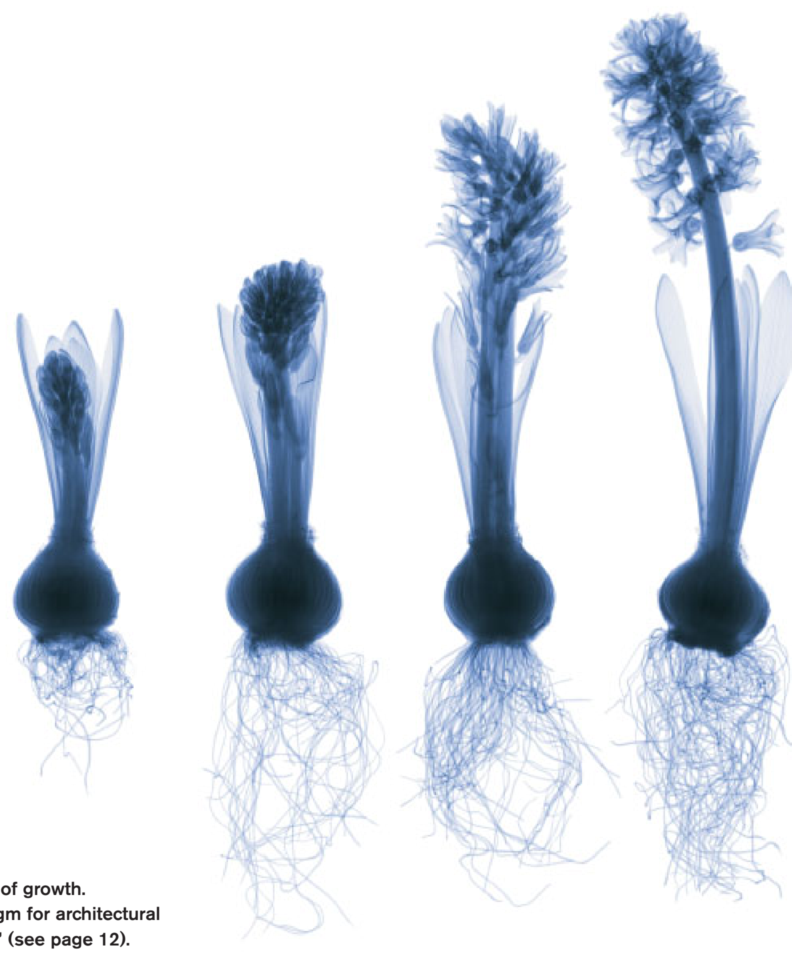
Introduction

Towards Self-Organisational and Multiple-Performance Capacity in Architecture

Techniques and Technologies in Morphogenetic Design expands and develops the themes of the previous, highly successful *Emergence: Morphogenetic Design Strategies* issue of AD (Vol 74, No 3, 2004), which was also guest-edited by Michael Hensel, Achim Menges and Michael Weinstock of the Emergence and Design Group. While the first volume elucidated the concepts of emergence and self-organisation in relation to the discipline of architecture, this issue augments its theoretical and methodological foundation within a biological paradigm for architectural design, while also discussing promising, related, instrumental techniques for design, manufacturing and construction. **Michael Hensel** introduces the issue and explains how it addresses a much broader range of scales, from the molecular to that of macro-structure and, beyond, to ecological relations.



Coloured X-ray of hyacinth flowers at different stages of growth. Environmentally sensitive growth can deliver a paradigm for architectural design, as discussed in 'Computing Self-Organisation' (see page 12).

Robotic timber-manufacturing employed for the 2005 Serpentine Pavilion, as discussed in 'Manufacturing Diversity' (see page 70).

Complex adaptive systems entail processes of self-organisation and emergence. However, both concepts express very different characteristics of a system's behaviour.[1] Self-organisation can be described as a dynamic and adaptive process through which systems achieve and maintain structure without external control. The latter does not preclude extrinsic forces, since all physcial systems exist within the context of physics, for as long as these do not assert control over intrinsic processes from outside. Common form-finding methods, for example, deploy the self-organisation of material systems exposed to physics to achieve optimisation of performance capacity. Self-organisational systems often display emergent properties or behaviours that arise out of the coherent interaction between lower-level entities, and the aim is to utilise and instrumentalise behaviour as a response to stimuli towards performance-oriented designs.

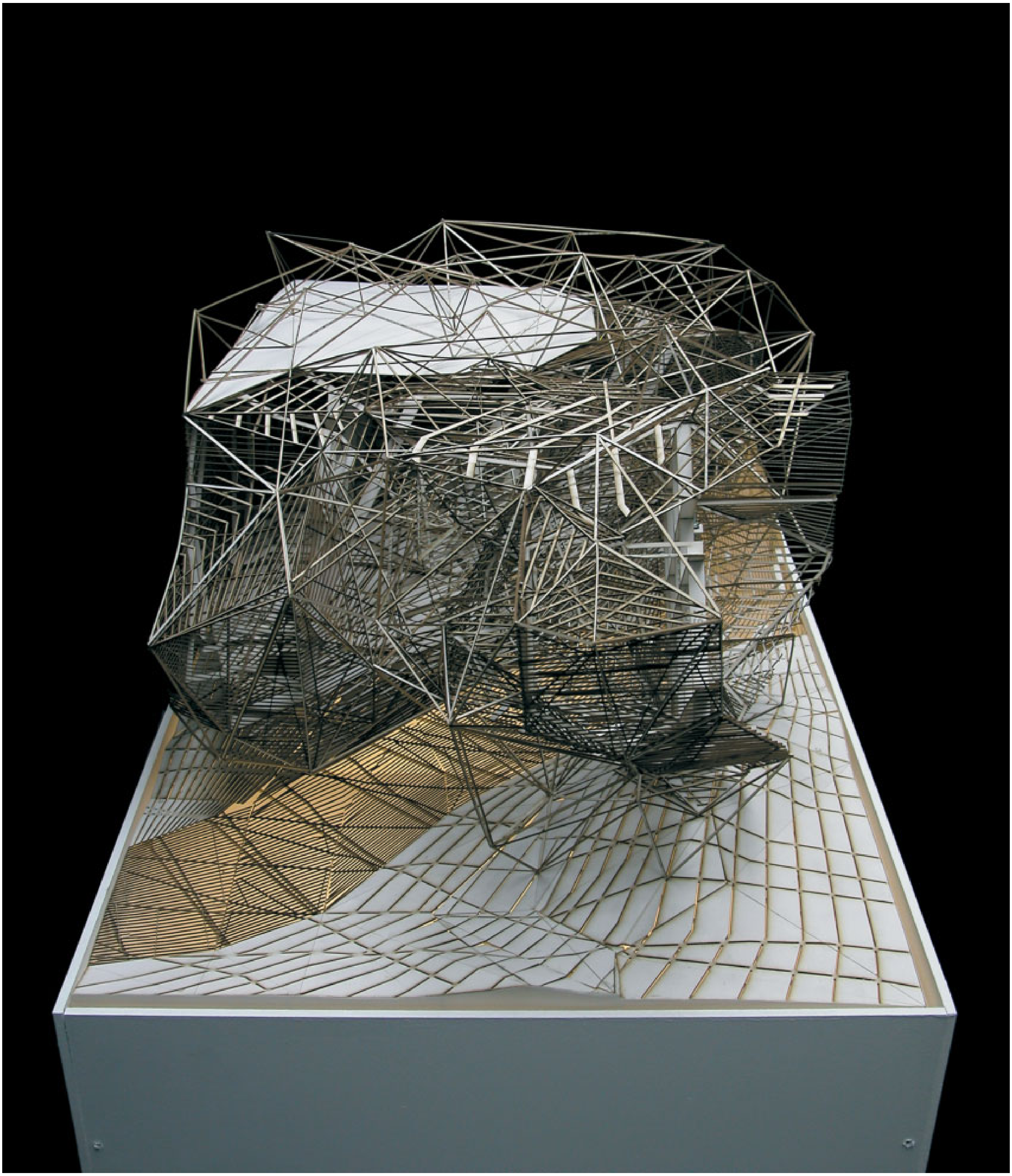
Both issues of AD guest-edited by the Emergence and Design Group seek to outline processes of self-organisation and emergence, and to integrate them within a theoretical, methodological and practice-oriented agenda for architectural design. This issue investigates how self-organisation promotes functions and properties of systems through an increase of order, how behaviour and performance capacity arises from these processes, how materials and material systems can be conditioned accordingly, which manufacturing and assembly approaches can facilitate this, and how these processes and approaches can be harnessed for architectural design to achieve a higher level of performativity and, thus, ultimately a higher level of sustainability.

Self-Organisation

The first section focuses on the introduction and discussion of processes of self-organisation based on a biological paradigm, and examines their uses in architectural design.

How do plants grow in relation to multiple extrinsic influences? How can environmentally sensitive growth be instrumentalised in architectural design? What are the available methods and tools, and how can they serve architectural design? Such questions are pursued by Michael Hensel in 'Computing Self-Organisation: Environmentally Sensitive Growth Modelling'. The article examines the work of Professor Prusinkiewicz's team at the Department of Computer Science at the University of Calgary in Alberta, Canada, and explicates its potential value for architectural design.

In '(Synthetic) Life Architectures: Ramifications and Potentials of a Literal Biological Paradigm for Architectural Design', the currently prevailing biological paradigm is taken to its most literal extreme in an inquiry into the consequences of understanding architectures as living entities and the potential benefits of applying life criteria to architecture. Here, Hensel examines recent advances in



Laser-cut model scale 1/75 of the Jyväskylä Music and Art Centre by OCEAN NORTH, as discussed in 'Differentiation and Performance' (see page 60).

Polymorphism is the state of being made of many different elements, forms, kinds or individuals. In biology it refers to the occurrence of different forms, stages or types in individual organisms or in organisms of the same species. Typogenesis refers to the occurrence of a new type.

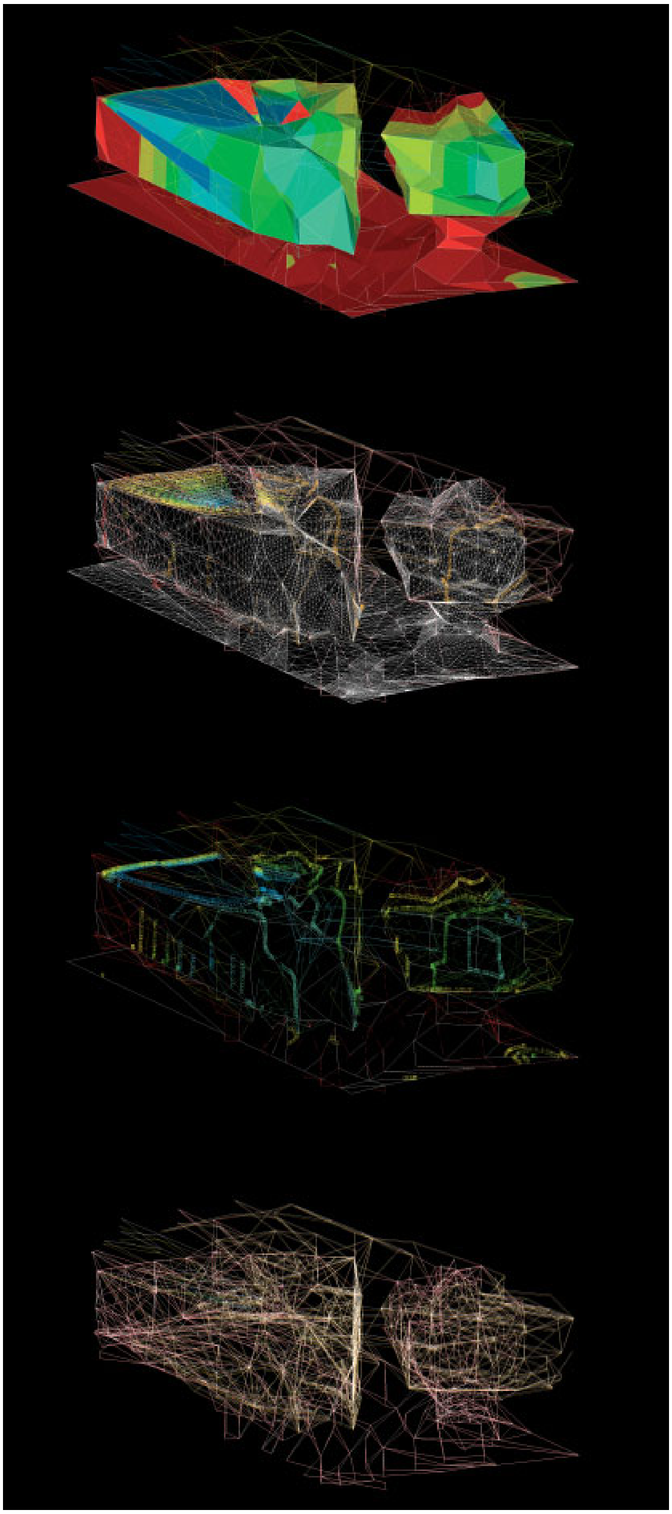
Proliferation and differentiation of a digital parametric component, as discussed in 'Polymorphism ' (see page 78).

Double curvature resulting from differential surface actuation, as discussed in 'Polymorphism' (see page 78).

synthetic life research and their potential implications for, and applications within, architecture.

The engineering principles of biological systems, the high degree of redundancy and complexity in the material hierarchies of many natural structures, and the means by which biological systems respond and adapt to environmental stresses and dynamic loadings, is discussed by Michael Weinstock in 'Self-Organisation and the Structural Dynamics of Plants'. Analysis and case studies reveal that the robust design of natural living systems is not produced by optimisation and standardisation, but by redundancy and differentiation. In this article, Weinstock gives an account of the experimental use of engineering analysis (finite element analysis/FEA) on two plant systems, presents an explanation of the nonlinear dynamics of natural structures, and suggests the abstraction of these principles for application in architectural engineering.

Recent advances in material science and related innovative methods of producing synthetic materials have had a radical impact on advanced industries, and new composite materials are being 'grown' that have increasingly complex internal structures based on biological models. In 'Self-Organisation and Material Constructions', Weinstock examines the manufacturing of advanced cellular materials informed by concepts of self-organisational processes in biological structures. New cellular materials, such as foamed metals, ceramics, polymers and glass, are indications of a significant change in the design of materials, where the boundaries between the 'natural' and the 'manufactured' begin to be eradicated.



Digital structural analysis of the Jyväskylä Music and Art Centre by OCEAN NORTH, as discussed in 'Differentiation and Performance' (see page 60). From top: Vertical displacement contours for deformation produced by gravity loading; vertical displacement vector plots for deformation produced by gravity loading; plot showing the deformed shape of the structure produced by gravity loading. (Red indicates highest deformation, blue indicates lowest deformation.)

Behaviour

Self-organising systems display capacity for adaptation in the presence of change, an ability to respond to stimuli from the dynamic environment. Irritability facilitates systems with the capacity to adapt to changing circumstances.

Adapting geometry to changing circumstances throughout the design process can be a time-consuming and costly ordeal or, on the other hand, can be anticipated and tools designed that facilitate the possibility of significant changes right up to the manufacturing stage. Whenever the design requirements and constraints and performance profiles of a design change, it is important that the design can absorb such changes through a modifiable geometric modelling setup capable of retaining geometric relations while being substantially modified.

Over the last two decades, the members of the SmartGeometry Group have worked on the conception of such tools, and pioneering new techniques and technologies in the field of computer-aided design (CAD). They are now in key positions in international companies and involved in the development of a new generation of parametric design software. In 'Instrumental Geometry', Achim Menges discusses with SmartGeometry Group members Robert Aish (Director of Research at Bentley Systems), Lars Hesselgren (Director of Research and Development, KPF London), J Parrish (Director of ArupSport) and Hugh Whitehead (Project Director of the Specialist Modelling Group, Foster and Partners, London) the group's instrumental approach to geometry and their unique collaboration based on the careful integration of architectural practice and interrelated software development.

In technology, simulation is the mathematical representation of the interaction of real-world objects. It is essential for designing complex material systems with respect to analysing their behaviour over time. In 'Advanced Simulation in Design', Michael Weinstock and Nikolaos Stathopoulos present a survey of concepts and techniques of advanced simulations within physics and engineering. Simulation is examined as a method for analysing behaviour, including the advanced physics of nonlinear behaviour, and the dynamic changes structures and materials undergo in response to changing conditions. In aerospace and maritime design, as well as automotive engineering, physical behaviour – including wear and fatigue throughout the life of a vehicle – is simulated during the design phase. In numerous industries, manufacturing processes are also simulated digitally during the design phase to facilitate 'virtual' manufacturing, prototyping and construction processes. In this article, a series of examples is used to demonstrate the incorporation of simulation methods and techniques within architectural design.

In biology, differentiation entails the process by which cells or tissues undergo a change towards a more specialised form or function, to become increasingly oriented towards fulfilling specific tasks, to acquire specific performance capacity. In 'Differentiation and Performance: Multiple-Performance Architectures and Modulated Environments', Hensel and Menges argue for an ecological model for architecture that promotes an active modulation of environmental conditions across ranges and over time through morphological differentiation. This approach promises both a new spatial paradigm for architectural design and advanced sustainability that links the performance capacity of material systems with environmental modulation and the resulting provisions and opportunities for inhabitation. Projects by OCEAN NORTH, Neri Oxman and Daniel Coll I Capdevila illustrate different approaches to designing differentiated and multi-performance architectures.

Material Conditioning

Conditioning refers to a learning process in which an organism's behaviour becomes dependent on the occurrence of a stimulus in its environment. In turn, this implies a careful calibration between behavioural and, by extension, performative scope in relation to specific ranges of environmental conditions. The capacity for this can be embedded in the makeup of materials and in the logic of material assemblies. Self-organisational and behavioural capacity of the built environment can thus be facilitated by a related material, manufacturing and assembly approach. This must be based on a related understanding and utilising material characteristics, behaviours and capacities, and ranges from using existing materials in different ways, to using computer-aided manufacturing (CAM) technologies strategically and, finally, to designing materials with greater performance capacities.

Recent developments in digital fabrication and CAM in the building sector have a profound impact on architecture as a material practice by facilitating a much greater and much more differentiated formal and material repertoire for design. In 'Manufacturing Diversity', Achim Menges describes advanced digital manufacturing techniques and technologies for steel, timber and membrane fabrication and construction, and introduces the pioneering work of selected manufacturing companies, including Covertex, Finnforest Merk, Octatube Space Structures, Seele and Skyspan.

Polymorphism is the state of being made of many different elements, forms, kinds or individuals. In biology it refers to the occurrence of different forms, stages or types in individual organisms or in organisms of the same species. Typogenesis refers to the occurrence of a new type. In 'Polymorphism', Menges instrumentalises the two concepts and presents morphogenetic design techniques and technologies that synthesise processes of formation and materialisation. Along a series of designs and design experiments, undertaken by himself along with Andrew Kudless, David Newton and Joseph Kellner et al, Menges explains an understanding of form, materials and structure as complex interrelations in polymorphic systems that result from the response to extrinsic influences and are materialised by deploying the logics of advanced manufacturing processes as strategic constraints upon the design processes.

In 'Material and Digital Design Synthesis', Michael Hensel and Achim Menges discuss the ramifications of integrating material self-organisation, digital morphogenesis, associative parametric modelling and computer-aided manufacturing into a seamless design process. They describe how the advanced material and morphogenetic digital design techniques and technologies presented call for a higher-level methodological integration, which poses a major challenge for the next generation of multidisciplinary architectural research and projects. This collaborative task encompasses the striving for an integrated set of design methods, generative and analytical tools and enabling technologies that facilitate and instrumentalise evolutionary design and evaluation of differentiated material systems towards a highly performative and sustainable built environment. The article includes works produced within the context of the Emergent Technologies and Design Masters programme at the Architectural Association (AA) in London, and a recent competition entry by Scheffler + Partner Architects and Achim Menges.

Throughout the issue, the authors have listed further references and recommended literature to provide further avenues of enquiry for interested readers. Unfortunately, due to space constraints, many relevant and important references have been omitted. However, since this publication introduces only the beginning of a new approach to multiple-performance-driven and sustainable architectural design, it is hoped that the key spectrum of concepts, methods, techniques and technologies has been presented, and that readers have been inspired to join in the quest to innovate and continue to develop such a morphogenetic design approach. Frei Otto stated that 'it is only of importance that we recognise our future tasks'.[2] It is in this spirit, and with great enthusiasm, that we hope to meet you as collaborators to work together on solving the complex tasks that today's and tomorrow's human environment and state of our biosphere present. Δ

Notes

1. For further elaboration see Tom De Wolf and Tom Holvoet, 'Emergence and Self-Organisation: A Statement of Similarities and Differences', in S Brueckner, G Di Marzo Serugendo, A Karageorgos and R Nagpal (eds), *Proceedings of the International Workshop on Engineering Self-Organising Applications 2004*. www.cs.kuleuven.be/~tomdw/.
2. Frei Otto in conversation with the Emergence and Design Group.