GEOMETRY
MATERIALS AND THE IMAGINATION

NEUES PALAIS · POTSDAM
AUG 31 – SEPT 4, 2026

Bringing together researchers working at the interface of geometry and materials science, spanning themes such as structure, biology and form+function across physics, chemistry, art and design.

ORGANISATION

Myfanwy Evans · Jacob Kirkensgaard · Gerd Schröder-Turk

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Universität Potsdam · University of Potsdam

Murdoch University

University of Copenhagen

Geometry, Materials and the Imagination

Monday 31 August to Friday 4 September 2026

	Monday	Tuesday	Wednesday	Thursday	Friday
09:30		**Session 3** Giulio Facchini (chair) Greg Grason (K) Lu Han (I) Annie Jessop (C)	**Session 6** Martin Pedersen (chair) Davide Michieletto (K) John Dunlop (I) Robert Magerle (C)	**Session 9** John Dunlop (chair) Arielle Blonder (K) Giulio Facchini (I) Martin Thuo (C)	**Session 11** Philipp Schönhöfer (chair) Randy Kamien (I) Reinhard Lipowsky (C) Adil Mughal (C) Lauren Niu (C)
10:00					
10:30					
11:00		Coffee Break	Coffee Break	Coffee Break	Coffee Break
11:30		**Session 4** Annie Jessop (chair) Hao Chen (I) Kanata Warisaya (I) Tolga Talha Yıldız (C)	**Session 7** Lauren Niu (chair) Andrew Goodwin (I) Bodo Wilts (I) Joe Pollard (C)	**Session 10** Kanata Warisaya (chair) Sabetta Matsumoto (K) Viola Bauernfeind (I) Daniel Ryuichiro King (C)	**Session 12** Myfanwy Evans (chair) Hannah Santa Cruz Baur (I) Tomaso Aste (I) Natalija Miodragovic (C)
12:00					
12:30	Registration				
13:00		Lunch break	Lunch break	Lunch break	Goodbye
13:30	**Session 1** Myfanwy Evans (chair) Łucja Kowalewska (K) Livia Salvati Manni (I) Domagoj Fijan (C)				
14:00					
14:30		**Session 5** Rhoslyn Coles (chair) Richard Morris (I) Eugene Starostin (C) Ana-Sunčana Smith (C)	**Session 8** Bodo Wilts (chair) Rob Corkery (I) Rob Kusner (C) Xiangbing Zeng (C)	**Stephen Hyde Honorary Session** Gerd Schröder-Turk (chair) Martin Pedersen (I) Philipp Schönhöfer (I) Rhoslyn Coles (C) Vanessa Robins (I) Christophe Oguey (I)	
15:00	Coffee break				
15:30	**Session 2** Jacob Kirkensgaard (chair) Stephen Hyde (K) José Bonilla (I) Matteo Tollemeto (C)				
16:00		**Poster Session**			
16:30					
17:00					
17:30				Conference dinner	
18:00	Drinks & Welcome reception				
18:30					
19:00					
19:30					
20:00					
20:30					
21:00					

Session 1

Speaker	Title
Łucja Kowalewska (K)	**From diamond to gyroid: non-lamellar bodies of plant plastids**
Livia Salvati Manni (I)	**Shape Shifters: The Magic of Lipid Polymorphism**
Domagoj Fijan (C)	**Tracking the Emergence of Local Symmetry Order in Self-Assembly and Crystal Nucleation**

From diamond to gyroid: non-lamellar bodies of plant plastids

Łucja Kowalewska, University of Warsaw

Cellular membranes self-organize into many shapes, of which the bicontinuous membranes are the most complex. They are periodic biological counterparts of triply-periodic minimal surfaces of the primitive, diamond, and gyroid types. They occur from bacteria to mammals, yet how they form and interconvert with lamellar membranes remains largely unknown. We study them in plant plastids using a combination of microscopy (TEM), biochemical, biophysical, and geometric-based tools. In this talk, I will follow two non-lamellar plastid bodies through plant development. The first is the prolamellar body (PLB), a diamond-type bicontinuous membrane in the etioplasts of dark-grown seedlings. I will cover its assembly in planta, its light-driven transition to lamellar thylakoids during greening, and its reconstitution in minimal in vitro systems from recombinant LPOR and defined lipids, which let us test the molecular requirements for diamond formation directly. I will also use the phylogeny of the PLB key protein, LPOR, to ask which features of this membrane protein are conserved across photosynthetic lineages, and how this may reflect variability in PLB structure between plants. The second non-lamellar plastid body is the gyrobody, a gyroid-type bicontinuous membrane we found in mature Arabidopsis thaliana chloroplasts and characterized by cryo-electron tomography and SPIRE. It forms when the thylakoid network refolds under reduced membrane surface charge and increased MGDG, while the chloroplast remains photosynthetically active. Together, these two bodies show how plastid membranes are tuned to fold and unfold bicontinuous arrangements across a plant's development.

Shape Shifters: The Magic of Lipid Polymorphism

Livia Salvati Manni, Monash University

Lipids are nature's geometric magicians. From a common pool of molecules emerges an astonishing variety of ordered structures, whose shapes are constantly rewritten by their surrounding environment. A change in salt concentration, a drop in temperature, contact with bacteria, or exposure to gases can transform a lipid assembly from one architecture to another. These transformations are not random, but follow deep geometric rules linking molecular packing, curvature and topology.

In this talk, I will explore how lipid self-assembly responds to the complex realities of natural and extreme environments. Biological fluids, microbial interactions and physicochemical extremes act as external sculptors, reshaping lipid mesophases and creating new structures with distinct properties and functions. Through examples spanning living and non-living systems, I will illustrate how environmental cues drive transitions between lamellar, cubic, hexagonal and other self-assembled structures.

Together, these examples reveal lipid assemblies as dynamic materials whose geometry is intimately coupled to their environment. Their ability to continuously reorganise offers a striking example of how simple molecular building blocks can generate complex, adaptive structures—and how geometry provides a language for understanding this shape-shifting behaviour.

Tracking the Emergence of Local Symmetry Order in Self-Assembly and Crystal Nucleation

Domagoj Fijan, University of Michigan

Nucleation and crystallization are central processes in materials chemistry, controlling the formation of molecular, ionic, metallic, colloidal, and soft-matter crystals. Although crystallization is fundamentally associated with the emergence of local structural order and symmetry, commonly used order parameters, such as Steinhardt bond-orientational order parameters, often provide limited structural insight into how local environments evolve and how symmetry develops during these processes.

Here we introduce the Point Group Order Parameter (PGOP), a continuous and bounded per-particle descriptor that directly quantifies the point-group symmetry of a particle's local environment. PGOP measures how closely a local environment matches its symmetry-generated counterpart and can be applied either to the full local environment or to the symmetry of the bond-orientational diagram. This makes it possible to distinguish local motifs in simple crystals, identify different local environments associated with Wyckoff sites in complex crystals, and follow the development of ordered domains during crystallization.

Because nucleation is rare and stochastic, we combine PGOP analysis with dupin, a framework for detecting rare events in molecular simulations. dupin enables systematic identification of nucleation events in large simulation datasets and can also operate online during simulations. This allows rare events to be stored with high temporal resolution while avoiding unnecessary storage of uneventful trajectory segments.

We demonstrate the combined PGOP-dupin workflow on nucleation in a Lennard-Jones liquid simulated with HOOMD-blue. The approach provides an interpretable picture of how local symmetry develops during nucleation and subsequent crystal growth, and offers a general framework for studying the emergence of symmetry during structural ordering processes.

Session 2

Speaker	Title
Stephen Hyde (K)	**Art vs. Science**
José Bonilla (I)	**Understanding the textural perception of foods through quantification of their microstructural elements**
Matteo Tollemeto (C)	**Challenging the PEG Paradigm in Mucosal Drug Delivery: Geometry, Flexibility, and Motion**

Art vs. Science

Stephen Hyde, University of Sydney / Australian National University

The Japanese sculptor, Keizo Ushio, has made many beautiful stone constructions which depict tori split into two equal fragments… sometimes. They raise an interesting question: which double-helical windings split the torus (or any higher-genus multi-handled torus)? The answer is not obvious - to me at least - if the helix forms a single closed boundary loop. Actually, the problem is related to the construction of Seifert surfaces of knots. Its counter-intuitive resolution helped resolve a deeper question. If a very hypothetical loop of RNA folds due to Watson-Crick complementary base pairing alone, which knots result?

Understanding the textural perception of foods through quantification of their microstructural elements

José Bonilla, University of Copenhagen

Foods are structured materials that get destroyed in our mouths. Besides chemical compounds responsible for flavor, the likeness of a food material depends greatly on the mental perception that we generate while we mechanically destroy such material, much of which depends on the material's properties. In this talk, I will show how we are performing quantitative microscopic investigations of complex food materials to elucidate how the different components of food (proteins, lipids, carbohydrates) come together at the microscale to structure food materials. The talk will show how we are obtaining data with advanced optical techniques, and how we are applying and developing image analysis methods to quantify such microstructures, including specific methods to quantify microscopic networks, droplets, and fibrils. The relations found between topological measurements (in networks), and shape descriptors (in droplets and fibrils) to the mechanical properties of the food materials will be shown. Currently, much of the understanding of mechanical properties of foods comes from bulk measurements (i.e. rheology) with theorized (imagined) microstructures responsible for it. With microscopic imaging we are moving this from the imaginary to the reality, and by doing so we aim to understand how each component of the food matrix contributes to our perception of food texture.

Challenging the PEG Paradigm in Mucosal Drug Delivery: Geometry, Flexibility, and Motion

Matteo Tollemeto, MIT - Massachusetts Institute of Technology

Mucosal surfaces in the respiratory and gastrointestinal tracts are major entry points for pathogens such as influenza and SARS-CoV-2, making them attractive targets for vaccination and drug delivery. However, effective mucosal delivery remains challenging because nanoparticles must simultaneously penetrate the mucus barrier while engaging target cells. Current design strategies frequently focus on optimizing surface chemistry to enhance transport, yet it remains unclear whether surface interactions alone govern nanoparticle mobility in mucus. Here, we use DNA origami nanostructures as a uniquely programmable platform to systematically investigate how geometry, flexibility, surface chemistry, and activity collectively influence transport through mucus.

By precisely controlling particle shape, ligand type and distribution, enzymatic activity, and mechanical flexibility, we generated a library of nanostructures spanning a broad design space. These included rods, rectangles, and icosahedra, particles functionalized with passive proteins or active enzymes, symmetric and asymmetric ligand arrangements, and hinge-mediated architectures ranging from rigid to highly dynamic structures. Transport was quantified in undiluted porcine intestinal mucus using single-particle tracking, enabling direct comparison of how individual design parameters affect nanoparticle mobility.

Our results reveal that mucus transport cannot be explained by surface chemistry alone. Rather, different transport mechanisms emerge depending on the local mucus environment and the dominant barrier to particle motion. Shape-dependent studies showed that diffusion is governed primarily by hydrodynamic dimensions and anisotropy rather than theoretical particle volume. Ligand density produced a non-linear relationship with transport, revealing an optimal range where transient interactions enhanced mobility, whereas stronger interactions reduced diffusion. Enzyme-driven motion required immobilization of the enzymes on the DNA origami surface, with both urease and catalase increasing diffusion in a manner dependent on enzyme identity and spatial organization. Increasing hinge-mediated flexibility enhanced transport when steric confinement dominated mobility but provided little benefit when adhesive interactions with mucus were the primary limitation. Together, these findings demonstrate that geometry, flexibility, activity, and surface chemistry contribute in fundamentally different ways to nanoparticle transport and that their relative importance depends strongly on the surrounding biological environment.

These observations challenge the notion that mucus penetration can be achieved through a single design strategy. Rather than a universal mucus-penetrating nanoparticle, successful transport requires matching nanoparticle properties to the dominant barrier presented by the local environment. By systematically decoupling geometry, flexibility, surface chemistry, and activity, this work establishes a framework for the rational design of next-generation mucosal vaccines and therapeutics capable of balancing barrier penetration with biological targeting.

Session 3

Speaker	Title
Greg Grason (K)	**Geometric routes to programming size in self-assembly**
Lu Han (I)	**From Design to Functionality: Mesostructural Features Elucidated by Electron Microscopy**
Annie Jessop (C)	**Woven Gyroids in Butterfly Wing Scales**

Geometric routes to programming size in self-assembly

Greg Grason, University of Massachusetts Amherst

In self-assembling systems, multiple disparate building blocks spontaneously form into multiunit structures. Nature uses self-assembly to build the remarkably functional elements of living organisms in the form of complex, multi-protein structures. These include the shells that viruses use to encase their genetic instructions, rope-like fibers that reinforce the insides and outsides cells. For materials scientists, self-assembly is especially attractive a possible to means to have high-value materials "build themselves" at size scales that are too small of traditional "top-down" manufacturing (e.g. lithography, 3D printing). In this talk, I will describe on recent efforts to design and encode particular target structures for assembly into particulate or molecular building blocks themselves. In particular, I will focus on specific mechanisms for encoding a finite, self-limiting size for a target structure into the physical features of building blocks from which they assemble, as well as parallel experiment efforts to realize these size-controlled assemblies through synthetically engineered, DNA-based colloids. First, I will describe basic trade-offs between economical designs and size-selection in "self-closing" shells, tubules and periodic frameworks from discretely interacting particles. Here, I will show that while high-symmetry tilings tend to minimize the number distinct subunit species needed to target specific sizes, those same symmetry elements plant the seeds for low-energy "off-target" states that reduce the probability of reaching the desired structure. Next, I will describe recent results that attempt to program the self-limiting size through the build-up of geometric frustration in assembly of intentionally misfitting subunits. While elasticity theories show that the competition between costs of frustration and cohesive energy between subunits can select large, yet finite, ground-state sizes, it has until recently been unclear if and how size-selection is possible at finite-temperatures for discretely interacting systems of misfit particles.

From Design to Functionality: Mesostructural Features Elucidated by Electron Microscopy

Lu Han, Tongji University

Mesostructures, which bridge the microscopic and macroscopic worlds, represent one of the most fascinating length scales and exhibit unique physical and chemical properties. They are not only a critical scale for biological functional architectures but also the characteristic structural dimension of artificial amphiphilic self assembly. Therefore, understanding their intricate structural features is of critical importance. In this context, electron crystallography—particularly transmission electron microscopy (TEM)—has emerged as the premier method for determining such structures. Over recent years, our group has investigated the self assembly and structural attributes of a diverse array of mesostructures, developed distinct synthetic strategies and structural solution methods, and uncovered structure-property relationships and formation mechanisms in a variety of mesostructures. In particular, I will discuss hierarchical biophotonic structures discovered in butterfly wing scales, synthetic triply periodic minimal surfaces, and soft matter quasicrystal structures.

Woven Gyroids in Butterfly Wing Scales

Annie Jessop, University of Salzburg

Nature offers a remarkable diversity of nanomaterials that have extraordinary functional and structural properties. Intrinsic to nature is the impressive ability to form complex ordered nanomaterials via self-organization. One particularly intriguing nanostructure is the gyroid, a network-like structure exhibiting high symmetry and complex topology. Although its existence in cells and tissues across many biological kingdoms is well documented, how and why it forms remains elusive and uncovering these formation mechanisms will undoubtedly inform bioinspired designs. A beautiful example is the smooth single gyroid that is found in the wing scales of several butterflies, where it behaves as a photonic crystal generating a vibrant green color. Here, we report that the gyroid structures of the Emerald-patched Cattleheart, Parides sesostris, develop as woven fibrillar structures, in contrast to the commonly held assumption that they form as smooth constructs. Ultramicroscopy of pupal tissue reveals that the gyroid geometry consists of helical weavings of fibers, akin to hyperbolic line patterns decorating the gyroid. Interestingly, despite their fibrillar nature, electron diffraction reveals the absence of crystalline order within this material. Similar fibrillar structures are also observed in the mature wing scales of P. sesostris specimens with surgically altered pupal development, leading to a blue coloration. Our findings not only introduce a variation of the gyroid in biology but also have significant implications for our understanding of its formation in nature.

Session 4

Speaker	Title
Hao Chen (I)	**Variance of Gaussian Curvature for TPMS and Configurations of Eight Points on the Sphere**
Kanata Warisaya (I)	**Generalized Crystallographic Origami Cellular Structures**
Tolga Talha Yıldız (C)	**From Cube Faces to Chainmail: Valence-Controlled Entanglement in Periodic Linked-Knot Structures**

Variance of Gaussian Curvature for TPMS and Configurations of Eight Points on the Sphere

Hao Chen, ShanghaiTech University

We prove that the Schwarz Primitive (P) and Diamond (D) surfaces are local minimizers of the variance of Gaussian curvature among nearby deformations within the moduli space of genus-three triply periodic minimal surfaces (TPMS). Our approach interprets the branch values of the Gauss map as a configuration of eight points on the sphere and expresses the variance of Gaussian curvature as the product of two integrals involving exponentials of Green functions. We then show that the Hessian of this product is positive definite at the cubic configuration when restricted to antipodal deformations, establishing the local minimality of the P and D surfaces. Along the remaining deformation directions, the Hessian has a few slightly negative eigenvalues, offering compelling hope that the Gyroid is also a local minimizer.

Generalized Crystallographic Origami Cellular Structures

Kanata Warisaya, The University of Tokyo

Origami cellular structures, i.e., tessellations of units made from foldable or bendable sheets, have attracted attention as a concept for modular deployable structures and for mechanical metamaterials. In many existing structures, the units are arranged periodically on the basis of translational symmetry, in order to ensure compatibility of the connections between unit boundaries. Inspired by generalized crystallography (Mackay 1986)—that is, ordered arrangements not restricted to periodicity—our research aims to extend existing origami cellular structures. In this talk, I will present methods and physical models, including mechanisms based on quasicrystalline lattices, mechanisms based on Voronoi dissections, and curved-surface fabrication based on tilings of non-Euclidean spaces.

From Cube Faces to Chainmail: Valence-Controlled Entanglement in Periodic Linked-Knot Structures

Tolga Talha Yıldız, Texas A&M University

How can a single periodic scaffold give rise to weaving, knitting, and chainmail and how can we know which one we will get before we build it? We approach periodic entanglement through Hypergraph Rotation Systems (H-GRS), a purely combinatorial description in which a space-filling cell complex is encoded by the cyclic ordering of faces around each edge, together with an integer twist label assigned to every edge. These twist labels act as local operators that reconnect strands: at an edge of valence m carrying twist k, the incident strands resolve into $\gcd(m, k)$ cycles of equal length, so the same integer produces qualitatively different linking depending on the local edge valence.

We illustrate this with a tessellation grown from an unexpected seed: the six face centers of a cube. Their periodic Voronoi diagram fills space with scaled octahedral cells whose edges fall into distinct valence classes. Because these classes coexist within one fundamental domain, a single twist assignment yields heterogeneous linking across the structure interlaced chainmail along some edges, continuous unicursal filaments along others letting us steer between weave-like and knit-like volumes from one underlying graph.

Crucially, we make these abstract topologies tangible. Each design is validated through hand-built paper sculptures: stiff paper strips form an open scaffold that preserves the cyclic edge orderings, while flexible strips are wrapped according to the twist labels. A mislabeled edge reveals itself instantly as a strip that refuses to close, turning combinatorial verification into a physical, visual act.

Session 5

Speaker	Title
Richard Morris (I)	**Capillary Physics Links HIV Capsid Geometry to Nuclear Pore Translocation**
Eugene Starostin (C)	**The Normal Axis Transform**
Ana-Sunčana Smith (C)	**TBD**

Capillary Physics Links HIV Capsid Geometry to Nuclear Pore Translocation

Richard Morris, University of New South Wales

The protective capsid encasing the genetic material of Human Immunodeficiency Virus (HIV) can traverse the nuclear pore complex (NPC) intact, despite being far larger than conventional passive cargo. This is attributed to the properties of the capsid surface, which promote partitioning into cohesive assemblies of the disordered proteins that form the NPC's permeability barrier: phenylalanine-glycine nucleoporins (FG-Nups). The implication, at the mesoscale, is that capsid-NPC interactions are characterised by the interfacial physics of wetting and capillarity. To capture this, we develop a minimal theory that reduces to an interplay between capsid geometry, effective cytoplasmic and nucleoplasmic contact angles, and a ratio of interfacial tensions. By combining analytical calculations, sharp- and diffuse-interface numerics, we make several predictions: a geometry-dependent trade-off between penetration depth and the wetting transition; asymmetric capillary forces that generate torques and lead to metastable "stalled" states that are tilted; a topological classification of the possible mechanisms underlying the largest energetic barrier; spontaneous symmetry breaking of displaced FG-Nups. These behaviours connect capsid shape and orientation to the topology and symmetry of FG-Nup displacement, and to the molecular compositions on each side of the pore. They are consistent with published cryo-electron tomography orientations, which provide an initial estimate of the cytoplasmic contact angle. Crucially, our results identify a capillary advantage for the HIV capsid's characteristic broken-symmetry geometry.

The Normal Axis Transform

Eugene Starostin, University College London

Mechanical studies of slender objects, such as animal whiskers, insect antennae, claws, horns, bird beaks, plant prickles, among many other natural structures, are best carried out using accurate geometric descriptions compatible with mechanical models. The most common approach in computer graphics and computer vision, the medial axis transform (MAT), fails to satisfy the assumptions underlying these mechanical models.

We propose a general framework that encompasses several existing skeletonisation methods, including MAT. As a particular instance, we require the axis to pass through the midpoints of orthogonal cross-sections. This orthogonality requirement ensures compatibility with standard engineering models such as the Euler–Bernoulli beam and Cosserat rod theories. The resulting centreline, together with its associated width function, defines the Normal Axis Transform (NAT).

Expressing the orthogonality condition as a nonholonomic constraint leads to a system of ODEs whose solution yields NAT, subject to suitable initial or boundary conditions. NAT provides a straightforward and computationally efficient representation of an object's shape, together with a more intuitive definition of thickness. This skeletal representation is particularly suitable for the mechanical analysis of objects undergoing large deformations. As a full shape descriptor, NAT is applicable to morphometric analysis and is also well suited to modelling growth kinematics.

TBD

Ana-Sunčana Smith, Friedrich-Alexander-Universität Erlangen-Nürnberg

TBD

Poster session

Presenter	Title
Samuel Allen	Frustration of ferromagnetic interactions by easy-plane anisotropy
Toky Andriamanalina	TangleBase3P: An open database of triply periodic filament entanglements
Helena Barker	Hidden Anisotropy in Tetrahedral Networks
Francesca Bertoglio	Temperature, knots and topology: tracking shape transitions in polymer simulations
Alicja Bukat	From tubular-lamellar arrangements to diamond-type membrane architecture in plants
Khoa Cao	Wrinkle Dynamics on Soft Substrates: From Computational and Experimental Study to Potential Applications in Cell Migration
Stefano Da Vela	Describing inclusions in marine Particulate Organic Matter through throughput-enhanced X-ray phase contrast microtomography
Florence Ellary	Distinguishing the disordered phases of network-forming liquids: ring statistics, vertex symbols and linking in colloidal water
Clémentine Ferrari	Substrate geometry determines Escherichia coli biofilm internal architecture and wrinkling pattern
Magali Jay	On Tiling Billiards
Merin Joseph	Bridging Coarse-Grained Self-Assembly and Mean-Field Phase Behavior in Block Copolymers
Eléonore Magne	The structure-function relationships of cuticle in butterfly wing scales
Allan Millsteed	Lost in the Details - A Sliding-Box Analysis of Sea Urchin Skeleton Microstructures
Tamara Núñez Guitar	Benefits of modular design for mycelium-based composites based on topological interlocking assemblies
Robert Paraoan	Topological disorder in Metal-Organic Frameworks and its effect on isoreticularity and mechanical behaviour
Lukas Schnelle	Topological interlocking assemblies: From crystallographic groups to interdisciplinary applications
Werner Stanggassinger	Stainless-Steel Knots: Sculpture as Input to a Knot-Identification Pipeline
Eugene Starostin	On bistable inextensible helical ribbons

Frustration of ferromagnetic interactions by easy-plane anisotropy

Samuel Allen, University of Oxford

Geometric frustration – an incompatibility between local interaction requirements and their underlying geometry – is ubiquitous in magnetism, and appears in many guises across physics and chemistry. Identification and characterisation of frustrated systems is therefore a key target for understanding a variety of complex phenomena. Most studies of frustration are predicated on the incompatibility between antiferromagnetic interactions and triangle- or tetrahedron-containing plaquettes. In this study, we demonstrate that local planar anisotropy set by crystal symmetry can cause frustration of a minimal Hamiltonian, even when interactions are ferromagnetic. By discussing a representative selection of states in these systems, including spin liquid, partially ordered, and unconventionally ordered states, we demonstrate that a hitherto unexamined form of geometric frustration is possible and predictable using mean-field calculations and Monte Carlo simulations. Experimental signatures of possible states in this paradigm, including magnetic neutron scattering, heat capacity, and magnetic susceptibility, are calculated. We summarise by motivating the experimental realisation of frustrated ferromagnetic systems and the application of such models to a variety of pseudospin phenomena.

TangleBase^{3P}: An open database of triply periodic filament entanglements

Toky Andriamanalina, University of Potsdam

Triply periodic entanglements of filaments can be used to model various biological, chemical, and physical systems, such as mammalian skin corneocytes, fibrillar structure in butterfly wing scales, DNA origami crystals, and, most particularly, volumetric textiles and mechanical metamaterials. Due to the abundance of possible design patterns, a design framework has been developed to generate a wide variety of structures. This framework uses a 3-periodic network, such as **srs**, as a scaffold for joining helices. TangleBase^{3P} catalogues these structures up to a given complexity. Geometric and topological data are provided to describe the structures and quantify entanglement complexity, a characteristic known to influence material behaviour.

Hidden Anisotropy in Tetrahedral Networks

Helena Barker, University of Oxford

The Continuous Random Network (CRN) model is used to describe the structure of some amorphous materials, such as a-Si and a-SiO2. Its basic premise is that amorphous networks are locally homogeneous and show uniform local connectivity. With access to increasingly sophisticated models of amorphous networks, it is important to quantify the meaningful differences between different CRN models. Analysis of ring statistics is a technique frequently used. These various descriptors hint at a diversity of local structures within CRN models, and an obvious question is that of length-scale. To what extent does the environment at one site affect that of others at varying distances. We address this by developing new representations for amorphous networks.

Making use of the uniform homogeneity in a-Si, we align local atomic environments within a given CRN onto a common reference frame. The resultant neighbour distributions for varying shells are represented as a 3D histogram, denoted gn(r). We then asses the persistence or loss of structure in gn(r), by developing an analogous methodology to the recently developed 3D-ΔPDF approach for disordered crystals. The 3D-ΔPDF is sensitive to the persistence of anisotropy in the arrangement of the n-th nearest neighbours. We have uncovered previously hidden anisotropy in a-Si and other related materials, to length scales not previously reported. We further adapt this descriptor to explore dynamics in a-Si.

Temperature, knots and topology: tracking shape transitions in polymer simulations

Francesca Bertoglio, University of Potsdam

The evolution of polymer chains into structured shapes, from overhand knots to helices, is physically and topologically complex. Here we investigate shape formation as a dynamical process.

Using Topological Data Analysis (TDA), we classify polymers from simulation data and show that persistent homology provides an effective descriptor of their underlying topological structure. To characterize the dynamics of foldings, we track the evolution of topological features through vineyards and Wasserstein distance.

From tubular-lamellar arrangements to diamond-type membrane architecture in plants

Alicja Bukat, University of Warsaw

Biological membranes can organize into highly ordered three-dimensional architectures known as cubic membranes (CMs), whose geometry is commonly described by triply periodic minimal surfaces. The prolamellar body (PLB) is a striking example: a specialised, highly curved, periodic membrane network with imbalanced diamond-type geometry. It develops in darkness within etioplasts of angiosperms and, upon illumination, transforms into the lamellar thylakoid membrane system of chloroplasts, making it a direct precursor of photosynthetically active thylakoids.

Although the cubic-to-lamellar transformation has been described in detail, the geometric and ultrastructural pathway underlying PLB self-assembly remains poorly understood. Here, we investigate PLB biogenesis in oat (Avena sativa) using transmission electron microscopy, with particular focus on structural intermediates linking lamellar, tubular and bicontinuous membrane arrangements.

Plastid development was followed during the first six days of etiolation and, additionally, along the developmental gradient of individual monocot leaves, enabling multiple stages of plastid maturation to be examined within the same organ. We identified several membrane structures associated with PLB formation, including parallel porous lamellar sheets, tubular-lamellar configurations, irregular sponge-like membrane networks resembling mature PLBs, and lamellae extending from established PLBs, with unit-cell-like elements visible at their tips. These findings provide new insight into the ultrastructural mechanisms underlying CM self-organization and suggest that PLB biogenesis may involve multiple structural intermediates.

This research was funded by the National Science Centre, Poland (grant no. 2022/47/I/NZ3/00498, OPUS 24 LAP). TEM was performed in the Laboratory of Electron Microscopy, Nencki Institute of Experimental Biology, using a JEM-1400 electron microscope (JEOL).

Wrinkle Dynamics on Soft Substrates: From Computational and Experimental Study to Potential Applications in Cell Migration

Khoa Cao, Mulhouse Materials Science Institute (IS2M)

Dynamic wrinkle patterns exhibiting both amplitude and phase variations serve as a versatile system for investigating traveling wave physics. These surface instabilities in soft materials hold a feasibality for applications in tunable optics and mechanobiology, yet achieving controlled, reconfigurable pattern formation remains a significant challenge. We present a technique for inducing dynamic buckling instabilities in a thin, rigid film deposited on a compliant elastomeric substrate. Subsequent uniaxial compression of the vessel with an elastomer block inside resulted in the formation of sinusoidal wrinkle patterns oriented normally to the compression direction, which was rotated with the use of a house-designed device. By using of the proposed programmable platform, the dynamic evolution of the wrinkle patterns could be recorded complementary. These peculiarities of the dynamic pattern behavior were simulated, on the qualitative level, via the Swift-Hohenberg equation with the time-dependent growth term.

Describing inclusions in marine Particulate Organic Matter through throughput-enhanced X-ray phase contrast microtomography

Stefano Da Vela, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research

The ocean hosts biogenic Particulate Organic Matter (POM) with a broad distribution of sizes, up to macroscopic flakes known as Marine Snow. These particles form following primary production in the sunlit layer of the ocean. They are an important part of the global carbon cycling due to their sedimentation and ability to sustain microbial life, and the food web, at varying depths. POM particles are highly complex and heterogeneous aggregates. Moreover, their fragile nature renders their detailed study a complex task. These particles are composed of a soft matrix mainly made of biopolymers, which can include minerals, cell debris and detritus. Such inclusions are a key determinant of POM buoyancy, and their thorough description in environmental samples is relevant to draw inferences on POM formation, destiny, and environment of origin. Despite their importance, organic-mineral interactions within POM are only scarcely explored. We produced POM particles from their precursors in natural water samples collected in the Raunefjorden (Norway) and established a methodology for stain-free POM fixation. This allowed the acquisition of sub-µm resolution tomograms of several unique samples employing synchrotron X-ray phase contrast microtomography. These datasets allowed us to clearly resolve the inclusions in quasi-native samples, and to measure their structural parameters. A novel metric for comparing POM samples was defined based on the quantification of geometric descriptors from the segmented tomograms. Our results highlight the relevance of structural investigation even for challenging naturally occurring samples lacking a defined ordered structure.

Distinguishing the disordered phases of network-forming liquids: ring statistics, vertex symbols and linking in colloidal water

Florence Ellary, University of Oxford

Polyamorphism—the existence of multiple distinct phases of a single disordered network-forming species—draws interest because it cannot be captured by symmetry or by the short-range atomic environment. Distinguishing such phases instead borrows from graph theory and knot theory, and in doing so challenges experimental probes that are largely insensitive to connectivity. The theorised liquid–liquid phase transition in supercooled water exemplifies this: a patchy-particle simulation by Neophytou, Chakrabarti and co-workers reproduced the transition in a colloidal-water model, distinguishing its phases by a topological order parameter based on the knotting and linking of the network.

Connectivity-based descriptors are therefore essential, and ring statistics have been a central analysis —anchoring the description of medium range order in continuous random networks, and providing a bridge to the crystalline nets and MOF topologies of the ordered world. The CARVS ("Cumulative All-Rings Vertex Symbol") vector of Thomas Nicholas builds this bridge explicitly, extending the crystallographic vertex symbol into amorphous networks and exposing the heterogeneity of node environments that a disordered structure conceals. Adopting a more lenient ring-counting criterion than the commonly used primitive ring, this descriptor has been found to reveal medium-range structural changes across the colloidal-water transition: the interpenetrated, knotted networks of the high-density phase are accompanied by a broad, bimodal and heterogeneous ring-size distribution, suggesting that ring statistics and entanglement are linked signatures of the same transition.

With the longer-term aim of screening, predicting and designing systems that might exhibit such topological phase transitions, this poster focuses on extending ring statistics and vertex symbols to carry the entanglement information that linking captures.

Substrate geometry determines Escherichia coli biofilm internal architecture and wrinkling pattern

Clémentine Ferrari, Max Planck Institute of Colloids and Interfaces

Microbial biofilms are composed of bacteria embedded in a self-produced extracellular matrix (ECM) enhancing their survival and challenging medical or industrial processes. Most biofilm research to date has been done on flat substrates, which are not representative of the textured surfaces prevalent in the relevant contexts. We thus investigated if biofilm morphology and internal architecture are influenced by the underlying topography. E. coli AR3110 biofilms were cultured on agar substrates displaying textures made of micro-cups of sizes below, comparable to, and above biofilm thickness. A clear transition was observed, where biofilms on 75 µm micro-cups developed radial wrinkles, while those on 500 µm cups formed toroidal wrinkles aligned with the substrate's convexities. The threshold appeared to lie around 250 µm as biofilms grown on the corresponding cups presented features observed in both conditions. Biofilm center showed a stepwise progression from disordered matrix filling the cups, to a well-defined, thickened structure like on 75 µm diameter cups, while biofilm periphery presented delaminated buckles aligned with the convexities. These findings reveal that mesoscopic substrate topography determines biofilm structural development via geometrical confinement rules. Controlling substrate geometry thus offers new possibilities to control biofilm formation or engineer functional materials by guiding matrix organization and emergent mechanical properties.

On Tiling Billiards

Magali Jay, Max Planck Institut für Mathematik in den Naturwissenschaften

In the beginning of the 2000's, physicists have conceived metamaterials with negative index of refraction. This discovery motivated Davis, DiPietro, Rustad, and St Laurent to introduce in 2015 a new mathematical dynamical system: Tilling billiards. It takes place in the Euclidean plane with a polygonal tessellation. The trajectories consist of light rays moving in an arrangement of metamaterials with opposite index of refraction.

I'll give a survey of the systems that have been studied by several mathematicians: in trihexagonal, triangle and cyclic quadrilateral tilings, the brick tiling biliards and generalizations on which I worked (generalized tiling billiards and wind-tree tiling billiards).

Bridging Coarse-Grained Self-Assembly and Mean-Field Phase Behavior in Block Copolymers

Merin Joseph, Technical University of Denmark

Microphase separation in block copolymers gives rise to a rich variety of morphologies due to the intrinsic chemical incompatibility, distinct molecular architectures, and varying rigidity of constituent blocks. These polymers can spontaneously self-assemble into diverse structures, which can be dynamically explored using coarse-grained molecular dynamics techniques such as Dissipative Particle Dynamics (DPD). However, the emergence of a self-assembled structure does not necessarily imply its thermodynamic stability for a given set of molecular parameters.

To address this, we combine coarse-grained simulations with mean-field theoretical methods, specifically Self-Consistent Field Theory (SCFT), to systematically study the stability and formation of self-assembled morphologies in block copolymers. Our framework enables a comprehensive understanding of how molecular architecture and chemical interactions influence the equilibrium structures, offering insights into the design of novel polymeric materials.

The structure-function relationships of cuticle in butterfly wing scales

Eléonore Magne, Université de Tours

How complex traits such as animal coloration and patterning evolve and function is a fundamental question in biology. Animal coloration functions in several different contexts, e.g., intra-specific recognition, mate choice, camouflage, aposematic signal, and thermoregulation. Many lepidopteran species serve as exemplary model systems in biology due to their simplicity and elegance and because of this, they are also increasingly being investigated by physicists and engineers in order to biomimetically inspire new devices and technology. However, these studies are predominantly done on a few charismatic species to date without any comparative evolutionary or ecological contexts. Moreover, we currently do not understand how organisms regulate the composition, deposition and functional properties of biological materials over space and time. Specifically, we do not know the precise materials composition of the insect cuticle that is deposited in scales. Here, we propose to take a comparative, materi-omic approach to understand the structure-function relations of the cuticle during hierarchical butterfly scale development.

Lost in the Details - A Sliding-Box Analysis of Sea Urchin Skeleton Microstructures

Allan Millsteed, Murdoch University

The porous sponge-like biomineralised calcite materials found in echinoderm skeletons are of interest in terms of both structure formation and biological function. Despite their crystalline atomic structure, they exhibit curved interfaces that have been related to known triply-periodic minimal surfaces. With the production of large 3D datasets utilising X-ray tomographic techniques at the Australian Synchrotron, location, identification, and characterisation of TPMS-like structures within the highly porous skeletal plates of sea urchins poses a challenging problem within the limits of common computational systems available to most researchers. We describe our development of an analysis methodology to analyse large datasets, in the hundreds of gigabytes, without requiring the entire dataset to be fully loaded into RAM at any single point of computation. This technique allows for analysis of large datasets on even modest machines and laptops. Our goal is to apply this analysis to our collection of 100 data sets covering around 30 Australian sea urchin species, so as to understand how prevalent different ordered (Diamond, Primitive) and disordered microstructures are in these animals.

(Based on a project with Jeremy Shaw, Peta Clode, Gerd Schroeder-Turk, Annie Jessop. We acknowledge the Australian Synchrotron for beam time and scientific support)

Benefits of modular design for mycelium-based composites based on topological interlocking assemblies

Tamara Núñez Guitar, Technische Universität Berlin

Tamara Núñez Guitar (1), Jörg Hugo (2), Lukas Schnelle (3), Lorenzo Guiducci (4,7), Vera Meyer (1,7), Christiane Sauer (2,7), Yuri Estrin (5,6)

Although fungal mycelium based composites have emerged as sustainable alternatives to several conventional fossil based materials, particularly for thermal and acoustic insulation, their use in construction remains limited. Their mechanical performance is inadequate for structural applications due to the low strength of the grown fibre network and the pronounced non uniformity in density and physical properties. Transitioning from monolithic blocks to modular assemblies based on topological interlocking geometries may help mitigate these limitations.

We will present a first characterization of the mechanical properties of a topological interlocking assembly (TIA) of osteomorphic mycelium-based composites produced with the tinder fungus F. fomentarius grown on hemp shives in both in-plane and normal loading modes. Our results demonstrate that TIAs can accommodate substantial structural and compositional variability, as well as localised failures within individual blocks, while maintaining their overall load bearing capacity. Topological interlocking assembly allows for structural robustness through geometry. This is an important advantage for future applications of regenerative materials given the inherent heterogeneity of grown substances. The proposed approach offers promising benefits for mycelium-based composites on an architectural scale and merits further investigation to broaden the scope of their practical use and design impact.

Our transdisciplinary research bridges the fields of Microbiology, Materials Science, Structural Mechanics, Architecture and Design.

(1) Chair of Applied and Molecular Microbiology, Technische Universität Berlin, Str. des 17. Juni 135, 10623 Berlin, Germany
(2) Department Textile and Material Design, Research Group DXM - Design Experiment Material, Weißensee Kunsthochschule Berlin, Bühringstraße 20, 13086 Berlin, Germany
(3) Institute of Structural Mechanics and Lightweight Design, RWTH Aachen University, Wuellnerstraße 7, 52062 Aachen, Germany
(4) Max Planck Institute of Colloids and Interfaces, Am Mühlenberg 1, 14476 Potsdam, Germany
(5) Department of Materials Science and Engineering, Monash University, Building 37, 19 Rainforest Walk, Clayton VIC 3800, Australia
(6) School of Mechanical and Chemical Engineering, The University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia
(7) Cluster of Excellence Matters of Activity. Image Space Material, Humboldt Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

Topological disorder in Metal-Organic Frameworks and its effect on isoreticularity and mechanical behaviour

Robert Paraoan, University of Oxford

Metal-organic frameworks (MOFs) are crystalline materials built from molecular components with well-defined geometries, whose combination gives rise to extended networks: inorganic clusters act as nodes and organic linkers as edges. In this sense, MOFs are a form of molecular architecture, in which local connectivity rules determine global topology - a principle found in structures across many lengthscales and fields, from abstract mathematical tilings to architectural frameworks.

Our work focuses on TRUMOF-1 and its family of analogue structures: MOFs in which octahedral clusters are connected by bent linkers to form aperiodic three-dimensional networks [1,2]. These structures can be described using the language of Truchet tilings, providing a geometric framework for understanding the topological disorder present. Remarkably, they can also be transformed into ordered phases with the same underlying cluster positions but different, ordered patterns of connectivity, whose topology depends on the nature of the linker used.

Topology plays a prominent role in dictating the mechanical properties of MOFs and framework structures of all kinds. TRUMOF-1 provides a rare opportunity to isolate the role of topological disorder in the properties of structures built from the same components, through comparison of its ordered and disordered phases. We present experimental results showing striking differences in mechanical behaviour between these structures, such as the enhanced resilience of the disordered phase in terms of the pressure at which it undergoes irreversible amorphisation [3]. Using coarse-grained simulations, we connect these contrasting macroscopic behaviours to differences in local deformation pathways and elastic anisotropy within the networks arising from their connectivities. More broadly, this work illustrates the capacity of disorder to serve as a design principle in tuning the properties of framework materials.

[1] Meekel, E.G. et al. Science 379,357-361 (2023).
[2] Greenbaum, G. et al. J. Am. Chem. Soc. 146, 27262-27266 (2024).
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Topological interlocking assemblies: From crystallographic groups to interdisciplinary applications

Lukas Schnelle, RWTH Aachen University

An assembly consists of multiple blocks, which are in contact with each other. It is called a topological interlocking assembly (TIA) if there exists a subset of its blocks, which when fixed, already prevents any movement within the entire assembly. Here we focus on assemblies consisting of congruent blocks. Geometries for such blocks admitting a TIA have been known since 1735, however until recently their number was very small. Recent mathematical advances present a new method of constructing large numbers of candidate geometries, which in all investigated cases admit a TIA. The method is based on the interpolation of deformed fundamental domains of crystallographic groups.

This talk will present this method as well as a generalisation to the three dimensional case. Additionally, we present results about the mechanical performance of some TIAs and some computational considerations. Further, we present applications of TIAs from multiple interdisciplinary collaborations, including aerospace, medical devices and biology connected to civil engineering.
As this is ongoing work it might contain preliminary results and present current research questions.

This is joint work with Alice C. Niemeyer and Kai-Uwe Schröder.

Stainless-Steel Knots: Sculpture as Input to a Knot-Identification Pipeline

Werner Stanggassinger, Independent sculptor (Stainless Steel 4u), Germany

I make stainless-steel knot sculptures — closed curves, about 170 cm tall and 120 kg, forged as single continuous loops. This contribution presents the sculptures alongside the mathematics that has grown around them. Each piece is a genuine knot, and we built a pipeline that takes the physical centerline of a sculpture and identifies the exact knot it represents: the curve is sampled, turned into a knot diagram, and characterised by standard invariants computed with established tools (SnapPy, SageMath, Regina, KnotJob) — the AI helped build the pipeline that drives those tools, but does not compute or invent the invariants. A companion construction runs the other way, generating new knot forms to specification by symmetry and closure constraints. Several sculptures turn out to be knots that lie outside the standard tabulations, which makes the sculpting itself a small source of mathematical objects. I would bring one or more pieces to look at, and present the geometry-to-algorithm loop: how a hand-built steel curve becomes a precisely identified topological object, and how that identification feeds back into making the next form.

On bistable inextensible helical ribbons

Eugene Starostin, University College London

We study helical equilibrium configurations of ribbons modelled as thin inextensible shells made of anisotropic material. Particular attention is paid to the existence of two stable equilibria with different helical parameters. This model may help explain the experimentally observed bistability of cholesterol ribbons.

We show how the existence of a second stable configuration and its geometric parameters depend on the orientation angle of the principal material anisotropy axes relative to the helical axis.

The analysis, which is equally applicable across all length scales, may be useful for the study and design of a wide range of natural and fabricated helical micro- and nanoribbons, which are promising components of future micro- and nanomechanical devices.

Session 6

Speaker	Title
Davide Michieletto (K)	**Topological Elasticity in DNA materials**
John Dunlop (I)	**The paths of bone cells on curved surfaces**
Robert Magerle (C)	**Emergence of directional motion in polymer blends**

Topological Elasticity in DNA materials

Davide Michieletto, University of Edinburgh

Topological motifs in limited-valence networks are increasingly recognized as key determinants of soft-matter mechanics, yet their role in real materials is only beginning to be quantified. I will present recent work on DNA nanostar hydrogels, where rheology, confocal imaging and coarse-grained molecular dynamics reveal a topological transition in tri-armed DNA nanostar (DNAns) gels: below overlap, the high-frequency elastic plateau is controlled by branching fraction and mesh size, while above overlap it is dictated by the abundance of linked “minimum loops” forming an interpenetrating, network-within-network structure, with the elastic modulus scaling linearly with the average linking number per loop (Palombo et al., Nat. Mater. 24, 454–461, 2025).

I will then show how similar concepts apply to a naturally occurring Olympic-ring genome: kinetoplast DNA in trypanosomes. High-resolution AFM, quantitative image analysis and AFM-steered simulations demonstrate that Crithidia fasciculata kinetoplast DNA forms a heterogeneous, subisostatic, percolating 2D network of mutually linked minicircles whose redundantly linked, stretched rim controls a buckling transition into a "shower-cap" morphology and endows the network with an ultrasoft effective Young's modulus (He et al., Phys. Rev. X 13, 021010, 2023).

Together, these studies establish topological elasticity as a generic mechanism in limited-valence DNA networks and suggest strategies to program mechanical responses via controlled loop linking and valence.

The paths of bone cells on curved surfaces

John Dunlop, University of Salzburg

It is becoming clear that the geometry of the environment surrounding a growing tissue, can not only influence the rate of tissue production by cells, but also the underlying microstructure. Bone cells for example have been shown in-vitro to produce a tissue at a rate proportional to the curvature of the substrate they are sitting on and lay down fibrous collagenous matrix in chiral multilayers much akin to what is found in bone. Despite many such observations occurring in the literature in the last years, it is still unclear what mechanism is controlling the chiral arrangement of cells and the collagen that they produce. This presentation will give an overview of the experimental evidence for this behaviour and give some theoretical insights into the physical mechanisms responsible, and ideas for new research in this field.

Emergence of directional motion in polymer blends

Robert Magerle, Technische Universität Chemnitz

The discovery that liquid–liquid phase separation of biomolecular condensates can drive morphogenesis in living organisms has sparked renewed interest in the phase separation dynamics of multicomponent polymeric fluids. Here, we report on the emergence of the self-propelled, directional motion of polymer droplets within thin polymer blend films. This motion resembles the chemotaxis of microorganisms, though the droplets are not alive. It is caused by a chemical decomposition reaction that fragments block copolymers and transforms them into a phase-separated polymer blend. The polymer domains coarsen and then some domains spontaneously start moving across the polymer film. Using atomic force microscopy and optical microscopy, we have monitored the dynamics of droplet formation and motion across scales. We will discuss analogies to phenomena observed in living systems, including metamorphosis, metabolism, motility, and swarming. This work was done in collaboration with S. Weiß, A. Horvat, A. Knoll, L. A. Tsarkova, N. Rehse, and G. Krausch from Bayreuth University.

Session 7

Speaker	Title
Andrew Goodwin (I)	**Truchet-tile architectures in materials chemistry**
Bodo Wilts (I)	**Weaving Light: How Butterfly Cells Build Complex Photonic Nanostructures**
Joe Pollard (C)	**Codifying the Interplay Between Chirality and Activity in Cholesterics**

Truchet-tile architectures in materials chemistry

Andrew Goodwin, University of Oxford

Truchet tilings are periodic arrangements of tiles decorated to lower their symmetry [1]. A generalised version of barcodes and QR codes, they combine elements of order and disorder in a way that allows efficient information storage [2]. This talk will explore the way in which the complex structures of some solid-state compounds - including a heavily disordered metal-organic framework [3] - can be understood in the context of Truchet tilings, and the prospect for exploiting Truchet's approach as a central principle in the design of disordered materials with unconventional electronic and vibrational properties [4].

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[2] Smith & Boucher, Leonardo 20, 373 (1987)
[3] Meekel, Schmidt, Cameron, Dharma, Windsor, Duyker, Minelli, Pope, Orzio Lepore, Slater, Kepert & Goodwin, Science 379, 357 (2023)
[4] Roth & Goodwin, Nature Commun. 14, 4328 (2023)

Weaving Light: How Butterfly Cells Build Complex Photonic Nanostructures

Bodo Wilts, University of Salzburg

Butterflies are renowned for their vivid colours, but many of their brightest hues do not come from pigments alone. Instead, structural colour arises from nanoscale architectures in the wing scales that interact with light through reflection, scattering, and interference. These biological photonic materials range from ridges and lamellae on the scale surface to highly ordered three-dimensional gyroid networks within the scale lumen. Despite extensive characterization of mature wing scales, the developmental and physical processes that generate these intricate architectures remain poorly understood. Recent advances in live imaging and correlative electron microscopy are beginning to reveal how butterfly scale cells construct optical nanostructures during metamorphosis and this talk will highlight recent advances in understand structure formation in vivo. For example, in gyroid-forming scales of Parides sesostris, hyperspectral microscopy can be used to track the emergence of optical signals during pupal development, linking changes in reflectance to the maturation of intracellular photonic structures. Electron microscopy further reveals that developing gyroids are not initially smooth continuous surfaces, as often assumed, but hierarchical woven fibrillar assemblies. Together, these findings suggest that butterfly structural colour emerges through an interplay of mechanical instabilities and forming cell organelles, offering new insight into biological self-organization and bioinspired photonic materials.

Codifying the Interplay Between Chirality and Activity in Cholesterics

Joe Pollard, University of New South Wales

Active cholesteric liquid crystals are a paradigmatic system combining activity and chirality, two features whose interplay is relevant across a diverse range of living systems, from bone to DNA, and even Zebrafish embryos. I will discuss the development of a multipole framework for cholesterics, which allows us to codify the active flow response to distortions. I will also discuss how chirality impacts the structure and dynamics of defects in cholesterics.

Session 8

Speaker	Title
Rob Corkery (I)	**Circular polarization from natural three-dimensional gyroid photonic crystals**
Rob Kusner (C)	**Willmore stability of minimal surfaces in S^n**
Xiangbing Zeng (C)	**Self-assembled bicontinuous phases in thermotropic liquid crystals**

Circular polarization from natural three-dimensional gyroid photonic crystals

Rob Corkery, Australian National University

In the century since Michelson's observations of circularly polarized reflection in beetle cuticle, every documented observation of circularly polarized reflection from a biological source has arisen from the same 1D helicoidal architecture — the Bouligand structure and its material variants, realized independently in chitin and, more recently, in plant cell-wall cellulose. Intrinsically chiral 3D photonic crystals offer a fundamentally different route to circularly polarised reflection. Single-gyroid chitin networks in butterfly wing scales are predicted to exhibit a circular-polarization bandgap for propagation along their ⟨100⟩ directions, yet this response has remained experimentally elusive in nature. We present the first experimental observation of the predicted circular-polarization response of biological single-gyroid photonic crystals, quantify its magnitude, and establish its structural origin. In Callophrys rubi, Stokes imaging correlated with electron microscopy on the same domains reveals opposite circular-polarization responses from the two structural enantiomorphs, directly linking the sign of the optical response to gyroid chirality; both structural and optical heterochirality are independently confirmed across further Callophrys species. In C. rubi, the coexistence of both enantiomorphs produces a bimodal distribution of polarization responses and suppresses the net signal through spatial averaging. In contrast, single-gyroid domains in Chalybs (C. janias, C. hassan, C. mitaraka and C. chloris) are structurally homochiral and preferentially oriented with a ⟨100⟩ chiral-bandgap direction normal to the scale surface. The same domain-matched approach in C. janias confirms optical responses of consistent handedness, directly matching structural chirality; this pattern is independently confirmed across the other three species, indicating heterochirality and homochirality are genus-level traits in Callophrys and Chalybs respectively. In C. janias, where whole-wing sampling permitted quantitative spectroscopy, this homochirality translates into a net degree of circular polarization of approximately 30% — substantially higher within individual domains — a magnitude otherwise unknown in nature outside these 1D helicoidal reflectors. More broadly, these observations establish that biological circular polarization can arise from genuine three-dimensional crystalline chirality, resolving a discrepancy between prediction and observation that has stood since the chiral bandgap was first proposed by Hyde and co-workers.

Willmore stability of minimal surfaces in S^n

Rob Kusner, University of Massachusetts Amherst

We prove that the Lawson minimal surface $\xi_{g,1}$ of genus g embedded in S^3 is stable for the Willmore bending energy $W := \int 1 + H^2$, and remains W-stable in S^n for every $n \geq 4$. We also show that each of the Lawson embedded minimal surfaces $\xi_{m,k}$, the Karcher-Pinkall-Sterling minimal surfaces in S^3, and the equilateral minimal torus in S^5, is the unique constrained Willmore minimizer in its conformal class. Finally, we observe that while the equilateral minimal torus in S^5 is Willmore stable in S^n for every $n \geq 5$, surprisingly it is not strictly stable nor locally W-minimizing: it has a 2-dimensional space of W-Jacobi fields on which the third-variation of W is nonzero.

Self-assembled bicontinuous phases in thermotropic liquid crystals

Xiangbing Zeng, University of Sheffield

Thermotropic liquid crystal molecules can be designed to self-assemble into bicontinuous cubic and non-cubic phases, and in this presentation we will show different examples of such molecules, including molecules with a rod-like core with flexible end-groups and/or side-groups, tree-like molecules, and polymers. We will demonstrate the variety of ways bicontinuous structures can be built from these molecules, with their different geometrical shapes, and different connectivity and compatibility between their constituent moieties. Special attention will be paid to the breaking of mirror symmetry in such systems, and different ways chirality can be induced, propagated, and formed spontaneously, and how these are linked to the spatial and orientational order of molecules inside the bicontinuous structures.

Session 9

Speaker	Title
Arielle Blonder (K)	**Curvature and Architecture: Rethinking the Relationship**
Giulio Facchini (I)	**Deciphering the origin of saddle-shape geometry in the microstructure of the echinoderm skeleton**
Martin Thuo (C)	**Understanding Phase transitions through Graph theory and higher dimensions**

Curvature and Architecture: Rethinking the Relationship

Arielle Blonder, Technion, Israel Institute of Technology

Geometry is often treated as something we draw. In nature, it is something that grows. Leaves, flowers, shells, and seed pods do not acquire their form through external shaping, but through the internal organization of matter. Curvature emerges from growth, differential expansion, internal stresses, and material interactions, coupling geometry with function, adaptation, and efficiency. Rather than prescribing shape directly, nature encodes geometry within the architecture of matter, allowing form to emerge through physical processes. Architecture has traditionally followed a different path. Even as digital tools have made increasingly complex curved forms possible, they are still largely realized by forcing materials into predetermined geometries through molds, machining, or assembly. What if, instead, geometry were encoded in the material itself? Drawing inspiration from natural morphogenesis, this lecture explores how geometry can be prescribed through material organization rather than external shaping. It argues for a shift from designing stress-free structures to designing internal incompatibilities. Instead of eliminating residual stresses, they become the very mechanism through which geometry is generated. Through the development of self-shaping materials for architecture—including Frustrated Composites and recent advances in self-shaping ceramics—I will show how programmed internal stresses transform flat sheets into complex curved structures autonomously. Beyond a new fabrication strategy, this approach suggests a new design paradigm in which geometry is encoded rather than imposed, internal incompatibilities become creative resources rather than defects, and imagination shifts from conceiving forms to conceiving the material processes that generate them.

Deciphering the origin of saddle-shape geometry in the microstructure of the echinoderm skeleton

Giulio Facchini, Université Paris Cité

The microstructure of the skeleton of echinoderms, such as sea stars and sea urchins, is an impressive example of complexity. This structure called stereom is a porous calcitic meshwork, whose surface is saddle-shaped, and reminiscent of minimal surfaces. Minimal surfaces have intrigued scientists for centuries, as they can spontaneously emerge from minimizing interfacial energy like surface tension. Several studies in sea urchins and other echinoderms have addressed the morphogenesis of the stereom, showing that it forms via the addition of tiny mineral bids at the tip of small skeletal elements that successively branch and bridge to form a complex network. Yet, a global, mechanistic, comprehension of how biomineralizing cells control preferential deposition is still lacking.

I present a recent experimental work on the morphogenesis of the particular stereom geometry observed in the sea star P. nodosus. Here, the stereom can take the form of a diamond Triply Periodic Minimal Surface (TPMS) which grants it specific mechanical properties. Using different labeling protocols and imaging tools, we provide the first experimental insight in the formation of the diamond TPMS stereom, and show that the formation of such a highly ordered structure relies on a precise and timely coordination of the branching and bridging episodes. Moreover, we provide experimental evidence of an organic precursor made of F-actin fibers exhibiting saddle-shape geometry. We hypothesize that such a fiber template may self-organize under mechanical tension, thus explaining the peculiar curvature signature of the final structure. We also propose that this morphogenetic mechanism has been conserved across evolution, and could explain the recurrence of saddle-shaped geometry in the echinoderm stereom.

Understanding Phase transitions through Graph theory and higher dimensions

Martin Thuo, North Carolina State University

From Miscibility to phase transition and formation of complex (order in disorder) particles, higher dimensions of space are vital, yet materials science continues to rely on 2D spaces (phase diagrams) as the primary tool of trade. Dominance of non-equilibrium in materials problem exacerbates this challenge. By defining complexity as order vs disorder, we adopt graph theory as a tool to simplify the complexity in phase change, miscibility and their application in preparation of multiphase complex particles. This talk explores the transition from 2D spaces to 3D spaces in resolving the Kauzmann paradox while redefining associated Kauzmann temperature. We extend this to graph-based landscapes to design mixed phase materials and, by extension, associated precipitation hardening.

Session 10

Speaker	Title
Sabetta Matsumoto (K)	**Smocked seams, magic braids and the hidden mathematics of crafts**
Viola Bauernfeind (I)	**Exploring the Role of Disorder in Biological Photonic Networks in Longhorn Beetles**
Daniel Ryuichiro King (C)	**Finite Mechanisms by Wyckoff-Splitting Analysis of Periodic Frameworks and Their Application to Triply Periodic Origami Metamaterials**

Smocked seams, magic braids and the hidden mathematics of crafts

Sabetta Matsumoto, Georgia Institute of Technology

Smocking is an embroidery technique that was originated during the middle ages. It was one of the few embroidery techniques that peasants used -- not because of its decorative qualities, but because it modifies inextensible woven fabric into a highly stretchable material. These properties are now being exploited by urogynecologic surgeons to treat pelvic organ prolapse, a debilitating condition that affects upwards of 25-50% of humans with vaginas. (Joint work with A. Patrick Cachine, Robert S. Kelley, and Serosh Naeem.)

Magic braids are used in leatherworking to make intricate straps and bands. They appear to be impossible to make. To determine which braids can be made with this leatherworking technique, we explore their relation to several braid groups. (Joint work with William Hobkirk, Abigail Hollingsworth, and Corbin Reid.)

Exploring the Role of Disorder in Biological Photonic Networks in Longhorn Beetles

Viola Bauernfeind, University of Fribourg (Alumni)

V. Bauernfeind (a,b), U. Steiner (a,b), and B. D. Wilts (b,c)

(a) Adolphe Merkle Institute, University of Fribourg, Switzerland
(b) National Centre of Competence in Research Bio-Inspired Materials, Switzerland
(c) Department Chemistry and Physics of Materials, Paris-Lodron University Salzburg, Austria

Photonic nanostructures can vary in their degree of local order and their final optical appearance is often further tuned by pigments [1]. Longhorn beetles display vivid colors and rely on varying degrees of (dis)order combined with pigments to create complex color patterns via colored scales that contain bicontinuous photonic networks and adorn the insects' bodies. Using light microscopy, volume imaging and FDTD simulations, we investigated the mechanisms underlying the vibrant color patterns in Sternotomini longhorn beetles [2,3,4]. For detailed insights into the network geometries, we combined focused ion beam tomography that allows for a statistical analysis based on network skeletonization with complementary ultra-small-angle X-ray scattering analyses. Our results suggest evolutionary relations between beetles with morphologically similar networks that differ in their extent of disorder and emphasize the need for further research to understand the formation of these complex three-dimensional photonic structures.

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Finite Mechanisms by Wyckoff-Splitting Analysis of Periodic Frameworks and Their Application to Triply Periodic Origami Metamaterials

Daniel Ryuichiro King, The University of Tokyo

Conventional kinematic metamaterial design begins from a local mechanism and uses its spatial symmetries to construct a periodic arrangement that tessellates space. We propose an inversion of this logic: begin from a periodic framework, identify the relevant finite mechanisms, then fit local origami units to the edge cycle motion prescribed by the mechanism. The global kinematic properties are therefore encoded from the outset rather than being produced by assembly choices.

We focus on the equiauxetic case, where the Poisson's ratio is -1 in every direction. The finite mechanism is identified by counting the degrees of freedom associated with the Wyckoff positions of the vertices and edges. Once a finite mechanism is identified, its explicit parametrisation is either solved from, or read off from, the vertices' Wyckoff positions in the relevant subgroup. The boundary motion of the edge cycles then constrains which origami units are geometrically admissible as local realisations.

We apply this method to nets derived from tilings of triply periodic minimal surfaces, where the surface topology typically ensures that the assembled origami units form coherent, non-self-intersecting, space-filling structures. The result is a diverse range of novel triply periodic origami architectures produced by rational design.

Stephen Hyde Honorary Session

Speaker	Title
Martin Cramer Pedersen (I)	**Patterns and pattern formation on triply-periodic minimal surfaces**
Philipp Schönhöfer (I)	**Microrobotic Behaviors of Flexicles: Combining Activity and Geometry**
Rhoslyn Coles (C)	**Packing, Exclusion and Form: What a fluid can do with a short string**
Vanessa Robins (I)	**Topology, Geometry, Materials and (my lack of) Imagination**
Christophe Oguey (I)	**Modelling foam dynamics, in particular T1 transformations, incorporating surfactant mass transfer and the Marangoni effect**

Patterns and pattern formation on triply-periodic minimal surfaces

Martin Cramer Pedersen, University of Copenhagen

We review the formalism for interpreting and classifying crystallographic patterns on the Primitive, Diamond, and Gyroid triply-periodic minimal surfaces via their universal cover: hyperbolic two-space. After this, we turn to the topic of generating such patterns in molecular/coarse-grained simulations and field theories confined to these surfaces, and discuss the physical implications of the emerging patterns - as well as of those not emerging in our simulations. We find that aside from the intrinsic length scales of given pattern being commensurate with the unit cell of the confining surface, the variation of Gaussian curvature across these surfaces play a key role in determining the formation and exclusions of particular patterns.

Microrobotic Behaviors of Flexicles: Combining Activity and Geometry

Philipp Schönhöfer, University of Michigan

The growing ability to synthesize colloidal nanoparticles of arbitrary shape and interaction anisotropy creates new opportunities to realize complex self-propelled particle systems with emergent swarm-like behavior. In this talk, we examine how the interplay between particle morphology, deformability, and activity gives rise to a wide range of microrobotic behaviors through a complex particle system we call flexicles: deformable artificial cellular superstructures composed of active particles encapsulated by a flexible membrane. By investigating single and many-flexicle systems, we show that flexicles adapt to their environment through complex shape changes, coupling morphological flexibility and propulsion to produce a diverse set of robotic dynamics. Our findings establish flexicles as a new class of complex active matter and illustrate how the combination of activity, geometry, and materials expand the imagination of what can be designed, realized, and programmed in colloidal robotics.

Packing, Exclusion and Form: What a fluid can do with a short string

Rhoslyn Coles, Technische Universität Chemnitz

Inspired by the role of water in governing the shape of biomolecules, my work uses the morphometric approach to solvation to simulate the folding of a short biopolymer string into an energetically favourable configuration. The model is simple: the biopolymer is represented as a homogeneous tube surrounding a polygonal curve immersed in a hard sphere solvent, modelling the aqueous environment of a cell under physiological conditions. Simulation results demonstrate that different fluid environments favour different configurations of the string, supporting the hypothesis that the fluid can play an essential role in regulating the functioning of biomolecules by way of their three-dimensional configuration.

Central to this work is the morphometric approach — a framework that quantifies geometry in a physically relevant way, enabling investigation of structure-property relationships amongst a broad range of materials — here used to explore physical packings of a simple tube. Despite simplicity, the tube model is a challenging toy model for geometric analysis, where techniques based on exact shape may miss the universality and robustness of the packed optimised form. An aim of this talk is to illustrate some of these challenges.

Topology, Geometry, Materials and (my lack of) Imagination

Vanessa Robins, Australian National University

Topological data analysis provides an adaptable suite of methods for measuring shape from data in many forms. This talk will illustrate the key concepts of TDA with examples from materials science. A surprisingly challenging tasks is to analyse periodic structures using TDA, and I'll try to demonstrate why this is the case.

Modelling foam dynamics, in particular T1 transformations, incorporating surfactant mass transfer and the Marangoni effect

Christophe Oguey, LPTM, CY Cergy Paris University

Ubiquitous in foam rheology, the T1 topological transformation is an exchange of inter-bubble contacts. In 2D, this event occurs when a bubble separating film shrinks to zero, a new film arises and expands rapidly because the new configuration is unstable, out of equilibrium. The evolution implies surfactant density variations that modify the local surface tension and, in turn, affect the foam dynamics. This coupling, the Marangoni effect, depends on Gibbs' elasticity EG. The T1 event may be almost entirely mechanical in the case of weak EG or mostly physicochemical for a strong EG.

Following Durand and Stone [2006], first models considered homogeneous concentrations within each film, instantaneous mechanical equilibration and took into account the surfactant transfer between connected films by the Marangoni effect. Both length and surfactant concentration of the newly created film undergo a rapid correlated initial evolution, long before the film approaches final equilibrium. A physical explanation was proposed in terms of slippage between material points flowing at the end of the new film, and the evolving location of the film endpoint itself.

More recently, we developed a model of the full foam dynamics by revisiting a previous model [DySMaL, 2014] and incorporating surfactant transport and surface tension variations. The liquid-gas interface is subdivided into small material segments and the algorithm solves the dynamics of this discrete coupled model.

The T1 topological rearrangement of four bubbles in a sheared box is a good benchmark test. The constant tension model shows spurious transient oscillations after the T1, caused by the sudden redistribution of capillary forces. On the other hand, when surfactant transport is taken into account, the rapid elongation generates surface tension gradients and Marangoni stress that oppose film stretching and significantly reduce these oscillations. Also clear from comparing the simulations, the Marangoni effect is very sensitive to the liquid fraction: it is weak in wet foams, which remain close to local equilibrium during the whole T1 transformation, but stronger in dry foams because the T1 is triggered later, at larger bubble deformation, thereby enhancing capillary force contrasts, acceleration and surface tension gradients.

Session 11

Speaker	Title
Randall Kamien (I)	**Disclinations and Dislocations**
Reinhard Lipowsky (C)	**Morphological complexity of biomembranes**
Adil Mughal (C)	**Dense Packing of Tetrahedra in Cylinders**
Lauren Niu (C)	**Laves' Labyrinth Lopped: Variations on a 3-Sphere**

Disclinations and Dislocations

Randall Kamien, University of Pennsylvania

You will be acquainted, too, with matters topological,
You'll see the dislocations move both parallel and vertical,
About the theory's moduli, I've information manyfold,
With many cheerful facts about the twisted ground state orbifold.

Morphological complexity of biomembranes

Reinhard Lipowsky, Max Planck Institute of Colloids and Interfaces

The cells and organelles of our body are enclosed by biomembranes that consist of molecular bilayers of lipids and membrane proteins. The membranes are ultrathin, with a thickness of only 4 to 5 nanometers, and represent two-dimensional liquids. Because of their fluidity, biomembranes have unusual elastic properties, governed by the interplay of curvature elasticity and membrane tension. As a consequence, these membranes can easily transform their shape, their topology, and their local molecular composition. This talk will describe recent theoretical insights into the composite nature of membrane tension; multispherical membrane shapes; topological transformations via membrane fusion and membrane fission; as well as nanotubular networks that mimic the fascinating membrane architecture of the endoplasmic reticulum.

Dense Packing of Tetrahedra in Cylinders

Adil Mughal, Aberystwyth University

Authors: Gabrielle N. Jones (1), Adil Mughal (2) [Presenting], Philipp W.A. Schönhöfer (1), and Sharon C. Glotzer (1, 3) Affiliations: (1) Department of Chemical Engineering, University of Michigan, Ann Arbor, MI 48109, USA (2) Department of Mathematics, Aberystwyth University, Aberystwyth, Wales SY23, UK (3) Biointerfaces Institute, University of Michigan, Ann Arbor, MI 48109, USA

We present the first systematic investigation into the dense packing of congruent regular tetrahedra confined within a circular cylinder. Using a combination of pressure-driven numerical simulations (HOOMD-blue) and analytical theory, we characterize the densest geometric arrangements over the cylinder-to-particle diameter range $1 \leq D/a \leq 1.21045$.

Our results reveal that these constrained packings organize into two mathematically tractable structural families: chiral Tetra-Helices and achiral Dimer-Chains. Crucially, we demonstrate that the celebrated Boerdijk-Coxeter helix is not an isolated geometric anomaly, but rather a specific limiting member of a broader continuous family of cylinder-confined packings.

At a critical diameter ratio of $D/a = 3\sqrt{3}/5$, the system undergoes a symmetry-breaking bifurcation where the chiral screw-symmetric tetra-helix family coexists with and gives way to a line of achiral, glide-symmetric dimer chains. We provide exact analytical formulations for the metrics, vertex positions, and bounding packing fractions for the six fundamental phases identified in this regime, opening new avenues for understanding anisotropy and faceted particle organization under geometric confinement.

Laves' Labyrinth Lopped: Variations on a 3-Sphere

Lauren Niu, University of Massachusetts Amherst

Inspired by the structure of **srs** Laves networks in R^3 that underpin the celebrated gyroid surface, we construct a Laves network of identical three-coordinated vertices on S^3 with double-twist. This network is a subset of the vertices and edges of the 600-cell, and can be viewed as a bipartite graph of disjoint 24-cell vertices inscribed in the 600-cell. We describe mutually entangled realizations of this network on S^3, and describe their relation to the well-known **srs** Laves network structure in R^3.

Session 12

Speaker	Title
Hannah Santa Cruz Baur (I)	**Beyond Hasse diagrams for 3D Tiling Classification**
Tomaso Aste (I)	**Geometry, Machine Cognition and Imagination**
Natalija Miodragovic (C)	**Imagine Building with Loops instead of Blocks**

Beyond Hasse diagrams for 3D Tiling Classification

Hannah Santa Cruz Baur, Vrije Universiteit Amsterdam

Hasse diagrams are a natural combinatorial tool for encoding the incidence structure of topological domains, and have recently found significant use in higher-order deep learning as a unified framework for message passing on cell complexes. However, in the classification of periodic three-dimensional tilings, the Hasse diagram is an insufficient descriptor; as we will see, it can fail to uniquely determine a tiling up to equivariant equivalence. In this talk, we introduce the unfolded Delaney–Dress graph as a robust alternative that preserves uniqueness through a compact labeling system.

We begin by reviewing the construction of the classical Delaney–Dress symbol: a colored multigraph with associated Coxeter matrices that serves as a complete invariant for equivariant tilings. Through a series of comparative examples, we illustrate in what settings the Hasse diagram may and may not uniquely determine the tiling. Finally, we describe the lifting of these symbols to their unfolded graph representations, and conclude by discussing potential applications for the structural analysis and design of Metal-Organic Frameworks (MOFs).

Geometry, Machine Cognition and Imagination

Tomaso Aste, University College London

Deep-learning architectures are often presented as sequences of algebraic operations. Yet they can also be viewed geometrically: as networks that define spaces, constrain flows of information, and shape the representations a machine can form. I will talk about our work on HNNs—neural architectures shaped by complex networks—and discuss how network structure can serve as an architectural principle for learning. This perspective brings geometry and computation into a shared conceptual space and suggests that artificial cognition is itself an exercise of the geometric imagination.

Imagine Building with Loops instead of Blocks

Natalija Miodragovic, HU Berlin / TU Braunschweig

Can we build with loops instead of blocks? This self-supporting structural textile prototype explores bio-driven architectural systems in which basketry and textile techniques, earthen structures, and filamentous fungal growth become design criteria. Through warp-knitted loops made from local willow, sheathed with wool, seagrass, flax, and hemp for earthen construction and plant and fungal biofilm growth, the project engages with the communities, landscapes, their knowledge and regenerative practices connected to these materials. Knitting has capacity to form complex geometries. Inspired by geometries of bulk-tissue, the cell wall and biofilm structures, the warped spaces are translated into architectural scale. Architecture is explored as relational and processual.

Filaments and fibers are among the most common organizational structures in nature [1]. Their application in architecture offers opportunities to rethink relationships between biological and built environments. Fibers are lightweight structures with vast surface areas relative to their volume, open to multiple simultaneous weak interactions [2]. How can we extend our bodies, systems, and architectures to meet our fiber-fibril-filament biological world halfway? Unlike conventional textiles, willow-based structures are stable while remaining adaptive and relational. They mediate between dichotomies: matter and void, solid and gaseous, growth and decay, nature and culture. Recent understandings of humans as holobionts rather than solitary organisms have initiated new approaches to biotechnology, material research, and digital fabrication, renewing interest in fiber-based construction and living materials. Structural textiles contribute to this discourse by bringing together textile knowledge, earthen construction, biological growth, and local biomaterials within architectural practice.