Dissertation Abstract

Modeling Shape-Changing models of Modern Structural Systems with Responsive Architecture Solutions

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Responsive architecture constitutes a niche field, undergoing dynamic transformation and continuously seeking both elementary solutions and more complex approaches within its thematic scope, with the aim of enhancing the efficiency of material resource utilization. This is achieved by reducing the material input required for the realization of structures through the substitution of matter with motion, thereby generating a positive balance between the implementation costs of responsiveness and those of static objects. The considerable individualization of approaches to modeling responsive solutions, combined with the inherently interdisciplinary character of the field—manifested in the complex influence of structural considerations at both the conceptual and implementation stages on the effectiveness of solutions—significantly hinders research progress, rendering the domain exclusive. The approaches to architectural modeling presented in this dissertation, addressing fundamental challenges of responsive architecture, are intended to increase the universality of the process of developing responsive solutions.

Simultaneously, the dissertation presents a set of issues that constitute a foundation for further, more in-depth research in each of the topics discussed, alongside an evaluation of a tool designed to investigate behavioral tendencies of geometric transformations in responsive structures, implemented in the form of an evolutionary algorithm. The dissertation examines models of geometric change, as well as the design of elements in terms of geometry and performance, fulfilling specific requirements of form and operation to enable motion in architectural contexts. A number of components aimed at shaping future structural systems of responsive architecture were developed during the research process. Methods for assessing their performance, temporal variability, efficiency, and functional scope were subsequently proposed.

The research objectives, centered on the use of an evolutionary algorithm, outline a trajectory of work largely dedicated to the temporal variability of structural forms. Differences in the modeling of motion across distinct types of structures are discussed, emphasizing their unique static and behavioral characteristics, as well as their impact on the realization of responsiveness. A wide range of studies were conducted, employing original research methods and a specially designed experimental setup that enables a more universal implementation of responsiveness. These investigations encompassed both structural motion forms and methods for evaluating their efficiency, measurement techniques for responsiveness potential, and the validity of elementary solutions. By means of experimental series, the dissertation demonstrates the influence of research complexity on outcomes, highlighting the necessity of macro-scale testing with minimized boundary conditions, owing to the inherent difficulties of precisely defining such conditions in responsive architecture.

The dissertation is divided into two major parts: the introductory section, which outlines postulates, historical development, and the current state of responsive architecture; and the research section, dedicated to analyzing behavioral models and evaluating responsive solutions. The research component is organized around six principal topics: responsiveness in truss structures, responsiveness through dynamic relaxation simulations, effective shell behavior models, geometric variability of spatial frames, structural system design for responsive models, and, as the key contribution of the dissertation, topological responsiveness. In all these areas, methodologies for investigating responsiveness are presented, along with original models of structural behavior and spatial forms, followed by performance assessments, analytical interpretations, and the delineation of future research directions.

The introductory discussion of responsiveness, consisting of three chapters, examines its historical evolution as a concept encompassing both variable models and independently developed measurement and computational systems. Current research directions and their characteristics are analyzed, alongside fundamental challenges of responsive architecture, both contemporary and originating at its inception. Research hypotheses and objectives are formulated, and the construction of a specialized experimental setup—tailored to the creation and investigation of responsiveness—is described.

The research section is characterized by a systematic structure, though each chapter addresses a distinct issue. Chapter IV discusses elementary responsiveness of spatial trusses, enabling deterministic motion based on dynamic relaxation of analogous structures, with a focus on parameter optimization to maximize efficiency. Chapter V examines shell structures and their motion systems, encompassing both the modeling of motion and the development of elementary structural solutions. Chapters VI and VII introduce modifiers for shell and frame models, enabling localized stress adjustments and geometric control. These solutions are first presented conceptually, followed by the development of simulation models and programmed behavioral mechanisms for structures incorporating them. Chapter VIII introduces the concept of "preactions," intended to enhance structural behavior models by accelerating responses to changes in external loads. Chapter IX diverges from previous chapters, focusing on the design of structural systems rather than behavioral models. Addressing the notable lack of dedicated structural systems for responsive objects, a method for system design is proposed.

Chapters X and XI present the concept of topological responsiveness. Its assumptions are formulated, anticipated effects are described, and models meeting these criteria are developed. These chapters combine behavioral modeling with physical experimentation, thus introducing a novel research approach. Multiple structural modules and their placement within spatial structures are investigated, assessing the parameters most effectively governed by topological responsiveness and defining the functional scope and limits of its practical applicability. Each research topic is treated as a distinct field of study, with results that cannot be directly transferred across domains. Accordingly, each topic is summarized individually, and directions for further research are proposed. Due to their originality, most areas require expansion of elementary studies before advancing to more complex conceptual work and subsequent simulation and physical modeling.