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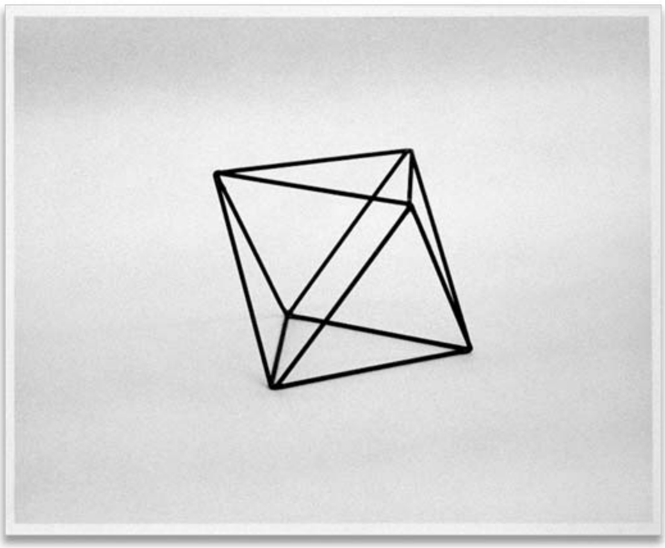

The Physical Model as Means of Projective Inquiry in Structural Studies. The Paradigm of Architectural Education

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ETH Zurich

2018

ABSTRACT

Engaging in the discussion on the shortage of structural design creativity, the present study advocates for the potential of the physical model as a tool for conceptual structural studies (*) of a synthetic rationale. The work embraces a trans-disciplinary mode of discourse, seeking to outline a theoretical framework and propose a relevant methodological means for the structural design inquiry. Within this context, fundamental concepts borrowed from design and visual studies are introduced across two representative case-studies from the structural and architectural realm to highlight the synthetic component of structural studies and the conceptual aspect of the physical model.

To start with, a brief overview of the physical model in architectural education comes to confirm the deficiencies of the prevailing modality: a means to reflect on structural performance, eventually confined in the ways of the scientific paradigm. Instances of a projective praxis – evoking the design culture – are sought as an alternative. Cecil Balmond's informal is suggested as a theoretical basis advocating for synthetic rationale and conceptual awareness.

In this track, Robert Le Ricolais' research is selected as an idiosyncratic, yet seminal, paradigm to disclose the design features (designerly ways) of structural studies; the physical model is employed here as a material diagram to visualize transcending patterns across project series. Seeking to unfold this potential in its full capacity, an example drawn from architectural studies is brought into play. The Austin pedagogy offers a paradigm by excellence to discuss conceptual awareness by means of perceptual constructs within a design context; the physical model serves here as a conscious methodological vehicle of diagrammatic nature for visual reasoning (dialectics of physical modeling), especially appropriate for the design inquiry.

Building on these foundations, a couple of educational practices – borrowed from the ETH-Zurich and the University of Thessaly respectively – explore the notions of the structural concept and the material diagram, suggesting possible strategies in projecting structural schemes by means of physical models.

In times of digital proficiency and proliferation of making, this proposition advocates for a physicality of an intellectual order, a conceptual reductionism by means of material constructs, to nurture the design competences and conceptual awareness for extending the structural inquiry in a creative track.

(*) *study: application of mental faculties in a particular field or to a specific subject* | In the present work, the term structural studies does not refer to a specific academic subject or discipline, such as structural education or structural engineering, but it relates to the term study in a broader sense, thus, discussing the field of inquiries on the theme of structures, building structures in particular.

ZUSAMMENFASSUNG

Als Anstoß für die Diskussion über den Mangel an Kreativität im Tragwerksentwurf spricht sich die vorliegende Untersuchung für das Potenzial des physikalischen Modells als Werkzeug für konzeptuelle Strukturstudien (*) einer synthetischen Denkweise. Diese Arbeit spannt einen fachübergreifenden Diskurs auf und skizziert einen theoretischen Rahmen, woraus ein einschlägiges methodologisches Instrument für Tragwerksuntersuchungen vorzuschlagen werden. In diesem Zusammenhang werden grundlegende Konzepte aus Design und Visual Studien mit zwei repräsentativen Fallstudien aus dem Architektur- und Tragwerksbereich vorgestellt, um die synthetische Komponente im Strukturstudien und den konzeptionellen Aspekt des physikalischen Modells zu verdeutlichen.

Zu Beginn zeigt ein kurzer Überblick über das physikalische Modell in der Architekturausbildung die Mängel des derzeit herrschenden Ansatzes auf: ein Weg, um die Reflexion über die tragstrukturelle Leistungsfähigkeit anzuregen, die letztendlich hauptsächlich auf eine wissenschaftliche Denkweise beschränkt bleibt. Als Alternative dazu werden Beispiele einer projektiven Praxis gesucht, die auf Designkultur hinweisen. Cecil Balmonds *„informal“* wird hierbei als theoretisches Gerüst für eine synthetische Denkweise und konzeptionelles Bewusstsein vorgeschlagen.

Unter dieser Prämisse wird die Forschung von Robert Le Ricolais als idiosynkratisches, doch gleichzeitig zukunftsweisendes Denkmodell verwendet, um Designansätze (*„designerly ways“*) in Strukturstudien zu zeigen; das physikalische Modell wird hier als *Materialdiagramm* benutzt, um transzendierende Muster im Rahmen von Projektserien zu veranschaulichen. Um dieses Potenzial vollkommen auszuschöpfen, wird ein Beispiel aus dem Architekturstudium herangezogen. Die Austin-Pädagogie bietet ein hervorragendes Leitbild, um konzeptionelles Bewusstsein anhand von Wahrnehmungskonstrukten innerhalb eines Entwurfskontexts zu diskutieren; das physikalische Modell dient hier als bewusstes methodologisches Mittel diagrammatischer Art für visuelles Denken (*Dialektik der physikalischen Modellierung*), das besonders für die Designuntersuchung geeignet ist.

Auf dieser Grundlage werden anhand von zwei Lehrmethoden – der ETH-Zürich bzw. der Universität von Thessalie – die Begriffe des strukturellen Konzepts und des Materialdiagramms untersucht, wobei mögliche Strategien bei der Projektierung struktureller Schemata mittels physikalischer Modelle vorgeschlagen werden.

In Zeiten digitaler Kompetenz ist das physikalische Modell ein konstruktiver Vorschlag, um Tragwerksuntersuchungen auf eine kreative Bahn zu bringen, indem die intrinsischen Eigenschaften der Architekturausbildung genutzt werden und um Entwurfsaspekte aus den Bereichen Architektur und Tragwerksentwurf zum gegenseitigen Nutzen zu aktivieren.

(*) *Untersuchung: Anwendung geistiger Fähigkeiten auf einem bestimmten Gebiet oder zu einem bestimmten Thema* |
In der vorliegenden Arbeit bezieht sich der Begriff Strukturstudien nicht auf einen bestimmten akademischen Fachbereich oder eine Fachrichtung wie der Tragwerkslehre oder Tragwerksplanung, sondern bezieht sich auf den Begriff Studien im weiteren Sinn, folglich wird der Untersuchungsgebiet für das Thema Strukturen, insbesondere Gebäudestrukturen diskutiert.

CONTENTS

Introduction

THE CONTRIBUTION

Creative structural design has had a significant impact in the history of building structures; its contribution, acknowledged by the large public, has come to be established in scholarly discourse in recent years. The fascinating forms of Gaudi or Otto, the emblematic structures of Maillart or Eiffel, the distinctive works of Isler, Nervi, Candela or Torroja, the influential legacy of Arup and Happold or the seminal contributions of Rice and Balmond, they all constitute seminal milestones in the course of human culture.

Across all noteworthy examples – often operating on the threshold of structural and architectural realm – creative imagination and conceptual awareness, coupled with an intuitive reasoning, are brought forward as the catalysts for structural design excellence.

THE DEFICIENCIES

While the schemes of prominent structural designers are celebrated in discrete instances, in the prevailing paradigm, however, a shortage of conceptual synthetic structural awareness – in the early design process in particular – has been denoted as a major shortcoming of the field; the assumed disciplinary profiles of structural engineering and architecture often accounting for the attested deficiencies.

In the bifold model seen in practice, conceptual structural design in orphan by definition, as the objectives, competences and skills are split between the two professions – conceptual for the architect, structural for the engineer – and the design process is confined in a sequential modality. Structural education comes to comply with this actuality, perpetuating the disciplinay gap. Aspiring to comply with engineering practices, it fails to activate the intrinsic features of the architectural realm, missing, in turn, on the opportunity of an interaction with the design culture. In brief, both engineering and architecture seem to lack the theoretical framework, the educational strategies and the didactic vehicles that would allow to discuss the conceptual design component of structural studies.

NEW PARADIGM:
HYBRID PRACTICES

Nonetheless, in recent years a new paradigm comes to the forefront, triggered by the advent of parametric modeling and fabrication technologies. In the light of the so-called "*structural turn*", a renewed interest in structure, materiality and the culture of making is manifested, stimulating a vivid exchange between disciplines. The trend is characterized by a keen emphasis on projective praxis coupled with, if not actuated by, a rigorous engagement with intellectual queries. The theme of "*structuring*"[1], both as a material and conceptual

[1] The Oxmans (Oxman & Oxman, 2010) pp.17, 23, 15 note on the "*new structuralism*" and the key role of design engineering in this emergent cultural shift:

> *The new structuralism integrates structuring, digital tectonics, materialisation, production and the research that makes this integration possible. […] This is an architectural design that is motivated by a priori structural and material concepts and in which structuring is the generative basis of design. […] the design engineer, in his prioritising of materialisation, is the pilot figure of this cultural shift which we have termed the 'new structuralism'.*

construct, becomes fundamental to this cultural shift, while a conscious quest for creativity is brought forward in professional and academic settings alike. Echoing propositions of multi-disciplinary origin, within and beyond the sphere of building structures, the evolutionary paradigm/ discourse comes to challenge the typological realm, while the "*informal*"[2] questions precedent-based thinking in professional practice. Embracing a projective modality, the notion of type is dissolved; the performative comes to substitute for the formal; the diagram offers an alternative to discuss mutliplicities vs. singularities, moving away from the discrete to the continuous.

A new model has risen; a generation of hybrids – operating between theory and practice, engineering and architecture, research, academy and the profession – have come to embrace this cultural turn. While the synergies, competences and profiles of the (building) design disciplines are revisited, structural design becomes relevant in scholarly discourse.

In reviewing the current state of affairs between engineers and architects, Flury[3] advocates for a condition of "*inquisitive openness*"[4]. The potential of the trans-disciplinary paradigm unfolds across a model of "a close design relationship between the architect and the engineer", where both contributors will assume authorship and jointly engage in the creative process.

> *The prerequisite for [active cooperation and teamwork] is an attentive, inquisitive almost Faustian readiness to cross borders: Architects can find the key to a fruitful dialogue if they rediscover the master builder in themselves, the building designer with a keen understanding of structure. The engineers, on the other hand, would refresh their approach if they combined 'sensibilità statica' (Pier Luigi Nervi) with a spatial sensibility […]. The engineer would become an author, like the architect, which would shift the focus of attention and redefine their relationship.*[5]

NEW ACADEMIA

A growing number of scholarly events – some with long-standing tradition (i.e. IASS, eCAADe, …) and others that have appeared only recently (i.e. ICSA, Advances in Architectural Geometry, Digital Modelling, Fabricate, RobArch, …) attract architects and engineers alike, calling for "researchers and practitioners […] with cross-disciplinary trajectories"[6].

As the fusion of disciplines is enabled within progressive professional milieus and research clusters, academia is being redrawn. Graduate education has welcomed – if not triggered – these shifts. A reinstated confidence in projective praxis is manifested, characterized by interdisciplinary practices and a proliferation of design-build activity. In undergraduate education, the imprint of these changes is smaller. While interdisciplinarity is limited, a dynamic has emerged in recent years reflecting on the synthetic component of structural studies. Shared by both engineering and architecture, a growing concern on

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[2] On Balmond's "*informal*" see (Balmond & Smith, 2002).

[3] See (Flury, 2012a).

[4] See (Flury, 2012b) p.15.

[5] Ibid.

[6] Borrowed from the call for proposals for the conference *Fabricate 2018*.

questions of rather epistemological or pedagogical nature emerges, addressing the mode and methods of the structural design inquiry.

In civil engineering curricula, a distinct track focusing on structural creativity stems from the works of Billington. Stepping beyond the boundaries of the scientific paradigm, the track explores the origins and conditions of structural design excellence across a series of exemplary practices insisting on the instrumental role of history as a source of inspiration; modes of inquiry largely employed by other disciplines (i.e. case-studies, visual evidence and physical modeling) are borrowed to emphasize the reflective component of structural studies as an essential requirement for a creative praxis. Engaging with a projective rationale, a new dynamic evolves in academia[7], advocating that engineering design involves "*discipline and play*" – a term popularized by Billington[8] – "where discipline refers to technical skills, and play refers to creative and aesthetic exploration"[9]. The initiative adopts an exploratory pedagogy via problem-solving scenarios and hands-on activities to enhance structural engineering creativity, eventually seeking to highlight the creative component of the so-called STEM disciplines[10]. Borrowing didactic strategies from the constructivist realm, an active-learning pedagogy – familiar to architectural education – is introduced as means to expand the analytic skills of the engineer to the synthetic realm.

Coming from the opposite direction, in architectural education, the necessity to integrate structural questions in a synthetic perspective has been part of a long-standing discussion[11], seeking to activate the design competences of the architect within the structural realm. Enhanced by a reinstated confidence in the projective modality, the quest for conceptual structural design competences has recently resurged, revisiting an enduring tradition in creative practices. A broad range of methods and tools – quantitative or qualitative, analytical or graphic, digital or physical – are employed in an attempt to activate the synthetic component of structural studies, bringing evidence of diverse educational models or pedagogical strategies. Allen[12] advocates for the contribution of synthetic-oriented assignments towards structural design competences:

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[7] For a representative example, see the initiatives of the academic consortium led by Prof. Dr. M.Garlock at Princeton University (CASCE, 2015), (Bhatia & Chen, 2015), (Bhatia, Garlock, & Laffey, 2016): *Workshop on the Creative Art of Structural and Civil Engineering* (Princeton University, June 2015), NSF-funded educational project *Creative Art of Structural and Civil Engineering-CASCE* (Princeton University, Virginia Polytechnic and State University, University of Massachusetts-Amherst, 2014), *International Network for Structural Art* (INSA).

[8] See (Billington & Cole, 2005). See also Billington (Billington, 1983) pp.213-232 on Isler's "perhaps startling idea of play".

[9] See (CASCE, 2015) p.5.

> *Through the introduction of problem-solving scenarios and exploratory learning, students will be engaged in finding solutions, allowing for a deeper examination of a subject and the development of critical thinking skills.*

[10] STEM disciplines: Science, Technology, Engineering and Mathematics.

[11] See (Dermody, Oakley, & Uihlein, 2016).

[12] See (Allen & Zalewski, 1998) p.97. See also (Allen, 1997).

The principles of statics may be learned through students' involvement with either the conventional assortment of small, abstract, purely analytical exercises, or the creative design of original, large-scale, often exciting structures. […] the creative approach, combining as it does both synthetical and analytical activity, is […] much more effective in starting students briskly along the road to becoming complete, confident designers of structures.

MEANS OF INQUIRY

Although numerical tools have been often held responsible for poor design competences, structural digital applications have insistently fostered intuitive reasoning within an analytic or synthetic perspective over the last couple of decades; quickly absorbing lessons of the past and investing in the visual culture and graphic skills of architecture students. Maturing within the parametric realm, digital modeling has grown to discuss generative practices via "*trans-typological*"[13] methodologies or "*white-box tools"*[14].

Physical models, on the other hand, have for long served as means to enable quantitative or qualitative understanding of structural performance or structural configurations, taking advantage of the modeling practices of the design culture. Hands-on activities are encouraged within an active-learning pedagogy, while the synthetic component unfolds across brief design assignments or competitions. Aspiring, however, to comply with the engineering realm, the physical model can't escape the, otherwise celebrated, tradition of the so-called "structural model"; it is mostly used to bring concrete evidence within the framework of a controlled experiment in a laboratory setting. Trapped within its very pragmatic materiality, the physical model serves primarily as means to reflect on structural configurations or performance, eventually confined in an analytic modality that originates from the scientific framework.

A perspective borrowed from the field of design studies could indeed serve as a broader context to evoke the features of the design culture in the structural realm and unlock the full potential of the physical model in serving a synthetic rationale in structural studies. Assuming that the attested deficiencies of the dominant model are not to be related to the employed medium, but to the prevailing mode of reasoning instead – reverberating a misconception of epistemological origin on the nature of the discipline – the present study embraces, therefore, a trans-disciplinary discourse seeking to outline a theoretical framework and propose a relevant methodological means for structural inquiries of projective nature.

Two representative examples, drawn from the structural and architectural realm respectively, are brought forward, seen through the perspective of design and visual studies, to disclose the synthetic component of structural

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[13] See (Mueller & Ochsendorf, 2013) on a "*trans-typological structural grammar methodology*".

[14] See (Block, Van Mele T, & Rippmann, 2016) pp.48, 54 on the imperative to "whiten the box":

It is time to whiten the box, but also to think outside it, to allow for alternatives, to exploit the indeterminacy of problems, to visualize the design space, and finally, to develop the means to explore that space. […] we should put greater effort into the development of computational "white box" tools. Instead of automated, design-by-analysis, black-box tools that merely give the designer the feeling that he or she is obtaining sophisticated, (r)evolutionary solutions, we advocate the use of tools that truly educate designers in the process of designing.

studies and the conceptual aspects of the physical model. Robert Le Ricolais' research is selected as an idiosyncratic, yet seminal, paradigm to illustrate creative practices in structural studies, revealing the design features (*designerly ways*) of the structural inquiry. The Austin pedagogy offers a paradigm by excellence to discuss conceptual awareness by means of perceptual constructs within a design context; unfolding the potential of physical modeling as a cognitive means for non-verbal reasoning, particularly apt for the design inquiry.

The context of architectural education provides a fertile ground to welcome a reflection-in-action on the nature of the structural inquiry; the design culture allowing to activate the creative aspects of the structural and architectural realm. Within this context, a couple of educational practices – borrowed from the ETH-Zurich and the University of Thessaly respectively – come to extend the contribution in a projective modality; the two examples suggest alternative strategies in exploring structural schemes by means of physical models.

Confident about the design component of the structural inquiry and the cognitive value of the physical model, the present study relies on the intrinsic features of architectural education to make a case for the potential of the physical model as means to extend structural design in a creative track. In times of digital proficiency and proliferation of making, this proposition advocates for a physicality of an intellectual order, a conceptual reductionism by means of material constructs, to nurture design competences and conceptual awareness for the structural inquiry.