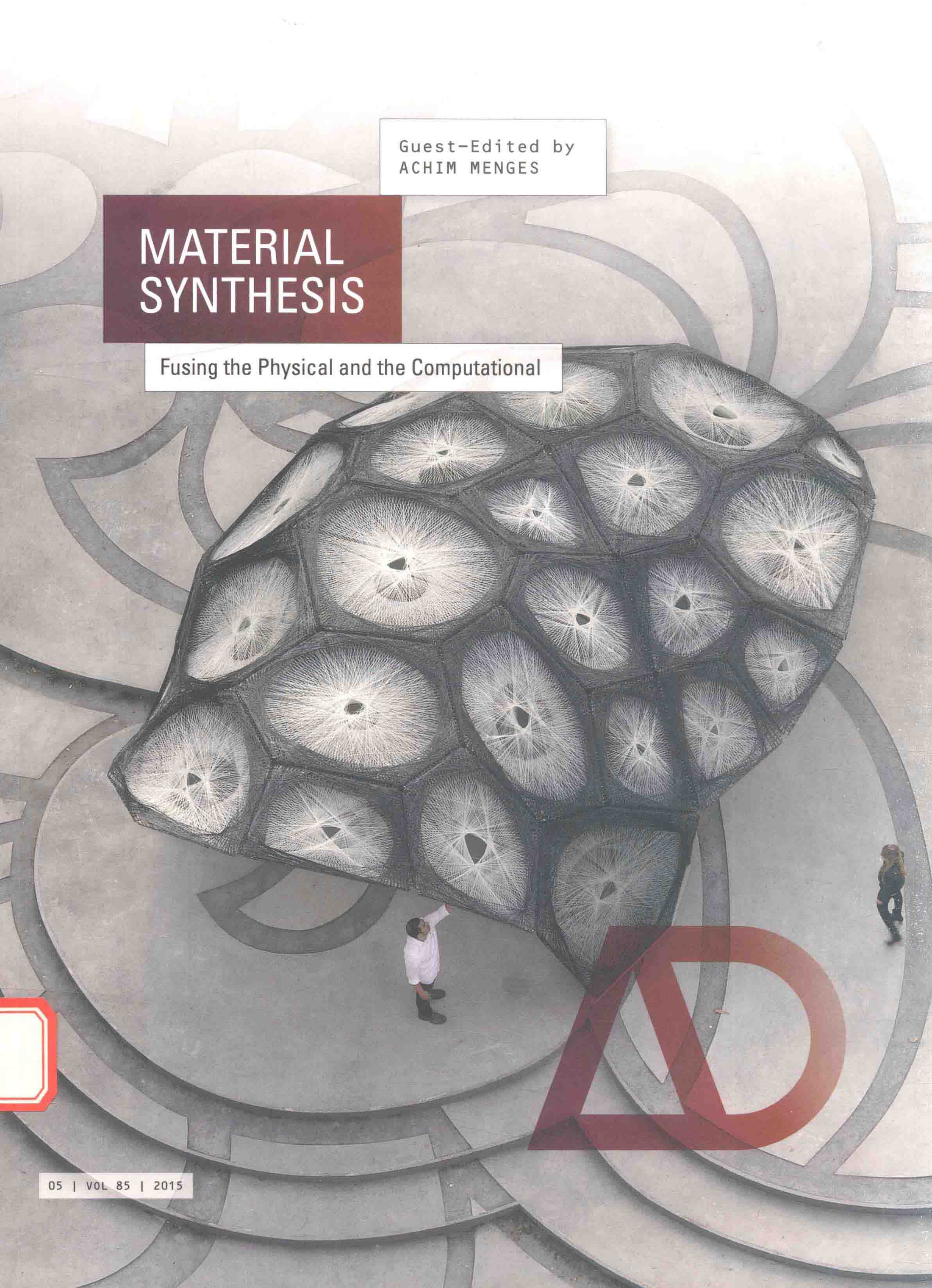
Guest-Edited by
ACHIM MENGES

MATERIAL SYNTHESIS

Fusing the Physical and the Computational



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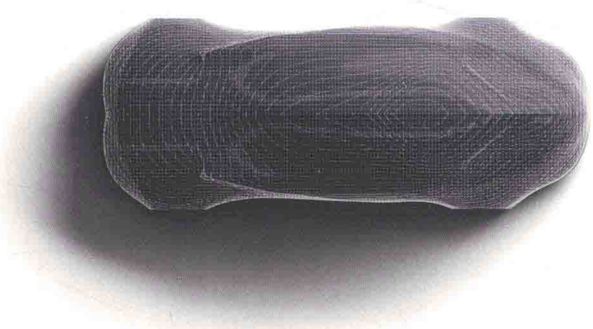

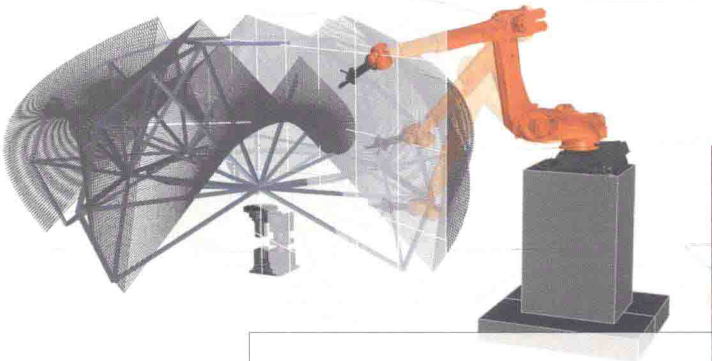

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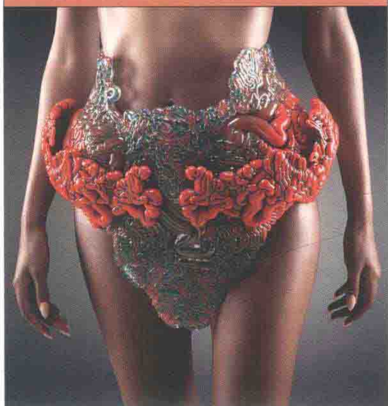

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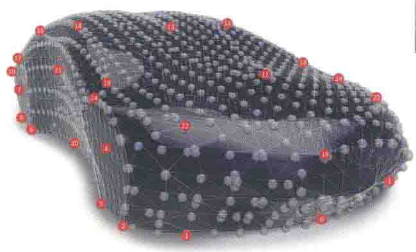

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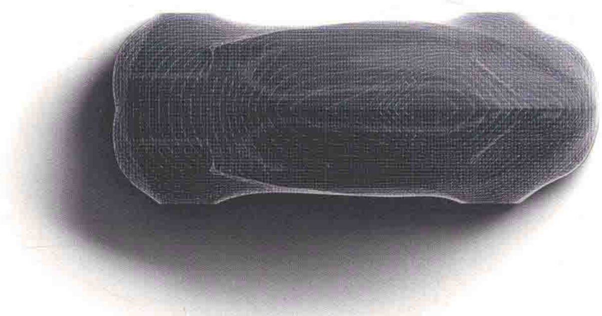

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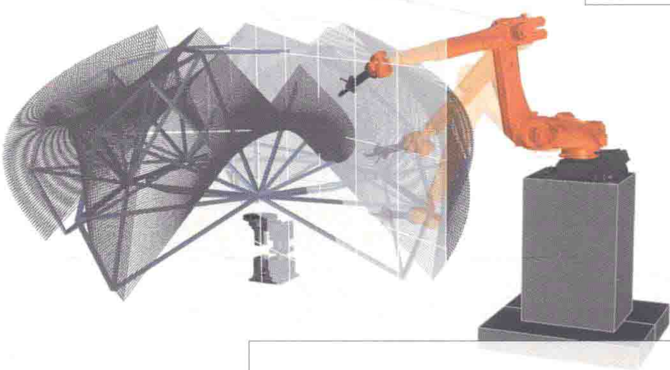

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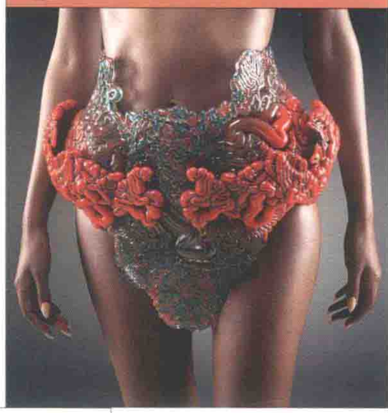

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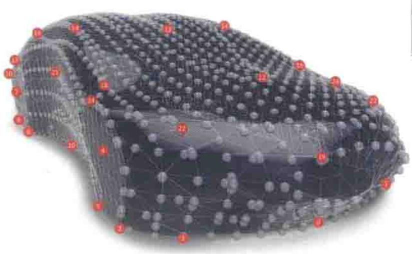

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EDITORIAL

HELEN CASTLE

Architecture has in the last decade or so taken a decidedly material turn, as has technology. With the major technology and software companies turning their attention to the Internet of Things, as data penetrates every aspect of the physical world, seemingly every consumer object is a smart device. In December 2013, Google allegedly acquired seven – also reported as eight – robotics companies; the purchase including San-Francisco-based boutique design company Bot & Dolly. In July 2014, Autodesk added innovative Brooklyn-based architecture studio The Living to its research group, well-known for its wackily ground-breaking material experimentations; having only a year previously appointed synthetic biologist Andrew Hessel an Autodesk Distinguished Researcher. It is clear that materials and material science are now firmly within the sights of technology companies' R&D.

Architects have not always lived in a material world. In fact they have done their best to remove themselves from it. As Guest-Editor Achim Menges points out in his introduction to this issue, for the last 600 or so years, since the introduction of perspective drawings and the printing press during Renaissance times, architects have, in the pursuit of design and the conceptual – and arguably social status – spurned hands-on contact with buildings and an intimate knowledge of the materials that they are made from. This is not to deny the role of materials in the creation of great works of architecture, or architects' veneration of them for lending distinct qualities to a structure. Materials have, though, most often assumed a passive, albeit enhancing rather than a generative role. Creativity has been assigned to the design or drawing, with materials most often being specified as a result of design rather than being considered a driver of it. The vision that Menges inspires in this title of AD on *Material Synthesis* changes all that by fusing the physical and the computational. Here, designers engage with their materials at a granular level, engaging with their full range of characteristics to performative effect, which leads ultimately to the design of matter itself.

Menges' approach is steeped in design research, carried out by himself and colleagues at the Institute for Computational Design (ICD) at the University of Stuttgart. What makes Menges' work, though, so unarguably compelling is the beauty of its material realisation – he preaches the biomimetic and serves us the ICD/ITKE Research Pavilion 2014–15 (see pp 60–5), inspired by the web of a water spider with all the inherent tautness and fragility of the original in tact. The *HygroScope* installation (see pp 66–9) that has a shell-like form designed to respond to changes in the Parisian weather from within the Centre Pompidou, evokes a giant fossil in its case.

The fusion of the material with computation and data are only, though, in their genesis. Pitfalls abound in the applicability of highly experimental adaptive materials. Branko Kolarevic uses his Counterpoint (see pp 128–33) to serve as a reminder of some of the ongoing challenges for architects, while also flagging up some further exciting areas of development in the field. AD

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Achim Menges with Oliver David Krieg and Steffen Reichert/ Achim Menges Architect BDA and Institute for Computational Design (ICD)

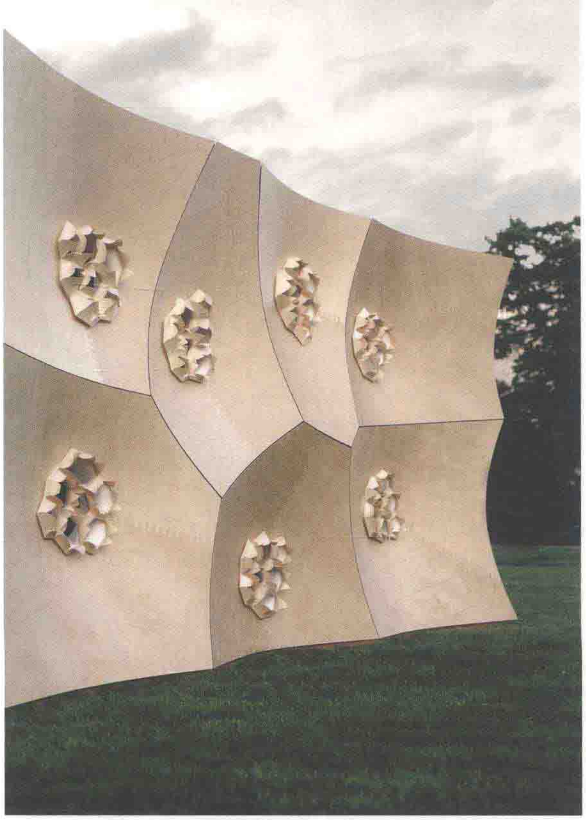
HygroSkin – Meteorosensitive Pavilion

FRAC Centre

Orléans, France

2013

The pavilion explores a novel convergence of spatial and environmental experience. The hygroscopic behaviour of wood is the basis for the pavilion's weather-responsive apertures, which are in one embedded sensor, no-energy motor and regulating element. The pavilion is in the permanent collection at FRAC.



Achim Menges with Steffen Reichert/Achim Menges Architect BDA, Institute for Computational Design (ICD) and Transsolar Climate Engineering

HygroScope – Meteorosensitive Morphology

Centre Pompidou, Paris

2012

The meteorosensitive morphology exhibits the potential of a no-tech approach to climate responsiveness. No additional mechanical or electronic equipment is required for the movement of the responsive elements, as the performance of sensing, actuating and responding is integrated in the material itself. The *HygroScope* installation is in the permanent collection at the Centre Pompidou.

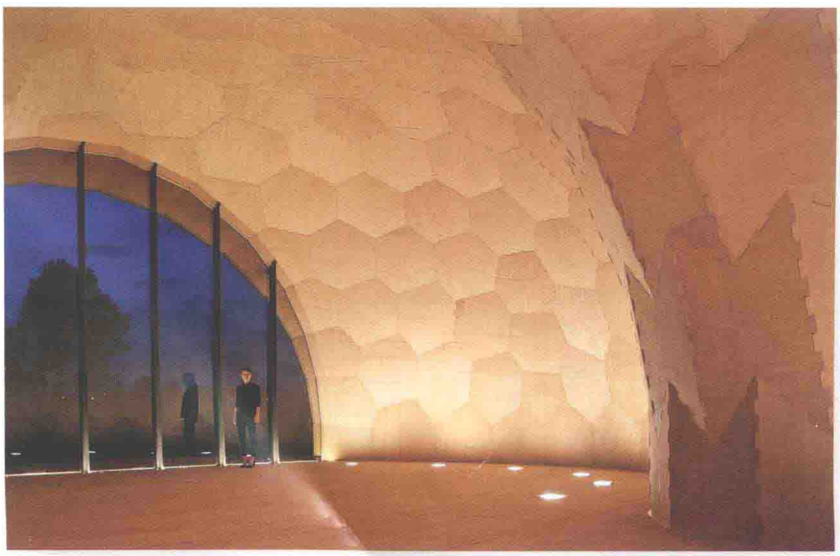
Institute for Computational Design (ICD), Institute of Building Structures and Structural Design (ITKE) and Institute of Engineering Geodesy (IIGS)

Landesgartenschau Exhibition Hall

Schwäbisch Gmünd, Germany

2014

The Landesgartenschau Exhibition Hall showcases the architectural potential of the timber-plate shell system developed in the University of Stuttgart's related Robotics in Timber Manufacturing research project.



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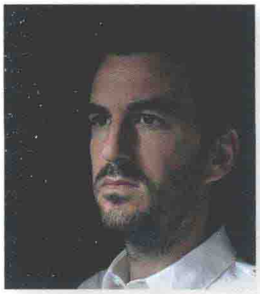
GUEST-EDITOR

ACHIM MENGES



The work of Achim Menges explores the reciprocity between the material and the computational in architecture, and its manifold and deep interrelations with technology, biology and culture. This enquiry is conducted through his academic research as Professor at the University of Stuttgart, where he is the founding director of the Institute for Computational Design (ICD), through his role as a visiting professor at Harvard University's Graduate School of Design (GSD), and through his architectural practice in Frankfurt. Menges graduated with honours from the AA School of Architecture in London, where he subsequently taught as Studio Master of the Emergent Technologies and Design (Emtech) graduate programme, and as Unit Master in the AA Diploma School. He also held several visiting professorships in Europe and the US.

Embracing the University of Stuttgart's long-standing history of creatively engaging the fields of engineering and natural science in architecture, and its location in the heartland of Germany's advanced manufacturing industry, the ICD pursues a multidisciplinary approach to design research based on an intense collaboration with structural engineers, computer scientists, material scientists and biologists. It also forms an integral part of the recently established Collaborative Research Centre TRR 141 Biological Design and Integrative Structures research programme, a major undertaking funded by the German Research Foundation (DFG). The related multidisciplinary design culture is also reflected in the teaching model of the university's new international Integrative Technologies and Architectural Design Research (ITECH) MSc programme led jointly by Menges at the ICD and Jan Knippers of the Institute of Building Structures and Structural Design (ITKE), which is open to students with a background in architecture, engineering or natural science. Over the last few years, the annual ICD/ITKE Research Pavilions have gained international recognition as leading architectural examples showcasing the possibility of a novel synthesis of spatial, structural and material performance.

Menges and his team have also completed a number of other groundbreaking projects including the HygroScope installation for the permanent collection of the Centre Pompidou (2012), the HygroSkin pavilion for the permanent collection of the FRAC Centre in Orléans, France (2013) and the Landesgartenschau Exhibition Hall in Schwäbisch Gmünd, Germany (2014). His projects and design research have received many international awards, been published and exhibited worldwide, and form parts of several renowned museum collections. He has published several books on his work and related fields of design research, and is the author/co-author of numerous scientific papers and articles. He has guest-edited four previous issues of AD, including *Emergence: Morphogenetic Design Strategies*, with Michael Hensel and Michael Weinstock (2004) and, more recently, *Material Computation: Higher Integration in Morphogenetic Design* (2012). AD

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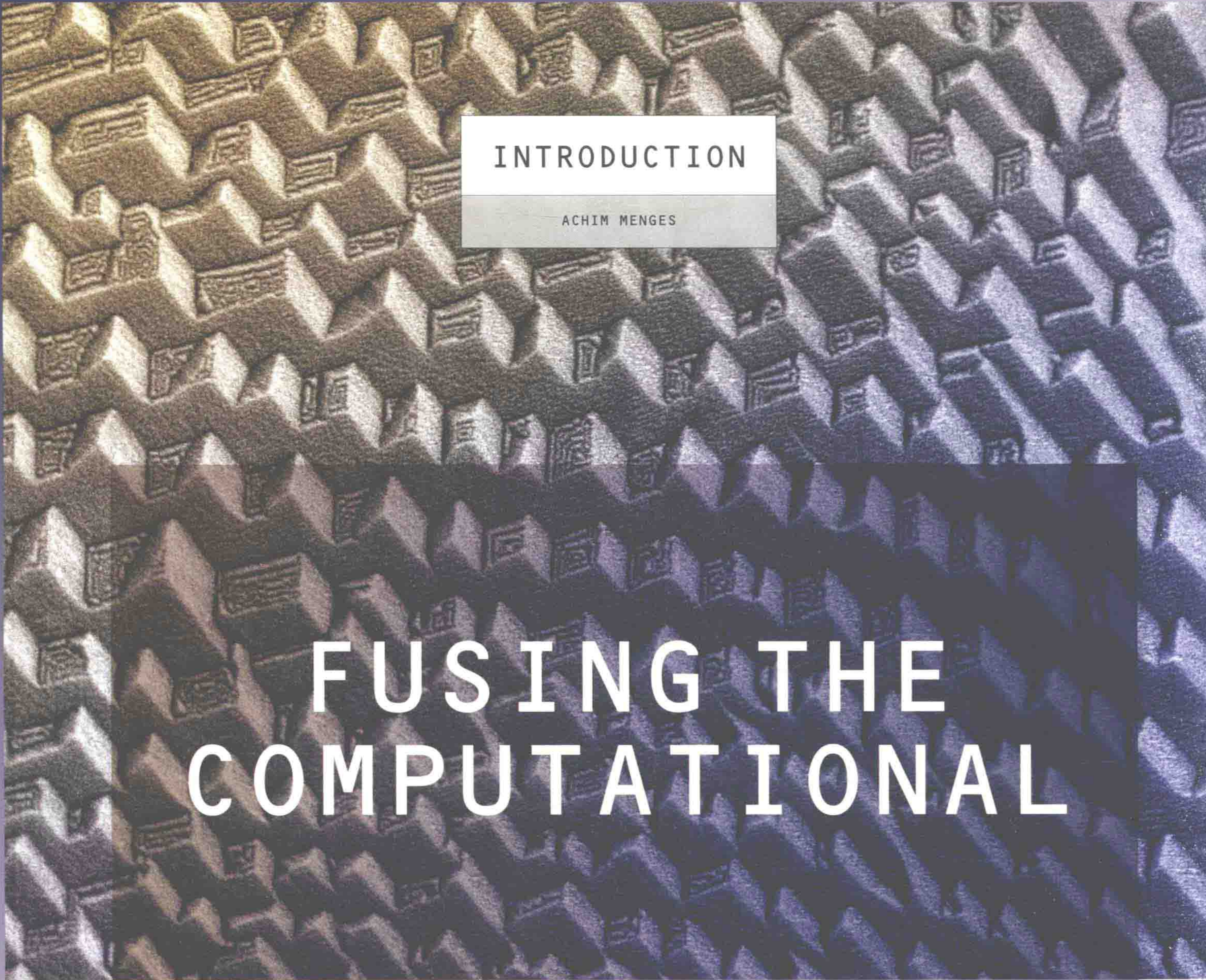
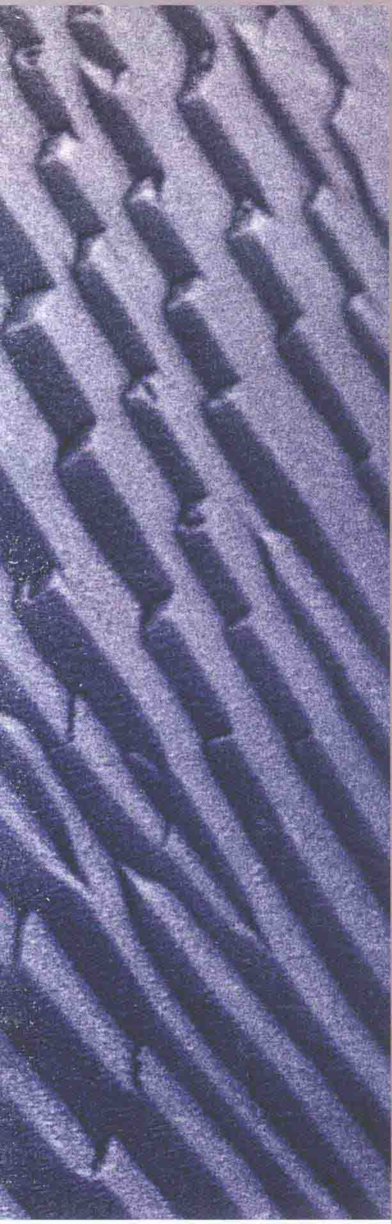


INTRODUCTION

ACHIM MENGES

FUSING THE COMPUTATIONAL AND THE PHYSICAL



Titanium crystals

Coloured scanning electron micrograph (SEM) showing the surface crystals of a sintered (heated and shaped) titanium bead on a joint implant. The outer surface of the bead becomes almost molten during the sintering process, forming surface crystals when it slowly cools down. Sintered beads act as the bone-contact surface on joint implants, as new bone tissue grows around the beads and into the gaps between each bead to provide a firm fixation for the implant.

Josef Albers

Material experimentation with folded paper

Black Mountain College

North Carolina

1946

Josef Albers's material experimentation, conducted as part of the foundation course at the Bauhaus in Dessau and later at the Black Mountain College in North Carolina, as shown here, was a precursor of generative material exploration in design. His studies were not conceived as scalar models or representations of ideas; instead he identified the material behaviour itself as a driving force in an open-ended creative process that unfolds new design possibilities and innovation in making.

Towards a Novel Material Culture

> Let's begin with the greatest cliché of all, heard frequently in design circles: 'The computer is nothing but a tool (no different from any other).' There are innumerable ways to address the poverty of this formulation. One would be to consider the meaning and function of the tool (or technical object) within human and animal history and ecology in the first place. Another would challenge the further – embedded – assumption that the computer belongs in a continuous and uncomplicated way to a series of technical innovations that have marked human interaction with, and mastery of, its environment over our long history.
>
> — Sanford Kwinter, 2012[1]

Material culture is described as the physical evidence and expression of a culture in its artefacts and architecture. If we understand the notion of material culture not only as having relevance for studies of the past, but also obtaining a projective capacity, we may now be at a significant turning point. As computation begins to profoundly change our conception of the material, so in architecture this will challenge the established relationship between the processes of design and the physical making of the built environment. Of course, computation was introduced into architecture more than half a century ago, and increasing digitisation has since pervaded all aspects of the discipline. However, it has remained strongly influenced by the conceptual separation of the processes of design and making that has dominated architectural design thinking since the Renaissance, and it is only now that designers are beginning to see the computational domain as no longer separate from the physical realm. Computation is emerging as a key interface for material exploration, enabling engagement with aspects of the material world that until recently were too far removed from the modalities of designers' sense and intuition.[2] This represents a significant perceptual shift in which the materiality of architecture is no longer seen as a fixed property and passive receptor of digitally derived form, but is transformed into an active generator of design and an adaptive agent of architectural performance. Similarly, and in stark contrast to previous linear and mechanistic modes of digital fabrication and manufacturing, materialisation is now starting to coexist with design in the form of explorative cyber-physical processes.

Material-driven design is not without precedent in architecture. However, what is meant here is not the often-quoted 'truth to materials' of modernist attempts, but rather a truly generative material exploration in design. Two precursors of such an approach represent some of the most radical academic architectural ventures of the 20th century. Josef Albers's material studies conducted in his foundation course at the Bauhaus in Dessau in the late 1920s, as well as his similar work pursued later at the Black Mountain College in North Carolina, provide a fascinating model for design processes driven by material experimentation. Instead of employing established processes of materialisation rooted in professional knowledge, which he claimed stifled invention, Albers identified the material behaviour itself as a creative source for developing new modes of construction and innovation.[3] It is important to note that his material studies were not conceived as scalar models or representations of ideas, but rather as a generative unfolding of material behaviour in space and time from which hitherto unsought design possibilities could originate.

Somewhat located at the other end of the spectrum of material-driven design approaches is the work Frei Otto undertook at his institute at the University of Stuttgart from the 1960s to the 1980s. In developing what he termed 'form-finding' methods, he conducted extensive series of experiments with various material systems, ranging from soap bubbles to sand, to gridshells and cablenets, in order to study their inherent capacity to physically compute form as an equilibrium state of system-intrinsic material behaviour and extrinsic forces. For Otto's most famous buildings, such as the Multihalle constructed in Mannheim, Germany, in 1975, these studies served as inquiries into the possible points of departure for developing architectural designs through material behaviour, rather than through the top-down determination of form and space.[4]

This issue of AD presents work that embraces both Albers's experimental approach of employing material as a driving force in an open-ended creative process, and Otto's scientific rigour in conducting related design research in the contemporary context of computational design, simulation and fabrication. It introduces the potential fusion of the computational and the physical in architectural design, which will have a profound impact on the discipline. It begins, therefore, with tracing the conceptual roots of this latent transformation in current developments in contemporary philosophy, architectural theory, emerging technologies and biomimetics.

Material and Computation
Emerging Conceptual Frameworks

'New Materialism', as an emerging line of 21st-century thought, is having a significant influence on a wide spectrum of fields, from philosophy and cultural theory to science studies, the arts and design. Philosopher Manuel DeLanda, who is often credited with coining this term,[5] has been a leading protagonist of this new conception of the material world. In his contribution to this issue, 'The New Materiality' (pp 16–21), he outlines how the Aristotelian view on matter as an inert receptacle of form superimposed from the outside, together with the Newtonian idea of an obedient materiality governed by general laws, now

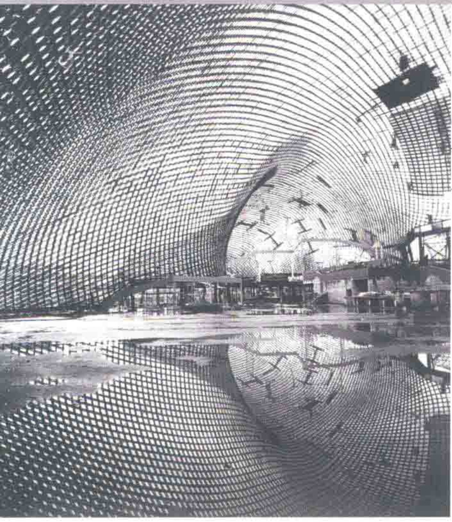
Frei Otto

Physical form-finding during the model construction for the Olympic Stadium in Munich

Stuttgart

1969

Another important precedent for material-driven design is the work Frei Otto pursued at his institute at the University of Stuttgart. Based on the investigation of different material systems, which ranged from soap bubbles to sand, and from gridshells to cablenets, as depicted here, he developed so-called form-finding methods. These enable form to be physically computed through system-intrinsic characteristics and extrinsic forces, and thus constitute a design process driven by material behaviour rather than by the top-down determination of form and space.



Frei Otto and Carlfried Mutschler with Ove Arup

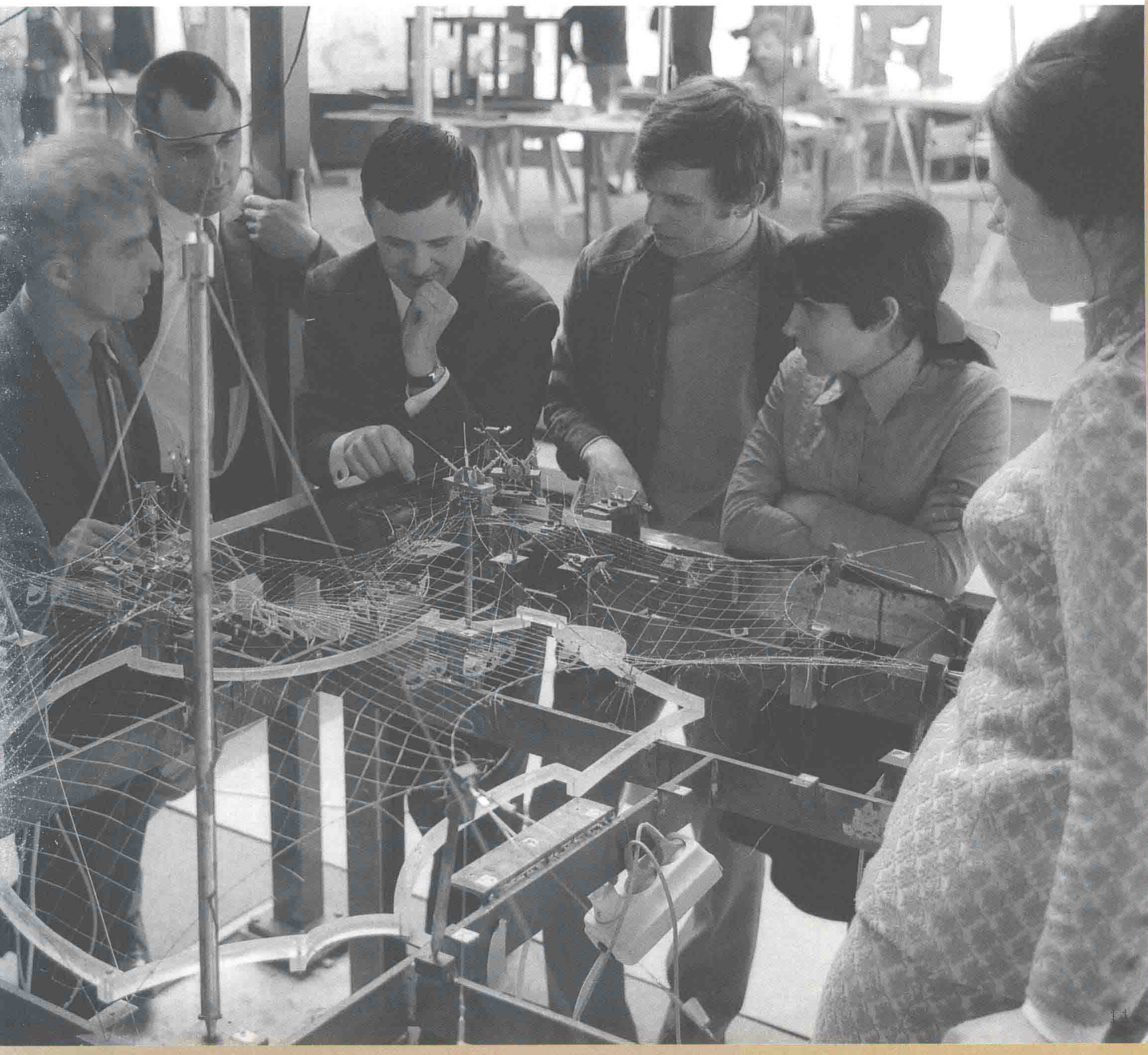
Multihalle Mannheim

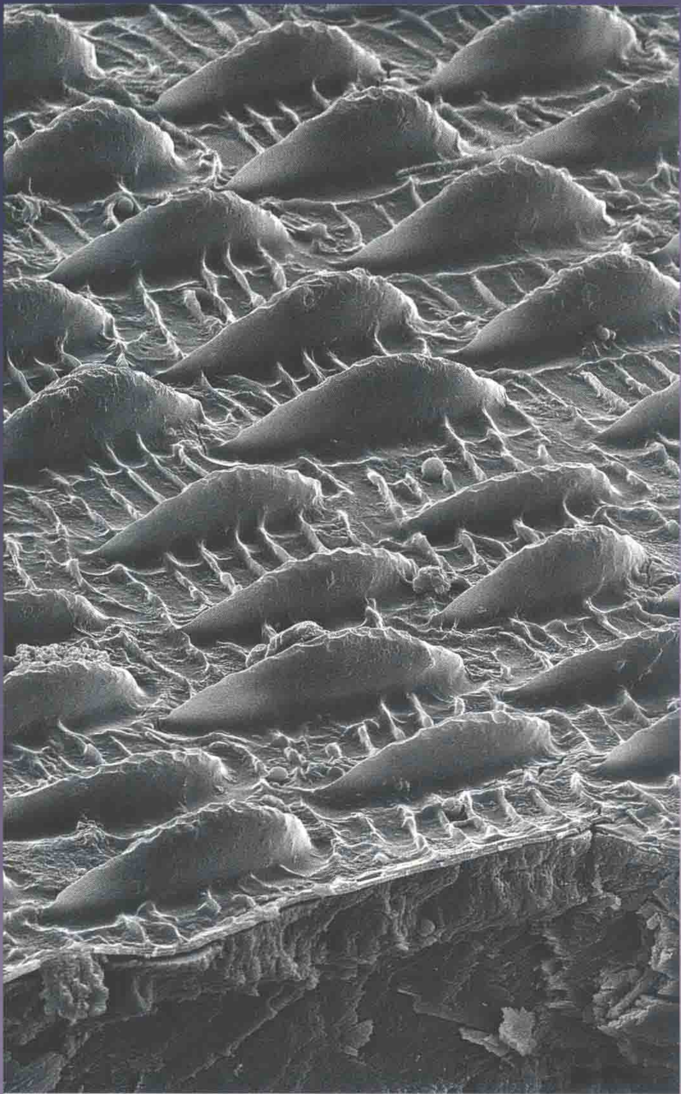
Mannheim

Germany

1975

The Multihalle Mannheim provides an interesting example of how Otto's form-finding method could be extended to a full-scale construcion technique on site. The timber gridshells were initially assembled as an entirely flat and regular wooden lattice, but once this was jacked up at a few strategic points, it could find its highly material-efficient, structurally stable, double-curved form by itself based on the elastic behaviour of the wood elements.





Christoph Allgaier

Surface features of terrestrial snail shells

University of Tübingen

Baden-Württemberg

Germany

2014

Surface features of terrestrial snail shells. Natural growth provides interesting process principles for biomimetic manufacturing. One promising biological model researched in the Collaborative Research Centre 'Biological Design and Integrative Structures' at the universities of Stuttgart, Tübingen and Freiburg is the shell formation of terestial snails, which produces complex shapes with highly structured functional surfaces. In contrast to most other shell-producing animals, but similar to technological 3D-printing processes, they produce building material extruded at a single groove of productive tissue.

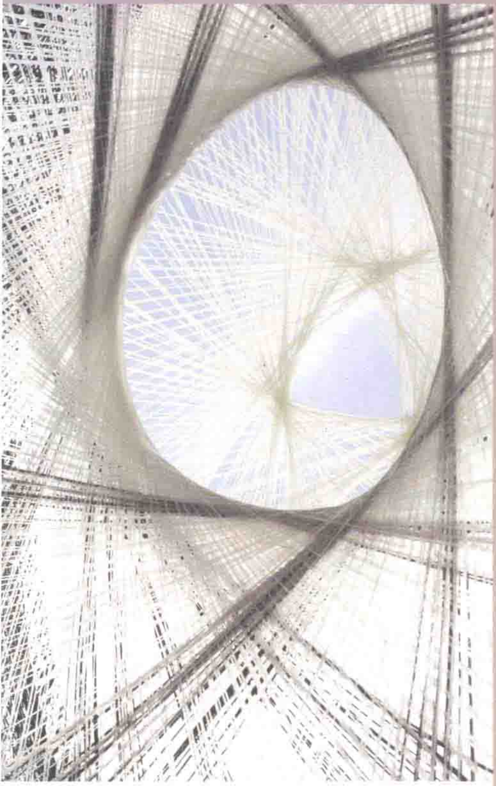
gives way to a new conceptualisation of an active matter empowered by its own tendencies and capacities. Consequently, the processes of unfolding material form are conceived as open-ended and driven from within by immanent patterns of being and becoming. This poses a significant challenge to both current digital design approaches devoid of material logics and the aforementioned, trite, modernist 'truth to materials' that lingers on in today's design thinking and relates the assumed essence of a material to a set of given – supposedly appropriate – structural and spatial typologies. A prime example of equating a material's quintessence to a defined constructional logic in such a linear, direct and idealised manner is the typological response that brick whisperer Louis Kahn imagined to receive.

Computation, simulation and, ultimately, cyber-physical production allows creative engagement with the divergence and multiplicity latent in material form, and to conceive of material systems as individual constructs rather than derivates of a given type. Typology may thus join the rapidly growing circle of increasingly outdated conceptual and scientific frameworks that were introduced to sort human knowledge into manageable amounts of information, as explained by Mario Carpo, one of the leading contemporary voices in theorising the relation between architecture and computation. In his article (pp 22–7) he argues that from the beginning of time, the need for sorting information has always been a primary driver in the cultural and scientific development of humankind, but today becomes increasingly obsolete through emerging technologies that allow for storing, and thus searching, almost infinite amounts of data. He provides a striking argument for the potential of big data and related technical developments to disrupt the way we design and calculate almost everything, and in doing so proposes a 'new science of form-searching'.

How this concept may not only apply to design in the virtual domain, but also to a fusion of the physical and the computational in emerging processes of synthesised design and making, becomes evident in light of cyber-physical production systems. My article on pp 28–33 introduces the notion of 'computational construction', which challenges our understanding of the genesis of form, tectonics and space, and argues that the advent of these technologies, which in other domains is often referred to as the 'Fourth Industrial Revolution', may take on a life of its own in architecture. As production machines no longer remain dependent on a clear set of instructions cast in determinate control code, they are increasingly capable of sensing, searching, processing and interacting with each other and the material world in real time, opening up the possibility of truly explorative processes of computational construction that merge design and making.

Biology and Technology
Expanded Synergies

In natural morphogenesis, formation and materialisation are always inherently and inseparably related. The investigation of the multifaceted biological processes of material formation therefore provide a promising starting point for the further development of integrative approaches to design and making in architecture. Moreover, the study of the biological materials



Institute for Computational Design (ICD) and Institute of Building Structures and Structural Design (ITKE)

ICD/ITKE Research Pavilion 2013-14

University of Stuttgart

2013-14

Robotically differentiated fibrous composite structures. Biological composites, which are abundant in nature, share their fundamental characteristics with technological composites such as glass or carbon fibre-reinforced plastics. Based on this similarity in composition, the ICD/ITKE research team investigated how principles of fibrous organisation in biology can be transferred to the design and robotic fabrication of highly differentiated and finely tuned composite structures in architecture.

and structures that emanate from natural morphogenetic processes is particularly interesting, as many biological material systems show self-x properties, such as self-healing, self-adaptation and self-organisation. Thomas Speck, Jan Knippers and Olga Speck explain how the field of biomimetics aims at analysing and tapping into biology's potential as a huge reservoir for innovative solutions that can be transferred to self-adapting, self-repairing or self-organising systems in technology (see pp 34–9).

In 'Fibrous Tectonics' (pp 40–47), myself and Jan Knippers make a case for the potential of a biomimetic design approach using fibrous systems. Given the myriad and hugely diverse forms of life in nature, it is surprising that almost all load-bearing biological structures are actually fibrous composites. As these natural systems share their fundamental characteristics with manmade, technological composites, their morphological and procedural principles can be transferred to architecture. By doing so, entrenched ways of employing these materials in construction can be challenged, as demonstrated by the series of pavilion projects designed and built by the Institute for Computational Design (ICD) and Institute of Building Structures and Structural Design (ITKE) at the University of Stuttgart from 2012 to 2015 (see pp 48–65). These showcase how considering fibrous composites not as amorphous receptacles of form imposed from an outside mould, but rather as active and highly adaptive agents in the processes of design computation, simulation and robotic fabrication enables the discovery of novel fibrous tectonics in architecture.

The work at the ICD by myself and Steffen Reichert on hygroscopically actuated wood (pp 66–73) shows another facet of biomimetic design research that exploits not only the material's innate capacity to physically compute form during the production process, but also throughout the lifespan of an architectural system that continuously adapts to weather changes. Here, material computation begins to replace mechanical machines and thus introduces the possibility of a truly ecologically embedded architecture. The methodological challenges arising from the complex relationship between design and biology in the light of emerging computational technologies are addressed in Neri Oxman's article (pp 100–107), which looks at how progress in additive manufacturing coupled with the latest capabilities in materials science and synthetic biology are today empowering designers to combine top-down design procedures with bottom-up digital or physical growth across various spatial and temporal scales.

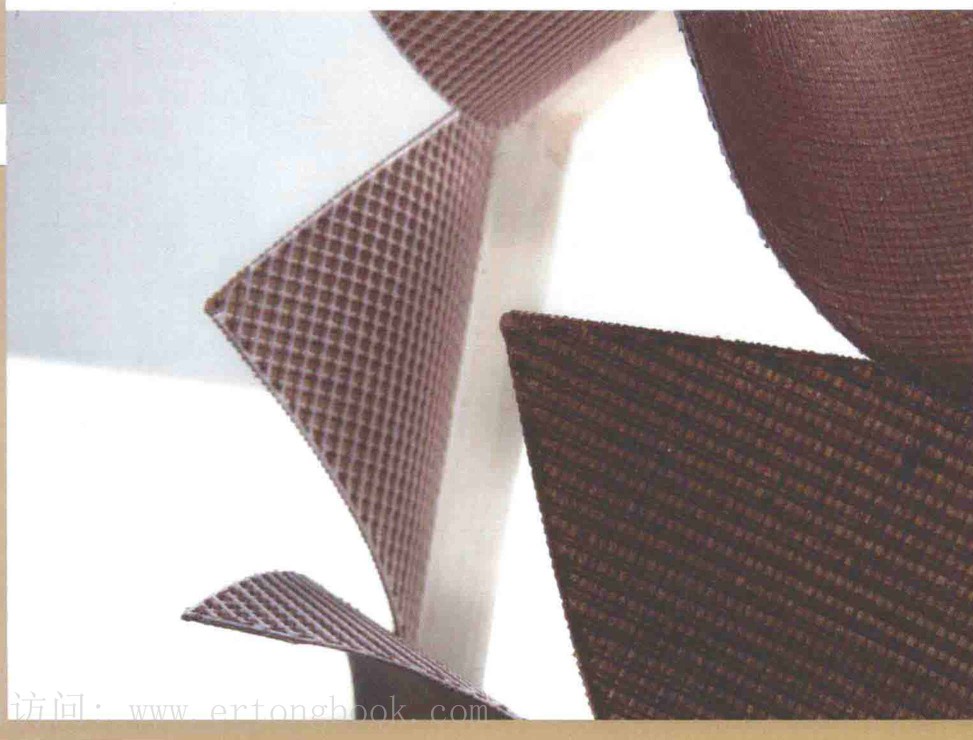
David Correa, Steffen Reichert and Achim Menges/Achim Menges Architect BDA and Institute for Computational Design (ICD)

3D-printed environmentally responsive material systems

University of Stuttgart

2014

Additive manufacturing allows design to be extended to the level of the material structure. Researchers at the ICD employed multi-material processes to produce systems that respond to environmental stimuli with a shape change. The related responsive movement does not require any mechanical or electronic components, or the supply of operational energy.



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