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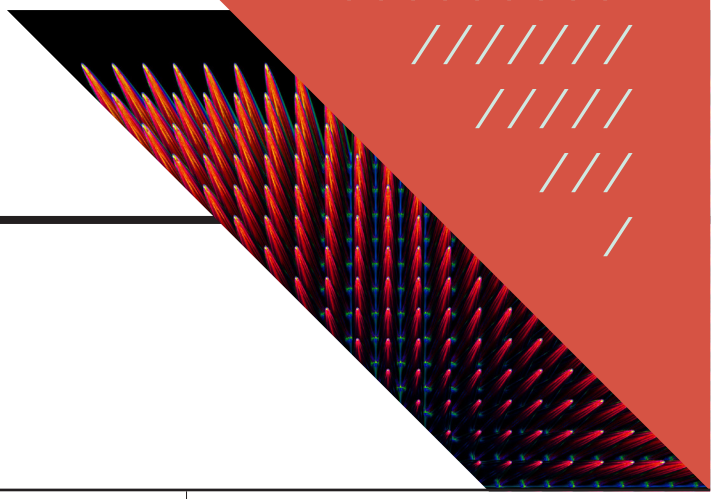

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STEFANO ZAPPERI
CC&B coordinator

Sustainable architecture with metamaterials

The construction sector is the world's most polluting industry accounting for about 40 percent of annual global emissions. As the global building stock continues to age, its heating and cooling efficiency also becomes obsolete. Intervening on the existing building infrastructure, however, would inevitably mean releasing huge amounts of emissions in the short term and therefore a reevaluation of the entire life cycle of materials is needed to reduce pollution. To tackle this problem CC&B joined forces with Finland's Aalto University and its corporate spin-off Woamy and the University of Stuttgart's Institute for Computational Design and Construction and proposed a project to the European Innovation Council under the Pathfinder Challenge call. The ARCHIBIOFOAM project was successful and received a €3.5 million grant to develop a bio-foam material that can be used in construction as an alternative to concrete, steel, and glass.

In this advanced technology project that aims to change the conception of buildings toward the idea of buildings that react naturally to environmental conditions, expanding and contracting to control airflow, an important role is played by the algorithmic design of metamaterials. In previous projects, funded by the European Research Council, we developed a strategy to design optimized metamaterials with specified functionalities. Metamaterials represent a novel class of artificial materials whose shape is engineered to have exceptional properties and responses that are difficult to find in conventional materials. Since in metamaterials the function depends on the geometric structure, rather than on the constituent material, one can use materials that are environmentally friendly and overcome their performance limitations.

We are currently witnessing a revolution in structural design due to algorithms that can find the most effective geometry for a desired function, such as programming shape changes under external stimuli. During the ARCHIBIOFOAM project, we intend to expand the capabilities of our software and adapt it to the physical characteristics of bio-foam and the needs of the building industry. I envision a pipeline where the architect specifies only his requirements in terms of shape, mechanical characteristics and response functions, and the computer provides a 3D digital model ready to be fabricated on a large scale.

One of the main motivations behind the ARCHIBIOFOAM project is to reduce emissions from the construction sector where a reevaluation of the entire life cycle of materials is needed to reduce pollution. If developed and used, load-bearing bio-foam materials (such as the bio-foam developed within the project) could replace typical non-renewable, resource-intensive building materials such as concrete, steel and glass. Through suitable engineering and optimization, bio-foams could reach comparable strength to these materials, even though they are composed of 90 percent air, is biodegradable, and adheres to circular economy principles.

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Views and opinions expressed are however those of the author only and do not necessarily reflect those of the European Union or European Innovation Council and SMEs Executive Agency (EISMEA).
Neither the European Union nor the granting authority can be held responsible for them.

The role of physical activity during breast cancer treatment

In a recent paper, coordinated by Dr. Ornella Garrone from Milan Polyclinic, we started to investigate the effect of Physical activity (PA) in the risk of developing breast cancer (BC) and mortality rate in BC patients starting PA after diagnosis. The study shows that PA induces changes in the expression of many circulating cytokines and therefore can modulate the immune system. The study also reveals that this effect is detectable even in BC patients during neoadjuvant chemotherapy and might be related to a reduction of chronic inflammation. It is known that chemotherapy is a 'double-edged sword', able to fight cancer, while supporting chronic inflammation favoring cancer resistance and tumor progression. The study suggests that a reduction of cancer-related chronic inflammation during neoadjuvant chemotherapy might improve patients' outcome.

Garrone, O., et al, 2024. Moderate physical activity during neoadjuvant chemotherapy in breast cancer patients: effect on cancer-related inflammation and pathological complete response—the Neo-Runner study. *ESMO open*, *9*(8), p.103665. https://doi.org/10.1016/j.esmoop.2024.103665

The use of deep learning in agriculture and farming

We investigated the possibility to forecasting microclimate using deep learning and introduce an innovative microclimate model that combines physical laws and deep learning to reproduce temperature and relative humidity variations at the meter-scale within a study area located in the Lombardian foothills. The model is exploited to perform a comparative study investigating whether employing the global climate dataset ERA5 as input reduces model's accuracy in reproducing the microclimate variations compared to using data collected by the Lombardy Regional Environment Protection Agency (ARPA) from a nearby meteorological station. The comparative analysis shows that using local meteorological data as inputs provides more accurate results for microclimate modeling. However, in situations where local data is not available, the use of global climate data remains a viable and reliable approach.
Then we proposed and experimentally validate a computational framework based on AI algorithms to optimize and validate the placement of sensors networks according to local temperature variations within a study area located in the Lombardian foothills, Italy. The strategy involves a clustering procedure to extract spatial locations with a similar thermal behavior. We used a similar approach to investigate the influence of microclimate conditions on diary production in an automatic milk system. This work formed the basis for the Ph.D. thesis of Marco Zanchi and was published in the following articles.

Marco Zanchi, Stefano Zapperi, Caterina AM la Porta Harnessing Deep Learning to Forecast Local Microclimate using Global Climate Data. Scientific Reports 13:21062, 2023, doi.org/10.1038/s41598-023-48028-1

Marco Zanchi, Stefano Zapperi, Caterina AM La Porta Optimized placement of sensor networks by machine learning for microclimate evaluation. Computers and Electronics in Agriculture 225, 109305, 2024

Marco Zanchi, Caterina A. M. La Porta, Claudio Forte, Stefano Zapperi, Laura Ozella Influence of microclimate conditions on diary production in an automatic milking system: trends and TSMixer. Computers and Electronics in Agriculture 229, 109730, 2025

The effects of urbanization on pollution and health

Professor Caterina La Porta of the Department of Environmental Science and Policy with her colleague Stefano Zapperi of the Department of Physics at the University of Milan both co-founders of the Center of Complexity and Biosystems at UniMi have studied with an innovative and multidisciplinary approach how the size of urban centers in Europe is related to per capita emissions of CO2 and PM2.5 and what the effect is on human health. The research was published in the international Journal of Urban Health, which is edited by the New York Academy of Medicine. There is much international discussion about how to create sustainable cities so that they can respond to the impact of urbanization on pollution and the well-being of those who live there. Using an innovative strategy, the two authors have shown that while emissions follow a trend proportional to the size of the city, the concentration of pollutants depend much more on geographic conditions. For example, northern Italian cities like Milan produce a moderate amount of emissions per capita but the presence of pollutants in the air is much higher than cities like Stockholm that have less pollution but emit more. This is due to the geographic structure of northern Italy, which has a flat area surrounded by mountains and thus creates limited air exchange and more stagnation than cities such as Stockholm where pollutants can disperse into the air more easily. Strategies to mitigate city emissions and pollution are linked to good urban policies such as promoting public transportation, adopting renewable energy and increasing green infrastructure. Trees and forests certainly play an important role in mitigating the effect of greenhouse gases through their ability to capture CO2. In this paper, the authors show how the strategy of implementing greenery and forests while it could be a viable strategy, it could only offset a fraction of the CO2 produced even if we increase forest areas that can still have a beneficial effect on the local microclimate.
The authors also considered the health effects of PM2.5, which is known to contribute to respiratory problems such as asthma, bronchitis and lung cancer. By analyzing PM2.5 levels across Europe over the years, the study highlights a marked reduction in deaths from respiratory problems along with a decrease in PM2.5. This confirms that Europe is addressing the problem and countering it with effective policies. Overall, the study highlights that while concentrating the population in large urban areas reduces emissions per capita, on the other hand this concentration leads to a major increase in pollution that is negative for the overall health of the citizens living in

that area. In particular, for areas with little air exchange due to geographical reasons. "In light our analysus, future strategies should seek to arrive at a positive balance of overall effects for the environment while preserving the health of citizens at the local level", suggests Caterina La Porta.

La Porta, C. A., & Zapperi, S. (2024). Urban Scaling Functions: Emission, Pollution and Health. *Journal of Urban Health, 101*(4), 752-763.

The effect of income inequality on health

Socio-economic background is often an important determinant for health, with low-income households having higher exposure to risk factors and diminished access to healthcare and prevention, in a way that is specific to each country. In a recent paper, published in Frontiers in Public Health, we showed that the income class determines the incidence of chronic pathologies, associated risk-factors and psychiatric conditions, but find striking differences in health inequality between the two countries. We then focused our attention on a fraction of very disadvantaged households in the USA whose income in persistently at the bottom of the distribution over a span of 20 years and which is shown to display particularly dire health conditions. Low-income people in the USA also display comorbidity patterns that are not found in higher income people, while in Italy income appears to be less relevant for comorbidity. Taken together our findings illustrate how differences in lifestyle and the healthcare systems affect health inequality.

La Porta, Caterina AM, and Stefano Zapperi. "Health and income inequality: a comparative analysis of USA and Italy." Frontiers in Public Health 12 (2024): 1421509. https://doi.org/10.3389/fpubh.2024.1421509

Young researchers from around the world practice at Villa del Grumello trying to improve the viability of the city of Como

In the beautiful setting of Villa del Grumello on Lake Como, the summer school "Advances in Complex Systems Addressing the Zero-Emission Goal for Urban well-being" was held from July 1 to 5 as part of the Lake Como School of Advanced Studies. The school is directed by Professors Caterina La Porta and Stefano Zapperi, from the Center for Complexity and Biosystems at the University of Milan, and Professors Matteo Colleoni and Simone Caiello, from the University of Milan-Bicocca. The participants are young researchers and PhD students who are majoring in various disciplines such as urban planning, computer science, physics, environmental engineering and sociology.

Several lectures were given in the morning by eminent experts in the study of human mobility and urban sustainability from leading Italian and global universities and institutions. The topics covered tools and techniques for the study of complex systems, new data sources, as well as the collective challenges that cities must respond to today. In the afternoon, students were engaged in a workshop activity focused on the viability and accessibility of the city of Como.

The first part, curated by Simone Caiello (University of Milano-Bicocca), introduced the tools of urban audit and objective and subjective assessment of walkability of routes and spaces, a key element in promoting accessibility in cities. The activity took the form of an outing with surveying "in the field," moving on foot through the streets of Como, transforming one's perceptions into a surveying tool. "Measuring the quality of pedestrian routes in cities is essential to ensure better use of public spaces and services," explained Simone Caiello. "The subjective dimension, varying according to individual characteristics and experiences, allows us to understand the final choices of individuals and thus to intervene on the conditions that help produce them."

In the second part, Luca Pappalardo (CNR and Scuola Normale Superiore di Pisa) introduced students to the problem of road routing, that is, how to find the optimal road route to reach the desired destination. The kind of problem that applications like Google Maps solve for us every day. Students were directed to develop an "innovative" routing algorithm that would be able to leverage information gathered in the field by students to provide a set of alternative routes to the shortest or fastest route. "Suggesting to all drivers the fastest or most emission-friendly route is not always the smartest solution," Pappalardo points out, "if we all choose the same route, this route will be neither faster nor greener!" Armed with computers and data, students came up with creative new solutions, from an algorithm that guides cars through safer streets or with more shade, to algorithms that propose more random routes with the aim of distributing vehicular traffic more evenly. A first step toward new ways of navigating our cities that go beyond the needs of individuals by also looking at the environment and urban safety.

https://acsz.lakecomoschool.org/

Three questions to...
Edoardo Marchi

Postdoctoral fellow

Can you describe your current research activities?

Currently, my efforts are focused on two main projects that are quite distinct from one another. On one hand, I am concluding the final project of my PhD, which I recently defended, on the theoretical modeling of chromatin dynamics. Chromatin, a highly complex biological system, presents fascinating challenges for a physicist due to its intricate, multi-scale organization and dynamics. Developing advanced polymer models is

essential to capture its diverse features. This last project focuses on creating a theoretical framework to explain the unique behavior of intrachain contacts between chromosomal loci observed in recent experiments. The objective is not only to accurately reproduce experimental findings but also to infer key parameters that are difficult to measure directly, such as the extrusion speed of cohesin.
At the same time, I have recently begun exploring the application of knowledge graphs in precision medicine. These graphs integrate and organize vast amounts of biomedical data—spanning diseases, phenotypes, genes, drugs, and more—to enable diverse kind of research, including studies on disease etiology, diagnostics, and disease-drug interactions. My current work involves constructing a tailored knowledge graph of diseases and phenotypes to investigate Minamata disease, a neurological disorder caused by mercury poisoning. By employing techniques like knowledge graph embedding (KGE), we aim to uncover non-trivial similarities between Minamata disease and other conditions, thereby contributing to the understanding of this disorder, which remains only partially characterized.

What you think are the key challenges in your research field?

Concerning chromatin modeling, one of the primary challenges lies in addressing experimental limitations. Despite significant advancements in experimental techniques, it remains difficult to directly study many aspects of chromatin dynamics due to constraints in temporal and spatial resolution. Consequently, models must not only accurately represent the experimental data, which is often noisy and incomplete, but also provide insights into alternative ways to investigate the system and potentially mitigate these experimental shortcomings.
Turning to my other project, building a biomedical knowledge graph presents several challenges. These graphs gather information on diseases and phenotypes from various ontologies and datasets, but inconsistencies between sources are common and often require expert validation. Additionally, it is highly debatable whether diseases can be considered as unique, discrete units of information for analysis, posing further difficulties in both the construction of the graph and the subsequent analyses.

- **What are the main possible outcomes of your research and what impact could they have on biological and medical research?**

Regarding my project on chromatin modelling, it is still unclear today how enhancer and promoter dynamically interacts with each other and how this interaction is related to transcriptional activity. By characterizing this process with polymer modelling I aim to shed light on these mechanisms and lay the groundwork for future investigations into this complex and crucial aspect of gene regulation.
With regard to the second project, the implementation of knowledge graphs for precision medicine is a relatively recent field; while extremely promising, it is still unclear how these graphs must be built and how they can be reliably used to conduct research. By addressing specific medical questions related to Minamata disease, this work aims to develop practical strategies that can extract meaningful insights and support decision-making in real-world medical contexts.

Three questions to...
Hannes Holey

Feodor Lynen fellow

Can you describe your current research activities?

My research focuses on bridging atomistic material behavior with macroscopic modeling to tackle complex material systems. One recent example is the mechanical response of metamaterials—materials whose properties stem from both their base material and geometry. For instance, I study shape memory alloys (SMA), which exhibit large, highly nonlinear elastic deformations due to stress-induced phase transformations. Currently, I am developing methods to integrate phenomenological models of this so-called superelastic effect into a beam-network solver, enabling the structural optimization of SMA-based metamaterials.
Another focus of my work is lubrication under extreme conditions, where the macroscopic friction coefficient is influenced by the nanoscale properties of nanometer-thin fluid films. To address this, I employ a multiscale approach, combining atomistic simulations with continuum models to capture the interplay between scales.

What do you think are the key challenges in your research field?

A key challenge in multiscale simulations lies in managing the vast separation of length and time scales, which often spans several orders of magnitude. Direct coupling across these scales is rarely feasible, and there is no universal solution. Instead, researchers must carefully select coupling variables, define appropriate boundary conditions, and make simplifying assumptions—each of which influences the interpretation of results.
Addressing these challenges demands a highly interdisciplinary approach, bringing together expertise from diverse fields to develop robust and tailored techniques in order to predict complex material behavior across scales.

Does your work have potential industrial applications?

While my work is largely fundamental, it is strongly driven by the goal of advancing industrial technologies. For example, friction accounts for nearly a quarter of global energy consumption, making it a critical area for improving efficiency and reducing emissions. Currently, lubricant development often relies on trial-and-error methods due to the complex interplay between fluid properties, surface chemistry, and surface roughness, which is difficult to observe experimentally. My research aims to change this paradigm by leveraging multiscale simulations to help understanding these interactions. This approach could pave the way for the design of ultra-low friction interfaces.

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