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THE SERIES IS INDEXED IN SCOPUS

Alessandra Zanelli · Carol Monticelli ·
Nebojsa Jakica · Zhengyu Fan
Editors

Lightweight Energy

Membrane Architecture Exploiting Natural Renewable Resources

Fondazione Politecnico di Milano

Springer

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Foreword

Starting from the title, this book contains all the keywords the built environment is asked to deal with, to address more effectively the huge challenge deriving from the environmental emergency. “Lightweight” is a strategy to reduce the CO_2 emissions burden, “energy” is needed to run our activities, “membrane” reminds us of the crucial importance the envelope is more than ever playing on a building performance, “natural” recalls the newly re-emerging biophilia trend which moreover appeared of dramatic urgency in pandemic times, “renewable”, one of the pillar concepts of circular economy, “resources”, in other words what we extract, produce and exploit in a hopefully circular way to make our activities run and, finally, “architecture”: because ultimately buildings are intended and designed to be comfortable, healthy and beautiful.

How to analyse, develop and combine all these aspects? This is the challenge behind this book, which moreover describes an innovative approach for building products and solutions, with a special focus on ultra-lightweight materials and membrane structures.

As a matter of fact, the challenges, I mentioned, ask for a holistic integrative approach. The progress in addressing the climate issues, even adopting some sustainability strategies, has been barely visible so far. A different mindset is needed, implying the transition to a regenerative scenario for the built environment and the building industry.

Beside the design strategies, isn’t a building anything else than an assembly of materials? Under this perspective, this is where most of the sustainability issues lie. Manufacturing companies are now called to a reconsideration and in most cases a radical transformation of their production processes, addressing the whole life cycle of their products. As the International Living Future Institute (ILFI) Living Product Challenge certification reads out, “What if products improved your quality of life and helped ecosystems thrive?” For that, research and continuous innovation, as well exemplified in this book are key.

To leave the fossil fuels era, which is hopefully the end goal the economic sector should pursue with conviction, a strategy towards carbon neutrality is to be adopted. This is where the solutions described in this book find a great relevance. Achieving

Zero Carbon buildings is again a matter of combining design strategies and materials in the most optimal way, to reduce the overall greenhouse gases emissions. From this angle, it is fundamental to reduce the products' embodied energy, which again depends on their characteristics, including their weight. This is where again the solutions described in the book find their place at the centre of the discussion.

The other global current hot trend is surely well-being, with a warning: well-being should be achieved without creating negative impacts on the environment. In other words: Are we able to guarantee a comfortable (biophilic, I would add) indoor environment, ensuring on the other hand a restorative or even regenerative scenario for our buildings, communities and cities? Are we able to design, build or renovate buildings with a positive handprint, which are fine for (human) beings as well for the environment? This is the challenge inside the challenge.

Once again, a smart, innovative, ground-breaking research approach might represent the starting point of a process able to ignite the mindset transformation of a new community of designers, manufacturers, builders and owners of the twenty-first century. This book will provide brilliant and informative insights into this direction.

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Introduction

The term membrane in construction refers to a thin flexible layer able to carry tension, overturning the conventional relationship between self-weight and carried loads. In architecture, membranes are commonly associated with the diffusivity of light through ultra-thin layers and often also with the temporary building.

In the realizations of these recent years, we notice countless improvements in the membrane architecture's technology, and an increasingly wide number of engineering firms are mostly specialized in tensile structures. Despite the emerging needs of lighter and faster alternatives for efficient buildings, membrane structures still have a low market penetration compared to the wider predominant building technologies, as there are still two main barriers. The first is a cultural bias, as soft materials are hardly considered strong and durable to qualify an entire building. The second barrier is the lack of shared knowledge for designers on how to make an architecture built with thin membrane layers energy efficient.

Furthermore, due to the current energy resource crisis, it is shared evidence that it is no longer sustainable to postpone the extensive use of renewable energy technologies and the design of Nearly Zero Energy buildings. The effective application of these strategies to lightweight, membrane-based buildings needs special attention.

A question comes up from these premises: May both lighter-mass and lighter-energy design criteria effectively coexist and reinforce each other to enhancing the development of membrane tensile architecture?

The authors aim to propose the first nucleus of systematic knowledge on the behaviour of architectural enclosures and building envelopes made of translucent membranes and transparent foils, then focusing on the potentiality, the current limitations and future developments of using the resistant support of membranes as a means of interaction with external resources. Through an in-depth examination of the interactions between natural resources—water, wind and sun—and ultra-thin membranes, designers will be able to understand how current and upcoming technologies bring very close the time when we can create the building enclosures as biological skins: without seams, a whole but with many performances, and always able to react appropriately to external conditions.

The book aims to explore membrane materials as a means of translating natural and renewable resources into a novel kind of architectural skins, more flexible, dynamic and reactive ones. The book also aims to demonstrate that, besides the attitude of continuously refining the overall membrane systems' efficiency, it is time to calibrate a set of environmentally sustainable design strategies, specific for these ultra-thin and extremely reactive to the climate kinds of architectural skin.

After the **first chapter** in which the authors give an essay of the present technologies and imagine a development path for membrane structures intended as an interactive and intelligent skins for the tomorrow architecture, the theme of designing in a more energy-saving way, making the best use of renewable solutions, is in the **second chapter** for the first time systematically treated in relation to lightweight building systems and tensile membranes.

As the coated textiles and transparent foils use has been recorded growing as enclosures for insulated buildings, the authors underline the need to explore the dual concept of lightweight and light-energetic building. The thin and flexible surfaces of textile architecture represent a frontier application nowadays to trigger a change in the designing approach of all buildings. In the **third chapter**, therefore, all the main design strategies are considered to obtain the efficiency of this particular type of construction with ultra-thin skin. Here the authors start a cross-cutting and combined exploration of the climate-based design methodology and strategies. Both active and passive systems are investigated, referring to alternative productive resources like sun wind and water, for energy storage and interiors' well-being. Furthermore, attention is paid to the opportunity to combine the use of multiple natural resources in the definition of innovative membrane architecture. The exploitation of water and wind resources, which can be adequately captured through the meshes of fabrics, is considered particularly relevant and innovative. In dealing with this topic, the authors want to convey their awareness that knowledge on this topic is currently being transferred from real applications conducted on other building technologies, while further experiments, supported by accurate evaluations of the peculiarities of the construction material, must be urgently oriented on membranes and fabrics. Consistent with this intention, the authors present some case studies and ongoing research projects in the second part of the book.

Understanding the energy behaviour of membranes and foils used as building envelopes therefore passes through another fundamental topic of discussion in this book, namely the integration of flexible photovoltaic in membrane construction systems. It seems an obvious fact, but it should be emphasized that a membrane skin of the building moves continuously under the effect of the wind, and therefore, also the photovoltaic cells integrated into this surface must be able to maintain their performance in this continuous swaying of the structural surfaces. The radiative effect of the sun on the ultra-thin layers of fabrics and transparent sheets is considerable, and therefore, the question clearly arises: Why not to exploit this solar energy directly through the surface of the membrane? Another evident fact is that the industrial processes for the production of membranes for architecture are the same that make it possible to encapsulate the materials used today to create flexible photovoltaic cells. Starting from these assumptions, in the **fourth chapter** that closes the first

part of the book, the authors present the state of development of flexible photovoltaic technology and it is still too rare application in the field of membrane structures.

After an in-depth framing of the methods and approaches of how to design a new kind of lightweight and energy-lighter building according to the entire life cycle and in relation to the key performances of textile architecture and membrane structures, the second part of the book shows case studies of basic and applied research and industrial development, which have seen the authors engaged in recent years, experimenting with new approaches and new forms of energy lightness for an increasingly dematerialized architecture.

Four main research and development paths are presented that seem mostly in line with the adaptability needs of contemporary architecture and with the eco-efficiency constraints of lightweight construction Through the different case studies, the authors return to discuss the issues addressed theoretically in the first part of the book, this time experimentally applying the eco-efficiency evaluations to the new results emerging from the various case studies.

The first two—the SOFT-PV project from the **fifth chapter** and the TIFAIN project from the **sixth chapter**—focus on those advances in facade materials and photovoltaic systems applicable to membrane architecture based on fabric and transparent sheet. In these two experimental cases—a basic research the first and an industrial development research the second—the multi-disciplinary approaches that typically drive innovation in the construction sector are highlighted. The life cycle assessments of a membrane-integrated-organic-photovoltaic skin and of a curved transparent envelope that can be integrated with various generations of photovoltaic cells are then explained step by step. The goal of optimizing daylighting, energy efficiency and energy storage in multilayer transparent facades is at the heart of these two case studies.

Subsequently, in the **seventh chapter**, the authors focus on another frontier theme for the development of ultra-light architecture, namely the efficiency of architectural textile collectors for the collection of dew and fog, thus being able to exploit a renewable water resource that is usually not used.

The last case study, presented in the **eighth chapter**, concerns a demonstrator pavilion, that the authors contributed to design and build, precisely with the intent of experimenting—thanks to a learning by doing approach—the complexity of the design theme that is at the centre of the discussion in this book: designing for the urgent achievement of an energetic and environmental lightness and not just with the weight and the shape in mind. Much further developments could arise from that the first transportable building prototype and its filtering skin, presented in the last chapter. Thanks to that case study, the authors are willing to start a systematic review of the knowledge on the internal comfort of ultra-lightweight skins and membrane architecture in general. Eventually, thanks to this last case study, the authors believe that this even small but meaningful quantum of experimental knowledge can have a great value in what is easily applicable to countless situations, in which similar construction technology is applied today, consequently increasing the overall quality of the built environment.

The ultimate goal of the book is that from these emblematic cases of lightweight and light-energetic architecture, suggestions for improvement can also be drawn for conventional and massive constructions, in order to obtain a lighter and more sustainable use of all forms of energy on our planet.

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Contents