

Frei Otto 100: Reassessing the Spirit of Lightweight Construction

Lucio BLANDINI* and Daria KOVALEVA^a

^a Institute for Lightweight Structures and Conceptual Design
Pfaffenwaldring 14, 70569 Stuttgart
lucio.blandini@ilek.uni-stuttgart.de

Abstract

This paper provides a critical reflection on the evolution of lightweight construction at the University of Stuttgart, rooted in the pioneering research of Frei Otto. Celebrating the centenary of Otto's birth, the June 2025 International Symposium at ILEK served as a generative framework to cross-examine the past, present, and future of the Stuttgart School of Lightweight Construction across multiple generations of researchers. Structured around a temporal framework, this paper analyzes Otto's "thinking-and-making" pedagogy—an unconventional approach based on hands-on student experimentation—alongside his "reverse path" (der umgekehrte Weg), which derived architectural form from material self-organization and natural processes. We trace how this material knowledge culture laid the foundation for modern parametric design and computational form-finding, despite Otto's historical skepticism toward early digital tools. The discussion outlines a critical paradigm shift required to meet 21st-century challenges, advocating for the integration of modern digital technologies across the entire lifecycle continuum—from computational inception and robotic fabrication to structural adaptivity and design for disassembly. Ultimately, this paper argues that the core tenets of the Stuttgart School of Lightweight Construction offer a resilient, cross-disciplinary framework to navigate the modern computational trap by balancing the power of numerical optimization with human creative intuition.

Keywords: Frei Otto, Stuttgart School of Lightweight Construction, Form-finding, Reverse Path, Pedagogy, Structural Optimization, Parametric design, Dynamic relaxation, Reverse Engineering

1. Introduction: The Centennial celebration and the Paradigm Shift

The centenary of Frei Otto's birthday in June 2025, was marked by the international symposium "Frei Otto 100: The Spirit of Lightweight Construction" hosted at the Institute for Lightweight Structures and Conceptual Design (ILEK) in Stuttgart (see Fig. 1). This conference, organized by the ILEK in collaboration with the Institute of Architectural History (ifag), provided a timely departure point not merely for retrospective celebration, but for a critical reassessment of the spatial, analytical, and structural methodologies and for the interdisciplinary approach that defined the Stuttgart School of Lightweight Construction [1]. At the physical and intellectual heart of this legacy stands the IL(EK)-Tent, an experimental building on the University of Stuttgart's Vaihingen campus (Pfaffenwaldring 14). Erected in 1966 as a 1:1 structural prototype to test the construction, prestressing, and assembly logistics of the iconic German Pavilion for the Expo 67 in Montreal, this cable-net structure was in 1968 relocated to its current site to become the home of the Institute for Lightweight Structures (IL) [2]. For sixty years, this living cultural monument has functioned as an active academic laboratory under three generations of professors, housing an unparalleled repository of primary sources, physical models, and measurement apparatuses that document the evolution from empirical to digital form-finding and from craftsmanship to digital fabrication. However, the authors consider this to be more of an extension to the toolkits than a simple replacement.



Figure 1: Opening of the symposium "Frei Otto 100: The Spirit of Lightweight Construction" at the IL(EK) Tent (a), and Symposium flyer showing Frei Otto with researchers and students outside of the IL (b).

Within the context of IASS Working Group 17 (Historical Spatial Structures), the evaluation of this legacy demands a paradigm shift in how architectural and engineering history is written. Despite the global visibility of mid-20th-century lightweight structures, conventional historiography has frequently suffered from an autographic bias, attributing milestone achievements to an isolated, singular genius. While Frei Otto and his "thinking-and-making" philosophy captured widespread public imagination, a preliminary critical examination of the documents available reveals a more complex structural reality: Otto was neither the chief operating architect nor the executive structural engineer for the landmark projects most indelibly linked with his name, including the Montreal Pavilion (1967), the Munich Olympic Roofs (1972), or the Mannheim Multihalle (1975). He operated instead as an intuitive provocateur, a conceptual catalyst, and a master networker.

The historical reality of these milestone structures represents what has been termed "Bauen am Limit" (Building at the Limit), a highly collaborative, interdisciplinary push that advanced structural mechanics, materials science, and descriptive geometry to their absolute boundaries [3]. Bringing these complex forms to life was a turbulent, conflict-heavy endeavor. It required a delicate balance of competing forces: the rigorous, pragmatic engineering of Fritz Leonhardt and Jörg Schlaich, the artistic vision of architects Rolf Gutbrod and Günter Behnisch, and the pioneering computational insights of geodesists and mathematicians Klaus Linkwitz and Hans-Joachim Schek [4]. In a wider context a critical reflection should position Otto's empirical, model-based form-finding within a broader, international triad of mid-century European masters alongside the empirical shell design of Heinz Isler and the analytical, mathematical optimization of Sergio Musmeci [5].

2. The origin of the Stuttgart School of Lightweight Construction

The institutionalization of research on lightweight structures at the University of Stuttgart in 1964 marked a fundamental subversion of traditional civil engineering. By appointing Otto as director of the Institute for Lightweight Structures (IL), the faculty shifted structural optimization from rigid, material-specific silos toward the active minimization of mass and force paths under external load constraints. To legitimize these empirical, model-based methods, the university leveraged collaborative frameworks funded by the German Research Foundation (DFG), most notably the Collaborative Research Center 64: Wide-Span Structures (SFB 64) active from 1970 to 1985. SFB 64 pooled knowledge across architecture, civil engineering, material sciences, geodesy, transforming the IL from an experimental workshop into a socio-technical ecosystem capable of urban-scale execution.

The first real-world application of this ecosystem occurred under extreme technical pressure during the design of the Munich Olympic Roofs (1968–1972). To translate Behnisch's visionary alpine tent-like landscape into permanent structural reality, Otto served as the critical link between conceptual intuition

and decentralized mathematical validation. The unprecedented scale of the prestressed cable nets pushed structural mechanics to its absolute boundaries. While Leonhardt and Schlaich engineered the massive perimeter pylons and boundary cables to resist immense tension forces, John Argyris applied early non-linear Finite Element Method (FEM) analysis to evaluate global stability against wind and snow loads. Concurrently, Linkwitz and Schek resolved the immense cutting-pattern challenges for thousands of individual roof panels by inventing the Force Density Method (FDM) in 1971 [6]. The success of this milestone project directly informed the subsequent establishment of SFB 230: Natural Structures (1984–1995), expanding the Stuttgart School's multi-layered network into biology, philosophy, and urban planning.

3. The "Reverse Path": Analogue to Digital Form-Finding

3.1 The Philosophy of the Reverse Path and Analog Computing

A central pillar of the Stuttgart School's methodology was Otto's formulation of "the reverse path" ("der umgekehrte Weg"), an epistemological concept that inverted the linear sequence of classical structural design [7]. In traditional structural engineering, an architect drafts an arbitrary geometric form, and an engineer is tasked with calculating internal stresses and modifying material thicknesses to force that preconceived shape into static safety. The reverse path turns this relationship upside down by deriving structural geometry directly from natural self-organizing processes, boundary constraints, and material behaviors. Form is not prescribed but found purely through physical equilibrium.

At the IL, this philosophy manifested as an intensive "thinking-and-making" pedagogy rooted in physical experimentation [8]. Because the non-linear differential equations governing large-deformation tensile structures were mathematically intractable using the analytical tools of the 1960s, Otto treated physical material systems as analog computers. By subjecting physical materials to specific boundary conditions, the material automatically self-organized into a state of minimum energy or uniform stress. To operationalize this philosophy beyond a private studio methodology, Otto relied on highly systematic visual taxonomies and morphological classifications to teach students how to read these self-forming forces. This early effort to map structural typologies laid the groundwork for a broader approach that linked physical form-finding directly to systemic, multi-disciplinary thinking.

3.2 The Pedagogical Crucible: US Studios and Proto-Parametric Education

While the establishment of the IL in 1964 is traditionally viewed as the genesis of the Stuttgart School of Lightweight Construction, the epistemological foundations of this "thinking-making-learning" approach were tested through radical pedagogical experiments in the United States between 1954 and 1962. As Rob Whitehead notes, Otto's development was deeply catalyzed by a 1954 study-abroad tour at the University of Virginia, where mentorship from Fred Severud, whose organic design philosophy linked structural form directly with natural inspiration, and close physical analysis of Matthew Nowicki's Dorton Arena directly shaped his early thesis work and publications.

Securing immersive teaching appointments at Washington University in St. Louis (1958), Yale University (1960), and UC Berkeley (1962), Otto countered the dominant code-driven, practical academic training by introducing an open-ended, discovery-driven pedagogy. Discarding rigid architectural programming for direct sensory experience, students engaged in an iterative design-make-test cycle to build, photograph, and measure pioneering "hanging shell" models. This era yielded definitive archival evidence of Otto's proto-parametric thinking; his Yale seminars on design-for-assembly introduced early structural typology diagrams mapping complex force relationships and morphological structures (see Fig. 2). Ultimately, frustration with the temporal constraints of short-term appointments led directly to Otto's 1963 blueprint for a "pure research institute," replacing standard classrooms with selective doctoral workshops that laid the organizational groundwork for the IL.

3.4 Chronological Metamorphosis: The Birth of Digital Mechanics

The friction between analog physical intuition and digital precision triggered the transition to computational form-finding, digitizing the material laws of the reverse path into algorithms. The breakthrough came with linearizing of network equilibrium through the Force Density Method (FDM), conceptualized during the design of the Munich Olympic Roofs and fully formalized by Schek [6]. In the late 1970s and 1980s, the school expanded this mathematical foundation to simulate the non-linear behaviors of continuous elastic gridshells and dynamic membranes. Under Ekkehard Ramm at the University of Stuttgart (SFB 230), researchers integrated non-linear Finite Element Methods (FEM) to analyze how physical material stiffness interacts with form-found shapes, successfully bridging pure form-finding (zero-moment states) with structural analysis (bending and buckling). As highlighted by Kai-Uwe Bletzinger (a researcher from SFB 230 in Ekkehard Ramm's team) this computational translation formalized Otto's intuitive physical modeling into numerical structural optimization, defining explicit objective functions, variables, load cases, and geometric constraints. At its core was the formalization of Otto's TRA principle—an expression of structural equilibrium via virtual work (see Fig. 3). By linking force magnitudes and transition distances directly to the Maxwell Load Path Theorem, this approach verified Otto's analog breakthroughs, proving that minimizing total internal material volume under tension and compression yields the absolute optimal structural morphology.

Today, this evolution is integrated within modern parametric modeling ecosystems like Grasshopper for Rhino. The static matrix calculations of FDM are preserved in commercial software like Technet's EASY [10], and open-source frameworks like COMPAS-FoFin [11]. Concurrently, the mechanics of hanging nets and membranes are executed dynamically via particle-spring architectures and Dynamic Relaxation (DR) solvers like Kangaroo Physics [12]. Inside a single Grasshopper canvas, specialized area elements like Live Soap simulate isotropic surface tension by iteratively minimizing mesh curvature to generate true digital minimal surfaces. Meanwhile, the core solver computes the vector inversion of hanging networks by balancing internal spring stiffness against external gravitational vectors over simulated time-steps, while agent-based routing scripts simulate the capillary coalescence of the wet threads experiment to generate live-updating branching columns.

By merging these mathematical engines into a single computational interface, parametric design eliminates the manual labor and physical degradation of the analog workshop while preserving the core philosophical intent of the reverse path. The software allows modern structural engineers to manipulate boundary conditions, load vectors, and material behaviors in real time, transforming Otto's physical "thinking-and-making" loop into a live, non-destructive digital feedback system that remains fundamental to the creation of material-efficient, low-carbon spatial structures today.

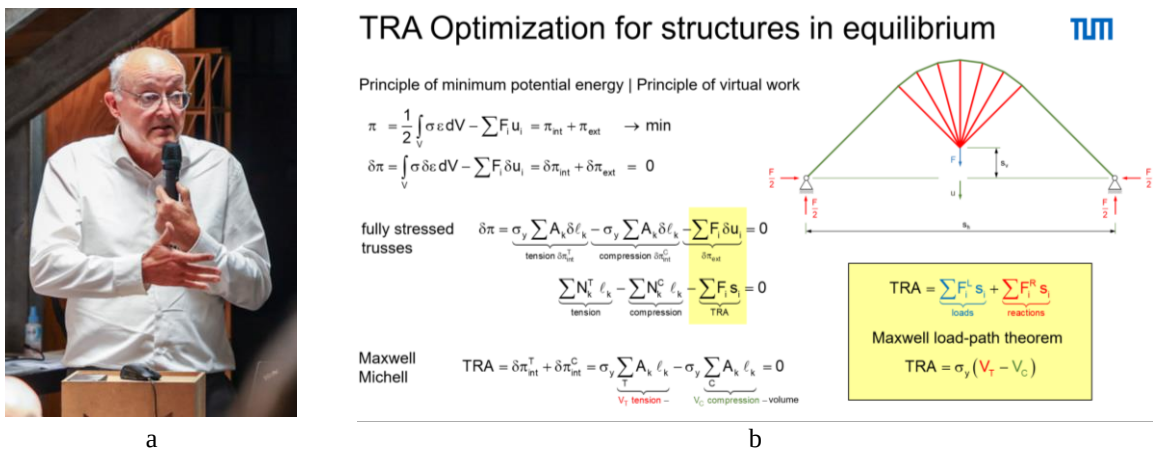


Figure 3: Kai-Uwe Bletzinger delivering his keynote during the symposium (a), and mathematical derivation of the TRA optimization framework for structures in equilibrium (extracted from K.U. Bletzinger's presentation) (b) [1].

4. Legacy: Lightweight Construction, the Circular Economy, and Digital Recovery

4.1 The 21st-Century Mandate: From Material Heroism to Resource Scarcity

Reflecting on the future, the core tenets of the Stuttgart School must undergo a profound paradigm shift from 20th-century "pioneer approach" toward an ecological lifecycle mandate. This transition is anchored by Otto's open-ended 1984 Berlin Eco House project and his participatory, housing concepts, which framed buildings not as static consumer products but as flexible socio-technical ecosystems. By linking individual user-driven adaptation with collective structural frameworks, these historical models directly anticipate contemporary climate-adaptive design and closed-loop lifecycle architecture. Expanding this legacy beyond the active use-phase, modern research in Stuttgart integrates digital technologies across the entire lifecycle continuum—spanning inception, automated robotic fabrication, and design for disassembly—to recover materials in strict alignment with the circular economy.

4.2 The SFB-TRR 141: Biological Systems and the Computational Biomimetics

The contemporary evolution of the Stuttgart School of Lightweight Construction operates not through a repeating catalog of historical structural typologies, but through the continuous advancement of its systemic methodologies. When tracing this academic lineage, the core philosophy of "the reverse path" expands beyond passive form-finding and branches into independent lines of 21st-century inquiry, each inheriting and modernizing a specific aspect of the early foundations established at the institute.

The first distinct strand traces the evolution of bio-inspired design from manual observation to computational abstraction. The foundational integration of structural mechanics with systems biology and evolutionary design was established during the operation of SFB 230: *Natürliche Konstruktionen* (1984–1995) [13]. Otto and his interdisciplinary network focused on how living organisms utilize minimum material mass to achieve maximum structural resilience by naturally redistributing forces and self-organizing in response to shifting environmental stimuli [14]. The direct transfer of this specific research into 21st-century scholarship was realized through the Transregional Collaborative Research Centre 141 (SFB-TRR 141: Biological Design and Integrative Structures, 2014–2019), coordinated by Jan Knippers (ITKE, University of Stuttgart). Operating as the direct intellectual successor to SFB 230, SFB-TRR 141 shifted the paradigm from analog biological observation to advanced computational bio-abstraction [15]. Rather than mimicking the appearance of natural forms, researchers leveraged advanced simulation, genetic algorithms, and multi-material digital fabrication to decode the underlying functional mechanics, material gradients, and morphology of biological structures. Landmark innovations generated under this framework, such as compliant, hingeless facade shading mechanisms,

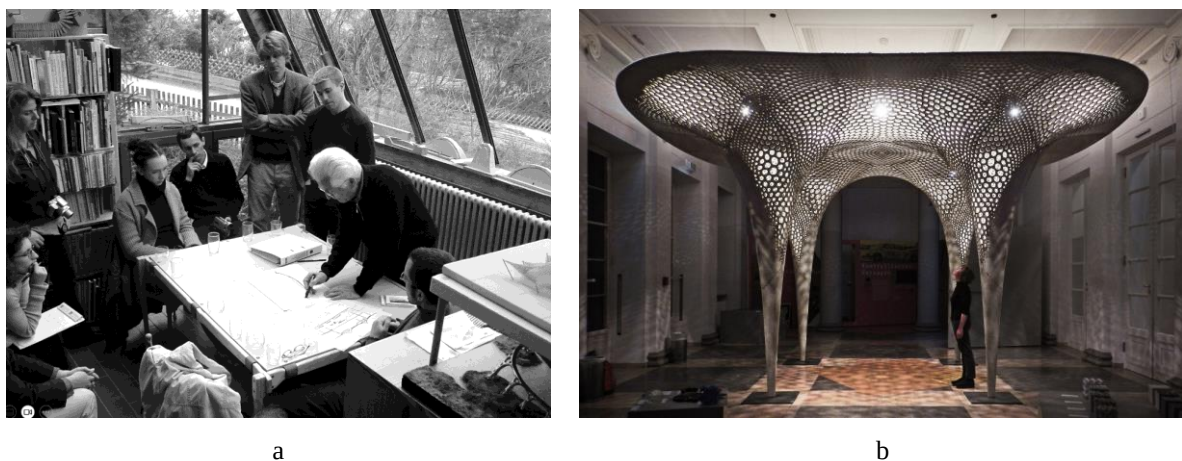


Figure 4: Jan Knippers with students during their visit of Frei Otto's Atelier in Warmbronn in 2001. Photo: Jan Knippers (a), and Rosenstein Pavilion at the *Baubionik* Exhibition in 2017 (Photo: ILEK) (b).

functionally graded mineral structures (see ILEK's Rosenstein Pavillion in Fig. 4b) or complex segmented timber shells, explicitly proved that natural morphogenetic and self-organization principles could be directly used as concept generators for resource-efficient engineering and architectural solutions.

4.3 The SFB 1244: Active Cybernetics and Adaptive Systems

In parallel to this biomimetic trajectory, the direct institutional and conceptual extension of the school's systemic line of inquiry into adaptive structures evolved as a separate, independent strand. This lineage culminated in the founding of the Collaborative Research Center 1244 in 2017 (SFB 1244: Adaptive Skins and Structures for the built Environment of Tomorrow). Initiated by Werner Sobek, who succeeded to Frei Otto as IL Director in 1995 and to Jörg Schlaich in 2001 [16], SFB 1244 was created with the explicit purpose of extending and deepening the research on dynamic adaptation and adaptive systems within the built environment, separating itself from biological abstraction to focus entirely on advanced control theory and structural cybernetics. Sobek's vision shifted the paradigm into active, digitally controlled structural mechanics. This evolutionary step fundamentally transcends classical lightweight construction; whereas Frei Otto's traditional form-finding sought a singular, static geometric equilibrium to passively absorb forces, Sobek's cybernetic framework introduces active, time-variant adaptation, allowing the structure to continuously rewrite its internal stress states in response to volatile external loads [17]. As a result, D1244, the first worldwide adaptive tower, was built in 2021 (see Fig. 5). Integrated sensor networks monitor structural deformations and internal stresses in real time, immediately feed this data to 24 hydraulic actuators integrated into columns and diagonals [18]. These actively introduce counter-strains and alter the structural geometry to redistribute dynamic loads, which drastically reduces the required material mass and embodied carbon of the structure, transforming passive lightweight architecture into an active, self-regulating cybernetic ecosystem.

Over the past five years, following the latest generation change at the chair of the ILEK, the SFB research focus has been further extended to adaptive facades. The aim is to create a new type of adaptable building envelope that can respond optimally to changing environmental conditions and user requirements. Innovative concepts are being developed for different objectives, including control of daylight illuminance, solar heat gains, and heat transfer (see. Fig. 5). New strategies are being tested for influencing microclimatic conditions in the vicinity of the building, for example, by means of rainwater retention and evaporative cooling, as well as by reflecting solar radiation towards the sky [19].



Figure 5: D1244 after erection in 2021 (Photo: René Müller) (a) and with the first integrated facades in 2025 (Photo: ILEK) (b).

4.4 The Cluster of Excellence IntCDC: Automated Fabrication and Circularity

Building upon both the bio-inspired geometric complexities of SFB-TRR 141 and the systems-level engineering of SFB 1244, the Cluster of Excellence IntCDC (Integrative Computational Design and Construction for Architecture) investigates the potential of digital tools to design and build a new generation of lightweight constructions. It was established in 2019 under the initiative of Achim Menges (ICD, University of Stuttgart), who delivered a keynote lecture on the second day of the symposium (see Fig. 6). IntCDC shifts the focus from purely isolated structural and material optimization toward a unified methodology where computational design, robotic fabrication, and material lifecycles are deeply integrated [20]. This research framework targets the massive productivity and ecological challenges of the construction sector by replacing fragmented, linear workflows with a cohesive digital feedback loop.



Figure 6: Achim Menges delivering his keynote during the symposium.

Under IntCDC, the open-ended design philosophy of the Stuttgart School of Lightweight Construction is translated into advanced automated assembly and robotic manufacturing workflows. This framework expands the definition of lightweight design into a diverse taxonomy of materials, including robotically wound flax and hemp fibers for long-span bio-composites, self-forming curved timber components engineered via material moisture-variability, and functionally graded concrete (FGC) elements that embed mineral hollow spheres to reduce dead-weight. Crucially, IntCDC extends the mandate of lightweight design to address the mechanics of the circular economy through computational Design for Disassembly (DfD) and multi-lifecycle material systems. By integrating structural metadata and precise geometric tolerances directly into the component's underlying code during the robotic fabrication stage, the system establishes a seamless digital twin of the material value chain. Complex spatial structures can therefore be mapped, disassembled, and sorted for subsequent use phases without material degradation, proving that structural efficiency can be achieved in tandem with full circular recovery.

The focus of the ILEK research within the IntCDC cluster and the associated research projects is on lightweight concrete constructions (see Fig. 7). They demonstrate that combining lightweight construction principles with circular economy principles and exploiting the potential of digital design and fabrication methods, can reduce mass by over 50%, increase recycling capacity, and improve CO₂ balances. Furthermore, the application of this research to real buildings represents a new attempt to bridge the gap between research and practice innovation.

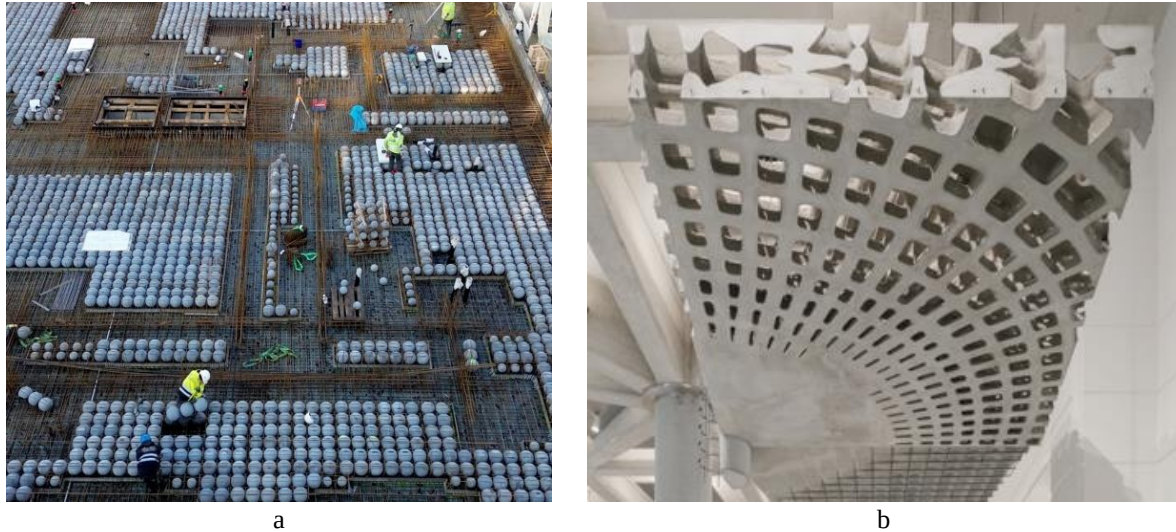


Figure 7: a) Functionally graded concrete foundation slab for the IntCDC Building under construction. Photo: ILEK/IntCDC; b) Coral Slab at the Vienna Museum of Science and Technology. Photo: Patrick Johannsen.

4.5 Digital Recovery Frameworks: Re-Evaluating the Archive Through Reverse Engineering

Within this framework of circularity, ILEK's planned research initiatives demonstrate contemporary relevance by arguing that sustainable structural engineering must learn to interrogate, maintain, and adapt existing built heritage. A planned collaboration between ILEK and the ifag deploys a digital recovery framework rooted in advanced structural reverse engineering. Leveraging primary archives, original drawings, and calculations from the institute's first thirty years, the project builds live, parametric computational replicas of historical milestones. Instead of a standard inspection technique, reverse engineering serves as a predictive historiographical tool to analyze structural tolerances and construction sequence logistics. Crucially, this approach closes the methodological loop of the Stuttgart School by revisiting historic structures using the non-linear digital frameworks and solvers that originally evolved from Otto's analog form-finding experiments. When a lightweight structure is translocated—as the IL-Tent was in 1968, the flexible network must absorb site deviations and geometric errors without compromising global equilibrium. By utilizing modern non-linear Finite Element Analysis (FEA) and particle-spring solvers to reverse-engineer these assembly sequences, the work aims to map exactly how structural tolerances were managed. Decoding these historical feedback loops provides invaluable data for modern modular, demountable workflows, demonstrating that analyzing past material culture directly fuels future low-carbon spatial structures.

5. Conclusion

The June 2025 centenary of Frei Otto's birthday prompts a critical academic re-evaluation of the Stuttgart School of Lightweight Construction. By analyzing primary ILEK records, this paper reframes the Institute for Lightweight Structures' (IL) achievements as products of a cross-disciplinary research ecosystem rather than a lone creator. This integrative philosophy continues to evolve through Stuttgart's key research clusters, SFB-TRR 141, SFB 1244 and IntCDC, led by different chairs within the frame of a flexible and strong network of competences. This proves that lightweight principles are essential tools for tackling 21st-century ecological mandates, resource scarcity, and lifecycle-driven circular design. It also shows that these principles are firmly established at the University of Stuttgart and that interdisciplinary collaboration is more important than ever.

Acknowledgements

All the pictures showing the Frei Otto 100 Symposium were taken by Uli Regenscheit and the ILEK holds the rights to publish them. The pictures from the presentations were provided by the referents.

References

- [1] Recordings from the Frei Otto 100 Symposium. [Online]. Available: <https://www.ilek-collections.de/freiotto100>
- [2] J. Kleinmanns, *Der deutsche Pavillon der Expo 67 in Montreal: Ein Schlüsselwerk deutscher Nachkriegsarchitektur*. Berlin: DOM publishers, 2020.
- [3] W. Lorenz and R. May, Eds., *Bauen am Limit: Traditionen und Transformationen eines hochmodernen Leitbilds*, 1st ed. Basel: Birkhäuser; [im Druck], 2025.
- [4] B. Schmid, "Messmodelle im Netzwerk: Bautechnikhistorische Studien zur Netzwerkbildung im Bauwesen der Hochmoderne am Beispiel der Modellstatik," Dissertation, Leopold-Franzens-Universität Innsbruck, 2024. [Online]. Available: <https://ulb-dok.uibk.ac.at/urn:urn:nbn:at:at:ubi:1-145808>
- [5] G. Boller and P. D'Acunto, "Structural design via form finding: Comparing Frei Otto, Heinz Isler and Sergio Musmeci," in *History of Construction Cultures*, J. Mascarenhas-Mateus, A. P. Pires, M. M. Caiado, and I. Veiga, Eds., London: CRC Press, 2021, pp. 431–438.
- [6] H.-J. Schek, "The force density method for form finding and computation of general networks," *Computer Methods in Applied Mechanics and Engineering*, vol. 3, no. 1, pp. 115–134, 1974, doi: 10.1016/0045-7825(74)90045-0.
- [7] J. M. Schneider, Ed., *Der umgekehrte Weg: Frei Otto zum 65. Geburtstag (Arcus: Architektur und Wissenschaft, vol. 10)*. Cologne, Germany: Rudolf Müller Verlag, 1990.
- [8] G. Vrachliotis, J. Kleinmanns, M. Kunz, and P. Kurz, Eds., *Frei Otto - Denken in Modellen*, 1st ed. Leipzig: Spector Books, 2017.
- [9] J. Medina-Warmburg and A.-M. Meister, Eds., *Frei Otto, 1925-2015: Bauen mit der Natur*. München [et al.]: Prestel, 2025.
- [10] L. Gründig, E. Moncrieff, P. Singer, and D. Ströbel, "A history of the principal developments and applications of the force density method in Germany 1970–1999," in *IASS-IACM 2000: Fourth International Colloquium on Computation of Shell & Spatial Structures*, Chania-Crete, Greece, 2000.
- [11] T. Van Mele, L. Scheder-Bieschin, J. Lee, and P. Block, *compas-FoFin: FormFinder for Rhino (Version 1.0)*, Block Research Group, ETH Zürich, 2024. [Online]. Available: <https://blockresearchgroup.gitbook.io/compas-fofin>.
- [12] D. Piker, "Kangaroo: Form finding with computational physics," *Archit. Des.*, vol. 83, no. 2, pp. 136–137, Mar. 2013.
- [13] K. Teichmann and J. Wilke, Eds., *Prozeß und Form "Natürlicher Konstruktionen": Der Sonderforschungsbereich 230*. Berlin: Ernst & Sohn, 1996.
- [14] F. Otto, R. Barthel, B. Burkhardt, and et al., *Natürliche Konstruktionen: Formen und Strukturen in Natur und Technik und Prozesse ihrer Entstehung*, 1st ed. Stuttgart: Deutsche Verlags-Anstalt, 1982.
- [15] J. Knippers, K. G. Nickel, and T. Speck, *Biomimetic Research for Architecture and Building Construction*. Cham: Springer International Publishing, 2016.
- [16] W. Sobek, "IL wird ILEK," *Bauwelt*, vol. 106, no. 20, pp. 14–17, 2015.
- [17] W. Sobek et al., "Adaptive Hüllen und Strukturen: aus den Arbeiten des Sonderforschungsbereichs 1244," *Bautechnik*, vol. 98, no. 3, pp. 208–221, 2021, doi: 10.1002/bate.202000107.
- [18] L. Blandini et al., "D1244: Design and construction of the first adaptive high-rise experimental building," *Frontiers in Built Environment*, vol. 8, 2022, doi: 10.3389/fbuil.2022.814911.
- [19] L. Blandini et al., "Adaptive Textile Façade Systems – The Experimental Works at D1244," in *Civil Engineering, Façade Design - Challenges and Future Perspective*, A. N. Haddad, C. Bedon, M. Kozłowski, and M. Stepinac, Eds.: IntechOpen, 2024.
- [20] J. Knippers, C. Kropp, A. Menges, O. Sawodny, and D. Weiskopf, "Integrative computational design and construction: Rethinking architecture digitally," *Civil Engineering Design*, vol. 3, no. 4, pp. 123–135, 2021, doi: 10.1002/cend.202100027.