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The Synergy of Aesthetics, Technology, and Structural Logic in Architecture: With a Focus on the Works of Frei Otto

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Abstract

Advances in structural technologies, computational methods, and digital design tools have significantly expanded the range of forms that can be realized in contemporary architecture. However, the ability to generate a form does not necessarily guarantee its aesthetic quality or architectural justification. These developments raise a fundamental question: when technology makes it possible to produce an almost unlimited range of forms, what makes a particular form aesthetically justified and necessary? In this context, the concept of self-generated form does not refer to a form created in the absence of a designer; rather, it describes a form that emerges through the interaction of physical forces, material properties, structural behavior, environmental factors, and the architect's guiding creative intervention. The works of Frei Otto provide a valuable framework for examining this concept, as his form-finding methods transformed the conventional relationship between architectural form and structure. Through physical experiments and models, including soap bubbles, cable nets, and tensile membranes, Otto allowed the behavior of physical systems to play a determining role in the emergence of architectural form. In this approach, structure is not merely a means of realizing a predetermined design but an active factor in the formation of its aesthetic qualities. This study adopts a descriptive-analytical approach and comparatively examines three selected works by Frei Otto. The findings indicate that the aesthetic quality of self-generated forms can be understood through four fundamental principles: necessity, economy, integration, and legibility. From this perspective, beauty is not an added attribute but emerges from the harmony between the logic of form generation, material behavior, structural function, and human perception. The study also distinguishes between possible form and necessary form, highlighting the importance of this distinction for contemporary architectural practice. In the context of parametric design and artificial intelligence, this perspective shifts the central question from "What forms can be produced?" to "What forms necessarily emerge from the existing forces, materials, structural systems, and environmental conditions?"

Keywords: Architectural aesthetics, Self-generated form, Frei Otto, Form-finding, Structural technology, Structural logic.

1 | Introduction

Form is one of the most fundamental concepts in architecture; however, the origin of form and its relationship with the designer's intention have always been among the central issues in architectural theory. In

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conventional approaches, form is generally regarded as the outcome of a design decision, while structure and technology enter the design process after the formal concept has been established, serving to realize it. Within this model, the relationship can be represented in simplified terms as follows:

Form Idea → Structure → Construction

Technological developments in contemporary architecture have made this situation more complex. Computational tools and digital design methods have enabled the generation of shapes and geometries that were previously difficult to achieve. However, the expansion of the range of producible forms raises a new question: if almost any form can be produced, what makes a form architecturally "necessary"?

This question is not merely technical; it is directly related to aesthetics. If beauty depends solely on novelty, complexity, or formal unconventionality, then under conditions in which form generation has become abundant and accessible, the criteria for distinguishing aesthetic quality may lose their validity. Therefore, the more fundamental issue is not the "possibility of form" but rather the "necessity of form."

Accordingly, this article proposes the concept of "self-generated form" as an important concept in the pursuit of "necessary form." Self-generated form does not refer to a form created without design or human intervention. Rather, it describes a form whose final configuration is not entirely determined by a predetermined formal decision, but emerges through the interaction of physical, material, environmental, and design conditions. In other words, it is the necessary outcome of such an interaction.

Therefore, the main research question is formulated as follows:

How can self-generated forms provide a basis for explaining architectural aesthetics, and what model does Frei Otto's approach offer for redefining the interaction among aesthetics, technology, and structure?

The research hypothesizes that, in self-generated forms, aesthetic quality largely derives from the degree of internal coherence and necessity between the form and the conditions from which it emerges.

2 | Research Methodology

This study adopts a descriptive-analytical approach based on case studies. The theoretical section examines the concept of form-finding and its relationship with structure, material, and nature. Subsequently, drawing on Frei Otto's works and writings, the concept of "self-generated form" is formulated as an analytical framework.

3 | From Form-Making to Form-Finding

One of the key concepts in this discussion is the distinction between form-making and form-finding. In form-making, the designer first determines the desired shape and then employs technology, materials, and structural systems to realize it. In this approach, the structure essentially responds to a form whose underlying logic has already been established.

In form-finding, however, the relationship is different. The designer establishes conditions in which the physical behavior of a system can reveal part of the form. Consequently, form is not merely "made" but is, to some extent, "found."

This distinction can be summarized as follows:

I. Form-making: idea → geometry → structure → construction.

II. Form-finding: conditions → forces and material → equilibrium → form.

This diagram does not imply the elimination of the designer from the form-finding process. Although the architect continues to determine the boundaries, objectives, materials, scale, function, and many other variables, their role shifts from "fully determining the shape" to "guiding the conditions under which the shape emerges."

4 | Self-Generated Form: A Proposed Concept

In this article, the term "self-generated form" is not intended as a direct translation of an established term in Otto's theory. Rather, it is proposed as an analytical concept for reinterpreting his approach. This distinction is methodologically important. Nevertheless, the proposed concept has a strong affinity with Otto's own discourse on "form-generating processes" and "natural structures."

In this study, self-generated form is defined as a form that:

I. Emerges from the interaction of multiple factors.

II. Is not entirely predetermined from the outset.

III. Involves the active participation of material and structure in its formation.

IV. Is guided by the designer through the establishment of the conditions for its emergence.

V. Maintains a meaningful relationship with the conditions that generate it.

Therefore, "self-generation" does not mean the absence of a designer. The architect establishes the initial conditions; however, once these conditions have been defined, they do not directly impose every characteristic of the form through a predetermined visual or formal configuration.

From this perspective, "self-generated form" can be understood as a form that emerges through the participation of its generating conditions in the design process.

5 | Nature: Form or Process?

In general, two distinct approaches can be identified regarding the ways in which architects draw inspiration from nature. In the first approach, nature is regarded as an image: the designer observes forms in nature and imitates them. In the second approach, nature is considered in terms of its underlying processes. The architect learns important principles from the ways in which forms emerge, grow, and evolve, as well as from the processes of order formation and form-finding. This article emphasizes the importance of adopting the second approach, which is also the approach followed by Frei Otto.

Within this perspective, material is effectively considered part of the process itself. Rather than having the designer mentally or mathematically predict all relationships, the physical system reveals part of the solution through its own behavior. In other words, the behavior of the material reveals the form.

6 | The Aesthetics of Self-Generated Form

Self-generation, in itself, is not a criterion of beauty. A process may lead to different forms, and not every self-generated form is necessarily architecturally valuable. What matters in this article is the relationship between form and the necessity of its emergence. A form in which the observer can perceive a certain harmony among shape, material, structure, and forces possesses aesthetic quality.

In Finding Form, Otto and Rasch distinguish between beauty and the overall quality of architecture, emphasizing the connection among ethical value, efficiency, minimalism, and beauty [1]. They even define desirable architecture through the relationship between ethical and aesthetic values. Therefore, beauty, in this context, is not a quality detached from structure and ethics; rather, it is closely connected to economy, material, efficiency, and the building's relationship with its environment.

6.1 | Necessity: The First Criterion of Beauty

Based on the present analysis, the first component of the aesthetics of self-generated form can be identified as "necessity." Necessity does not imply that only one possible form exists; rather, it means that the selected form possesses an internal justification in relation to its set of conditions. From this perspective, a form that can demonstrate its relationship with forces, materials, function, and the environment possesses a greater

degree of necessity. Conversely, a form that is merely added to a structural system to create a visual effect does not necessarily possess the same quality, even if it is complex and visually striking.

6.2 | Material Economy and Beauty

The second important component in the aesthetics of self-generated forms is "material economy." One of the fundamental characteristics of Otto's work was his interest in lightweight structures and the efficient use of materials. Finding Form also directly addresses the need for buildings that are lighter, less resource-intensive, more compatible with their surroundings, and more closely aligned with natural principles [1].

Material economy should not be understood merely as cost reduction or technical minimization. Here, economy means "sufficiency": neither less than what the system requires nor more than what is necessary. From this perspective, material economy has aesthetic implications, since eliminating redundant elements can make the relationships among components more legible and render the overall system more coherent.

6.3 | Integration of Form, Structure, and Technology

The third component is integration. Form and structure are not two independent layers. Form is what makes structure perceptible, while structure shapes the underlying logic of form. For this reason, the structural technology of self-generated forms, such as those found in Otto's works, is not merely a "behind-the-scenes" matter. In tensile roofs, nets.



Fig. 1. German Pavilion at Expo 67, Montreal.

The defining characteristic of the project lies in the fact that the roof form cannot be separated from the logic of its cable-net structure. The structural network is not a concealed framework behind the architecture; rather, it constitutes an integral part of the architectural expression itself. From the perspective of the aesthetics of Self-Generated Form, the project exhibits three significant characteristics:

I. Form is inseparable from structural logic.

II. Lightness is a direct outcome of the structural system.

III. Geometric complexity emerges from the Form-Finding process rather than from formal ornamentation.

Consequently, the complexity of the roof is not perceived as an exercise in formal elaboration.

6.4 | Munich Olympic Complex

The roof of the Munich Olympic Complex is the most renowned example in Otto's work of the integration of architecture, engineering, and tensile structures. The project was developed by an interdisciplinary team that included Günther Behnisch, Frei Otto, Fritz Leonhardt, and other engineers and specialists.

Jörg Schlaich's study of this project demonstrates that the design and construction of the roof evolved through a complex, multi-stage process, and that the feasibility of constructing the structure itself was initially uncertain [2].



Fig. 2. Munich Olympic complex.

This point is particularly important to our discussion: the final form was not merely the outcome of an architectural image, but rather the result of continuous interaction among ideas, models, calculations, experiments, and construction feasibility. Instead of resting on the building as a heavy mass, the roof of the Munich Olympic Complex extends across the landscape as a lightweight, expansive surface. In this way, a lightweight structural system gives rise to a lightweight form, resulting in greater transparency and a stronger connection with the surrounding site and landscape. This sequence demonstrates that structural technology is not a secondary factor in this project, but rather one of the principal determinants of its aesthetic quality.

6.5 | Mannheim Multihalle

The Mannheim Multihalle is one of Otto's most significant projects in the field of Form-Finding. Completed in 1975 for the Federal Garden Exhibition, the building took the form of a timber gridshell structure. Keller's research identifies the Multihalle, alongside the Montreal Pavilion, as one of Otto's most important projects for examining the relationship between Form-Finding, nature, and architectural politics [3]. In this project, the timber grid is not merely a visual pattern; rather, it is an integral part of the building's structural logic.



Fig. 3. Mannheim Multihalle.

The complexity of the form does not result from formal elaboration; rather, it emerges from the transformation of a geometric and structural logic into architectural space. From this perspective, the Mannheim Multihalle provides an appropriate example for distinguishing between complexity and unnecessary formal elaboration. Complexity becomes problematic when it results from the addition of

unnecessary elements and relationships. In this project, however, complexity arises from the very process through which the building takes shape.

7 | Four Principles of the Aesthetics of Self-Generated Form

Based on the theoretical analysis and the study of Otto's projects, the following four principles can be outlined once again in summary:

I. Necessity: form should maintain a meaningful relationship with the conditions that generate it.

II. Economy: materials, forces, and structural elements should be employed only to the extent necessary and sufficient.

III. Integration: form, structure, material, and technology should function as components of a unified system.

IV. Legibility: the logic underlying the emergence of form should be perceptible through the building's spatial and experiential qualities, even without technical knowledge.

These four principles can be summarized as follows:

Table 1. Four fundamental principles of form-finding and their corresponding aesthetic evaluation criteria.

Criterion	Aesthetic Question
Necessity	Why has the form taken this particular shape?
Economy	Is there anything redundant or unnecessary?
Integration	Do form and structure function as a unified system?
Legibility	Is the logic underlying the form perceptible?

8 | From Possible Form to Necessary Form

At this point, we can arrive at the most important theoretical conclusion of the paper. A distinction must be drawn between two concepts:

I. Possible form: a form that technology makes it possible to produce.

II. Necessary form: a form whose justification and necessity emerge from the interaction of existing conditions—including material, forces, structure, environment, function, and human needs.

In architecture before the advent of digital technologies, limitations in production sometimes naturally reduced the number of possible forms. Today, the situation has been reversed. We are confronted with an abundance of forms. Computational design software and artificial intelligence tools can generate a vast number of alternatives. Consequently, the value of design no longer lies solely in the ability to produce form, but rather in the ability to identify a justifiable form. At this point, the reference to Otto becomes significant. Otto reminds us that formal freedom is valuable only when it is tested against the actual necessities of material, structure, nature, and human needs.

9 | Technology as an Instrument of Knowledge

One of the most important implications of Otto's method for contemporary architecture concerns the changing role of technology. In conventional approaches, technology is employed to realize a form; in the Form-Finding method, however, technology itself becomes an instrument for discovering form.

This distinction also transforms the relationship between aesthetics and technology. When physical models, soap bubbles, or cable nets enable the designer to discover a form that did not previously exist in their mind in a fully defined state, technology becomes part of the architectural thinking process itself. Under these circumstances, structure is no longer merely a servant of form; rather, it becomes a collaborator in the emergence of form.

Perhaps this is the most significant meaning that can be derived from the interaction of aesthetics, technology, and structure in Otto's work.

10 | Why Is Frei Otto Important to Contemporary Architecture?

Otto's significance for contemporary architecture does not lie in the superficial resemblance of his works to digital forms. Rather, his importance lies in a methodological question:

Should technology expand our freedom to create forms, or our ability to discover appropriate forms?

These two objectives are not the same. If technology merely enables the production of more forms, it may lead to the proliferation of visually striking yet unnecessary forms. However, if technology is employed to understand the relationships among forces, materials, the environment, and function, it can lead to an architecture in which form emerges from its actual conditions.

The significance of this question has become even greater today. In 2026, new research in Form-Finding employs machine-learning methods and physics-informed neural networks to discover structurally efficient forms. In other words, contemporary computational technology is once again pursuing the same fundamental problem that Otto addressed through physical models and the behavior of materials [4].

Therefore, Otto's legacy is not a formal language, but rather a way of thinking about the origins of form. Even the Pritzker Prize, in its assessment of Otto's legacy, emphasized the research and exploratory pathways he opened up for architecture, rather than merely presenting a collection of forms to be imitated [8].

11 | Conclusion

By introducing the concept of "self-generated form," this research has sought to redefine the relationship among aesthetics, technology, and structure from the perspective of the process through which form emerges.

An examination of Frei Otto's method has demonstrated that his significance lies not merely in the development of tensile structures, cable nets, or lightweight architecture. His more fundamental contribution was the transformation of the relationship between the designer and form. In Otto's approach, form is not necessarily something that the architect determines entirely in advance and subsequently imposes on the structure. Rather, form can emerge through the interaction of boundary conditions, material, forces, structure, environment, and the designer's guiding intervention [1], [5], [6].

The study of the three principal case studies (the German Pavilion at Expo 67, Montreal; the Munich Olympic Complex; and the Mannheim Multihalle) demonstrated that, in Otto's work, structural technology is not merely a means of realizing a formal idea. Instead, technology is an integral part of the form-generation process itself.

Based on this analysis, four criteria were proposed for the aesthetics of self-generated form: necessity, economy, integration, and legibility. Necessity refers to the relationship between form and the conditions that generate it; economy concerns the sufficiency and efficient use of material and forces; integration refers to the unity of form, structure, and technology; and legibility concerns the possibility of perceiving this order through architectural experience.

From this perspective, the beauty of self-generated form cannot be reduced either to natural beauty or to structural beauty. Rather, it emerges at the intersection of process, material, form, and perception.

Most importantly, this research distinguished between "Possible Form" and "Necessary Form." Possible Form is a form that technology allows us to produce, whereas Necessary Form is one whose justification and necessity arise from existing conditions. This distinction is particularly significant in the age of digital architecture, because the problem today is no longer a scarcity of forms, but rather their abundance. Computational design software and artificial intelligence can generate an enormous number of forms.

Therefore, the fundamental question of architecture must shift from "What can be built?" to "What should be built?"

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All aspects of the research and manuscript preparation were carried out by the author. The author has read and approved the final version of the manuscript.

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Ethics Approval and Consent to Participate

This article does not contain any studies with human participants performed by the author.

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