embryo-project | Architecture

Poster 1/2

Physical to Digital Form-Finding

Bridging the gap between physical and digital realms for structural design and analysis: Exploring form-finding models and their dynamic behavior

Principal Investigator / PI
João Pedro do Carmo Fialho

Integrated Researchers of CIAUD
António José Morais
Cristina Figueiredo
João Pedro do Carmo Fialho

Collaborating Researchers of CIAUD
Alexandrino José Basto Diogo
David Afonso Gonçalves

External Researchers

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Physical models; Form-Finding; 3D Scanning; Structural design and analysis

Partner Institutions
Gaudí Knowledge Association

Qualisys | Motion Capture Systems

Expected Future Partner Institutions
Faculty of Architecture, Innsbruck University

Creaforrm | 3D Scanners

OBJECTIVES

The goal of the research is to establish a comprehensive methodology that combines physical modeling and digital techniques for structural design and analysis.

The investigation focuses on the design of structures using various form-finding techniques (such as funicular, tensile, pneumatic, or tensegrity models). Subsequently, the intention is to capture the geometry of physical models through 3D scanning and motion capture. With these, it's possible to analyze the static equilibrium and dynamic behavior of the models when subjected to different forces such as wind, earth movements, or snow.

The objective is to validate the methodology with practical examples and case studies that demonstrate the different steps and its usefulness in evaluating and designing new structures.

The investigation also aims to share research findings through publications, conferences, and workshops. In conclusion, the investigation seeks to have a positive impact on society and industry promoting sustainability, enhancing safety and aesthetics, fostering innovation, driving cost efficiency and contributing to economic development in the construction sector.

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ABSTRACT + IMAGES

Over the past few years, computer-aided design (CAD) and the advent of parametric modeling has enabled the creation of complex three-dimensional shapes that allows the exploration of a wide variety of architectural solutions. However, the digital environment is not ordered by the physical constraints we face in the real world. In most cases, neither the forces nor the materials are considered, only its geometry.

Understanding the capabilities of materials is critical for the design of an efficient structure. The stability of buildings composed of materials resistant to compression (such as brick, stone and concrete) depends on geometries that do not produce tension. On the other hand, the stability of buildings made of materials that resist tension (such as ropes, steel cables or fabric) is determined by geometries that do not produce compression. Thus, the stability of structures in compression or tension depends on the absence of transverse forces, as they generate bending and, consequently, both stresses simultaneously. To ensure the resistance of a structure undergoing flexion, it is necessary to use materials capable of withstanding both efforts simultaneously. Generally, these materials are composites, that is, they are made up of two components with different resistance capacities. (such as reinforced concrete or glass fiber reinforced polymers). In short, the choice of material determines the resistance capacity and the restricted/infinite set of geometric possibilities that allow the stability of a structure.

Understanding the type of materials available provides important data to trigger a systemic bottom-up design process. A light, economical, safe and expressive structure requires a harmonious relationship between its form, forces and matter and this unity can only be achieved with systemic design and construction methods. Among some architects and engineers, the awareness that the design of a structure shouldn't be simply based on visual concerns (form-making), but as the direct consequence of the different forces and materials (form-finding) motivated a shift in their methodology.

Physical models of form-finding aren't just prototypes of a certain geometrical composition in a smaller scale; they also inform the properties of its structure. This ability to make new structures while understanding its physical properties is precisely the reason why these models should continue to play an important role in architectural and engineering practice.

Each in its own way, physical models of form-finding are all based on a simple and prevailing principle: the greater the deformability of a system, the more its shape will approach the external forces that it is subject to. As a result, the final state of equilibrium appears from the deformation of matter in a transitory state of unbalance: a bubble or a cluster of bubbles acquires the right shape of a pneumatic membrane; a soap-film between threaded strings search for the exact form of a tensioned structure; the inverted form of a hanging chain, net or fabric displays the most efficient arrangement of an arch or vault in pure compression; and a group of bars under compression linked with strings and membranes under tension organize themselves to obtain a perfectly balanced tensional integrity.

Presently, physical form-finding models are mostly used as a pedagogical tool for statics and structural design classes. The abandonment of these processes as a tool for structural design and analysis was due to the arrival of computational methods that simulate their behavior (such as dynamic relaxation, thrust network analysis, particle spring systems and others). Replacing physical models with computational ones allows the design, analysis and fabrication in a "digital continuum". However, the form-finding models have other qualities: they not only allow a closer understanding of the relationship between the physical properties, its scale and proportions; but also enable to intuitively find geometries that, in many occasions, cannot be easily described.

This investigation presents a methodology for structural design and analysis that involves a continuum between physical modelling and its transposition to the digital environment. The methodology is carried out through the design of structures with funicular, tensile, pneumatic or tensegrity models. After and during model making, the geometries are collected through 3D scanning or motion capture. With this, it is possible to obtain the geometry of the structure in static equilibrium and the dynamics of the internal stresses when it is subjected to various impulses (such as wind, earth movements and snow).

Overall, this investigation will present the methodological framework and practical examples of its application for the evaluation and design of light, stable and aesthetically pleasing structures.

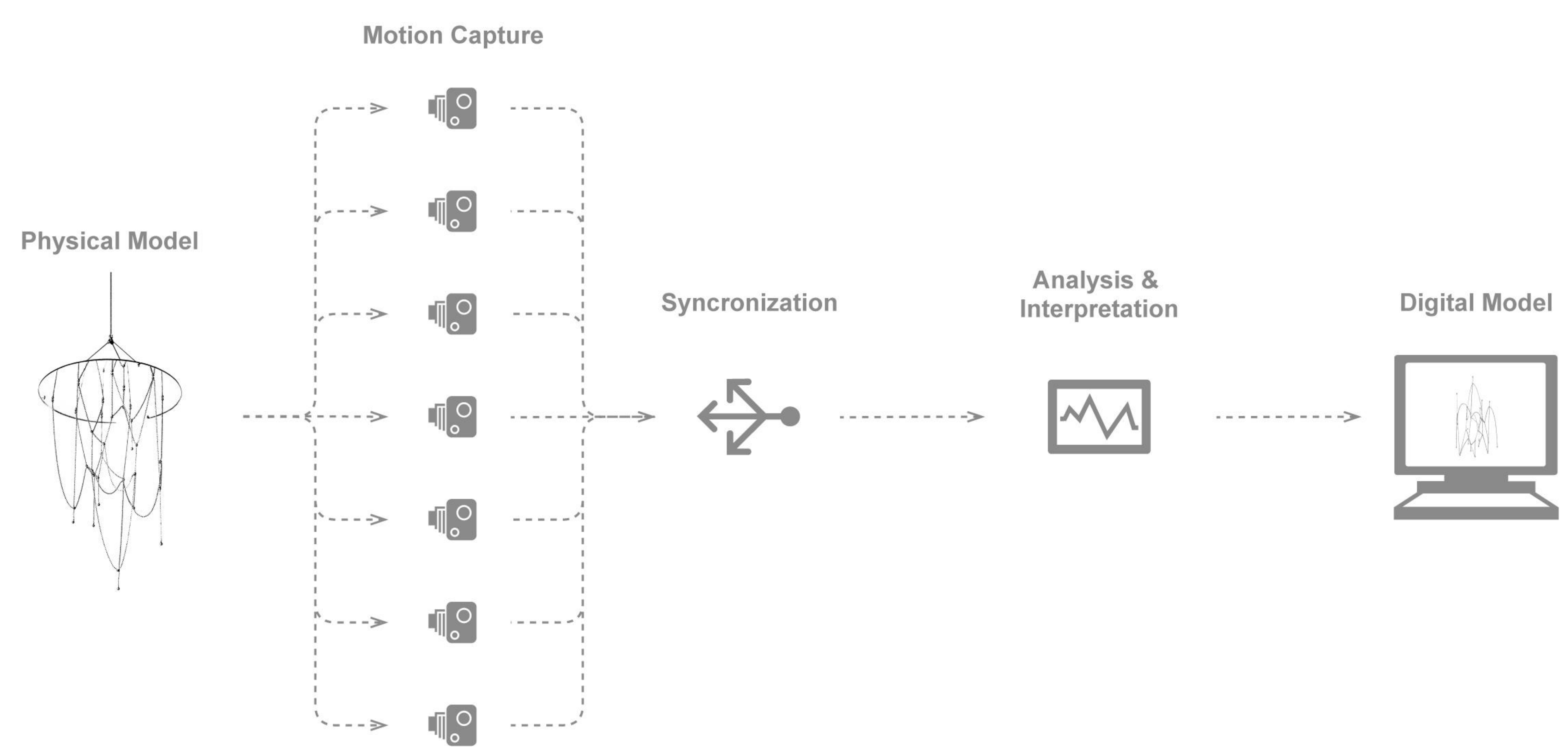

Fig. 1 – Motion capture process. (Gonçalves, D.)

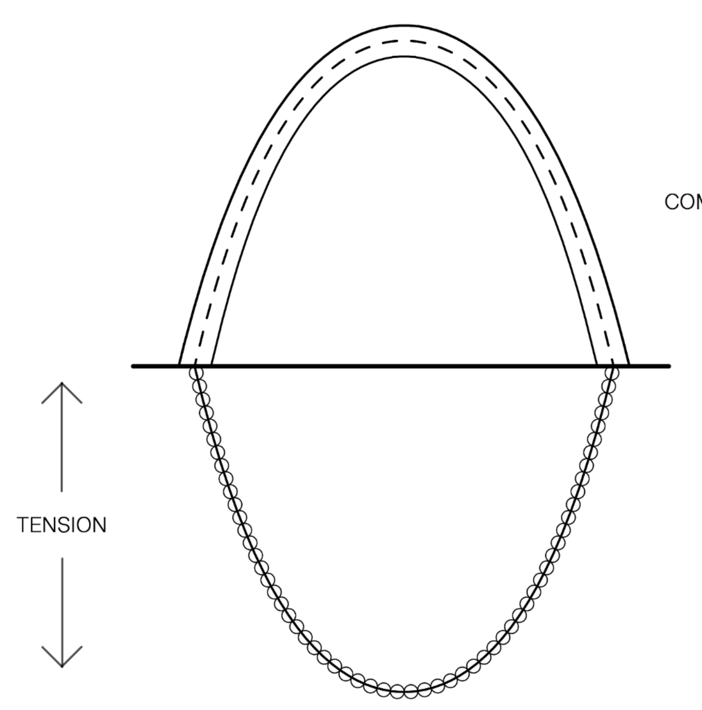

Fig. 2 – Illustration of Hooke's principle of inversion (copy of an illustration by Poleni G.).

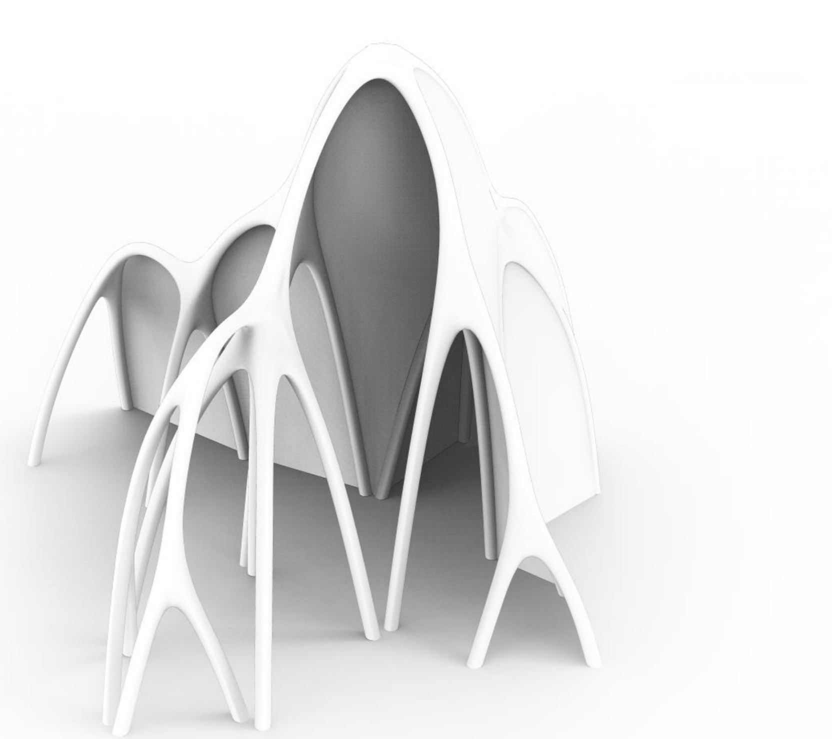

Fig. 3 – Digital representation of an antifunicular structure composed with the data extracted from a physical model of suspended chains. (Gonçalves, D.)

embryo-project | Architecture

Poster 2/2

Physical to Digital Form-Finding

CiAUD Centro de Investigação em Arquitetura, Urbanismo e Design

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SCIENTIFIC RELEVANCE FOR THE DISCIPLINE

The following are some of the scientific relevance of this investigation:

1.Advancement of Methodological Integration: By combining physical modeling and digital techniques, the investigation pushes the boundaries of traditional approaches to structural design.

2.Optimization of Structural Performance: By capturing the geometry and analyzing the behavior of physical models under different forces, the investigation aims to optimize structural performance.

3.Integration of Physical and Digital realms: The investigation seeks to seamlessly integrate physical modeling with advanced technologies such as 3D scanning and motion capture. This integration facilitates data capture, analysis and interpretation.

4.Practical Application and Impact: By demonstrating the effectiveness of the methodology with practical examples, the investigation has the potential to influence industry practices, informing architects, engineers, and designers about the benefits and possibilities of integrating physical and digital techniques in structural design.

EXPECTED ECONOMIC AND SOCIAL IMPACT

1.Sustainable Design Practices: By optimizing structural performance the investigation promotes sustainability.

2.Improved Safety: The analysis of structural behavior under different forces helps improve the safety and resilience of structures.

3.Enhanced Aesthetics and Public Spaces: The integration of physical models of form-finding and digital techniques allows for the creation of visually appealing and distinctive structures. This can positively impact the quality of life and cultural experiences for individuals.

4.Cost Efficiency: By designing lightweight and efficient structures, construction, material expenses, and long-term maintenance costs can be reduced, making projects more economically viable.

5.Market Differentiation and Innovation: The integration of physical and digital techniques in structural design offers a unique selling proposition for professionals and firms involved in the construction industry.

6.Economic Development: The investigation's impact extends beyond individual projects, potentially contributing to broader economic development..

RESEARCH PLAN AND TASKS

By following this research plan and conducting the specified tasks, the investigation aims to develop a comprehensive methodological framework that integrates physical and digital techniques for structural design and analysis. The research seeks to contribute to the scientific community's understanding of the integration of these techniques and their implications in the field.

The first task in the research plan is to conduct an extensive literature review. This review will involve exploring existing literature on structural design methodologies, form-finding techniques, the integration of physical and digital modeling approaches and methods to capture physical data. By examining key concepts, methodologies, and technologies, the research will establish a strong theoretical foundation for the investigation.

The subsequent task is the development of the methodological framework. Building upon the knowledge gained from the literature review, the framework will be defined and constructed. This will include the selection of appropriate tools, software, and equipment necessary for the implementation of the methodology. Consideration will be given to the integration of physical and digital modeling techniques, and the steps and procedures involved in this integration will be determined to ensure a cohesive and effective approach.

Another important aspect of the investigation is the selection of specific model types that align with the research objectives. Model types such as funicular, tensile, pneumatic, or tensegrity models will be explored in detail. Their characteristics, advantages, and limitations will be studied to determine their relevance to the research goals. This exploration will provide a comprehensive understanding of each model type's potential and limitations in the context of structural design and analysis.

To capture the geometry and behavior of the physical models, an experimental setup will be established. This setup will include the necessary equipment for physical modeling, 3D scanning, and motion capture. Physical instruments will be designed to facilitate the form-finding process of model-making. Through carefully designed experiments, the research will capture data using 3D scanning or motion capture technologies. This data will serve as a basis for analysis and evaluation in subsequent stages of the investigation.

The captured data will undergo thorough analysis and evaluation. Relevant geometric and structural information will be processed and analyzed to extract meaningful insights. The static equilibrium of the models will be evaluated, and the dynamic behavior of internal stresses under various external forces, such as wind, earth movements, or snow, will be investigated. Advanced analysis techniques and software will be applied to interpret the data and draw valuable conclusions. This analysis and evaluation process will provide a comprehensive understanding of the behavior and performance of the physical models.

Practical examples and case studies will be developed to showcase the application of the developed methodology for structural design. Specific structural scenarios will be designed and analyzed using the integrated physical and digital techniques. These examples will serve as demonstrations of the effectiveness and applicability of the methodology in real-world situations. The results of these examples will be thoroughly documented and presented, highlighting the benefits and effectiveness of the methodology in addressing structural design and analysis challenges.

The documentation of the research process will be a crucial aspect of the investigation. The entire research process, including the experimental setup, data acquisition, analysis methods, and results, will be carefully documented. This documentation will provide transparency and reproducibility, enabling other researchers to build upon and validate the findings of the investigation. Additionally, the research findings, methodology, and insights will be disseminated through research reports, papers, and presentations. Contributions to relevant conferences, workshops, or journals will be made to share the research outcomes and engage with the scientific community.

Towards the end of the research plan, the project will undergo evaluation to assess the success and effectiveness of the developed methodology in achieving the research objectives. The evaluation will consider the extent to which the methodological framework meets the research goals and whether it provides valuable insights and solutions in structural design and analysis. Reflection on the limitations encountered during the investigation and potential areas for improvement in future research will be provided.

In conclusion, by following this research plan and conducting the specified tasks, the investigation aims to develop a comprehensive methodological framework, explore different model types, capture and analyze data, provide practical examples, document the research process, and contribute to the scientific community's understanding of integrating physical and digital techniques in structural design and analysis. This research has the potential to advance the field by offering new insights, methodologies, and practical applications for structural design and analysis, ultimately leading to more efficient and sustainable structures.

Research Plan and Tasks List:

1. Literature Review:
   - 1.1 Conduct an extensive review of existing literature on structural design methodologies, form-finding, and physical and digital modeling approaches;
   - 1.2 Identify key concepts, methodologies, and relevant;
2. Methodological Framework:
   - 2.1 Define and develop the methodological framework;
   - 2.2 Identify and select appropriate tools, software, and equipment;
3. Selection of Model Types:
   - 3.1 Identify and select specific model types, such as funicular, tensile, pneumatic and tensegrity models;.
   - 3.2 Study the characteristics, advantages, and limitations of each model type;
4. Experimental Setup and Data Acquisition:
   - 4.1 Set up the experimental environment, including: physical modeling, 3D scanning, and motion capture;
   - 4.2 Design and construct physical instruments;
   - 4.3 Conduct experiments to capture the geometry and behavior of the physical models using 3D scanning and motion capture technologies;
5. Data Analysis and Evaluation:
   - 5.1 Process and analyze the captured data to extract relevant information;
   - 5.2 Evaluate the static equilibrium of the models and investigate the dynamic behavior of internal stresses;
6. Practical Examples and Case Studies:
   - 6.1 Develop practical examples to showcase the application of the developed methodology;
   - 6.2 Design and analyze specific structural scenarios using the integrated physical and digital techniques;
   - 6.3 Document and present the results, highlighting the benefits and effectiveness of the methodology in real-world applications.
7. Results Presentation and Documentation:
   - 7.1 Prepare research reports, papers, and presentations summarizing the findings;
   - 7.2 Document the research process, including experimental setup, data acquisition, analysis methods, and results;.
   - 7.3 Contribute to relevant conferences, workshops, or journals to disseminate the research and insights gained;.
8. Project Evaluation and Conclusion:
   - 8.1 Evaluate the success and effectiveness of the developed methodology based on the research objectives and outcomes.
   - 8.2 Reflect on the limitations and potential areas of improvement for future research.
   - 8.3 Provide a comprehensive conclusion summarizing the key findings, contributions, and potential implications of the research.

EXPECTED SCIENTIFIC RESULTS

1.Development of a Methodological Framework: The research aims to establish a robust methodology that combines physical modeling and digital techniques for structural design and analysis.

2.Enhanced Understanding of Structural Behavior: By capturing the geometry of form-finding models through 3D scanning or motion capture technologies, the research will yield insights into the static equilibrium and dynamic behavior of structures.

3.Validation of the Methodology: Through practical examples, the research will demonstrate the application of the methodology. The successful application of the methodology in real-world scenarios will serve as a validation of its practical utility.

4.Advancements in Form-Finding Techniques: By utilizing funicular, tensile, pneumatic, or tensegrity models, the research will contribute to the exploration of new possibilities for lightweight, efficient, and innovative structures.

5.Dissemination: The research outcomes will be disseminated through research papers, conferences, and workshops. This will contribute to the broader scientific community's fostering further research and innovation in the field.

BUDGET: € 7.500,00

The necessary expenses for conducting this investigation include:

1. Purchase or rental of 3D scanning equipment or motion capture system.
2. Acquisition of necessary hardware and software for data processing and analysis.
3. Acquisition of physical modeling materials and tools (such as chains, magnets, fabrics, metallic plates, etc.)
4. Purchase of consumables and expendables required for the experiments, such as reflective markers, tapes, calibration objects, etc.
5. Travel expenses for attending conferences, workshops, or research meetings to present findings and exchange knowledge with the scientific community.
6. Fees associated with publishing research papers in scientific journals or conference proceedings.