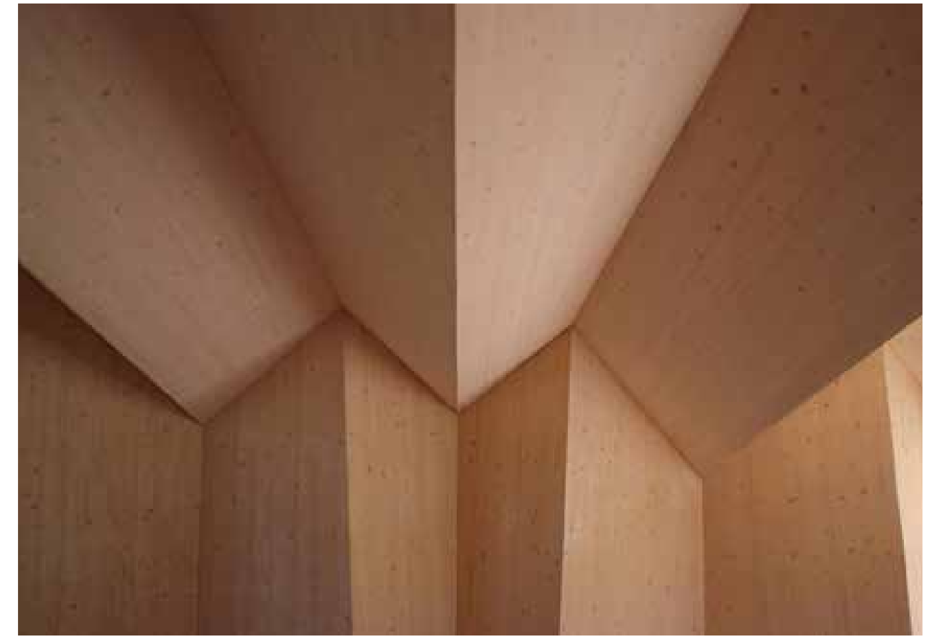
Dal 2006 l'IBOIS ha esplorato le geometrie complesse delle costruzioni in legno. Uno dei primi prototipi realizzati fu il guscio a graticcio in legno con delle linee geodetiche su superfici di forme libere. Nel 2008 fu realizzata la struttura piegata della Cappella di St. Loup con sistemi di pareti prefabbricate in legno. Dal 2010 le caratteristiche statiche e geometriche di questi esempi sono state allargate alle superfici curvate, come il padiglione dell'IBOIS a Mendrisio. Ciò si traduce ovviamente in una maggiore resistenza alla flessione, ma comporta altre difficoltà come la definizione delle giunzioni. Questo padiglione (lungo 13,5 m, largo 4,5 m e alto fino a 3,2 m) era composto da cinque elementi curvati di compensato; due di essi servivano come pareti, tre da copertura. Con uno spessore di 77 mm, la struttura arrivava a una portata di 13,5 m.

Figg. 7-10

Una sfida particolare per i progettisti Yves Weinand, Christopher Robeller e Sina Nabaei è stata l'invenzione dei giunti agli angoli della struttura piegata, punto cruciale per l'intero processo progettuale.[19] Anche nel caso del padiglione per Mendrisio, la forma non è stata creata ma generata da parametri come raggio di curvatura, angoli, geometria delle giunzioni, realizzazione pratica e caratteristiche del materiale. Confrontando questi parametri con le analisi della statica, la forma è stata ottimizzata in maniera iterativa: tramite la simulazione numerica dei carichi si calcolava infatti lo spessore necessario del materiale. Al fine di minimizzare i costi di produzione, per tutti i cinque pezzi del padiglione è stata scelta la stessa curvatura, con una campata di 5,9 m.[20]



_ Figura 9.
Cappella St. Loup, disegni dalla fase di progettazione (IBOIS).



_ Figura 10.
Cappella St. Loup, particolare della congiunzione tra parete e copertura della struttura piegata (foto Fred Hatt).

Le giunzioni non ortogonali dei pannelli a curvatura semplice in legno lamellare a strati incrociati (*Cross Laminated Timber*/CLT) non sarebbero state possibili con la tecnica tradizionale, che avrebbe richiesto una fase di incollatura o l'impiego di inserti metallici. Per poter arrivare a una soluzione esteticamente e costruttivamente convincente, all'IBOIS sono state modificate le tradizionali tecniche della falegnameria delle giunzioni a coda di rondine, *dovetail joints*. È stato possibile congiungere gli elementi verticali del prototipo per Mendrisio in scala 1:1 con la tecnica delle giunzioni a coda di rondine, mentre non si è potuto utilizzare tale tecnica nella zona dei giunti radiali dove gli angoli erano minori di 160 gradi. A connettere gli elementi di copertura, sono stati quindi fresati degli intagli di 30 mm nei pannelli, che sono stati successivamente riempiti di elementi di legno impiallacciato (*Laminated Veneer Lumber*/LVL) e infine incollati.[21] L'intera geometria di giunzione è stata resa possibile grazie a un apposito strumento di calcolo numerico. È stato così possibile tagliare tutti gli elementi da un unico pannello flesso di 17 m con sette robot CNC, senza spreco di materiale. Per Weinand è di particolare importanza la produzione integrata dell'elemento costruttivo e del giunto. Entrambe avvengono in un unico processo e i costi vengono così ridotti sensibilmente: «È sorprendente osservare come l'ingegnere calcoli molto per poter ottenere la sezione trasversale minore, mentre la quantità di legno rappresenta solo la metà del costo …; se si può risparmiare sulla tecnologia dei giunti, si ottiene molto di più che attraverso la riduzione della sezione trasversale». Inoltre, sottolinea ancora Weinand, i giunti parametrici legno con legno rappresentano un importante punto di partenza per lo sviluppo di una nuova tettonica.

Etica professionale dell'ingegnere e dell'architetto

La progettazione di innovativi metodi di giunzione come *dovetail joints* o *parametric woodworking joints* richiede una stretta collaborazione tra architetto e ingegnere. Già dalla scelta dei materiali Yves Weinand constata differenze sostanziali tra gli uni e gli altri: «Si sa che gli ingegneri optano sempre per un unico materiale». La scelta dell'ingegnere per il legno o per il cemento comporta differenze e conseguenze di ampia portata. Nel costruire con il legno, il progetto va infatti definito preventivamente in toto, dato che poco si lascia modificare durante la fase di cantiere. Successivi interventi progettuali modificano non solo i giunti in legno ma anche l'aspetto dell'edificio e la tettonica della costruzione. Optare per il cemento armato dimostra invece, secondo Weinand, anche l'immagine professionale che hanno di sé gli ingegneri: «Costruire con il legno richiede una maggiore armonia interdisciplinare, per ottenere una determinata soluzione».

Il fatto che, storicamente, la costruzione con il legno sia stata un ambito di studio degli Istituti di ricerca sull'acciaio e poi sul cemento armato ha causato una mancanza di ricerca su questo materiale. Soltanto a partire dagli anni Settanta si sono create le prime cattedre autonome per le costruzioni in legno, per primo l'IBOIS a Losanna, nel 1979. Secondo Yves Weinand, «il sapere intuitivo dei carpentieri si è andato perdendo da quando nel XVIII secolo si è sviluppato il mestiere di *Ingénieur des Ponts et Chaussées*: i nuovi ingegneri non usavano il legno perché lo consideravano a priori un materiale inferiore rispetto all'acciaio e al cemento».[22] L'argomento – sostenuto da alcuni ingegneri anche durante la nostra conferenza – che le strutture a guscio possano essere realizzate solo in paesi con un basso costo del lavoro, viene rifiutata da Weinand con un sorriso: «Ora non posso che citare la provocazione del mio predecessore, che disse: se si vuole gettare il cemento, va prima di tutto costruita una cassaforma in legno». Da questa constatazione, Weinand ha sviluppato idee per strutture di giunzione in cemento e legno: gusci in legno sui quali viene gettato un sottile strato di cemento, armato e connesso, in modo tale che entrambe le costruzioni collaborino e siano strutturalmente attive.

Yves Weinand è affascinato dalle figure che lavorano al confine tra architettura e ingegneria. Come l'ingegnere e architetto Salomon de Caus, di cui si occupò in occasione di un progetto multidisciplinare finanziato dalla Deutsche Forschungsgemeinschaft (DFG). [23] Il decoratore di teatri e progettista del giardino del Castello di Heidelberg si guadagnava da vivere disegnando prospettive, che suscitarono l'interesse di Weinand: portare la presenza della tecnica in superficie e mostrarne la struttura è stata la motivazione che l'ha spinto a studiare, oltre all'architettura, ingegneria edile. «Nell'architettura mi affascina sempre questa componente strutturale che ha a che fare anche con la tettonica. Questo non c'entra ancora direttamente con la forma o con il *form-finding* ma con il piacere di evidenziare la forza espressiva degli elementi strutturali nell'architettura».

Estetica della forma, della struttura e dello spazio

Weinand cerca di unire gli elementi forma, struttura e spazio, nonostante per lui lo spazio abbia un ruolo secondario che influenza solo indirettamente il progetto.

> Esistono principalmente tre elementi: forma, struttura e spazio. Noi parliamo meno dello spazio. Lo spazio è davvero quella cosa che è connessa all'aspetto architettonico. Nel nostro studio suggeriamo programmi che rimangono molto semplici perché a noi interessa in primo luogo la tensione tra forma e struttura. Ovviamente anche lo spazio ha un ruolo. Ma molti colleghi iniziano con l'organizzazione degli spazi. Noi non facciamo così. Io credo a un'interazione tra forma e struttura che in alcuni casi è decisamente armonica e grazie a questo esprime la propria forza. Queste sono le costruzioni che ci interessano davvero molto.

Qui si nota una chiara differenza con Frei Otto o Lisbeth Sachs, per i quali la particolarità delle strutture a superfici autoportanti non è soltanto «il piacere di inventare la pelle»,[23] quanto piuttosto il loro fluido sviluppo spaziale.

Un'altra esigenza estetica dell'IBOIS è di realizzare costruzioni le cui strutture e superfici, struttura portante e forma, siano assolutamente identiche. Per questo è per Weinand così importante lavorare con materiali a pannelli. Con lastre portanti in legno, come nella Cappella di S. Loup, si riescono a creare forme libere, nelle quali le superfici costituiscano anche lo strato portante.

Senza dubbio la Multihalle di Mannheim è stata un importante punto di partenza per Weinand. Egli critica invece aspramente un'altra costruzione a guscio, opera di Shigeru Ban, molto apprezzata da Frei Otto:[24] «Nel Centre Pompidou di Metz viene costruita soltanto un'immagine. Non si legge una interazione tra forma e struttura e inoltre ci sono grossi problemi nei dettagli costruttivi. Il materiale non viene più spinto in questa forma come nel caso di Mannheim. Non è nemmeno come nelle sedie Thonet, dove la forma si impone, ma piuttosto viene preso un pezzo di legno dritto e lo si fresa curvo». Weinand non accetta la motivazione secondo la quale la forma deriva dalla struttura intessuta di un cappello di paglia. Un architetto non dovrebbe mai utilizzare superficialmente un'immagine senza capirla anche del tutto costruttivamente. Nel Centre Pompidou di Metz gli elementi costruttivi sono stati «fresati come sculture» causando notevoli problemi costruttivi, dal momento che non è stata tenuta in considerazione la consistenza delle fibre del legno. Ciò ha portato a una diminuzione del 20% della capacità di resistenza del materiale. Decisamente più interessanti sono per lui il sistema Zollinger, la Salzlagerhalle di Hugo Häring o altri sistemi analoghi che presentano una logica costruttiva maggiore. Weinand stesso cerca di trovare soluzioni facili e convincenti che soddisfino quante più esigenze possibili.

Conclusione: una nuova tettonica per la costruzione in legno digitalizzata

Weinand non riprende dogmaticamente il concetto del *form-finding* di Frei Otto, ma piuttosto lo utilizza solo in alcuni progetti: per questo non si creano banali analogie. Infatti, non vengono imitate delle forme ma sono piuttosto sviluppati dei concetti insiti nel materiale: «Abbiamo un approccio piuttosto pragmatico e non filosoficamente così profondo come credo lo cercasse Otto», riassume Weinand in maniera autocritica. Le sue idee si spingono però ben oltre il puro pragmatismo e forse sono più vicine a quelle di Otto di quanto egli stesso creda, come mostrano le piante per il prossimo padiglione dell'IBOIS.

Già i primi padiglioni a pannelli portanti in legno hanno sorpreso con il loro rovesciamento del rapporto tra asta e pannello e la conseguente nuova tettonica dei pannelli in legno. Tuttavia, nelle strutture piegate realizzate grazie allo strumento dell'origami sta in primo piano la geometria globale, mentre la geometria locale del giunto viene presa in considerazione solo in un secondo momento. Nel prossimo padiglione dovrà essere definita soltanto una certa tolleranza negli angoli, grazie alla quale poter spostare agevolmente le giunzioni tra i pannelli. Weinand spiega che è stato sviluppato un algoritmo in grado di calcolare il margine di libertà per la disposizione delle tavole, così da poter fissare e realizzare ciascuna connessione. «Vogliamo utilizzare la specificità di giunti in legno e la fabbricazione come strumenti concettuali per il *form-finding*. Anche se non sappiamo bene cosa ne uscirà. È un esperimento». Anche qui sono innegabili delle analogie con Frei Otto: l'idea progettuale di base nasce da una riflessione concettuale, mentre la forma finale si sviluppa in un processo sperimentale.

> Andremo a generare le forme finali partendo dalla giunzione. E credo che questo possa portare a una tettonica particolare. Quella cioè che la *veritas* della costruzione secondo Vitruvio si legge anche nella giunzione. … Ce ne sono sempre meno al giorno d'oggi. Ci sono forme che vengono generate virtualmente e forme che devono essere imitate. Noi non vogliamo imitare delle forme, le vogliamo generare.

Weinand definisce qui due differenti principi in base ai quali generare una forma. Questo termine include sia il produrre, il creare o l'immaginare in maniera attiva, sia un atteggiamento più passivo del prendere forma, del lasciar succedere o del prodursi. Da un lato c'è la creazione attiva, la genesi (alla fine grazie a uno spirito creatore); dall'altro la creazione che si autoregola e che non si lascia influenzare dall'esterno. Il formare consapevole – e, secondo Frei Otto, il *deformare* – contrasta con il lasciare sviluppare la forma (*form-finding*). Un terzo tipo di approccio consiste invece in un atteggiamento formalista, nel quale vengono sfruttate in maniera superficiale le infinite possibilità della tecnologia digitale.

Il principio di Weinand, che parte dallo studio del materiale e dalla considerazione approfondita del dettaglio architettonico (e in particolare il giunto), ricorda la *tectonic of assembly* di Renzo Piano e Richard Rogers che Roberta Grignolo descrive nel suo saggio[25] e che appare profondamente radicata nell'artigianato. Il materiale, le sue caratteristiche e le sue possibilità di connessione sono al centro delle ricerche dell'IBOIS, e in generale, come ha constatato Irina Davidovici,[26] sono temi tipici dell'architettura svizzero-tedesca a partire dagli anni Ottanta. Tuttavia, curvando, intessendo, intrecciando, piegando, componendo e saldando il legno, Weinand – architetto belga con una cattedra nella Svizzera francese – trascende gli stretti confini del "corretto costruire" dell'area svizzero-tedesca.

L'IBOIS sviluppa strumenti parametrici di progetto che si basano sulle caratteristiche specifiche del materiale legno. Vengono ricercati nuovi pannelli lignei, nuovi metodi di lavorazione e nuove tecniche di giunzione così come possibilità innovative di rappresentare e calcolare le strutture portanti. L'obiettivo è di unire efficacemente progetto e costruzione, oltre che di integrare i vincoli architettonici, strutturali e produttivi. Weinand stesso descrive così questo approccio: «Noi abbiamo un principio pratico. Vogliamo sovrapporre la geometria del taglio delle piastre con il taglio della giunzione legno con legno che vengono parametrizzate contemporaneamente».

A convincere, in maniera particolare, è il fatto che il processo che genera la forma viene determinato soltanto dal materiale stesso e da come viene deformato sotto carico. Secondo Weinand è una sfida per i matematici e gli ingegneri, ma allo stesso tempo una garanzia per la qualità tettonica della forma. Poiché la forma si lascia creare e modificare dal controllo dei parametri, la tettonica ottiene una nuova attualità perché il modello parametrico può mediare tra spazio e tecnica.[27] La canonizzazione del parametricismo a stile del XX secolo operata da Patrik Schumacher non riesce a convincere;[28] al contrario, convincono molto gli strumenti progettuali dell'IBOIS, che nascono prima da un processo riflessivo e solo successivamente vengono utilizzati per verificare possibili forme.

(Traduzione di Rosalba Maruca, Elisabeth Bergmann e Gabriele Neri).

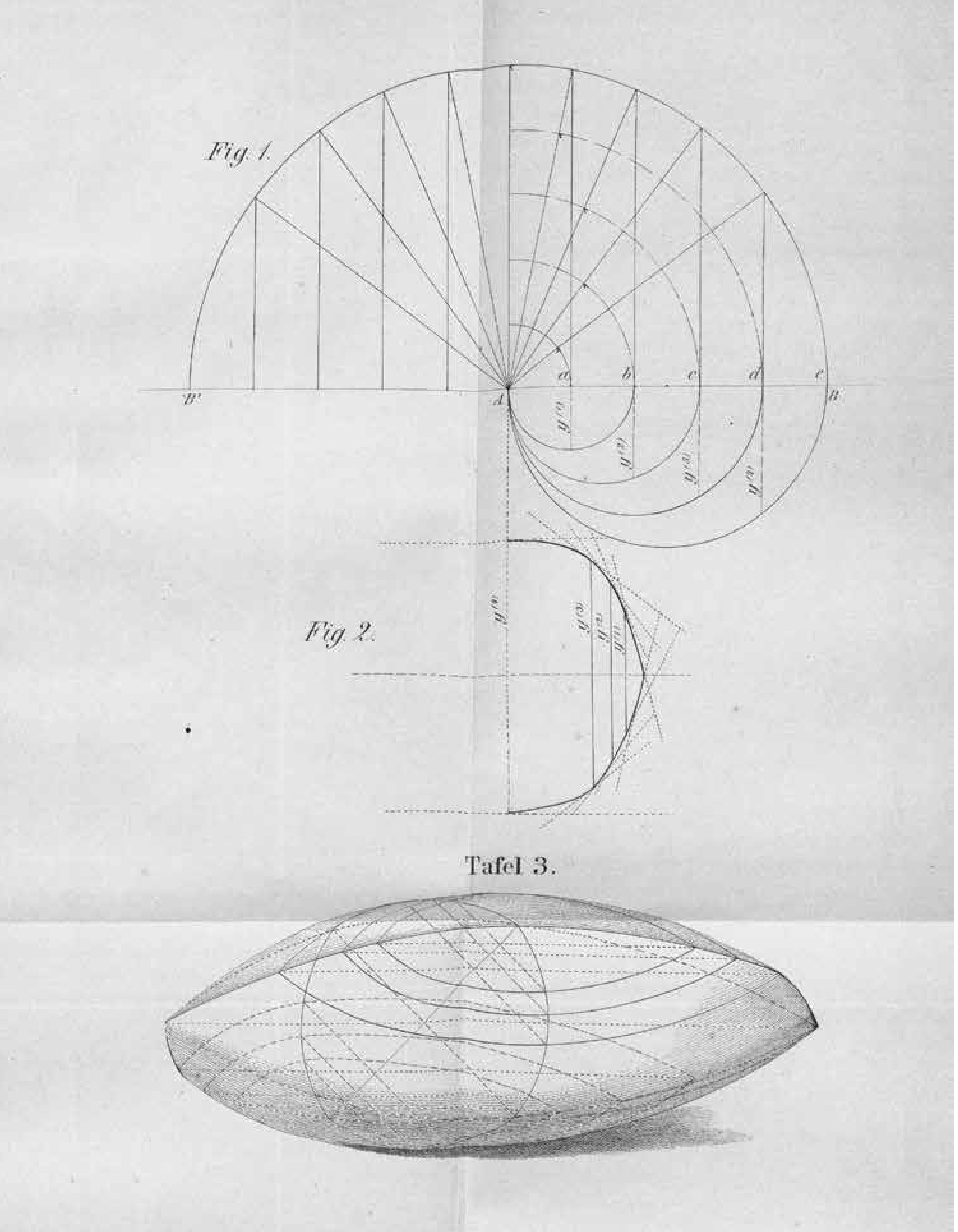
Abstract

Timber Constructions at the IBOIS.
Bending, weaving, interbraiding Timber:
a Conversation with Yves Weinand

How is it possible today to build with timber in an innovative manner? With appealing aesthetics, a convincing structural concept, and appropriate to the material involved? Architect and civil engineer Yves Weinand runs an office in Belgium and has also since 2004 been the director of IBOIS, the laboratory for timber construction at the Ecole Polytechnique Fédérale de Lausanne (EPFL). He heads an interdisciplinary team of researchers, including architects, engineers, mathematicians, and computer scientists. The aim of IBOIS is to develop innovative timber materials that can be manufactured in an economical way. Important fields of research are load-bearing timber panels and volumes, origami-like folded plate structures, new types of connection such as friction welding of wood, and the application of textile principles on the scale of a building.
Weinand's approach to form, like Frei Otto's, starts from area-covering structural elements. Both architects develop their design concepts through a process of conceptual reflection, while by contrast the final form arises in an experimental process. Weinand does not adopt Otto's idea of form-finding in a dogmatic manner, but only for a few projects. More important to him is the work-inherent derivation of form starting from the material or from an important architectural detail such as the timber joint. His approach is thus similar to Renzo Piano's and Richard Rogers' concept of a "tectonic of assembly" – described by Roberta Grignolo elsewhere in this publication – and is also deeply rooted in handicraft. But by bending, weaving, interbraiding and joining timber, Yves Weinand is bursting the narrow limits of the Swiss-German art of "correct building". What appears to me to be the most persuasive aspect is that in his load-bearing timber fabrics with textile modules, the process of form generation is determined by the material itself and by its deformation. According to Weinand, this represents a substantial challenge for mathematicians and engineers, but at the same time it guarantees the tectonic quality of the form. Tectonics is thus becoming a topical subject once again, as the parametric model developed by the IBOIS team manages to mediate between space and technology.

Note

_ 1. Tutte le citazioni seguenti senza nota: Yves Weinand in un'intervista con l'autrice, Losanna, 26 novembre 2013.
_ 2. «Ich glaube sehr stark an in der Fläche tragende Bauwerke. Flächige Tragwerke sind direkt Hülle und Struktur. Struktur und Oberfläche sind eins, Tragstruktur und Form völlig deckungsgleich».
_ 3. Un aspetto che la messa in scena delle *Architetture elastiche* di Riccardo Blumer e dei suoi studenti di primo anno dell'a.a. 2012-2013 ha suggestivamente reso evidente durante il convegno.
_ 4. H.U. Buri, Y. Weinand, *Die Tektonik der Holzarchitektur im digitalen Zeitalter*, in *Bauen mit Holz. Wege in die Zukunft*, catalogo della mostra (München, Architekturmuseum der TU München, Pinakothek der Moderne, 10 novembre 2011-5 febbraio 2012), Prestel, München 2011, pp. 56-63, p. 56; H.U. Buri, Y. Weinand, *Holz – Tektonik – Digital*, "Baunetzwoche", n. 253, 2012, pp. 7-13, p. 8 (disponibile in: http://www.baunetz.de/baunetzwoche/baunetzwoche_ausgabe_2427387.html, visionato il 27 giugno 2014).
_ 5. K. Frampton, *Studies in Tectonic Culture. The Poetics of Construction in Nineteenth and Twentieth Century Architecture*, MIT Press, Cambridge 1995.
_ 6. K. Bötticher, *Die Tektonik der Hellenen*, Verlag Ferdinand Riegel, Potsdam 1844.
_ 7. Buri, Weinand 2011 (vedi nota 4), p. 56.
_ 8. Buri, Weinand 2012 (vedi nota 4), pp. 7-13; A. Picon, *L'Architecture et le virtuel. Vers une nouvelle matérialité*, in J.-P. Chupin, C. Simonnet (a cura di), *Le Projet Tectonique*, Infolio, Paris 2005.
_ 9. M. Hudert, Y. Weinand, *Tragendes Holzgewebe*, "Holzforschung Schweiz", 1, 2009, pp. 7-9; M. Hudert, M. Sistaninia, Y. Weinand, *Structural Timber Fabric. Applying Textile Principles on Building Scale*, 2010 (disponibile in: http://infoscience.epfl.ch/record/151427, visionato il 7 maggio 2014); M. Hudert, *Timberfabric. Applying Textile Assembly Principles for Wood Construction in Architecture*, EPFL, Lausanne 2013.
_ 10. Y. Weinand, *Neue Wege für Holztragwerke. Das Forschungslabor IBOIS an der EPF Lausanne*, in A. Flury (a cura di), *Kooperation. Zur Zusammenarbeit von Ingenieur und Architekt*, Birkhäuser, Basel-Boston-Berlin 2011, pp. 91-101, pp. 92-94.
_ 11. J.-B. Rondelet, *Traité théorique et pratique de l'art de bâtir*, Imprimerie de Fain, Paris 1802-1817. E.E. Viollet-le-Duc, *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle*, V.A. Morel, Paris 1854-1868. G. Semper, *Der Stil in den technischen und tektonischen Künsten, oder Praktische Ästhetik. Ein Handbuch für Techniker, Künstler und Kunstfreunde*, vol. 1: *Die Textile Kunst, für sich betrachtet und in Beziehung zur Baukunst*, Verlag für Kunst und Wissenschaft, Frankfurt am Main 1860; vol. 2: *Keramik, Tektonik, Stereotomie, Metallotechnik für sich betrachtet und in Beziehung zur Baukunst*, Friedrich Bruckmann, München 1863.
_ 12. Hudert, Weinand 2009 (vedi nota 9), pp. 7-9, immagini p. 9; Hudert, Sistaninia, Weinand 2010 (vedi nota 9).
_ 13. Cfr. il saggio di Stefan Neuhäuser et al. in questo volume.
_ 14. H.U. Buri, *Origami. Folded Plate Structures*, tesi di dottorato, EPFL, Lausanne 2010; H.U. Buri, Y. Weinand, *Origami aus Brettsperrholz*, "Detail", 50, 2010, n. 10, pp. 2-4.
_ 15. Nel 2008 viene realizzata la Cappella di St. Loup di H.U. Buri e Y. Weinand a Pompaples (Svizzera); cfr. H.U. Buri, Y. Weinand, *Gefaltet*, "TEC21", 135, 2009, n. 8, pp. 18-22; Buri, Weinand 2012 (vedi nota 4), pp. 7-13; H.U. Buri, Y. Weinand, *Die provisorische Kapelle von St. Loup*, "Holzforschung Schweiz", 2008, n. 2, pp. 16-20.
_ 16. Buri, Weinand 2012 (vedi nota 4), p. 12; H.U. Buri, Y. Weinand, *Kapelle St. Loup in Pompaples*, "Detail", 50, 2010, n. 10, pp. 1028-1031.
_ 17. Progetti presentati in: http://icd.uni-stuttgart.de/?p=4458; http://www.uni-stuttgart.de/hkom/presseservice/pressemitteilungen/2010/mitteilung_0088.html?__locale=en, visionati il 5 maggio 2014.
_ 18. N.N., *Interview mit Achim Menges*, "Baunetzwoche», n. 253, 2012, pp. 14-16 (disponibile in: http://www.baunetz.de/baunetzwoche/baunetzwoche_ausgabe_2427387.html, visionati il 27 giugno 2014).
_ 19. C. Vielhauer, *Besondere Verbindung: doppelt gekrümmte Holzschale der EPFL Lausanne*, "Detail. Das Architekturportal", 26 novembre 2013 (disponibile in: http://www.detail.de/architektur/themen/besondere-verbindung-doppelt-gekruemmte-holzschale-der-epfl-lausanne-022346.html, visionato il 5 maggio 2014); C. Robeller, S. Nabaei, Y. Weinand, *Design and Fabrication of Robot-Manufactured Joints for a Curved-Folded Thin-Shell Structure Made from CLT*, in *Robotic Fabrication in Architecture, Art and Design*, Wien-New York 2014, pp. 67-81; M. Savoyat, *IBOIS Pavillon, Mendrisio. Origami aus gekrümmtem Holz*, "TEC21", 140, 2014, n. 34, pp. 26-29.
_ 20. Savoyat 2014 (vedi nota 19), p. 28.
_ 21. I giunti a coda di rondine hanno funzionato; soltanto la fessura della copertura non ha resistito alla pioggia torrenziale dell'inverno ticinese 2013-2014, secondo Weinand prevedibilmente visto il risparmio di vernice protettiva. La fessura si ingrandì, andando a pregiudicare la sicurezza della costruzione. Pertanto il padiglione è stato segato e ridotto a fatica in piccoli pezzi dal personale tecnico dell'Accademia di architettura a fine marzo 2014.
_ 22. Y. Weinand, *Neue Wege für Holztragwerke. Das Forschungslabor IBOIS an der EPF Lausanne*, in Flury 2011 (vedi nota 10), p. 91; Buri, Weinand 2011 (vedi nota 4).
_ 23. Y. Weinand, *Die Maschinen des Salomon de Caus - Dokumentation der Planung und Realisierung einer Konstruktion*, in B.E.H. Schmuhl (a cura di), *Maschinen und Mechanismen in der Kunst*, Wißner-Verlag, Augsburg 2006, pp. 257-305.
_ 24. Cfr. E. Bergmann, *La "filosofia architettonica" di Frei Otto*, in questo volume.
_ 25. Frei Otto in un'intervista con l'autrice, Warmbronn, 17 maggio 2013.
_ 26. Cfr. il saggio di Roberta Grignolo in questo volume.
_ 27. I. Davidovici, *Forms of Practice. German-Swiss Architecture 1980–2000*, gta Verlag, Zürich 2012.
_ 28. Buri, Weinand 2012 (vedi nota 4); Picon 2005 (vedi nota 8).
_ 29. Cfr. E. Bergmann, *La "filosofia architettonica" di Frei Otto*, in questo volume.



_ Figure 1.
Gottfried Semper, *Ueber die bleiernen Schleudergeschosse der Alten...*, 1859, plates 2 and 3 showing the geometrical analysis of a Greek projectile (ETH-Bibliothek Zürich, Alte und Seltene Drucke).

Sonja Hildebrand

Towards an Expanded Concept of Form

Gottfried Semper on Ancient Projectiles

At the *Anymore Conference* in Paris in 1999, Bernard Cache – an early leading thinker in the field of digital design and digital fabrication – suggested that a historical basis for digital design might be found in Gottfried Semper's architectural theory. There is a "clear affinity", he argued, between the digital procedures that he was exploring together with Patrick Beauce in their *Objectile* studio and Semper's theory – not only due to the latter's focus on materials and technology, but also in the "principle of dressing" that he defined. In particular, the affinity was also based on the way in which Cache's own "investigations into the generation of software to map key elements of modern topology, like knots and interlacing, consist of a contemporary transposition of Semper's ... primitive pattern". The lecture was published in 2000 under the title *Digital Semper*.[1]

The roots of digitisation

The arguments developed in the essay are attractive. The basing of digital design on Semper's theory links the virtuality of digital procedures, which nevertheless lead to material results, with pre-digital procedures developed in concrete materials.[2] The products of digital design, which are often difficult or impossible to understand, thus in a sense acquire a genealogy in the material and factual sphere, which – as a kind of reading aid – connects the new types of form to a comprehensible and even everyday world of experience.

Cache starts with a systematic presentation of what he describes as Semper's correlation of materials (fabric, clay, wood, stone) with the technical arts associated with them (textiles, ceramics, tectonics/carpentry, stereotomy/masonry). This is based on the typology that Semper developed – first described in his *Die vier Elemente der Baukunst* (The Four Elements of Architecture) in 1851 – of pre-architectural craft techniques and basic architectural elements. On analogy with Semper, Cache regards the technical arts as procedures. According to Semper, these procedures were originally developed with specific materials, but were later also applied to different ones. Ashlar blocks, for example, are assigned as an original material to the category of masonry and stereotomy. In the form of stone slabs, however, they can also be used for cladding or dressing, thereby acquiring the space-enclosing function of walls which were originally made of textile materials. Typical features deriving from the textile procedure – such as knots, seams and hems – are preserved here in the form of ornaments, the network of joints and dividing elements. On the basis of Semper's observations and interpretations, Cache presents a systematic table in which each of the four basic materials is linked to the four basic procedures, with a few exceptions.

Fig. 2

The decisive aspect of Cache's argument is the continuation of this table that he then proposes. He considers that the way towards this continuation was opened up by Semper himself. In his principal theoretical work, *Der Stil* (*Style*), Semper introduces metal as the fifth basic material, but does not assign it to any specific technique. Metal can be processed equally with all four of the basic techniques.[3] The supplementation of the system with a technically and historically secondary material that this involves, along with Semper's occasional inclusion of other materials as well in various other passages, is used by Cache to justify supplementing the table with the modern materials of glass and concrete. But he does not leave it at this quantitative extension of the materials included. Following on from Semper's attempt to make the anatomic classification system developed by evolutionary biologist Georges Cuvier fruitful for his theoretical work, Cache also expands the system qualitatively and assigns the four classes of the animal kingdom defined by Cuvier to the four basic procedures: the mollusks to textiles, the radiates to ceramics, the vertebrates to tectonics and the articulates to stereotomy.[4]

Fig. 3

Table 4 Historical and traditional materials (including metal)

Abstract Procedures	Textile	Ceramics	Tectonics	Stereotomy
Fabric	Carpets, rugs, flags, curtains	Animal skin flask, ex. Egyptian situla		Patchwork?
Clay	Mosaic, tiles, brickwork cladding	Vase-shape earthenware, ex: Greek hydria		Brickwork masonry
Wood	Decorative wooden panels	Barrels	Furniture, carpentry	Marquetry
Stone	Marble and other stone cladding	Cupola	Trabeated system	Massive stonework, Goldsmith's
Metal	Hollow metal cladded statuary; Olympian Jupiter reconstituted by Quatremère de Quincy; metal roofing;articulated metal structures; curtain wall	Metal vases or shells	Cast iron columns	Forge, ironworks

_ Figure 2.
Bernard Cache, *Digital Semper*, 2000, Table 4: *Historical and traditional materials*
(C.C. Davidson, ed., *Anymore*, Anymore Conference, Paris, 23-25 June 1999, MIT Press 2000, p. 195).

Cache continues a tendency that is inherent in Semper's theory – towards abstraction from the actual material to the way in which it is represented by ornamental residues – to the final and decision extension of the system, the introduction of information technology:

> ... it would be in the nature of these procedures to look relentlessly for more "immaterials" in order to find a new occasion for their progressive abstraction. Thus, information technologies would not simply be accidentally accounted for by Semper's theory: it would be in their very nature to fit into his system as the best vehicle to push the abstraction of the four technical procedures further.[5]

In accordance with this conception, Cache proposes that "ceramics could deal with revolving solids and operations in radial coordinates" and tectonics with "nonrotational transformations adequately described in Cartesian coordinates"; stereotomy would be connected with "the art of tiling and paving as it results from Boolean

operations". The textile procedure, as a "procedure of going alternatively over and under" could be equated with the procedure of modulation. The basic procedure of sequencing in digital modulation, in the form of mere repetition, alternation or rhythmic repetition, Cache argues, is also implicit in Semper's concept of eurhythmia. Cache emphasizes this (not entirely accurately) as "the key concept of the Prolegomena" of *Style* and also connects it very closely with textiles.[6]

Semper's abstraction

However, when we follow Cache's suggestion of carrying out a "close reading of Semper",[7] the potential genealogy that he proposes emerges much less clearly. Semper's theoretical exploration of "the regularity and order that become apparent in artistic phenomena during the creative process of becoming"[8] cannot be made consistent with Cache's interpretation without frictional losses. Semper's assignment of raw materials to the "four main artistic activities" – "1. textiles, 2. ceramics, 3. tectonics (carpentry), 4. stereotomy (masonry, and so on)" – is based on the specific properties of the materials, which suggest certain processing methods, "inasmuch as they require greater or lesser effort and technical procedures to make the raw material serve a definite purpose". Materials that are "pliable, tough, highly resistant to tearing, of great absolute strength" belong to the field of textiles. In ceramics, raw materials are used that are "soft, malleable (plastic), capable of being hardened". The field of tectonics includes "stick-shaped, elastic" materials that are "principally of relative strength, that is, resistant to forces working vertically along the length". By contrast, the materials in stereotomy are "strong, densely aggregated, resistant to crushing and compression" and "thus of significant reactive strength"; these properties mean that they are "suited to being worked into any required form by removing parts of the mass or by inserting regular pieces in strong systems".[9] This results in a much less clear definition of materials than Cache's tables suggest. Semper is concerned with the properties of materials, and only secondarily with materials that share these properties.

Table 5 Materials of Modern and Contemporary Architecture

Abstract Procedures	Textile	Ceramics	Tectonics	Stereotomy
Metal	Hollow metal cladded statuary; Olympian Jupiter reconstituted by Quatremère de Quincy; metal roofing;articulated metal structures; curtain wall	Metal vases or shells	Cast iron columns	Forge, ironworks
Concrete	Prefabricated concrete screens; light warps; curtain wall	Ruled surfaces, like hyperbolic paraboloid	Slabs on stilts	
Glass	Thermoformed glass; curtain wall	Blown glass	System glued glass [illegible]	Glass bricks
Biology	Mollusks	Radiates, D'AT: Surfaces de Plateau	Vertebrates, D'AT: skeletons and bridge structures	Articulated D'AT: bees' cells
Information	Modulation interlacing (Eurythmy)	Revolving solid, polar coordinates	Translation, Cartesian coordinates	Boolean operation, tiling algorithms

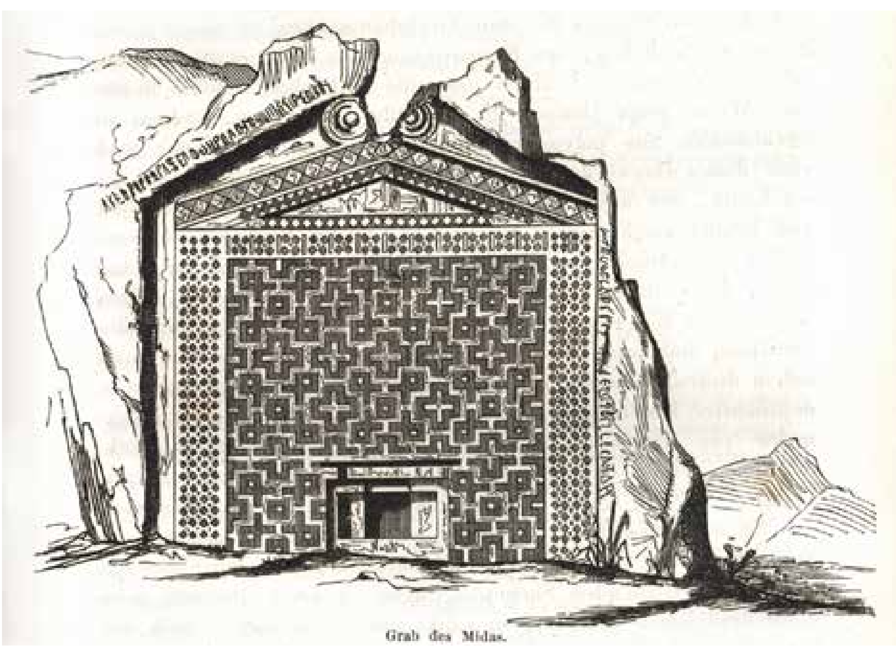
_ Figure 3.
Bernard Cache, *Digital Semper*, 2000, Table 5: *Materials of Modern and Contemporary Architecture*
(C.C. Davidson, ed., *Anymore*, Anymore Conference, Paris, 23-25 June 1999, MIT Press 2000, p. 195).

The four categories of raw materials that Semper defines in relation to their appropriate and originally craft-based processing are intended as a complete description. There is a biographical background for the fact that he devotes an entire section in *Style* to "Metallurgy (Metalwork)": Semper's work on the *Metals Catalogue* which he compiled in 1852 during his exile in London, at the request of Henry Cole. On the other hand – and at a more important level of content – Andreas

Hauser explains this section convincingly by arguing that metal acts as an eye-opener. Due to its absence of material-specific properties, metal is not predestined for any specific processing techniques. Accordingly, as Semper explains in the introduction, it does not represent a separate "formal field" in the way that "the topics of weaving, pottery, carpentry and masonry" do: "The flexibility of this material embraces all branches of technology".[10] However, since metal can be processed with any of the four basic techniques, it is able to clarify these techniques and the quality of the formal results all the better.[11]

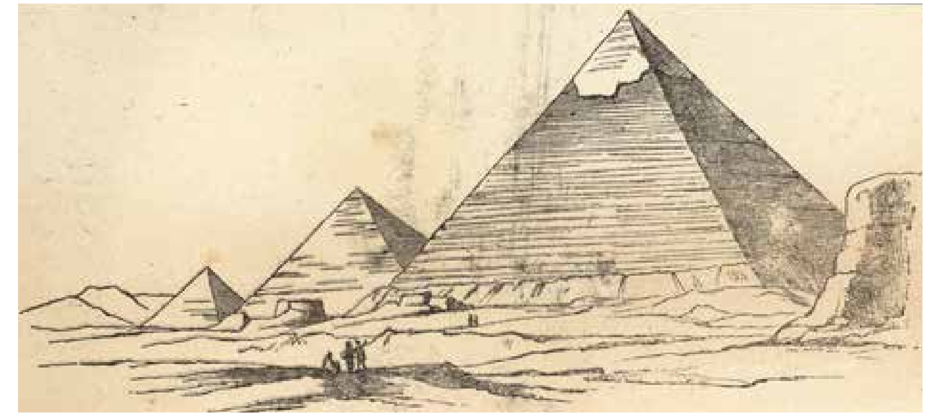
By contrast, mechanized working processes are a different matter, leading to a weakening of the limiting and defining power of the original material qualities that Semper regarded as being essential. Observations of this type that he made at the 1851 Great Exhibition in London gave rise to his well-known critique of "abundance of means" in *Wissenschaft, Industrie und Kunst* (Science, Industry, and Art): "The hardest porphyry and granite are cut like chalk and polished like wax. Ivory is softened and pressed into forms. Rubber and gutta-percha are vulcanized and utilized in a thousand imitations of wood, metal, sandstone carvings, exceeding by far the natural limitations of the material they purport to represent".[12] In Semper's eyes, this does not represent an increase in available options, but primarily a loss of meaning and impact. Nothing could compare with the magical power with which "the granite und porphyry monuments of Egypt exert an incredible sway over our feelings ... because they are the neutral ground where the hard, resisting material engages the soft hand of man with his simple tools ... and they enter into a pact: "So far and no further, in this manner and no other!"".[13]

Semper thus regarded his classification of the properties of materials, and of the associated technical procedures, as being complete. New processing options



_ Figure 4.
"Dressing": *Tomb of Midas*, illustration in Semper's *Style*, vol. 1, 1860, p. 429.

_ Figure 5.
"Dressing": Pyramid with rest of plaster cover, press proof for illustration in Semper's *Style*, c. 1859 (gta Archive, ETH Zurich, Gottfried Semper estate, 20-0163-94B).



were to reflect the essential material qualities and conditions, in terms of both their content and form. Nothing else was valid for the categories of raw materials that he had defined, under which every new material ought in principle to be classified. For Semper, concrete would belong to the field of ceramics, to which he also assigned glass. The fields of biology and information that are introduced by Cache belong to a completely different class of categories. An information-technology procedure such as modulation, which is assigned by Cache to textiles, is a procedure that is applied to numerical "material" (information data) and not a product like a carpet, for example. And the theory-immanent abstraction that he introduces corresponds to a quite specific one in Semper's historical reconstruction: from the wattled wall via tapestry, wall relief and wooden or metal panels to the colourful painting of a Greek temple. During this process, however, the traces of textile modulation also disappear. Eurhythmia fits into Cache's extension of the system to the extent that Semper regarded textile art "as the primeval art, from which all other arts ... borrowed their types and symbols",[14] and in which consequently eurhythmic forms were achieved for the first time. But eurhythmia is also not a product, but rather a formal quality, which can be represented with the help of textile motifs such as the knot or seam.

Figg. 4-5

Architectural form

The above discussion should make it clear that it may well be problematic to appeal to Semper to construct a connecting line that runs all too smoothly from material-based craft work to digital procedures. Despite this, Cache's approach points in a direction that can be pursued further with regard to the degree of abstraction of digitally generated form and the associated problems. The starting-point is provided by the fact – also noted by Cache – that in Semper's theory, the potential for abstraction from the material is already implicit, and even fundamental. Exploiting this potential leads Semper to a very comprehensive interpretation of architectural form. It includes aspects of both form and also space, and anticipates both internal and external movement. It includes both a typology developed out of usage and also an aesthetics that argues on the basis of the material and technical conditions for formal design.

Through its anthropological linkage with the sphere of essential cultural practices and human production, form also acquires a fundamentally ethical dimension.

It is beyond the scope of the present discussion to go into detail on all of these aspects. Semper's far-reaching ideas – developed in his famous comparison of the Greek hydria with the Egyptian situla and elsewhere – on form as defined through specific usage, a form which at the same time encapsulates the entire character of a culture and reflects the nature of a people, cannot be pursued further here.[15] Nor can Semper's concept of successive abstraction from textile clothing to form-descriptive surface, developed in connection with the principle of dressing, be examined in any greater detail.[16] Instead, the aim here is to focus on a text that has a special position in Semper's work to the extent that it marks an intersection between his theory of art forms anchored in the material world and an abstract formal aesthetics: his essay *Ueber die bleiernen Schleudergeschosse der Alten und über zweckmässige Gestaltung der Wurfkörper im Allgemeinen* (On the Leaden Projectiles of the Ancients and the Purpose-driven Formation of Launched Bodies in General).[17] Starting from an explanatory approach to form via the analysis and description of physical laws, Semper moves in the essay towards a formal aesthetics that describes abstract rules, but nevertheless remains linked to the concrete variety of the material world.

The curvature of the Parthenon: ellipse versus hyperbola

According to Semper, what prompted the study was a lecture given by the British architect David Ramsey Hay at the Royal Institute of British Architects in February 1853 that he had attended.[18] Hay argued in the lecture in favour of as simple as possible a system of harmonic proportion, based on simple geometrical forms and arithmetical operations, which for him was the "fundamental element of the beautiful in architecture".[19] Starting from the observation that "a right line has only three directions – the horizontal, the vertical, and the oblique"[20] and that curved forms must be regarded as equivalent to angular basic shapes, he establishes a canon of six basic forms: "perfect square, oblong rectangle, isosceles triangle, circle, ellipse, and composite ellipse".[21] The reductionism of Hay's approach becomes clear not only from its strict two-dimensionality, but also in its limitation to forms that can be constructed geometrically and relationships that can be expressed arithmetically. Thus, the "composite ellipse" that he describes not only "closely resembles the parabolic and hyperbolic curves; but it has what these curves have not, viz. the essential quality of inscribing harmonically one of the rectilinear elements of architecture". By contrast, parabolas and hyperbolas were "merely curves of motion, which never can harmonically inscribe, nor resolve themselves into a figure of any kind".[22]

Geometric simplicity was a fundamental conviction (*Hintergrundüberzeugung*)[23] for Hay. It also determined his critical reaction to investigations by Francis Cranmer Penrose on the entasis of columns and curvature in the Parthenon:

> I cannot help demurring to the conclusions at which Mr. Penrose has arrived with respect to the aesthetic developments of the Parthenon; especially to his idea that the entases of the columns are hyperbolic curves, that the soffit of the corona of the pediment is a curve of the same kind, and that the echinus of the capital is composed of two different hyperbolic curves, and one circular curve. ... this mode of proof must at first sight seem conclusive; but it can only be so in the absence of a knowledge of the composite ellipse and of the various other modes in which ellipses may be combined. For an acquaintance with these will show that arcs of the composite, or mixed ellipse, resemble so closely those of the hyperbola and parabola, that the most careful investigator might be mistaken.[24]

Semper was also familiar with Penrose's work. He touched on it briefly in *The Four Elements of Architecture* in 1851, characterizing the optical correction produced by curvature as "a transposition of painterly effects into the field of architectural effects".[25] Following Hay's lecture he started to approach the topic of proportion in antiquity, including curvature and entasis, in a mathematical way, as Hay had done. However, his evidence points in the opposite direction from Hay's arguments. The principle that Hay had explicitly rejected – the form-generating laws of motion – Semper regarded as being fundamental to design. For Hay, motion was in itself an argument for rejecting parabolas and hyperbolas as "merely curves of motion".[26] By contrast, it was precisely these that Semper made the object of his investigation. His essay is therefore subtitled, *An attempt to demonstrate the dynamic origin of certain forms in nature and in art*.

The "dynamicist" Semper argues against the "staticist" Hay using examples that are sometimes quite strikingly reminiscent of the results of form-manipulating procedures in parametric design. This applies in particular to Semper's example of the Venus de' Medici: if the statue were to be placed in torchlight, according to Semper, the fine silhouette would cast a grotesquely distorted shadow. Again, when specific sectional planes are chosen, a building that is in principle beautiful may appear ugly in the sectional drawing. The graphic depiction (or shadow image) of a sculpture or a building does not represent the object directly, but refers to it "in a mediated fashion". Only those "who have previously recognized its true essence correctly and are practiced in reading from the musical score"[27] are able to infer the underlying beautiful form from the drawing or the shadow image. Semper even goes further: what is "physically beautiful" is "only truly beautiful and proportionate in specific conditions [of the light, location, and possible angle of view], while in others it is – even when the colour and shape are unchanged – indifferent or ugly ... These specific conditions are subject to infinite variations, however, so that generally valid numerical rules of proportion for beauty cannot be given".[28]

Form – or beautiful form, which is what Semper is always concerned with – is dependent on the conditions of perception. An analytical description of beautiful form aiming to define rules for producing it must take this relational aspect into account. In connection with the material indifference of metal relative to various processing techniques in Semper's theory, Andreas Hauser has compared the relational potential of metal with Wilhelm von Humboldt's category of form-describing words. In contrast to object-describing words, these do not refer to anything substantial, but rather to something relational – i.e., grammatical relations. According to Humboldt, purely form-describing words without any objective connotations only occur in more highly developed languages. They make the "'mysterious life force' of human language perceptible" and "correspond to the animal's organs of sensation and movement" – i.e., the organs that distinguish animals (and human beings) from plants.[29]

The relational principle as a fundamental condition for form: Semper's projectiles

Despite the relational character of art forms, the way in which their perception and effect are dependent on external circumstances that are in principle infinite in number, it continued to be Semper's aim to provide rules for the form-generating architect to use. These rules or "formulas" were to be treated exclusively "as equations in which variable and constant values act in combination in the most multifarious ways".[30] One of these attempts is the style formula in the form of a mathematical equation that Semper presented as a model in a lecture at the Department of Science and Art in London in 1853. He explained the proposed mathematical equation by saying that "every work of art is a result, using a Mathematical Term, it is a Function of an indefinite number of quantities or powers, which are the variable coefficients of the embodiment of it".[31] The rules that the architect is to learn and follow include, for example, taking into account the specific properties of the materials in relation to their processing, and the complex requirement for form to be expedient.

Semper made it his life's task to define these rules in the course of wide-ranging research and a critical analysis of historical artefacts. When his concept is examined in relation to the procedures of form-finding and form-shaping, it can be seen that he moves in an intricate balance between these poles: the architect needs to find pre-architectural forms, such as those generated by craft practices. These pre-architectural forms are the results of form-shaping processes, but the processes are determined by laws and properties that lie outside the sphere of human design. The same applies to usage as a form-defining parameter. It is determined by an interplay between an indefinite number of different factors, among which those that Semper discusses in the greatest detail are the handling of an object in a specific situation of activity and the social function of a building, and the interaction between this and political and religious convictions.

In his study of Greek projectiles, Semper now enters a field in which he is able to use dynamics to study a relational principle as a fundamental condition for form. The variability of external factors coincides here with the form-defining variability of the object in space. The underlying physical and mathematical laws, by contrast, are natural laws of gravitation, statics and dynamics that are fixed (or regarded as being fixed). Mathematical procedures from the infinitesimal calculus are available that describe the effect of (minimal) alterations in the input values on functions. The mathematically calculated results are optimized values that approximate "reality". Fig. 1

The mathematical methods thus correspond to Semper's basic assumption that there are infinitely many variables of form, on the one hand, and on the other with his conviction that "certain generally valid general laws operate reliably through this immense variety of possibilities".[32] Semper defines his research field in distinction from Hay's rigid geometric formalism and against the background of Penrose's description of the curvature and entasis of the columns of the Parthenon. The context for Semper's discussion is provided by Greek temple architecture, which he describes as a unique example of "organic" architecture: only the Greeks had succeeded in "giving life to its tectonic shape in an almost organic way. The monuments and appliances of the Hellenes are not constructed, turned, or cast; they have grown".[33] However, it was not possible to approach this phenomenon in scientific terms using the means available. Although mechanics was able to explain the basic principles of movement and gravity, a "power" existed that had "so far escaped the acumen of our dynamicists – the life-force". The "most interesting creations", according to Semper, always arise when the life-force is placed "in conflict with the elementary forces". Accordingly, art forms were all the more perfect the more they conveyed the impression that they were "the results of a similar conflict between elementary forces and life-forces".[34]

On the basis of the effect of curvature and entasis Semper attempts to provide evidence that the Greeks, in the formal design of their buildings, did not merely follow the "inspiration of a vague artistic instinct". Instead, they had "a clear-sighted view of their task".[35] Semper is thus concerned with the rationalization of form-shaping processes. He describes these as being intellectual, although linked with nature. The Greeks' mathematical calculations, he argues, were based on a prior study of nature. But the decisive element is emancipation from nature through a scientific and mathematical explanation of it. Accordingly, Semper formulates the goal of his study as being:

> A desire to demonstrate, using an example that is as simple as possible, that the Greeks did not merely observe the laws of nature and strive to imitate the forms that had arisen from them, but rather had genuinely investigated these laws and derived from them – independently of any sort of imitation of nature – their own forms, which only coincided with nature in sharing its laws: this was what urged me to carry out the following study.[36]

Form-finding, the observation of natural forms, passes into form-shaping calculation.

Fig. 6 Semper applies an analogous procedure to Greek projectiles in his study. Their shape is similar to that of almonds or plum stones, which is why they were called *balanoi* by the Greeks and *glandes* by the Romans.[37] Projectiles, however, were not plum stones or almonds made of lead, but rather objects whose shape had been optimized and mathematically calculated and were made by human beings.

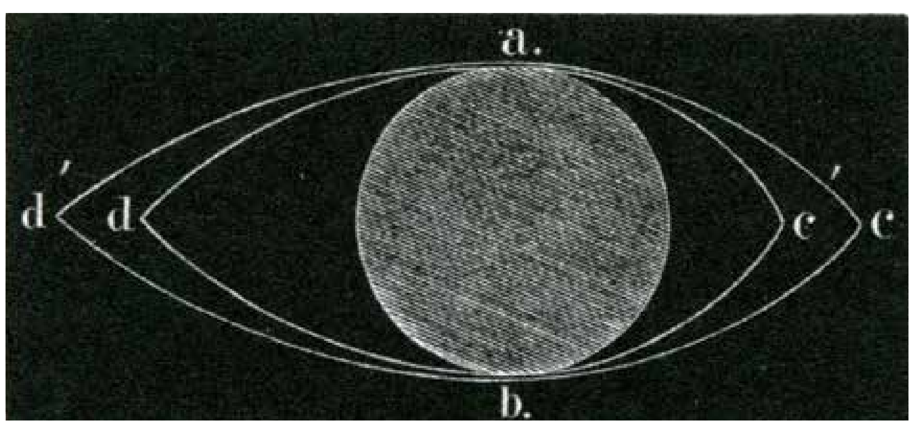
Almond-shaped projectiles represent such a conclusive example in the context of Semper's theory of form because their shape can be described in a certain sense as part action and part reaction. One half of them (the front part during movement) encounters air resistance actively with its sleek shape. The rear part during movement, although it has the same shape, is the result of a reaction: filling the space surrounded by the flow of air. Semper describes this as follows: "During the rapid movement of a system, there is a thinning of the air behind it that can be regarded as a result or function of the speed of the body. In its forms, nature fills out this relative vacuum ...".[38] In its material form, the projectile is thus a response to the course of the forces at work. At the same time, its curved shape corresponds to the curve of its trajectory. In this sense, dynamics – to the laws of which the projectile's shape is a response – offers the best possible substitute for a life-force that cannot be described scientifically.

Agency

For Semper, the inability to penetrate to the "real matter" using rational means continued to be an insuperable challenge during his subsequent theoretical work as well. But he succeeded in making his awareness of this deficiency productive in a way that led, at the level of theoretical reflection, to the greatest possible activation of architectural form. The key passage for this is the final paragraph of the *Prolegomena* in *Style*.

In the context of his reflections on "formal beauty", which begin with his study in Greek projectiles, Semper defined three "axes of formation" that correspond to the three extensions of space and from which the "three spatial characteristic qualities of beauty" emerge: symmetry, proportionality and direction.[39] In the projectile, for example, the symmetrical axis runs along the longitudinal axis; the vertically structuring proportion in the human figure or in trees, by contrast, coincides in the projectile with the axis of directionality. These aspects of formal arrangement and beauty, which Semper mainly presents using decorative objects, form the elements of a higher order that Semper describes as "unity of purpose or unity of content". The highest level of development is reached when the three "axes of formation", as in human beings, do not coincide wholly (as in a crystal) or partly (as in the projectile), but each develops further along their own axes. In architecture, this stage is reached for Semper in the Greek temple: "Yet in the Greek temple, in its most perfect splendor and great freedom, unity and purpose stand out much as it does in humans – in its purest harmony! Athena's crowning pediment embodies, like the visage of its goddess, the dominance of proportion, the quintessence of symmetry, and the reflection of the approaching sacrificial procession".[40] However, since the sculptures in the pediment reflect the sacrificial procession and at the same time represent its goal in terms of content and location, they become agents of its move-

Fig. 7



_ Figure 6.
Gottfried Semper, *Ueber die bleiernen Schleudergeschosse der Alten ...*, 1859, p. 14, schematic drawing of flying projectile with thick air in front of it and thin air behind (ETH-Bibliothek Zürich, Alte und Seltene Drucke).

_ Figure 7.
Gottfried Semper, Reconstruction of the Acropolis of Athens, 1832-1833 (gta Archive, ETH Zurich, Gottfried Semper estate, 20-0215-2).

ment. In their movement, human beings implement a spatial potential that is inherent in form.

What makes Semper's theoretical reflections relevant in connection with the question of the relationship between form-shaping and form-finding is his awareness of the boundaries between nature and art, between existing natural forms and created art forms, as well as the intersection between these two areas that can at least be theoretically postulated: the laws of natural form that can be defined in rational operations, which can be applied to artistic form. By demonstrating these laws mathematically using the example of projectiles, Semper demonstrates at least in principle the possibility of transferring ratio and beauty in existing natural form through a form-shaping, rational process of mathematical calculation into a form produced by human beings. In this way, Semper does achieve one of the potentials that Bernard Cache associates with the tools of digital design: "The most important thing enabled by the digital is not the design of beautiful curved surfaces, but rather the construction of a long chain of relations between the initial hypotheses of a project and its formal result – and this applies as much to an orthogonal architecture in the Hilberseimer mould as it does to 'curvy broken-style' architecture".[41]

(Translation by Michael Robertson).

Abstract

Verso un concetto espanso di forma.
Gottfried Semper sui proiettili antichi

Il contributo prende spunto dal saggio di Bernhard Cache *Digital Semper* del 2000 per elaborare una riflessione sul concetto relazionale di forma, sviluppato da Semper nel suo testo del 1859 *Ueber die bleiernen Schleudergeschosse der Alten und über zweckmässige Gestaltung der Wurfkörper im Allgemeinen*. Viene affrontato criticamente il tentativo da parte di Cache di ampliare il sistema categorie-materiale in Semper e le rispettive tecniche originarie di artigianato verso un processo di tecnologie dell'informazione. Anziché utilizzare questo sistema di Semper come fondamento teorico per le tecnologie dell'informazione progettuale coadiuvata dal computer, viene proposta una correlazione tra la creazione formale sulla base di fattori variabili, analizzati da Semper nel suo lavoro sui proiettili greci, e il processo di disegno digitale.

Notes

_1. B. Cache, *Digital Semper*, in C.C. Davidson (ed.), *Anymore* (*Anymore Conference*, Paris, 23-25 June 1999), MIT Press, Cambridge MA-London 2000, pp. 190-197, p. 191.
_2. Elsewhere, Cache traces the "roots of the digitisation of architecture" back to Vitruvius; B. Cache, *Projectiles*, AA Publications, London 2011, p. 18.
_3. G. Semper, *Style in the Technical and Tectonic Arts, or, Practical Aesthetics*, 2 vols. (1860-1863), trans. H.F. Mallgrave and M. Robinson, Getty Research Institute, Los Angeles 2004, chapter 11: "Metallurgy (Metalwork)", pp. 823-900, p. 824.
_4. In the table concerned, Cache also supplements the biological classes with D'Arcy Thompson's classification of construction principles in nature: *surfaces de plateau* – ceramics; skeletons and bridge structures – tectonics; bees' cells – stereotomy; Cache 2000 (see footnote 1), p. 195. Cf. D'Arcy Wentworth Thompson, *On Growth and Form*, Cambridge University Press, Cambridge 1961.
_5. Cache 2000 (see footnote 1), pp. 195-196.
_6. *Ibidem*, p. 196.
_7. *Ibidem*.
_8. Semper (1860-1863) 2004 (see footnote 3), p. 71.
_9. *Ibidem*, p. 109.
_10. *Ibidem*, p. 824.
_11. A. Hauser, *Der 'Cuvier der Kunstwissenschaft'. Klassifizierungsprobleme in Gottfried Sempers 'Vergleichender Baulehre'*, in Th. Bolt (ed.), *Grenzbereiche der Architektur*, Birkhäuser, Basel-Boston-Berlin 1985, pp. 97-114, pp. 104-105.
_12. G. Semper, *Science, Industry, and Art: Proposals for the Development of a National Taste in Art at the Closing of the London Industrial Exhibition* (1852), in G. Semper, *The Four Elements of Architecture and Other Writings*, trans. H.F. Mallgrave and W. Herrmann, Cambridge University Press, Cambridge 2010, pp. 130-167, p. 134-135.
_13. *Ibidem*, p. 138.
_14. *Ibidem*, p. 113.
_15. Cf. G. Semper, *London lecture of November 11, 1853*, ed. with a commentary by H.F. Mallgrave, "Res. Anthropology and Aesthetics", 1983, n. 6, pp. 5-31, esp. pp. 9-10.
_16. See the famous passage in Semper's *Style* (1860-1863), 2004 (see footnote 3), p. 243: "Among these ancient and traditional formal elements of Hellenic art, none is of such profound importance as the principle of dressing and incrustation. It dominated pre-Hellenic art and by no means lessened or languished as a part of the Greek style but survived in highly spiritualized fashion, serving beauty and form alone, in a sense more structural-symbolic than structural-technical".
_17. G. Semper, *Ueber die bleiernen Schleudergeschosse der Alten und über zweckmässige Gestaltung der Wurfkörper im Allgemeinen. Ein Versuch die dynamische Entstehung gewisser Formen in der Natur und in der Kunst nachzuweisen*, Verlag für Kunst und Wissenschaft, Frankfurt am Main 1859.
_18. Semper does not mention Hay's name, and erroneously dates the lecture to 1854; *ibidem*, p. 1. However, the occasion can be clearly identified on the basis of the content Semper reports. Cf. the published extracts of the lecture in D.R. Hay, *An Attempt to Develop the Principle which Governs the Proportions and Curves of the Parthenon of Athens*, "The Builder", 11, 1853, n. 527, pp. 162-164; with a more detailed report from the ensuing discussion in "RIBA Transactions", 3, 1850-1853 (no continuous page numbering).
_19. Hay 1953 (see footnote 18), p. 162.
_20. *Ibidem*.
_21. *Ibidem*, p. 163.
_22. *Ibidem*.
_23. Cf. W. Detel, *Wissenskulturen und universelle Rationalität*, in J. Fried, M. Stolleis (eds.), *Wissenskulturen. Über die Erzeugung und Weitergabe von Wissen*, Campus, Frankfurt am Main 2009, pp. 181-214.
_24. Hay 1853 (see footnote 18), p. 164. Penrose started to publish the results of his research in 1847; cf. the review of his major work, *An Investigation of the Principles of Athenian Architecture; or the Results of a Recent Survey, Conducted Chiefly with Reference to the Optical Refinements Exhibited in the Construction of the Ancient Buildings in Athens* (Society of Dilettanti, London 1852 [recte: 1851]), "The Edinburgh Review", 95, 1852, n. 194, pp. 395-405, esp. p. 395.
_25. G. Semper, *The Four Elements of Architecture* (1851), in Semper 2010 (see footnote 12), pp. 74-129, p. 80.
_26. Hay 1853 (see footnote 18), p. 163.
_27. Semper 1859 (see footnote 17), p. 2.
_28. *Ibidem*, p. 3.
_29. Hauser 1985 (see footnote 11), p. 104.
_30. Semper 1859 (see footnote 17), p. 3.
_31. Semper (1853) 1983 (see footnote 15), p. 11; cf. U. Poerschke, *Architecture as a Mathematical Function: Reflections on Gottfried Semper*, "Nexus Network Journal", 14, 2012, n. 1, pp. 119-134.
_32. Semper 1859 (see footnote 17), p. 3.
_33. *Ibidem*, p. 4.
_34. *Ibidem*, pp. 4-5.
_35. *Ibidem*, p. 5.
_36. *Ibidem*, p. 6.
_37. *Ibidem*.
_38. *Ibidem*, p. 11.
_39. G. Semper, *On the Formal Principles of Adornment and its Meaning as a Symbol in Art (second section)* (1856), trans. by K. Schoefert, S. Papapetros, "Res. Anthropology and Aesthetics" 2010, n. 57-58, pp. 299-308, p. 303.
_40. Semper (1860-1863) 2004 (see footnote 3), p. 96.
_41. Cache 2011 (see footnote 2), p. 16.

_ Figure 1.
Peter Zumthor, Atelier, Haldenstein, 1986.
The thin, vertical wood strips of the outer skin, behind which the insulation layer is visible, explicitly reveal the non-bearing nature of the outer layer of the building, thus expressing an embodiment of "cladding tectonics"
(foto Hélène Binet).

Roberta Grignolo

Within the Technical Image

An Alternative Reading of Contemporary Swiss-German Architecture

In today's image-based society, the outer surfaces of architecture appear to have become one of the most notable elements of design: it is they that are meant to convey the image of a building and to capture the attention of viewers. During the 1990s, some members of the architectural cultural community – including Hans Kollhoff,[1] Werner Oechslin,[2] Fanelli and Gargiani,[3] and Kenneth Frampton[4] – criticized the gradual computerization and dematerialization of architecture, calling for a return to a material and constructive dimension. Epithelial architecture – i.e., architecture that gives a leading role to its outer skin – is denounced by some critics as being the outcome of a generalized spectacularization of technique that has developed at the expense of other aspects of architectural research, such as space or context. Critical positions of this type have developed mostly in response to the work of Frank O. Gehry, Zaha Hadid, and Coop-Himmelb(l)au, but some scholars are also extending the critique to Swiss-German architects. Kenneth Frampton, for instance, has stated that some Swiss "architects – like Herzog & de Meuron and the partnership of Christian Sumi and Marianne Burkhalter – appear to be increasingly seduced by the hallucinatory surface effects of the mediatic world".[5]

However, can the spectacular images of the works by Frank Gehry, Zaha Hadid, Herzog & de Meuron and Burkhalter Sumi be placed on the same level? What lies behind the generalized use of the technical image of materials and techniques as a vehicle for contemporary architectural form?

By addressing these questions, this paper attempts to explore a broader issue: the nature of technical image, especially that of architectural work, which is generally considered as belonging to the technical world. One of the objectives of this paper is to propose critical tools that can provide a better understanding of the technical dimension of architecture. Other aspects – such as ideological and social issues – are temporarily set aside, to focus first of all on building techniques. This seems to offer one way of understanding whether construction techniques have been used in a technically appropriate way – i.e., in a way that is consistent with their technical features, those linked to production, assemblage, on-site work, etc.

The above questions, therefore, hide a more general one, which could be put as follows: what gives a building its technical image? The paper could thus be defined as an investigation within the sphere of technical image.

From this standpoint, the approach adopted falls into the realm of reception, of the person who observes an architectural work. But to answer such a question, one is forced to shift from the observer's point of view to the object, the building itself, in an attempt to figure out how it conveys its technical image through its "nuts and bolts".[6] The above questions can therefore also be posed as follows: what features of an architectural work refer to its technical dimension? And further questions arise from the latter: is the building truly interesting from a technical standpoint? For what reason? Are they "good" reasons from a technical point of view? Referring to Michael Baxandall's preface to his book *Patterns of Intentions*,[7] the attempt here is to start from the effect – i.e., the result produced by an architectural work on the observer, in order then to discover the cause – i.e., what features of the building induce such effects on the viewer and convey a technical image. The approach adopted is therefore an inferential one. As Baxandall points out, inferential criticism is "precarious",[8] but "it is the impossibility of firm knowledge that gives inferential criticism its edge and point".[9] This kind of criticism aims at "thinking and saying" about particular objects "things apt to sharpen our legitimate satisfactions in them".[10]

Thus the predominance of the technical dimension in this paper does not mean that the only way of reading the architectural works selected is through their technical image. The technical dimension is only one of the several modes of existence of any architectural object. The attempt here is rather to understand what leads both critics and the general public to consider an architectural work as a technical performance.

In architecture, the term technique (or techniques) refers to the strategies, methods and tools that are used to develop a building. The term refers to at least two aspects of architectural creation: construction techniques (covering materials and construction systems with their many production and assembly methods) and tectonics (the exterior and formal expression of construction techniques).

Construction techniques are in fact not always revealed as such in a finished architectural work. Making assemblies visible gives them a key role in architectural expression, so that, conversely, designers may choose to "conceal" them by making the details appear as simple as possible. In deciding what to place in the forefront and what to leave in the background, architects develop their construction rhetoric: they are fully aware of the tectonic dimension, even if they do not call it by that name.

The notion of tectonics appeared in architectural discourse in the mid-nineteenth century, with Karl Bötticher and Gottfried Semper taking the lead. Bötticher was among the first to consider the issue of tectonics in architecture explicitly, theorizing the distinction between *Kernform* and *Kunstform* to distinguish respectively between the nucleus (the form necessary for static purposes) and the artistic form of a constructive element (which relates to the symbolic dimension of architecture). Hence, in his view, the connection between *Kernform* and *Kunstform*, between the nucleus and the artistic form (decorative cladding), is marked by necessity and truth.[11]

_ Figure 2.
Peter Zumthor, Atelier, Haldenstein, 1986.
Detail of the outer skin.

During the following years, Semper developed an alternative proposal, based on the *Stoffwechselthese* or theory of the change of materials (or theory of the transmigration of forms). He claimed that architectural forms derive from those of the technical arts, and that in changing from using one material to another, the formal motifs of the original material are reincorporated into the new material, even though they may not be necessary.[12] In the case of architecture, again according to Semper, there are some forms that are no longer necessary for a building, but they remain as traces of the past and of the evolution of materials and techniques, becoming free compositional elements. This theory also refers directly to the other mainstay of the Semperian theory: the *Prinzip der Bekleidung* or "principle of dressing". According to Semper, freed from any constructive necessity, the forms of architecture become cladding, endowed with a purely aesthetic and symbolic value.[13]

Despite the obvious differences between the theories of these and other authors – one might mention Arthur Schopenhauer[14] or Rudolf Redtenbacher[15] – the lowest common denominator can be found in the meaning of the notion of tectonics: in the nineteenth-century debate, it refers to what can be seen of construction. Thus it concerns the constructive dimension of architecture, but does not fully coincide with the construction itself. Tectonics can be defined as the architectural (or aesthetic) dimension of construction. But how can this notion be of use to us today?

For both Bötticher and Semper, tectonics provides an explanation of whether and how architectural form should talk (or not talk) about construction. Different degrees of legibility exist: the technical and constructive dimension can, to a greater or lesser extent, be the key protagonist of architecture. Returning to use the term tectonics today in analysing contemporary architecture allows us to understand the role that architects attribute to construction techniques in the design process, as well as the use they make of them.

Max Bill's Expo '64 Pavilion in Lausanne (1960-1964) features a flattening of tectonics on construction: here, the technical image is the direct expression of the construction techniques that have been used, and they, in turn, depend on the ma-

_ Figure 3.
Herzog & de Meuron, Ricola Warehouse, Laufen, 1986-1987.

terials, the production techniques, the assembly techniques and structural considerations. One could almost speak, with Roland Barthes, of the Degree Zero of architectural writing.[16]

Conversely, in the Neue Nationalgalerie in Berlin (1962-1968), Mies van der Rohe chose to give prominence to the simplicity of form and the underlying structural principle, which can be described as "tectonics of forces". Thus, Mies's design makes it possible, even for a non-expert, to understand the downward loads, but at the same time it downplays the tour de force of the construction process, which is really much more complex than the simplicity of the overall form leads one to imagine.

Finally, in the Beaubourg (1971-1977), Piano and Rogers explore the breadth of the tectonic dimension by articulating several declensions of it: "tectonics of assembly" through the exposed structure and its subdivision into the greatest number of elements; "tectonics of the building process" through the visible traces of the construction process; and "tectonics of systems" purposely revealing the building's systems. Now, coming back to the initial question concerning the "epithelial architecture" of the 1990s, can it all be read in the same way, as a spectacularization of technique?

In the Guggenheim Museum in Bilbao (1992-1997), Frank O. Gehry does not mean to give the titanium sheet cladding legibility as such: he sees the building first and foremost as a plastic work of art. The titanium cladding wraps the construction up with an approach similar to the one used by the artist Christo. Building-site photographs show a sort of rollercoaster structure, which is then clad with a thin titanium skin, a flat epidermis, which hides every trace of construction.

Despite apparent similarities, the treatment of external surfaces in contemporary Swiss-German architecture – by this I mean the architecture produced in the German-speaking parts of Switzerland – would appear to have different bases. As Irina Davidovici has highlighted in her recent book,[17] Swiss architectural culture has its roots in craftsmanship: architects are professional figures who have retained strong ties to the tradition of master-builders, with a special interest in materials, their properties, and the ways they are assembled. Before anything else, Swiss-German architecture is the art of building correctly.

However, in my opinion, there is more to it. Owing to Switzerland's adoption of national energy-efficiency standards well before other countries, Swiss-German architects had already become acquainted with energy-saving construction techniques as early as the 1970s.[18] Experiments on the approaches to envelope insulation increasingly proved that insulating buildings from the inside does not obtain satisfactory energy-efficiency results, whereas external insulation, on the outer side of the load-bearing structure, produces a drastic reduction of energy losses.[19] This combination of factors seems to have helped make Swiss-German architects aware, very early on, of the need to have stratified modern envelopes, calling for the "hard" load-bearing structure to be placed behind a "soft" stratified insulation package, comprising weather-proofing as well as thermal and acoustic insulation.

Gehry may have chosen to hide the structure completely behind such a package and only consider the outer surface layer of the envelope, but in the 1990s Swiss-German architects, who based their design work on construction, did not accept this approach. For them, if all that is visible of a building is its outer layer (because its structure is hidden for energy-efficiency reasons), it is precisely on the cladding that they will focus their design research and their technical and building experimentation.

Figg. 1, 2

Let us consider a few examples, which should help clarify their approach. In the case of Peter Zumthor and his Haldenstein studio (1986), a wooden load-bearing structure was used with wood cladding elements both inside and outside, between which a thick layer of insulation was placed. The outer skin thus consists of thin vertical wood strips that are clearly to be understood as purely cladding elements. Furthermore, to place even greater emphasis on the non-structural function of the envelope, the insulation layer is visible behind the open jointed wood strips. By flagrantly revealing the non-bearing nature of the outer layer of the building, the architect seems to be expressing a form of "cladding tectonics" [20]: he provides the observer with the

_ Figure 4.
Herzog & de Meuron, Ricola Warehouse, Laufen, 1986-1987.
All the elements which make up the building's stratified skin are purposely made visible in their articulation: uprights, stringers, wood brackets, fibre-cement panels, yellow thermal insulation sheets, even screws and nails. The way in which the elements have been positioned makes it clear that the envelope has a mere cladding function. Its articulation becomes legible to the point of having a didactic effect: it actually informs viewers of how an outer skin is built.

necessary clues to grasp that the outer layer is mere cladding, independent of the load-bearing structure.

By trying to problematize the necessary independence between the structure and the stratified envelope, Swiss-German architects soon became aware of the formal possibilities of stratifying the technically necessary envelope.[21] Furthermore, their mastery of the art of building enabled them to realize that cladding can provide a great deal of architectural freedom, opening up unexplored experimental possibilities.

Figg. 3-4

The envelope of Herzog & de Meuron's Ricola warehouse in Laufen (1986-1987) has a stratified skin, consisting of an articulated set of visible assembled elements. The basic frame comprises wood uprights and stringers, to which horizontal wood brackets are secured, supporting the grey fibre-cement panels that form the outer layer of the envelope. The panels are inclined slightly outwards to allow water run-off and to ventilate the envelope, but this calculated inclination also allows the observer to read all the constitutive elements of the facade: the outer fibre-cement panel cladding, the yellow thermal insulation under the panels, the shelves, the uprights and stringers, even the screws and nails that secure the elements together. The way in which the layers have been positioned makes it clear that they are cladding: as far as architectural expression is concerned, one has the impression of a return to architectural truth. In this case, architecture is a direct representation of how the exterior envelope is assembled and of its non-load-bearing nature. In this case too, the term "cladding tectonics" can be used to describe the building's technical image. The cladding articulation becomes legible to the point of having didactic consequences: it actually informs viewers of how an outer skin is built.[22]

Furthermore, the stratification is also used for its formal possibilities: the inner layers of a wall, especially the insulation, are not considered as merely functional elements

_ Figure 5.
Herzog & De Meuron,
Pfaffenholz Sports Centre,
St. Louis, 1989-1993.

_ Figura 6.
Herzog & De Meuron,
Pfaffenholz Sports Centre,
St. Louis, 1989-1993.
The outer glass sheets of the envelope, with their silkscreen texture, imply transparency and appear to reveal what lies beyond, but they actually only allow the constitutive layers of the cladding to be seen, i.e. the compressed chipboard Eraclit panels, installed below. Here too the cladding purpose of the outer skin becomes explicit, despite the difficulty for viewers to fully perceive its depth.

that should remain hidden. Rather, they become one of the elements of architectural expression, in a process similar to the research developed by Arte Povera in the art world around the same time. The influence of Joseph Beuys on Herzog & de Meuron and Peter Zumthor's discovery of the basic meanings of materials is well known.

Following this initial stage, at the end of the 1980s, during which the decomposition of the envelope into its constitutive layers provided greater legibility of its articulation into elements, Swiss-German architects took on the stratification of the modern envelope as a design theme. They systematically explored all its formal declensions, equally experimenting with the effects, in some cases perceptive effects, that they could obtain from the depth of the outer skin.

Figg. 5-6

In the Pfaffenholz sports centre in St. Louis near Basel, designed by Herzog & de Meuron (1989-1993), the outer wall cross-refers to the actual texture of the insulation – formed by compressed chipboard Eraclit panels, installed below – and to the silkscreen texture printed on the outer sheets of glass, which in turn refers back to the chipboard panels. The glass sheets are a reference to transparency and pretend to reveal what lies beyond, but they actually only allow the constitutive layers of the cladding to be seen. This gives depth to the epidermis and allows for the cladding nature of the outer skin to become explicit, even if it remains difficult for the viewer to measure it.

Figg. 7-8

Similarly, Annette Gigon and Mike Guyer play with the depth of their stratified envelope in the Kirchner Museum in Davos (1989-1992). The outer facade of the exhibition halls consists, from the inside towards the outside, of a reinforced concrete load-bearing wall, a whitish fibre-glass thermal insulation layer, an air gap, and finally translucent sheets of glass supported by a slender metal frame that forms rectangular fields on the outer surface. Seen from the outside, the envelope remains enigmatic: the glass provides visibility of the underlying insulation, but its distance

_ Figure 7.
Gigon & Guyer, Kirchner Museum, Davos, 1989-1992.
On the outside the envelope remains indecipherable: the translucent surface of the glass creates a sense of indefinite depth; however the glass sheets provide visibility of the underlying whitish fibre-glass insulation, thus making the stratification evident.

from the glass panel and its translucent effect create a sense of indefinite depth while also making the stratification evident.

This brief overview seeks to provide an understanding of how the "epithelial nature" of contemporary Swiss-German architecture, which some critics interpret as an advance of spectacularization, is actually closely linked to technical, constructive and energy-efficiency issues. Martin Steinmann has confirmed this in commenting on the legibility of the constructive features of the architecture of German-speaking Switzerland. He describes it as architecture *parlante*: "architecture that speaks, in that it speaks of itself – of its technical essence".[23]

While "informal" architecture rejects ties between form and materiality, as if becoming aware of its constructive nature might endanger its "artistic" principles, recent architecture from German-speaking Switzerland does not imply a programmatic negation of its material and constructive nature. It could be described as "epithelial architecture" if one considers the relevance attributed to the envelope. However, it does reintegrate a tectonic dimension. While the legitimation of contemporary "informal" architecture is obtained by referring to sources that lie outside the discipline – such as literary theory, philosophical doctrines, computer algorithms and graphic or sculptural expressions – contemporary architects from German-speaking Switzerland are developing their architectural design work by focusing their research on materials and on building techniques, in other words on endogenous factors from within their discipline.

This becomes evident if one happens to look at the last pages of the publication documenting Burkhalter Sumi's first exhibition of their architectural works. The cross-sections of every work presented in the book allow one to compare the ener-

Figg. 9-11

_ Figure 8.
Gigon & Guyer, Kirchner Museum, Davos, 1989-1992.

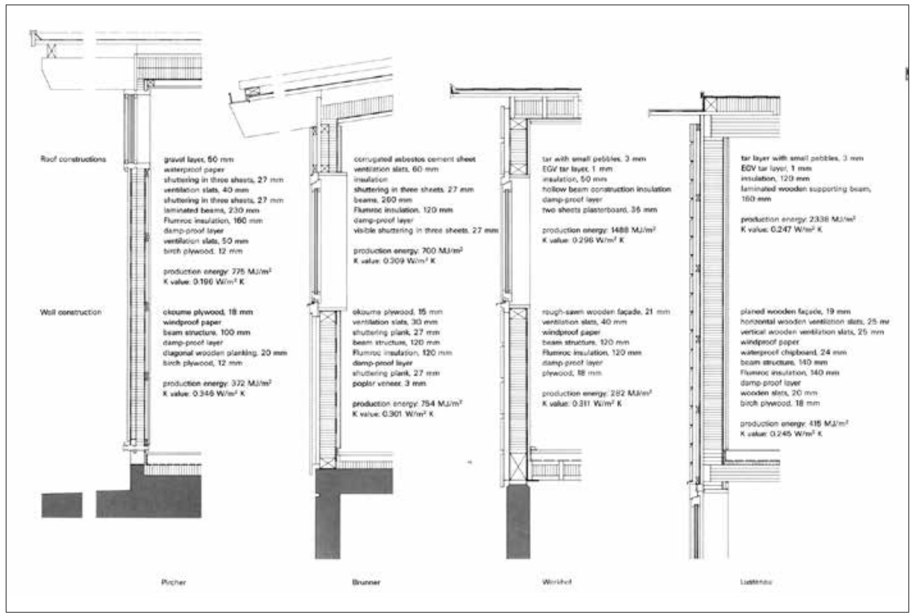
gy efficiency of each building envelope. Furthermore, in their chronological left-to-right arrangement, the sections allow one to grasp how the office's architectural research has gradually evolved towards thicker and more complex insulation solutions.[24]

By taking envelope stratification as the theme of their design work, Swiss-German architects are transforming a technical problem into a design asset, thus proving their extremely realistic approach. Such an approach is driving Swiss architects to take on the real problems of society not just from within the architectural community, but also by engaging with the market. Swiss building companies have had a fundamental role in diffusing new technical solutions that stem from and evolve through collaboration between engineers and architects – e.g., exterior insulation and finishing systems, cladding, etc. – and are then disseminated to the whole professional community, an example of a virtuous circle not to be found in many other countries.

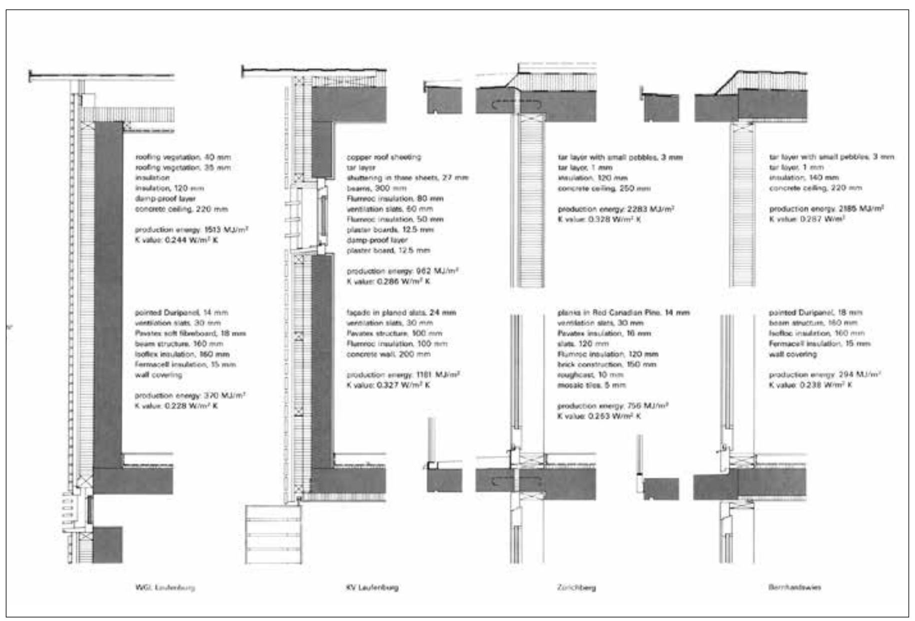
The aesthetics of Swiss-German architecture of the 1990s rests, therefore, on a total acceptance of the tools that are most typical of architecture: construction techniques. It appears to be a return to a design process that is intrinsic to architecture. If most of today's real technical innovations, for example numerical control machines, are of little interest from a formal standpoint and would seem to belong to the order of the invisible, then Swiss-German architects seem to have found a new lease of life in cladding and in its endless formal declensions. The realistic attitude of contemporary Swiss-German architects seems to rest on an ideological, moral and civil driving force that prompts them to face the real problems of society, such as the sustainability of architecture.

In conclusion, it seems important to highlight, yet again, the fact that the goal in the above analysis is not to define a "correct" way of using contemporary technical solutions. As underlined in the introduction, inferential criticism adopts a conjectural approach and does not aim at producing certain knowledge. The intention underlying this paper is to reposition the architectural works analysed in a broader and more articulated discourse on technique and to develop new (and still tentative) critical tools. The paper has used the two dimensions of the technical image illustrated above – construction techniques and tectonics – proposing them as investigation tools to help dispel some of the commonplaces used by critics as well as some of the more or less conscious mystifications by architects.

To borrow Baxandall's words, the ultimate goal of such an attempt is to guide the viewer towards gaining a "sharper sense"[25] when reading architectural works, helping him or her to set aside some of the ballast of the critical apparatus, while reasserting authoritativeness to the experience of architecture, which can only be gained from a thorough, direct examination of built objects.

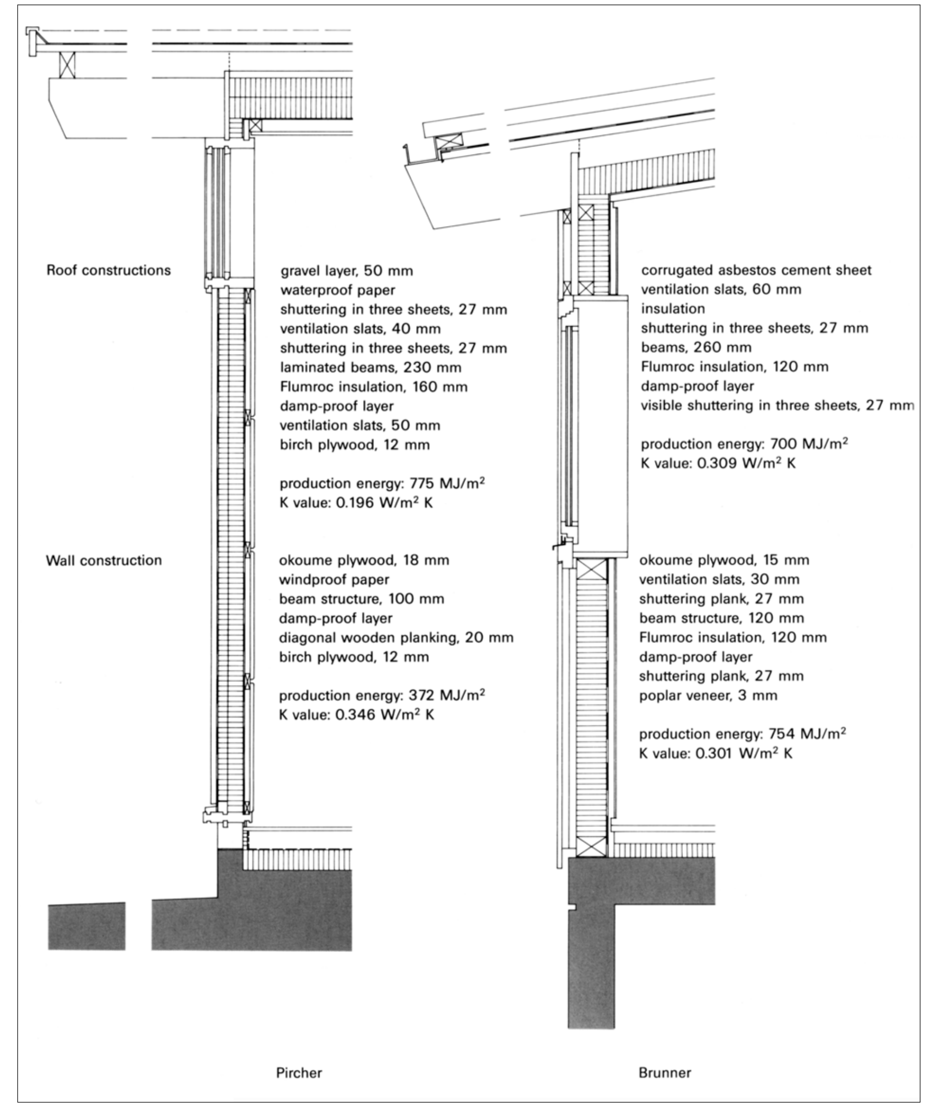


_ Figure 9.
Cross sections of Burkhalter Sumi's architectural projects, published at the back of their book *Die Holzbauten* (Zürich 1996). The series of drawings enable a comparison of the energy efficiency of each building envelope (© Burkhalter Sumi).



_ Figure 10.
Burkhalter Sumi, Cross section of their architectural projects enabling a comparison of the energy efficiency of each building envelope (© Burkhalter Sumi). In their chronological left to right arrangement, the sections allow the reader to grasp how the office's architectural research has gradually evolved towards thicker and more complex insulation solutions, responding to increasingly demanding energy efficiency regulations.

_ Figure 11.
Enlarged cross sections of Burkhalter Sumi's architectural works (© Burkhalter Sumi).



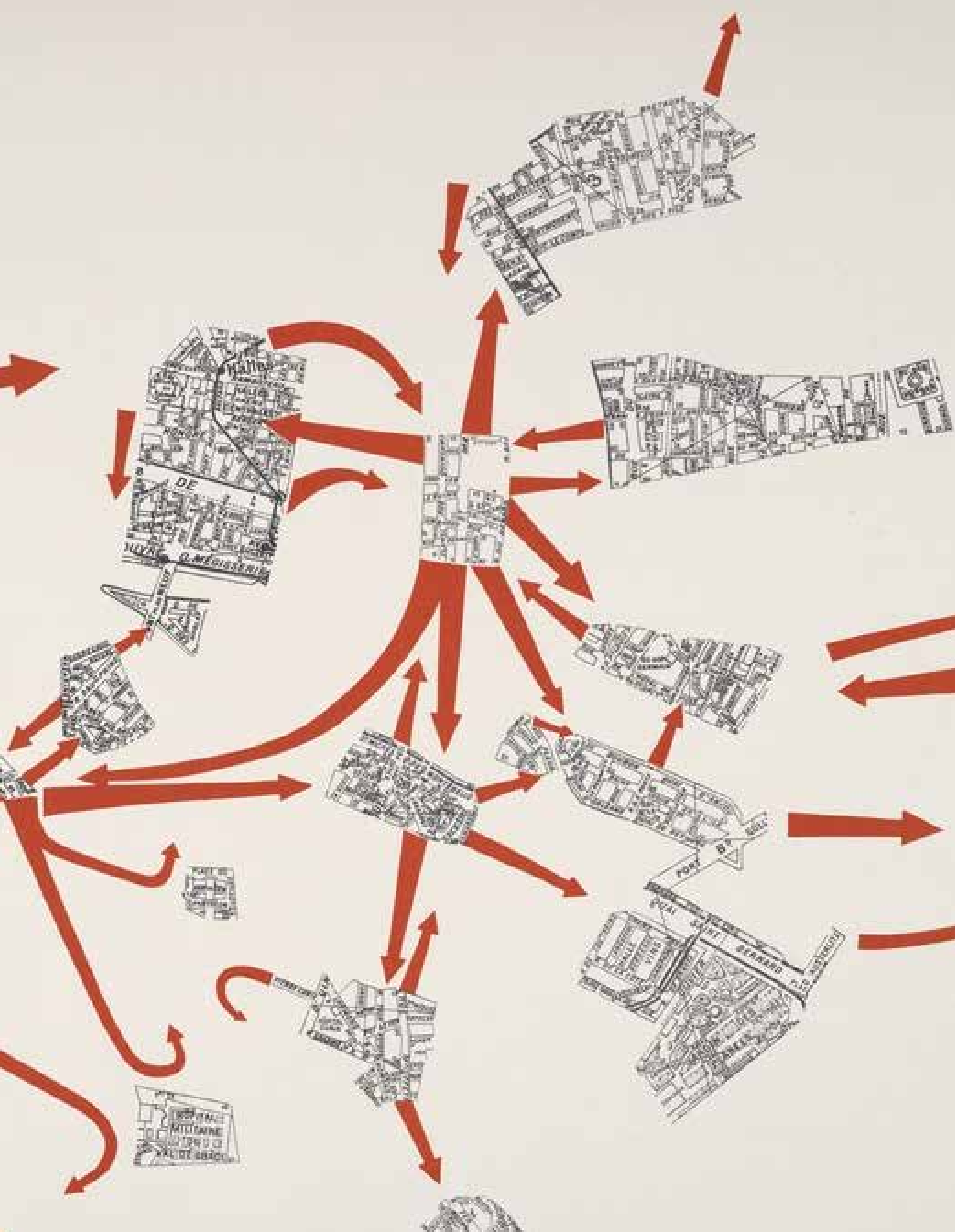
Abstract

Dentro l'immagine tecnica.
Per una lettura alternativa dell'architettura svizzero-tedesca contemporanea

Nel corso degli anni Novanta del XX secolo, l'involucro esterno è diventato un elemento cruciale dell'architettura costruita. Ma tutte le "architetture epiteliali" possono essere lette secondo le medesime chiavi di lettura? Il testo indaga cosa si cela dietro o, ancora meglio, dentro agli spettacolari involucri dell'architettura recente e alle loro forme apparentemente arbitrarie. Lo fa attraverso diversi casi studio, tra cui numerose architetture recenti della Svizzera tedesca, mettendo in luce come non tutti i casi possano essere letti come esito di un processo arbitrario.
L'architettura svizzera poggia su di una tradizione costruttiva consolidata: l'architettura consiste prima di tutto nel costruire correttamente. A questo si aggiunge il fatto che gli architetti svizzeri contemporanei hanno sviluppato una precoce consapevolezza delle questioni relative alla sostenibilità: già dagli anni Settanta, prima della maggior parte delle nazioni europee, i regolamenti federali pongono un'attenzione crescente alla sostenibilità del parco costruito e promuovono la sperimentazione in questo campo. Così contestualizzato, l'approccio degli architetti svizzeri pare dunque eminentemente realistico: l'ineluttabile stratificazione dell'involucro moderno, che decreta di fatto la sparizione della struttura dall'immagine dell'edificio, viene assunto dagli architetti svizzero-tedeschi non solo per le sue performances tecniche, ma anche per il suo potenziale formale e progettuale. Il progetto dell'involucro esterno diventa così per loro occasione per mettere in evidenza gli elementi costruttivi e i loro assemblaggi, aprendo la via a quella che può essere definita una "tettonica del rivestimento".

Notes

_ 1. In 1991 Kollhoff organized a symposium in Basel on *Tektonik. Bau-Kunst Heute?* The proceedings were published in the volume H. Kollhoff (ed.), *Über Tektonik in der Baukunst*, Vieweg, Braunschweig-Wiesbaden 1993.
_ 2. W. Oechslin, *Stilhülse und Kern. Otto Wagner, Adolf Loos und der evolutionäre Weg zur modernen Architektur*, Ernst & Sohn, Zürich 1994.
_ 3. G. Fanelli, R. Gargiani, *Il principio del rivestimento. Prolegomena a una storia dell'architettura contemporanea*, Editori Laterza, Roma-Bari 1994.
_ 4. K. Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*, MIT Press, Cambridge (MA) 1996.
_ 5. K. Frampton, *Minimal Moralia: Reflections on Recent Swiss German Production, "Scroope: The Cambridge Architectural Journal"*, 1997, n. 9, pp. 19-24; also in K. Frampton, *Labour, Work and Architecture, Collected Essays on Architecture and Design*, Phaidon, London-New York 2002, pp. 325-331, p. 328.
_ 6. R. Carvais et al. (eds.), *Nuts and Bolts of Construction History: Culture, Technology and Society*, proceedings of the *4th International Congress on Construction History* (Paris, 3-7 July 2012), Picard, Paris 2012.
_ 7. M. Baxandall, *Patterns of Intention. On the Historical Explanation of Pictures*, Yale University Press, New Haven 1985.
_ 8. *Ibidem*, p. 135.
_ 9. *Ibidem*, p. vii.
_ 10. *Ibidem*, pp. vii-viii.
_ 11. K. Bötticher, *Die Tektonik der Hellenen*, Verlag von Ferdinand Riegel, Potsdam 1844.
_ 12. G. Semper, *Der Stil in den technischen und tektonischen Künsten, oder Praktische Ästhetik. Ein Handbuch für Techniker, Künstler und Kunstfreunde*, vol. 1: *Die Textile Kunst, für sich betrachtet und in Beziehung zur Baukunst*, Verlag für Kunst und Wissenschaft, Frankfurt am Main 1860; vol. 2: *Keramik, Tektonik, Stereotomie, Metallotechnik für sich betrachtet und in Beziehung zur Baukunst*, Friedrich Bruckmann, Munich 1863.
_ 13. G. Semper, *Die vier Elemente der Baukunst*, Vieweg, Braunschweig 1851.
_ 14. A. Schopenhauer, *Die Welt als Wille und Vorstellung*, Brockhaus, Leipzig 1819.
_ 15. R. Redtenbacher, *Die Architektonik der modernen Baukunst. Ein Handbuch bei der Bearbeitung architektonischer Aufgaben*, Ernst & Korn, Berlin 1883.
_ 16. R. Barthes, *Le degré zéro de l'écriture*, Seuil, Paris 1953 (english translation, *Writing Degree Zero*, Hill and Wang, New York 1968).
_ 17. I. Davidovici, *Forms of Practice. German-Swiss Architecture 1980-2000*, gta Verlag, Zurich 2012.
_ 18. Already in 1970, before the oil crisis, the Federal Commission for Housing had defined guidelines for building insulation; see *Commission fédérale de recherche pour la construction de logements* (CRL), *Isolation thermique des bâtiments, Recommandation SIA n.180, Société suisse des ingénieurs et architectes* (SIA), 1970. In 1985 such guidelines were updated by the SIA 380/1 Standard (see SIA, *L'énergie dans le bâtiment, Recommandation SIA n. 380/1*, SIA, Zurich 1985), which shifts its focus from the performance of single building elements to an evaluation of the overall energy balance. This gives the architect a greater freedom in design if compared to the minimum values set by the 1970 guidelines.
_ 19. M. Ragonesi, *L'énergie dans le bâtiment: technique de la construction*, "Schweizer Baudokumentation / Documentation Suisse du Bâtiment", August 1999-September 2000, *Introduction* (August 1999); *Chapitre 1 – Le bilan énergétique dans la construction* (August 1999); *Chapitre 2 – Energie et écologie* (August 1999); *Chapitre 3 – Isolation thermique et confort / risque de dommages* (January 2000); *Chapitre 4 – Assainissement thermotechnique et énergétique de bâtiments* (January 2000); *Exemples tirés de la pratique* (January 2000).
_ 20. This concept was developed by Bruno Reichlin in several conferences, lectures and texts. Here I refer particularly to the essay: B. Reichlin, *Conjectures à propos des colonnes réfléchissantes de Mies van der Rohe*, in R. Gargiani (ed.), *La colonne: nouvelle histoire de la construction*, Presses polytechniques et universitaires romandes, Lausanne 2008, pp. 455-466, p. 463.
_ 21. Michael Alder's Hagmann House in Itingen (1983-1984) and Herzog & de Meuron's House in Bottmingen (1984-1985) can also be ascribed to this same experimental period.
_ 22. B. Reichlin, *Objectlike: The Ricola Storage Building*, in "Assemblage", 1989, n. 9, pp. 108-113, p. 110.
_ 23. M. Steinmann, *Neuere Architektur in der Deutschen Schweiz*, in P. Disch, *Architektur in der deutschen Schweiz 1980-1990*, Lugano 1991; French translation: *Architecture récente en Suisse alémanique*, in M. Steinmann, *Forme forte. Ecrits/Schriften 1972-2002*, J. Lucan, B. Marchand (eds.), Birkäuser, Basel-Boston-Berlin 2003, pp. 93-109, p. 108.
_ 24. M. Burkhalter, C. Sumi, *Die Holzbauten*, gta Verlag, ETH, Zürich 1996, pp. 114-115. Another double page at the back of the catalogue analyses the production energy in terms of materials. The interest of Burkhalter Sumi for the architectural expression of construction techniques is still ongoing. Cf. the research project "DETAILS. Architecture seen in section" by Marco Pogacnik, Research Unit "Arte del costruire – Art of Building", Università Iuav di Venezia, 2014 (http://www.detailsinsection.org).
_ 25. Baxandall 1985 (see footnote 7), p. 136.



Lara Schrijver

Rem Koolhaas and Oswald Mathias Ungers

A Plausible Relationship Between the Formal and the Social?

_ Figure 1.
Detail from Guy Debord, *The Naked City*, "Illustration de l'hypothèse des plaques tournantes en psychogéographique" (Map, 1957, reprinted in S. Sadler, *The Situationist City*, Cambridge MA 1998, p. 83).

In 1999, Rem Koolhaas noted that the core activity of his OMA office was to "reinvent a plausible relationship between the formal and the social".[1] In the light of the twentieth-century history of radical programmes and manifestos in architecture, as well as their strong connection with social reform, this aim seems strikingly humble. Modern architecture was intended to revolutionize everyday life. From high modernism to the grassroots activism of the 1960s, the formal expression of architecture projects embodied a social programme. In this sense, a merely "plausible" relation between the social and the formal seems to deny the very history of twentieth-century architecture. Yet, this paper suggests that the significance of this position is yet to be apprehended. In essence, it draws on an intuitively felt connection between the virtues of beauty and the good; a hope that, perhaps, the values we hold will shine brightly through our aesthetic conventions. It builds on the classical perception of a natural relationship between formal or aesthetic expression and inherent perceptual content. Yet the modern position is also founded on dismissing traditional formal language, and, in doing so, reinventing cultural habits. The intimate relation between rhetoric, form and meaning is dissembled in order to reconstruct a new social habit. Yet oddly, this dissembling is founded on the possibility of envisioning an essential form that expresses an essential meaning.[2]

Berlin Stories

A recent film by the two Polish directors Bartek Konopka and Piotr Rosolowski, *Rabbit à la Berlin*, offered a fantastic rethink of the architecture of the Berlin wall. Representing the history of the wall from the point of the view of the rabbits enclosed within, it included a voice-over that narrates the perspective of the founding fathers of the "Mauerhase" (the "wall rabbits"), and their pride in their commune that is situated safely within the no-man's-land between West and East Berlin. The film was nominated for an Oscar in the documentary category, but it is a more sophisticated blend of fact and fiction. Based on real events, it puts a gentle spin on perception, thus calling attention to the boundaries between reality as documented, and other possible perspectives.

What the film so elegantly shows is not only the unbelievable impact of the built environment, but also its multiple interpretations, depending on individual perspective. As such, it shows how fluid the ideological content of the built environment is, purely by offering a thought experiment: the alternative perspective of a rabbit. In this, it recalls the technique of Orwell's *Animal Farm*, which offers a critical yet humorous perspective on communism. The film also takes the weight and the horror of a wall separating a city, separating its occupants – dividing families right down the middle and intervening in its inhabitants' lives in a previously unthinkable manner – and gently, provocatively, unabashedly, presents this wall, with its grass and its minefields, as an earthly paradise for the rabbit population, now protected from their natural enemies and offered shelter in the shade of anti-tank crosses. Fig. 1

It is this film that I would like to take as a departure point in order to trace a line of thought within the work of Oswald Mathias Ungers that I believe seeks out this space for unconstrained thought, for a cultural playing-field in which the form of a building might be considered outside of its political agency, or as an agent that is beyond ideological content. In other words, in response to a world increasingly marked by the political ramifications of its spaces, Ungers turns to the very notion of gestalt as something that is beyond political action, that exceeds it, and therefore negates the political dimension of form. The built environment embodies a complicated network of constraints and affordances that mark out an equally complicated relation between the social and the formal.

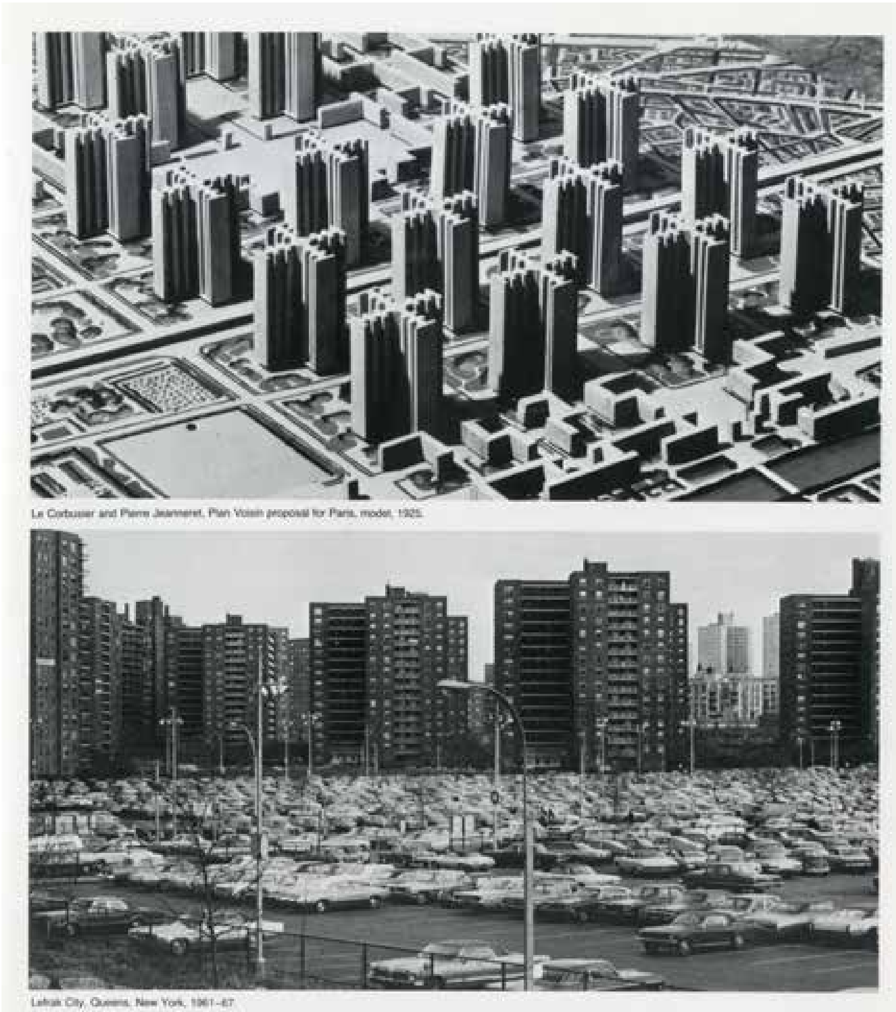
_ Figure 2.
Still from *Rabbit à la Berlin*, directors Konopka and Rosolowski, 2009.

_ Figure 3.
Rem Koolhaas, illustration in *Field Trip: A(A) Memoir*, 1972 (*S,M,L,XL*, New York 1995, p. 223).

This argument begins with stories of Berlin. The retrospective gaze of the camera in *Rabbit à la Berlin* positions the audience in the rabbit's-eye view, and in so doing, shows an alternate reality that recreates the stifling gesture of a walled-in city. Yet it asks us to appraise it with the kind of humor that acknowledges the absurdity of human actions. Berlin is the city in which Ungers was first appointed professor in 1963, where he took the artificial conditions of a city with a given circumference, delimited by a wall, as a laboratory for architectural analysis and intervention. His studios explored the city, analysing the particular conditions of its enclosed reality, and provided design propositions founded on these analyses. They took the city as an artificial ground, continually reconfiguring its (potential) identity, while, in the meantime, exploring the possible relations between morphological layers of the city and their cultural or architectural significance. The studio results were regularly published within the series *Veröffentlichungen zur Architektur*. The particular themes in the studios were then published as theme issues such as "highways and buildings", "streets and squares", or "living along the park".[3]

Berlin was also the city in which Koolhaas found himself speculating on what he saw as a bizarre disjunction between form and meaning, contrary to everything he had learned at architecture school. In his retrospective essay *Field Trip: A(A) Memoir*, he recalls that upon confronting the physical presence of the Berlin Wall, the optimism at the Architectural Association about the potential impact of architecture "seemed

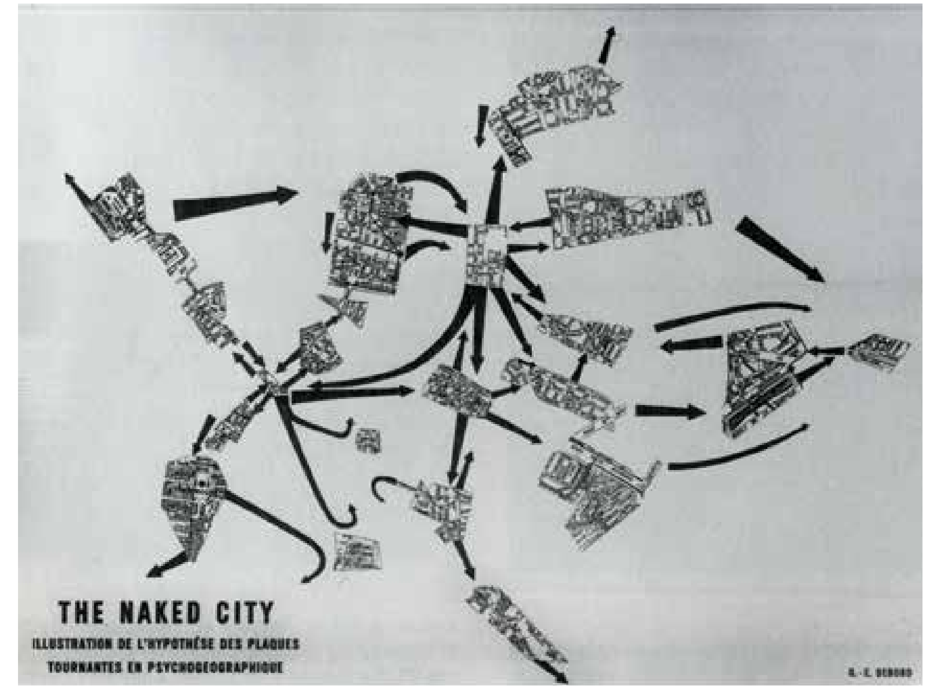
_ Figure 4.
Cage or chalkboard? Everyday life along the Berlin wall, photograph by Rem Koolhaas in *Field Trip: A(A) Memoir*, 1972 (*S,M,L,XL*, New York 1995, p. 229).



_ Figure 5.
(Above) Le Corbusier, Plan Voisin, 1925; (below) Lefrak City, Queens, 1967
(J. Wines, *De-Architecture*, New York 1987, p. 39)
© FLC / 2015, ProLitteris, Zurich.

feeble rhetorical play. It evaporated on the spot". Instead, he experienced the powerlessness of architecture. More importantly, there was a tension between the appearance of the wall and the message it was communicating, which was why he "would never again believe in form as a vessel for meaning".[4] Yet taking a closer look at the many different guises of the wall along its 155-kilometre circumference, he also notes the "bizarre, spontaneous meaning and credibility that emanate from this place. ... On my walks through Berlin I encountered on the one hand a deeply striking ambiance. ... And on the other I discovered many little objects along these neglected *terrains vagues*, these unbelievable spaces of freedom, which stood in their places with a great self-evidence".[5] For Koolhaas, it thus became possible to observe the formal articulation of the wall, and the compositional qualities of the objects that constructed it, as distinct from the ideological implications.

_ Figure 6.
Guy Debord, *The Naked City*, "Illustration de l'hypothèse des plaques tournantes en psychogéographique", Map, 1957 (S. Sadler, *The Situationist City*, New York 1998, p. 60).



Postwar Architecture: Reconstructing the Fait Social

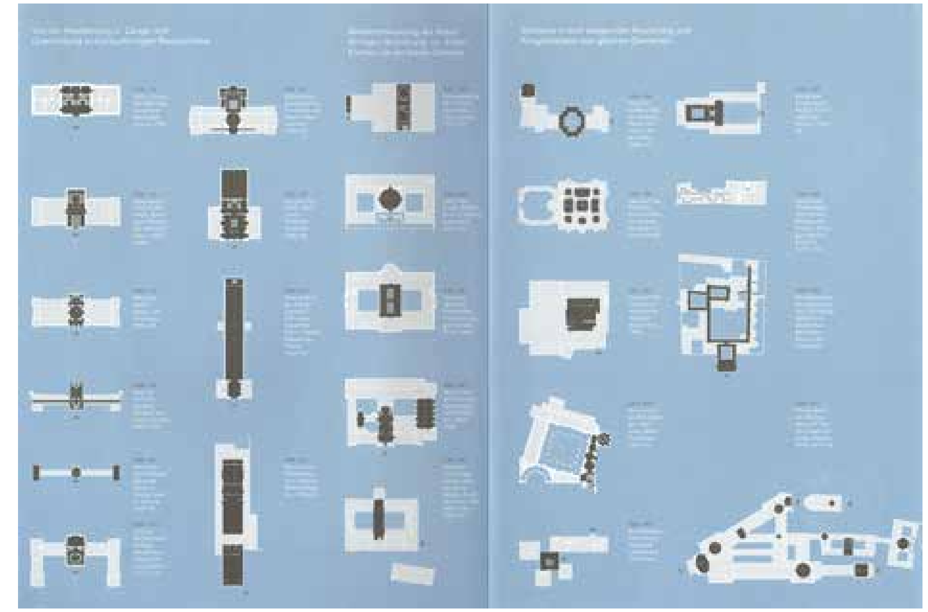
Figg. 2-4 In the wake of the Second World War, the entanglement of aesthetic activity with questionable ideological doctrines became a central issue in architecture discourse. The rationality and functionalism of modern architecture was in many cases by now seen as overbearing and potentially totalitarian, leading to gentle critiques from within, such as Team *X*'s new agenda of habitat, which introduced a sense of community within the modern city. Yet the recent memories in Germany of a constructed nationalist identity that was supported by traditional and monumental architecture also triggered a different path, leading to the 'anti-formal' architecture of Frei Otto. As Sean Keller presents in his article in this book, the formlessness actively sought by Frei Otto was a manner of counteracting the horrors of political totalitarianism by refusing the possibility of stable form.[6] Propaganda is counteracted by flexibility and change, by objects that refuse monumentality and authoritarian qualities in their grandeur. In contrast to Frei Otto, yet in a similar spirit, Ungers turns to a broad vision of gestalt theory in order to escape political complicity.

Where Otto feels the need to refuse the monumentality that has been compromised by its political implications, Ungers sees precisely artifacts of human intervention as revealing a formal substrate that transcends sociopolitical context. Ungers suggests that *Gestaltung* appeals to fundamentally human qualities, outside of sociopolitical constraints. It is this that forms the main distinction between the ideas of Otto and those of Ungers and Koolhaas. Otto has a clear vision of emer-

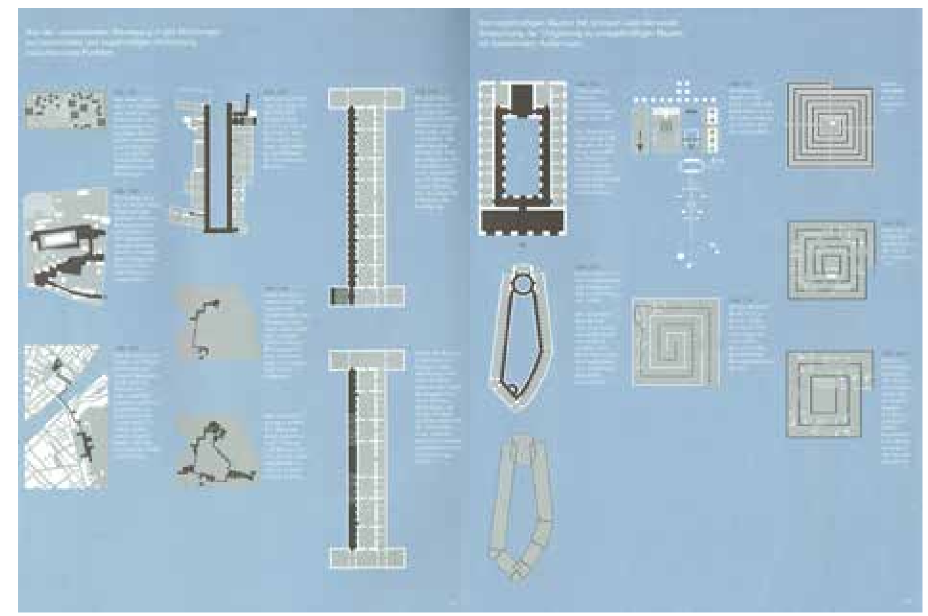
_ Figure 7.
Venturi and Scott Brown, *Learning from Levittown*, studio, 1970 (in Venturi and Scott Brown, *On Houses and Housing*, London-New York 1995, p. 50).

gent form, related to structure and nature, while Ungers seeks out concerns of gestalt theory precisely as a human distinction. This approach is directly related to the postwar turn to "anti-form" and non-monumentality. As the resistance to architectural form rapidly becomes a dominant mode of progressive architecture thinking, the turn of Ungers to gestalt theory, and that of Koolhaas to monumental form, may equally be seen as countering a simplified interpretation of architectural form.

_ Figure 8.
O.M. Ungers, Winter lectures Berlin, 1964-1965 (*Arch+*, n. 179, 2006, pp. 124-125).



_ Figure 9.
O.M. Ungers, Winter lectures Berlin, 1964-1965 (*Arch+*, n. 179, 2006, pp. 87, 105).



One of the key issues confronting postwar modern architecture was the vast difference between architecture as conceived and architecture as lived.[7] The rational blocks of Le Corbusier's *Plan Voisin* were comprehensible as a response to an overcrowded nineteenth-century city. Yet the reality of CIAM planning became more apparent in Lefrak City, where the cars required to transport the occupants from their dwellings to their workplaces provided a vastly different environment

Fig. 5

than envisioned in the models of the radiant cities. As such, the simultaneous separation of form and function, and their entwining in a new constellation, became glaringly obvious. Throughout the 1960s and 1970s, this perceived formal inadequacy of modernist architecture was countered with an effort to reclaim "meaningful form". In many cases, this comprised the inverse of modernist principles: an anti-rational, distinctly diverse or symbolic architectural language. From the maps of *Situationist dérives* to the studies of symbolic form by Venturi and Scott Brown, there was a conscious effort to imbue particular compositions with meaning. Yet these oppositional strategies also reinforced the underlying assumption of physical determinism.[8]

Figg. 6-7

Architecture may at times act as a social agent, a trigger, a barrier – it may suggest a particular sensibility that affects those within, and it can certainly offer both constraints and affordances. However, these implicit values are not stable, nor are they permanent. The discourse of social concern runs throughout modern and contemporary architecture, as is immediately obvious in the many programmes and manifestoes of modern architecture. Yet the very question of form-finding, or form-giving, becomes hidden underneath the social programme that forms the explicit legitimation of particular architectural gestures. The very concern for the social begins to mask the problem of architectural form, as Denise Scott Brown also suggests in an article that distinguishes between the social concern as articulated by planners, and that constructed by architects. She draws the boundaries between a research tradition in planning that is founded upon empirical study and quantitative analysis, and the "realm of form – architectural, physical form and its aesthetic theories", which is less immediately susceptible to analysis.[9]

From Form to Spirit: Speculations on Reality

As early as 1960, Ungers and Reinhard Gieselmann explicitly focused on the logic and effect of architectural form in their statement *Towards a New Form in Architecture*.[10] In the essay, they relate formal cohesion to the potential for urban diversity to develop. Form is presented as a manner of evoking a specific "spirit" in architecture, which suggests a correlation between form and content. At the same time, the turn to a metaphysical notion such as spirit precludes a directly legible or articulated content, encouraging instead a more general sensibility.

In the 1960 statement, Gieselmann and Ungers suggest that architecture's "creative function is to manifest the task by which it is confronted, to integrate itself into that which already exists, to introduce points of emphasis and rise above its surroundings".[11] Architecture is meant to be perceptible as a human intervention. In other words, it is not meant to "disappear" or blend in, but rather to explicitly introduce points of emphasis, a notion that will later return in Ungers' work on metaphors and form. This focus on formal aspects of architecture such as typology and composition returns some years later in the essay *Grossformen im Wohnungsbau*.[12]

The very notion of *Grossform* is founded on a formal coherence, and the essay develops this analysis in both text and images. Although Ungers refuses a direct connection between ideas and their visual or physical manifestations, he does

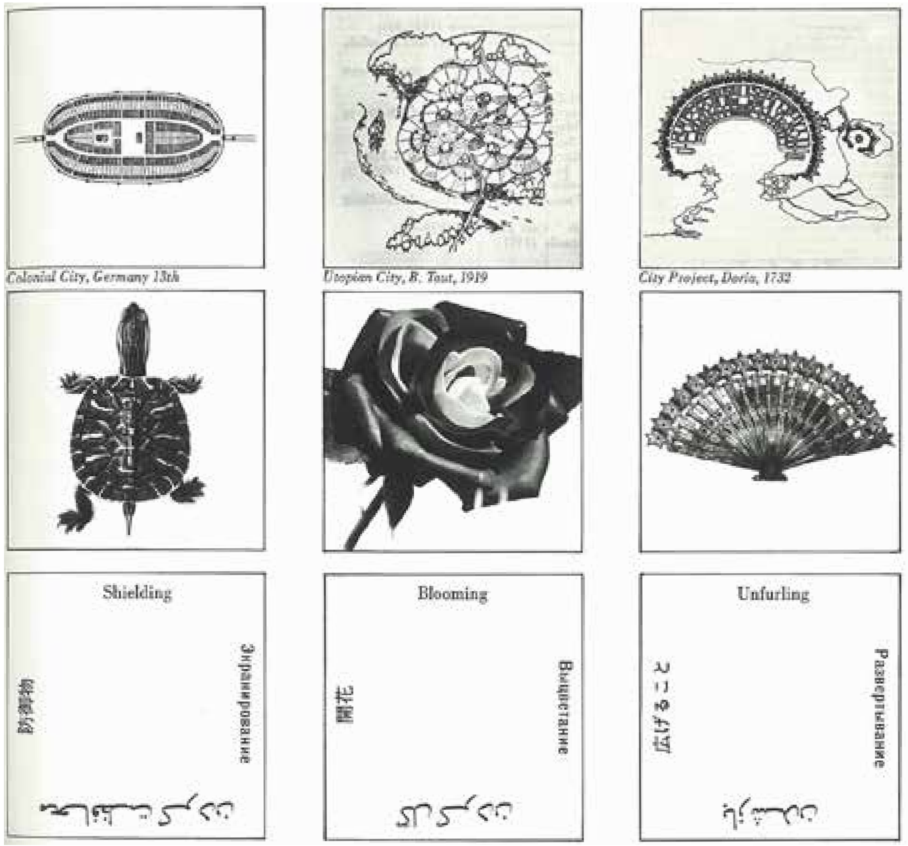
Figg. 8-9

_ Figure 10.
Koolhaas, Zenghelis et al., *Exodus, or the Voluntary Prisoners of Architecture* (M. van Schaik, O. Macel, eds., *Exit Utopia*, Munich 1999, p. 239).

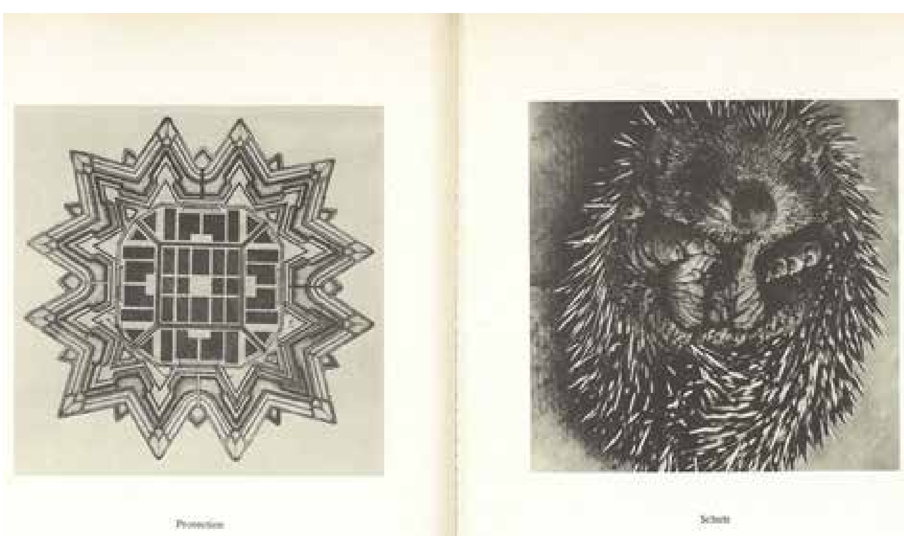
utilize the gap between language and visual perception in order to explore those features of architecture that might transcend the limitations of its immediate context. By focusing on what he sees as robust gestures such as the "over-accentuated element",[13] Ungers argues that architectural design can have a fundamental impact on the surroundings and the life within. At the same time, by acknowledging that the life within architecture is mutable, he removes the need to shape the life within through architecture. Severing the direct link between social and formal content, Ungers creates a different gap: one in which the architectural project as realized may acquire various forms of significance that accrue over time not because its form serves a single purpose, but because it is multivalent, open to interpretations, which the architect might also not foresee. It is this line of formal reasoning that runs throughout his winter lectures at the TU Berlin, identifying categories of spatial quality, or of formal compositions.

Around the same time, Koolhaas was tracing out a similar interest in strong formal gestures, which became most evident in his studies of the Berlin Wall, and in his final project *Exodus, or the Voluntary Prisoners of Architecture* of 1972.[14] Inserting an architectural island in the middle of London, Koolhaas provokes the existing urban fabric with a brutal project that recalls not only the Berlin Wall, but also Superstudio's *Continuous Monument* of 1969. In the accompanying text, the total surrender of the future occupants to the omnipresence of architecture is tempered only by the presence of historical London as an object of contemplation, and by the individual suburban allotments, a temporary relief from the collective.

Fig. 10



_ Figure 11.
O.M. Ungers, contribution to exhibition *Man TransForms* (curator Hans Hollein), Cooper-Hewitt Museum, 1976 (exhibiton catalogue *MAN TransFORMS*, New York 1976, p. 107).



_ Figure 12.
Protection/Schutz, in O.M. Ungers, *City Metaphors*, Köln 1982, pp. 30-31.

Both Ungers and Koolhaas seek out a robust formal expression. In arguing against the grain of anti-formalism, they are simultaneously arguing against political intentionality. In this increasing distinction between the physical manifestation and sociopolitical implications, they do not, however, claim that architecture has no effect on the social. Ungers places the effect of architecture within the realm of culture, focusing on the material manifestations of architectural tradition. The correlation between form and its effects does not reside within a causality of behavioural response, nor is it a concrete manifestation of abstract ideas. It rather suggests an evocative role.

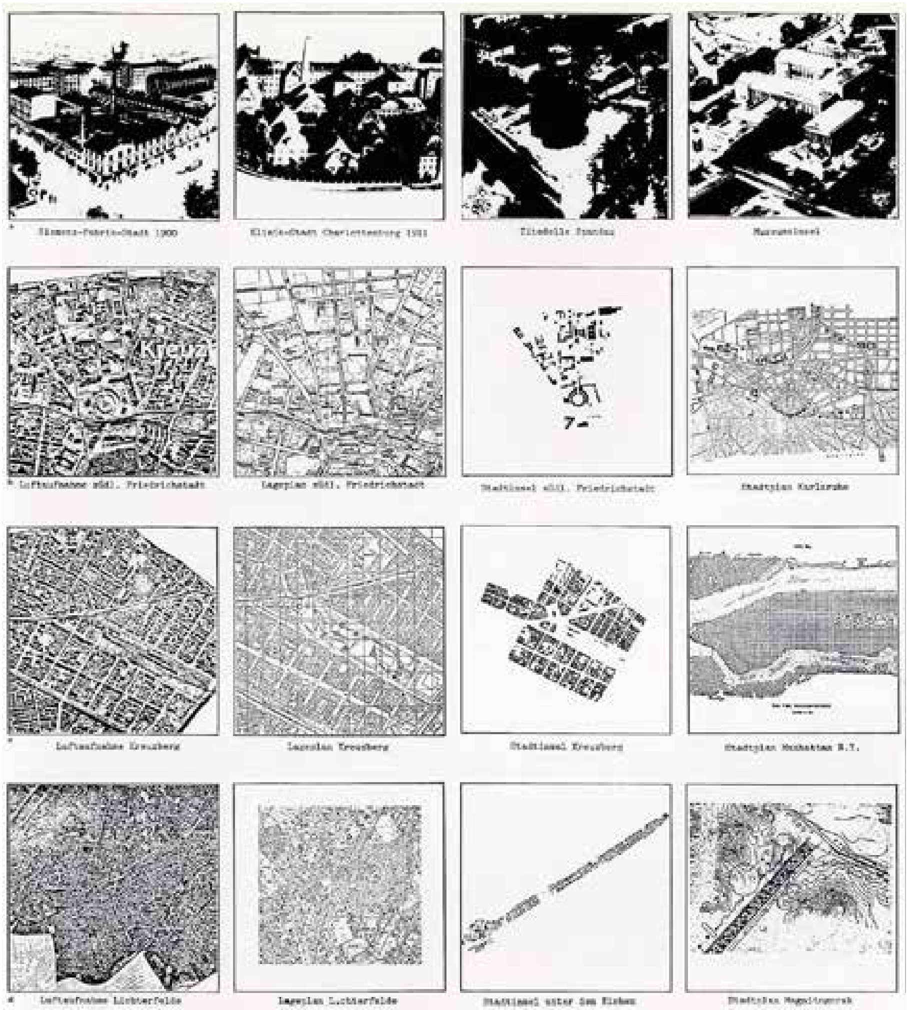
Form-Finding and Pattern-Seeking: Gestalt and the Human Condition

This approach to spatial composition thus builds on the premise that formal expression carries a perceptible spirit. The categories identified, such as shells or spirals, suggest particular sensibilities of intimacy, strength or protection. They may evoke a spirit of the time, or of context. Similarly, Koolhaas often refers to particular examples as evoking a sense of modernity, or urbanity, or collectivity. His propositions on architecture make use of specific examples in order to trigger an intuitive response. As such, the formal compositions are seen as layered with multiple meanings, one of which might be the sociopolitical context, but by no means will this delineate the full extent of architectural meaning.

The 1976 exhibition *Man TransForms* at the Cooper-Hewitt Museum in New York was an experiment with the conceptual and visual ordering of ideas, images and urban plans. The work shown in the exhibit was published as the book *City Metaphors* in 1982, with the accompanying essay *Designing and Thinking in Images, Metaphors, and Analogies*.[15] Ungers uses his long-standing interest in gestalt theory to place the perceptible form of objects at the centre of our understanding of the world. "The way we experience the world around us depends on how we perceive it. Without a comprehensive vision the reality will appear as a mass of unrelated phenomena and meaningless facts, in other words, totally chaotic".[16] In other words, the ordering system itself is proposed to be fundamentally human, rather than a construction of sociopolitical intent. This understanding of gestalt proposes a (universal) human drive towards pattern-seeking, applying order to a world that would otherwise be overwhelmingly chaotic. More importantly, this order is based not only on a conceptual, but primarily on a visual understanding of the world.

Figg. 11-12

In retrospect, the earlier focus on form, and the proposition of *Grossform* does not presume a single aesthetic to be applied throughout the world, but it does presume an internal coherence, which helps to control the uncontrollable. This coherence offers the quality "beyond the mere sum of parts", which is illustrated in the accompanying examples. Instead of presupposing a causal relation between form and behaviour, it constrains the unpredictable within a comprehensible form. This begins to mark out a "plausibility" between the formal gesture and the social content of architecture. In this sense, the examples work almost as a traditional handbook of architecture: on the one hand, by explaining the logic of design choices in abstract categories; and, on the other hand, by showing particular examples, which correlate but do not exhaustively illustrate the ideas. This approach is



_ Figure 13.
Understanding the Gestalt of urban areas: O.M. Ungers et al., *The City within the City: Berlin, a Green Archipelago*, 1977 ("Lotus", 19, 1978, p. 89).

further developed in a nearly autonomous visual and conceptual ordering in *City Metaphors*. Although Ungers is in search of a scientifically valid approach, the visual material he uses addresses the sensibility that cannot be quantified or derived from analytic modelling.

As in the gestalt theory of perception, it is the overall synthesis that defines architecture: it brings together the various layers and manifestations of culture, everyday life, function, and the desire to transcend.[17] This is what distinguishes architecture from the sciences, analytic disciplines that take apart our world in order to understand its elements. As such, *City Metaphors* places the synthetic whole at the core of what it means to be an architect, but also at the centre of what it means to be human. In resisting the hegemony of the natural sciences, it also resists the possibility for architecture to become merely politically instrumental.

> Therefore, the city-images as they are shown in this anthology are ... interpreted on a conceptual level demonstrating ideas, images, metaphors and analogies. The interpretations are conceived in a morphological sense, wide open to subjective speculation and transformation. The book shows the more transcendental aspect, the underlying perception that goes beyond the actual design. In other terms, it shows the common design principle which is similar in dissimilar conditions.[18]

Fig. 13 What sets Ungers apart from his contemporaries is his clear distinction between the social, and the aesthetic and formal concerns. While others were trying to inscribe the social within architecture and the city, he simply acknowledged the social as the field within which the architect works, but not an area that could be directly transformed through architecture. "It is equally difficult to derive a formal structural project from mere social conditions ... Social factors naturally influence architecture, but careful analysis of people's habits and customs does not necessarily lead to the choice of an architectural form as well".[19]

Plausibility of Combining the Formal and the Social

It is in the domain in which form or gestalt speak to us outside of their calculated intents that we find the correlation between Koolhaas and Ungers. Both address a notion of autonomy in architecture that does not disavow social embeddedness, but rather seeks to dislocate it. They reinterpret the cultural aspect of architecture as a parallel domain that responds to sociopolitical conditions but is not wholly determined by them. *City Metaphors* brings to bear the importance of gestalt theory as counterweight to political focus. This approach forms both the correlation with the ideas of Frei Otto and a distinction from his perspective. In seeing formal articulations as an undercurrent of shared human drives, Ungers posits a mode of totalized thinking that is not so much concerned with reality as with "the search for an all-round idea, for a general content, a coherent thought, or an overall concept that ties everything together. It is known as holism or gestalt theory and has been most forcefully developed during the age of humanism in the philosophical treatises of the morphological idealism".[20] As such, *Gestaltung*, form-shaping, is a neutral ground that may transcend political difference. Form is thus not merely an illustration of a conceptual content – it does not take second place to the idea, but it is present in parallel, according to its own logic. As such, the "plausible" relation suggested by Koolhaas is present within the gestalt of the city. It replaces the direct causality of physical determinism with a complex field of interaction between the forms of architecture and their agency in the socio-cultural fabric of the city.

Abstract

Rem Koolhaas e Oswald Mathias Ungers.
Una relazione plausibile tra il formale
e il sociale?

Nel 1999, Rem Koolhaas osservò che l'attività principale di OMA, il suo studio, era «reinventare una relazione plausibile tra il formale e il sociale». Alla luce della storia del XX secolo, costellata in architettura di programmi radicali e di manifesti, e permeata da un forte interesse per le riforme sociali, questo sembra un programma straordinariamente umile. L'architettura moderna intendeva rivoluzionare la vita quotidiana. Dall'alto modernismo all'attivismo dal basso degli anni Sessanta, l'espressione formale dei progetti architettonici incarnava un programma sociale. In questo senso, una relazione meramente "plausibile" tra il sociale e il formale sembra negare la storia stessa dell'architettura del secolo scorso. Tuttavia, la tesi qui sostenuta è che il significato di questa presa di posizione è ancora tutto da valutare.
Mettendo in relazione l'opera di Koolhaas con quella di Ungers, che fu suo mentore, emerge una complementarietà nell'approccio al contenuto sociale dell'architettura. L'architettura di Ungers, mentre rifiuta qualunque correlazione tra il sociale e il formale, impiega forme rigorosamente geometriche che permettono all'edificio di trascendere il proprio immediato contesto sociale. Il lavoro di Koolhaas incorpora riferimenti tanto distinti quanto il "condensatore sociale" del costruttivismo russo e le immagini oniriche di Coney Island, minando la chiarezza di un programma sociale singolo. L'attenzione di entrambi per il formale, sia nell'autonomia di Ungers sia nella specificità di Koolhaas, recupera il mestiere dell'architettura dall'attivismo sociale degli anni Sessanta. Come tale, la relazione "plausibile" suggerita da Koolhaas sostituisce la causalità diretta del determinismo fisico con un campo complesso di interazioni tra le forme dell'architettura e le loro implicazioni etiche nel tessuto socio-culturale della città.

Notes

_1. *Spot Check* (Rem Koolhaas in conversation with Sarah Whiting), "Assemblage", 40, 1999, pp. 36-55.
_2. Similar lines of questioning are present in A. Colquhoun, *Form and Figure*, "Oppositions", 12, 1978, pp. 28-37; C.A. van Eck, *Figuration, tectonics and animism in Semper's 'Der Stil'*, "The Journal of Architecture", 14, 2009, n. 3, pp. 325-337.
_3. O.M. Ungers (ed.), *Schnellstraße und Gebäude*, "Veröffentlichungen zur Architektur" ("VzA"), n. 4, TU Berlin, Berlin 1966; O.M. Ungers (ed.), *Straßen und Plätze*, "VzA", n. 8, TU Berlin, Berlin 1967; O.M. Ungers (ed.), *Wohnen am Park*, "VzA", n. 10, TU Berlin, Berlin 1968.
_4. R. Koolhaas, *Field trip: A(A) Memoir (First and Last …)*, in O.M.A., R. Koolhaas, B. Mau, *Small, Medium, Large, Extra-Large (S,M,L,XL)*, ed. by J. Sigler, The Monacelli Press, New York 1995, pp. 215-232, p. 226-227.
_5. "… immer wieder eine Mischung von Verführung und Ungenießbarkeit ins Spiel bringen" (Rem Koolhaas in conversation with Franziska Bollerey), in "Bauwelt", 78, 1987, n. 17/18, pp. 627-633, p. 633. My translation.
_6. Keller argues that form-finding in the work of Frei Otto is a kind of natural "coming into being" of the final shape. This naturalized process is a manner of coming to grips with the role of architecture in relation to totalitarian regimes. I argue that the postwar turn to "anti-form" and non-monumentality rapidly becomes a dominant mode of progressive architecture. As such, the turn of Ungers to gestalt theory, and that of Koolhaas to monumental form, may equally be seen as a resistance to simplistic ideological interpretation of architectural form.
_7. This particular distinction is raised by Henri Lefebvre in his discussion on everyday life. For an excellent overview of the work of Lefebvre, see L. Stanek, *Henri Lefebvre on Space: Architecture, Urban Research, and the Production of Theory*, University of Minnesota Press, Minneapolis 2011.
_8. See also H. Gans, *Urban Vitality and The Fallacy of Physical Determinism, People and Plans*, Basic Books, New York 1968, pp. 25-33; L. Schrijver, *Radical Games: Popping the Bubble of 1960s' Architecture*, NAi Publishers, Rotterdam 2009.
_9. D. Scott Brown, *On Architectural Formalism and Social Concern: A Discourse for Social Planners and Radical Chic Architects*, "Oppositions", 5, 1976. pp. 99-112, reprinted in K.M. Hays (ed.), *Oppositions Reader*, Princeton Architectural Press, New York 1998, pp. 317-330, p. 319.
_10. R. Gieselmann, O.M. Ungers. *Towards a New Architecture*, in U. Conrads (ed.), *Programs and Manifestoes on 20th-Century Architecture*, MIT Press, Cambridge MA (1970), pp. 165-166.
_11. *Ibidem*.
_12. O.M. Ungers, *Grossformen im Wohnungsbau*, "Veröffentlichungen zur Architektur", n. 5, TU Berlin, Berlin 1966.
_13. *Ibidem*, criteria for defining *Grossform*, [p. 7] (unpaginated).
_14. This project is credited to Koolhaas together with Madelon Vriesendorp (his then wife), Elia Zenghelis, his tutor at the Architectural Association, and Zoe Zenghelis. These four would go on to found OMA in 1975.
_15. Exhibition catalogue *Man TransForms*, (Cooper-Hewitt Museum, New York, 7.10.1976-6.2.1977), Smithsonian Institution, Washington D.C. 1976. O. M. Ungers, *Morphologie / City Metaphors*, Walther Koenig Verlag, Cologne 1982 (bilingual edition); the German title emphasizes the connection to gestalt theory. Of particular note is that this 'synthetic' form of thinking, understanding patterns no matter how complex, is identified as one of the uniquely human capabilities. While computer intelligence has become increasingly powerful, it typically falls short of being able to identify patterns or grasp associative correlations. Without a background in neuroscience, it appears that Ungers, from the questions rising within architecture, sensed an important quality of architectural thinking.
_16. Ungers 1982 (see footnote 15), p. 8.
_17. In Ungers' inaugural lecture at the TU Berlin, he refers to architecture as not a constrained art (gebundene Kunst), but as a binding or gathering art (bindende Kunst); O.M. Ungers, *Architekturlehre: Berliner Vorlesungen 1964-65*, "Arch+", n. 179, 2006, p. 12.
_18. Ungers 1982 (see footnote 15), p. 14.
_19. O.M. Ungers, *Architecture's Right to an Autonomous Language* (1979), in *The Presence of the Past*, First International Exhibition of Architecture, The Corderia of the Arsenale, La Biennale di Venezia 1980 (Architectural Section, Director: Paolo Portoghesi), Edizioni La Biennale di Venezia, Venezia 1980, pp. 319-323, p. 319.
_20. Ungers 1982 (see footnote 15), p. 8.

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