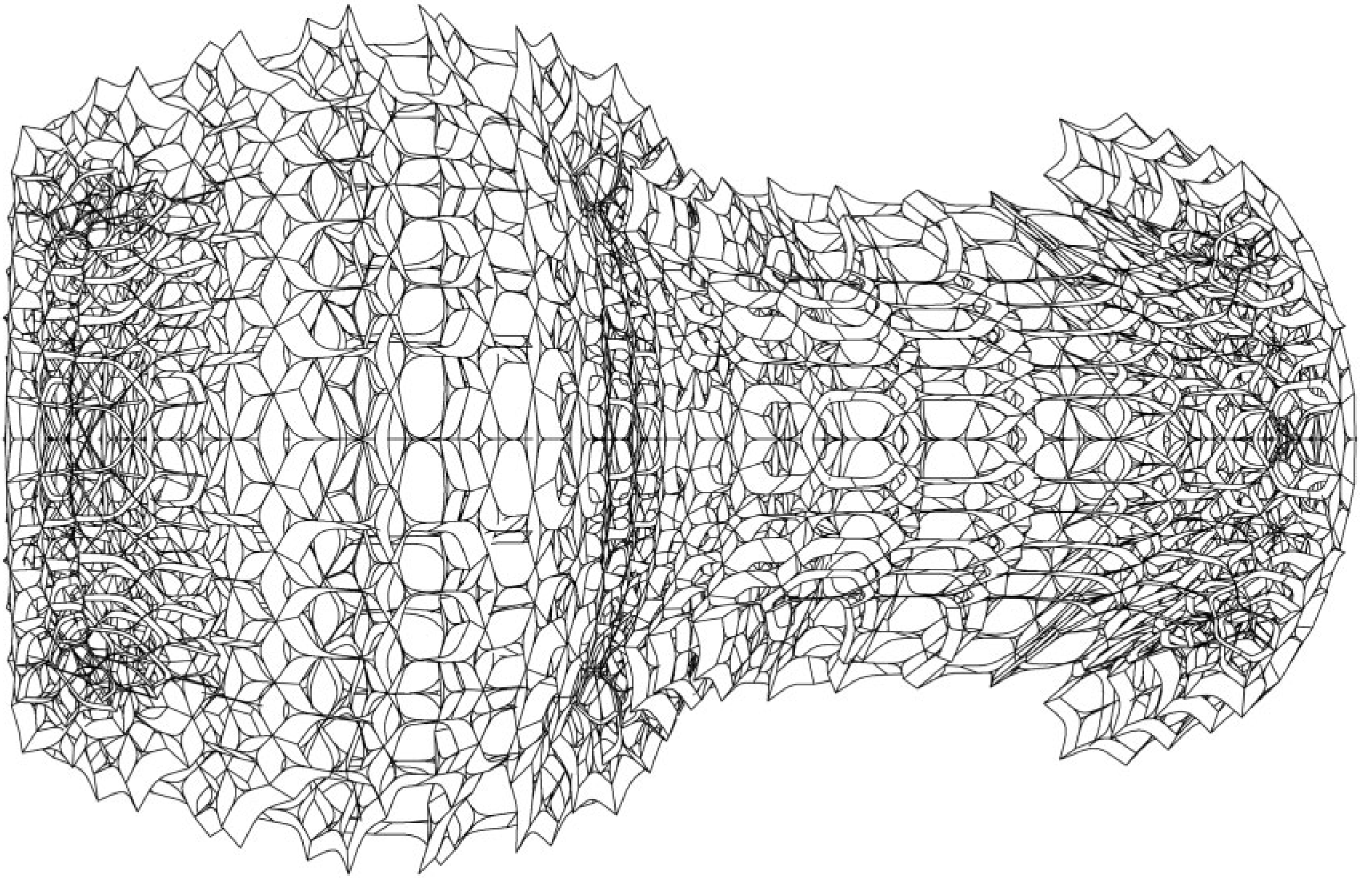
Differentiation and Performance: Multi-Performance Architectures and Modulated Environments



Daniel Coll I Capdevila, Strip Morphologies, AA Diploma Unit 4 design study for environmentally differentiated healing environments, London, 2004–05
View of a parametrically defined strip system differentiated in response to structural, luminous and sonic performance requirements.

The architectural tradition of the West is fundamentally characterised by substantial structures and building typologies that link tectonics with function and representation. It has been focusing on the relation between the material constituents that frame space and its direct relation to programme on the one hand, and to social formations on the other. Interior environments are largely homogenised, a preference inherited from Modernist open-plan arrangements and facilitated by vast paraphernalia of electrical and mechanical equipment. Here, Michael Hensel and Achim Menges argue for an ecological understanding of architecture that promotes the differentiation of environmental conditions through a morphological intelligence, which promises not only a new spatial paradigm for architectural design, but also a far more sustainable one that links the performance capacity of material systems with environmental modulation and the resulting provisions and opportunities for inhabitation.

In his seminal work, *The Architecture of the Well-Tempered Environment*,[1] Reyner Banham describes two traditions of architecture: one with substantial structures and one without. 'Societies who do not build substantial structures inhabit a space whose external boundaries are vague, adjustable and rarely regular,'[2] wrote Banham, referring to the example of a camp fire that provides a gradient of temperature and light that is at the same time dynamically affected by other extrinsic influences, such as airflow and other environmental conditions. These dynamically differentiated spaces provide for the individual preferences of inhabitants. Differentiation is thus expressed in gradient threshold conditions rather than by a hard division between inside and outside, warm and cold, and so on, which Banham posits 'might prove to be of fundamental relevance for power-operated environments'[3] by suggesting a more sustainable approach to architecture.

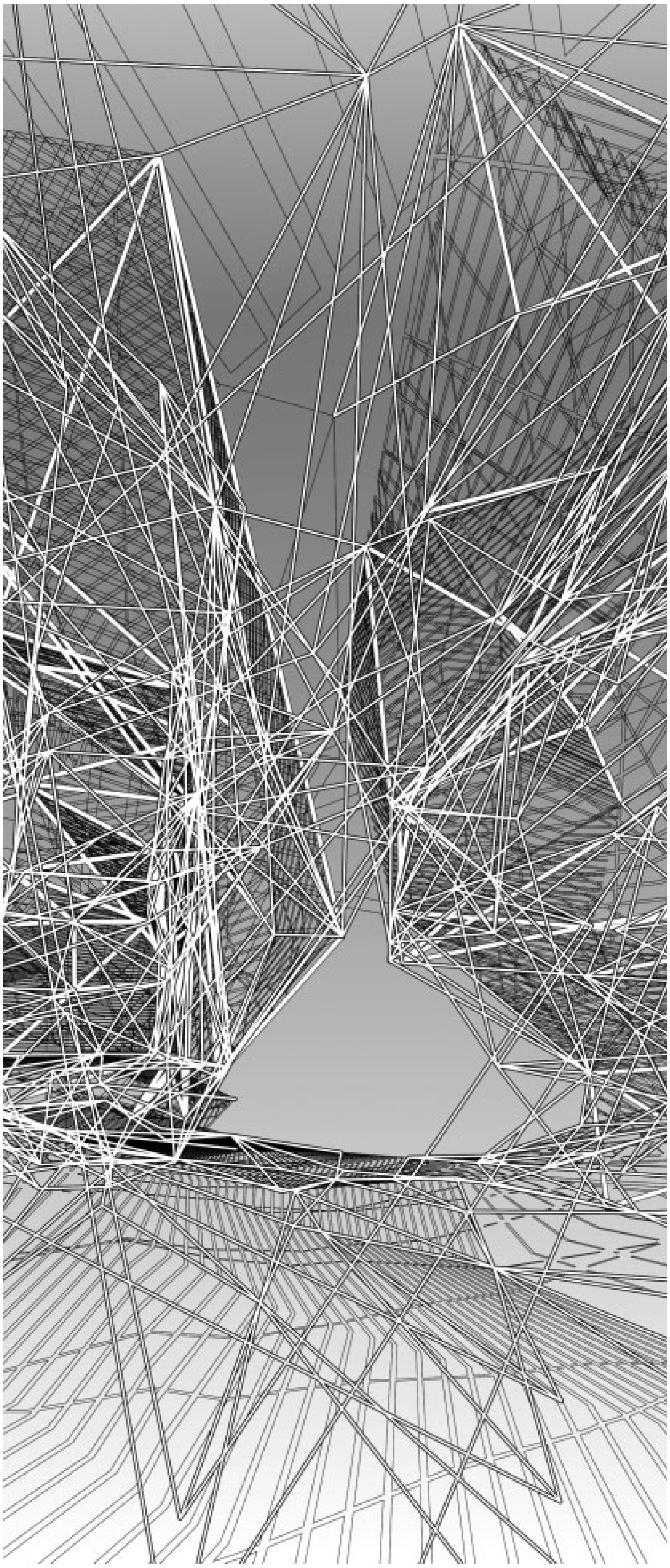
This article introduces a take on architectural design that incorporates Banham's varied and temporal spatiality into substantial yet equally varied structures, by shifting away from the homogenous and largely monofunctional material systems that make up the built environment today, and towards heterogeneous and multi-performance systems. The aim is to show how these systems can modulate and, in turn, be modulated by environmental conditions, and to suggest alternative spatial strategies based on gradient threshold conditions.

Modernist discourse postulated universal space as the key paradigm for democratic space. The open plan, ideally extended to an infinite homogenous grid, for example, was intended to deliver equal opportunity for inhabitation, while the ribbon window and glass curtain-wall facade was meant to replace privileged framed views. The preference for universal space brought with it the modularisation of building elements and systems, as well as a homogenisation of entire climates. In order to achieve universal space and intended uniformity, each building element or system was required to perform one principal function (such as primary structure, secondary structure, sun shading, rain cover or climate envelope) and was thus optimised towards that particular singular function. This single-objective approach to optimisation is based on an understanding of efficiency that entails the minimum use of material and energy to fulfil one single task.

Single-objective optimisation gave rise to the notion of lightweight structures with minimum use of material to achieve projected structural capacity and performance. With a desired decrease in the use of material came questions of liability that led to an added percentage of performance capacity to guarantee functionality and safety. Thus redundancy was, and still is, largely understood as an unfortunate necessity. A critical view yields the question of whether an alternative understanding of optimisation, efficiency and redundancy in relation to multi-performance material systems can facilitate a very different take on spatial organisation and environmental modulation.

Architectural discourse in the last decades has largely moved away from universal space and declared a preference for heterogeneous architectures. This preference is evident in two distinct strategies. The first entails a two-step approach to varied space, commencing from generic shells that are subsequently tailored to the needs of their eventual inhabitants. The second strategy is the design of exotically shaped buildings that are, from the outset, varied in expression and spatiality. The first strategy embraces modularised building systems, while the second strategy operates on the differentiation of established building elements (for example, individually articulated frames and tile elements). Both strategies concur, however, in embracing standardised requirements for interior environments, such as statistically determined homogenous interior climates for public or office buildings, as well as the limited range of building systems.

The latter is evident in recently developed parametric software that is bound to established engineering and



OCEAN NORTH, Jyväskylä Music and Art Centre, Phase 02 and 03 design study, London, 2004–05
Perspective view of the interstitial space between and below the volumes of the music hall and rehearsal rooms along the main public circulation trajectory.

Unfortunately, environmental design and engineering remains a question of post-design optimisation rather than informing the design process from a very early stage. Moreover, a homogenised interior environment simply cannot satisfy the multiple and contrasting needs of its inhabitants.

manufacturing protocols relative to material and machining technologies. Herein lies the problem. While plan organisation, form of the envelope, or the fittings and finishes might have become more varied, material and building systems are not being critically reviewed with respect to established types and their monofunctionality, as well as building-type-dependent interior climate requirements and uniform condition zoning. Architecture has thus largely remained ‘neufertised’.

The homogenisation of interior environments had its first significant peak with the advent of the office landscape approach of the late 1950s through the work of the Quickborner Team für Planung und Organisation, a German management consulting group that proposed vast open-plan arrangements in which the anticipated workflow is manifested in the furnishing of working clusters arranged according to workflow.[4] Applying a large number of rules to the furnished organisation of office space, circulation and workflow, it was argued that a homogenous interior environment would imply the least visual, aural and tactile distraction that needed to be removed. Subsequently, this form of spatial-environmental homogenisation migrated to other building types, from public to private spaces.

The combination of optimised monofunctional elements or subsystems together with homogenised comfort zones very often requires an abundance of heating, cooling, air conditioning, ventilation, lighting and servicing equipment. While capital energy, embodied in the materials and building processes, might be kept fairly low, operational energy required for the running of a building is extremely high. Unfortunately, environmental design and engineering remains a question of post-design optimisation rather than informing the design process from a very early stage. Moreover, a homogenised interior environment simply cannot satisfy the multiple and contrasting needs of its inhabitants.

A remedy may be found in an understanding of architecture as ecology, involving dynamic and varied relations and mutual modulation between material systems, macro- and micro-environmental conditions, and individual and collective inhabitation. The proposed approach to architectural design is based on the deliberate differentiation of material systems and assemblies beyond the established catalogue of types, on making them dissimilar or distinct in degree and across ranges. Varied ranges of material systems can provide for diverse spatial arrangements together with climatic intensities. This involves the deployment of the inherent behavioural characteristics and modulation capacities of building elements and systems, rather than a retrospective optimisation process towards monofunctional efficiency. From this arises an understanding of efficiency as a dynamic characteristic of the effective, based on utilising redundancy predominantly as latent capacity to perform a series of different tasks, rather than a safety measure.

Instrumentalising multiple-performance capacity requires an understanding of material elements and systems in a synergetic and integral manner. It considers these systems in terms of their behavioural characteristics and capacities with respect to the purpose they serve locally and within the behavioural economy of larger systems. Today's so-called sustainable design claims this understanding, but operates on it mainly as a question of energy consumption, material lifecycles and waste production. An instrumental approach to relational behavioural characteristics as a way of modulating spaces and environments, however, requires operative retooling for architects with respect to analytical and generative methods and techniques and their relation and phasing within the design process.

Such an approach can benefit from learning from living nature, particularly the fact that most biological systems are articulated through higher-level multifunctional integration across at least eight scales of magnitude. This allows scale-dependent and scale-interdependent hierarchical and multiple functionality. In addition, architects can learn from connections and transitions between systems and subsystems of biological entities. In the building sector, connections between parts and elements are almost always discontinuous and articulated as dividing seams, instead of a smoother transition in materiality and thus functionality (such as can be seen in the way tendon and bone connect, deploying the same fibre material yet across a smooth transition of mineralisation). The understanding and deployment of gradient thresholds in materiality and environmental conditions can yield the potential for complex performance capacities of material systems. This will require a detailed understanding of the relation between material make-up and resultant behavioural characteristics.

Approaching material systems as a way of deploying behavioural characteristics and tendencies in an instrumental manner requires analytical methods, skills and tools with respect to the performance capacity of the overall system under investigation, and the narrower capacities of local elements that enable the global system to unfold its wider capacities.[5] What is needed is an approach to design that strongly integrates analytical and generative methods. Analysis is of central importance to the entire generative process not only in revealing behavioural and self-organisational tendencies, but also in assessing and designing spatial-environmental modulation capacity. In so doing, feedback between stimuli and responses and the conditioning relation between constraint and capacity will become the operative elements of heterogeneous spatial organisation. This suggests an architecture that modulates specified ranges and gradient conditions across space and over time, and that is based on strategically nested capacities within the material systems that make up the built environment. Such an approach to architectural design merges the tradition of substantial structures with that of ephemeral spaces and gradient thresholds towards complex performance capacity of the built environment.

The following projects pursue different methods of differentiating material systems, as researched by Michael Hensel and Achim Menges within OCEAN NORTH *and the academic context of Diploma Unit 4 at the Architectural Association in London. Daniel Coll I Capdevila's Strip Morphologies deploys a bottom-up approach from a simple building element and its behaviour towards a differentiated assembly and its performance capacity. Neri Oxman's Vertical Helix introduces an integral approach to differentiating systems across a range of scales based on combined extensive scripting, modelling and analysis. And* OCEAN NORTH*'s Jyväskylä Music and Art Centre pursues an iterative growth process based on multiple-performance systems towards a heterogeneous and dynamically modulated space.*

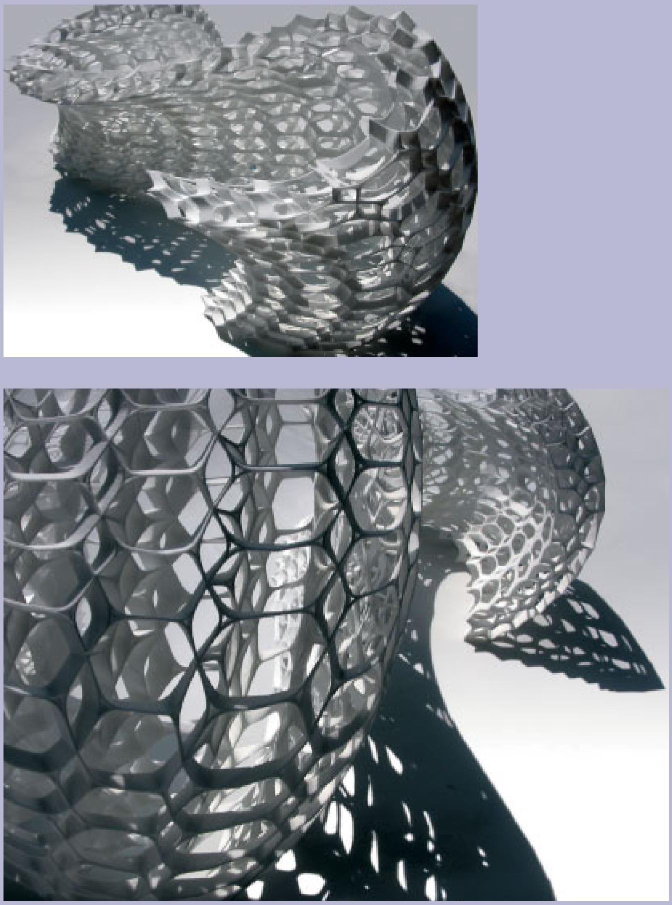
Notes

1. Reyner Banham, *The Architecture of the Well-Tempered Environment*, University of Chicago Press (Chicago, IL), 1973.
2. Ibid, p 20.
3. Ibid.
4. See John Pile, *Open Office Planning*, The Architectural Press (London), 1978. See also Branden Hookway, *Pandemonium: The Rise of Predatory Locales in the Postwar World*, Princeton Architectural Press (Princeton, NJ), 1999.
5. Evolutionary biology can provide some useful analytical methods for this purpose. See Robert Cummings, 'Functional analysis', *Journal of Philosophy*, 72, 1975, pp 741–65.

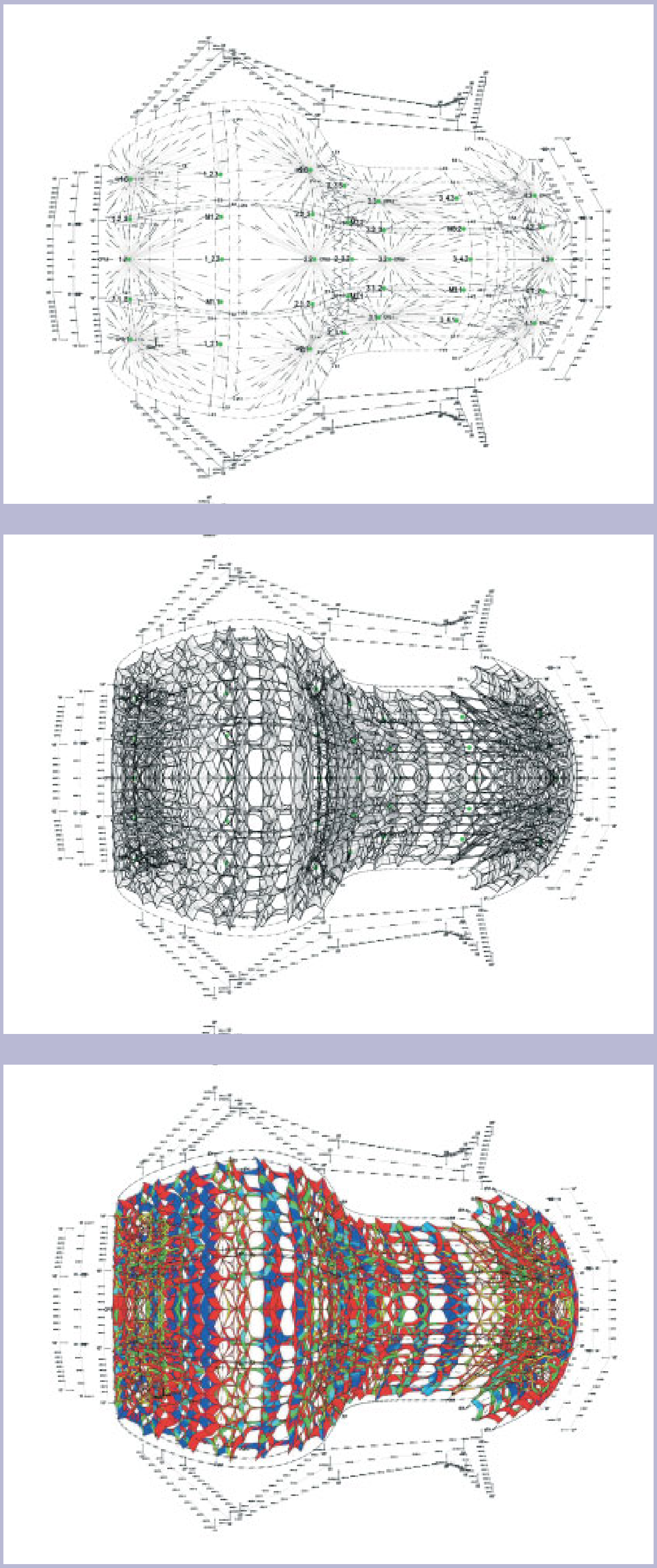
Daniel Coll I Capdevila, Strip Morphologies, AA Diploma Unit 4 Design Study for Environmentally Differentiated Healing Environments, London, 2004–05

Spaces for healing environments are usually poorly designed homogeneous environments that are disadvantageous for the recovery of patients. However, individual needs and preferences of patients in the recovery period vary greatly, including ranges of privacy and exposure to light, sounds, temperature and airflow. This project therefore focuses on the development of a multi-performance material system with the capacity to provide for different spatial arrangements and to modulate the environment.

The selected material element is simple: steel strips cut from sheet material. Form-finding through bending and twisting enabled a systematic study of geometric behaviour. The derived geometric logic informed the definition of a digital element that integrates material characteristics, manufacturing constraints (the planar cutting from sheet material) and a related assembly logic. The digital parametric element comprises sets of geometric association that remain invariant within a defined range of transformations, ensuring



View of a rapid prototype model (selective laser sintering) showing one instance of a global configuration of the strip system, together with its specific modulation of light penetration and shadow casting.



A parametrically derived strip system. Top: Global surface geometry with tangency control framework. Middle: Corresponding population of digital strip components. Bottom: Curvature analysis of resultant strip morphology.

that any derived arrangement of strips can be directly fabricated and assembled.

Three strips were combined into a basic component for the digital and material system. The connection between the three strips that define the component is characterised by areas of tangency alignment, which introduces an additional control parameter that defines the orientation of the strip faces. These control points, together with arrays of points defined by the u/v parameterisation of notional control surfaces, provided the geometric setup for the population of a larger system. Proliferation entails that the parametrically defined components populate a larger system by adapting their specific geometric articulation to it. Each local component is differentiated by adjacent components, the global geometry of the control surface and external control points.

Establishing the system as an associative geometric framework in a parametric modelling application delivers various levels of control to the designer. On the local scale the width and thickness of the steel strips can be changed and the orientation of each strip can be altered. On a regional system scale the density of strips can be changed, and on a global system scale the geometric and topological articulation of the entire system can be manipulated. Apart from modifications derived by changing the parametric variables of the system, the underlying geometric aspects of the system can be altered and redefined too.

This setup enables the designer to implement complex changes to the system instantaneously. Digital simulation of the system's capacity to modulate the luminous and sonic environment and its visual transparency serves to analyse and compare different instances of system articulation towards their performance capacities. The ability to achieve and evaluate system performance across multiple variations accelerates the feedback between analysis and design evolution. In this way, a material system can be devised for the improvement of healing environments or other programmes that are context-sensitive with respect to given spatial constraints and environmental input. Thus the desired ranges of spatial organisation and environmental modulation can be achieved through a rigorous, iterative and swift, thus economical, design process.

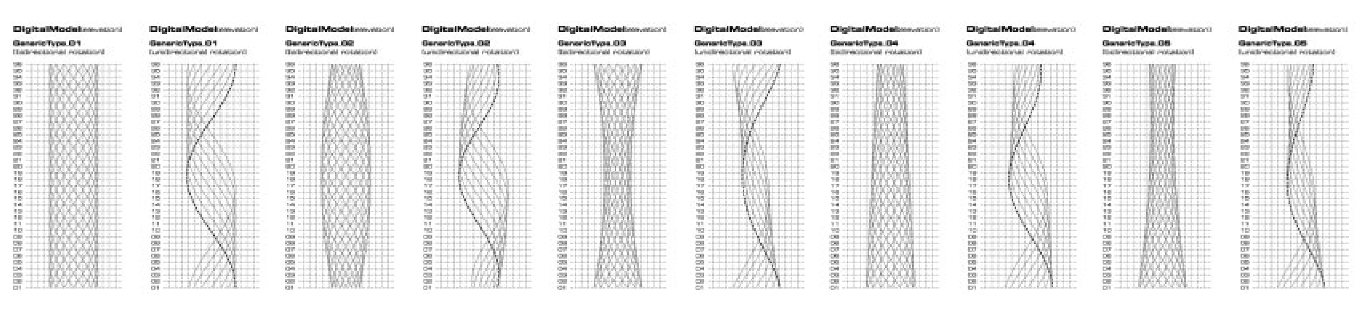
Production of a full-scale prototype. Left: Partial prototype. Right, top to bottom: Laser-cut steel strips, tangency alignment of strips, and spot welding of the aligned strips.

Neri Oxman, Performative Morphologies: The Vertical Helix, AA Diploma Unit 4 Design Study for a New High-Rise Morphology, London, 2003–04

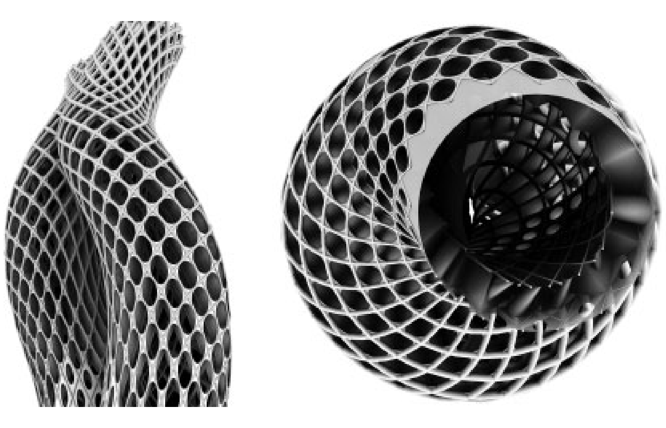
Performative morphologies are derived from a condition-based design process. Design is generated or modulated by condition statements and requirements. These can be intrinsic (for example, programmatic related circulation) or extrinsic to the designed system (such as environmental conditions). This project aimed at developing design methods that are conditioned by multivariant influences, and utilises specific attributes of helical morphologies in order to achieve spatial, organisational and performative differentiation.

Neri Oxman deployed a helical morphology for the differentiation of vertical structures and buildings, and instrumentalises geometric and structural characteristics from local component to overall building scale. The morphology distributes loads over its envelope, facilitated by a hybrid structure that combines the vectorial load path of a linear component with the field distribution of a structural surface. The load paths are treated differentially, with loads being bundled along vectors where necessary and distributed across surfaces wherever possible and useful, towards embedding latent capacities that can compensate for local disruptions to the structural systems. In addition, circulation is not limited to service cores. Instead, it is distributed across a multitude of helical paths, providing for different spatial experiences and evacuation routes.

A rigorous toolset was developed that can facilitate the design process towards morphological differentiation through scripting and parametric applications. Digital tools were customised to fit the characteristics of helical arrangements in terms of geometric articulation. Modelling in Rhinoceros, in combination with Excel scripting, served to derive different instances of geometric articulations of the system. This approach is neither top-down, from an



Geometrical studies of the different generic types of global-scale helical configurations. Five basic geometrical curves were scripted to produce geometrical variation by merging and/or changing the mathematical data in a systematic manner.



Digital model of the entire structure (isometric and top views). The structure comprises an external and an internal surface connected by a cellular fabric acting as a differentiated structural skin element. Cell depth and thickness are modulated according to structural performance and spatial criteria.

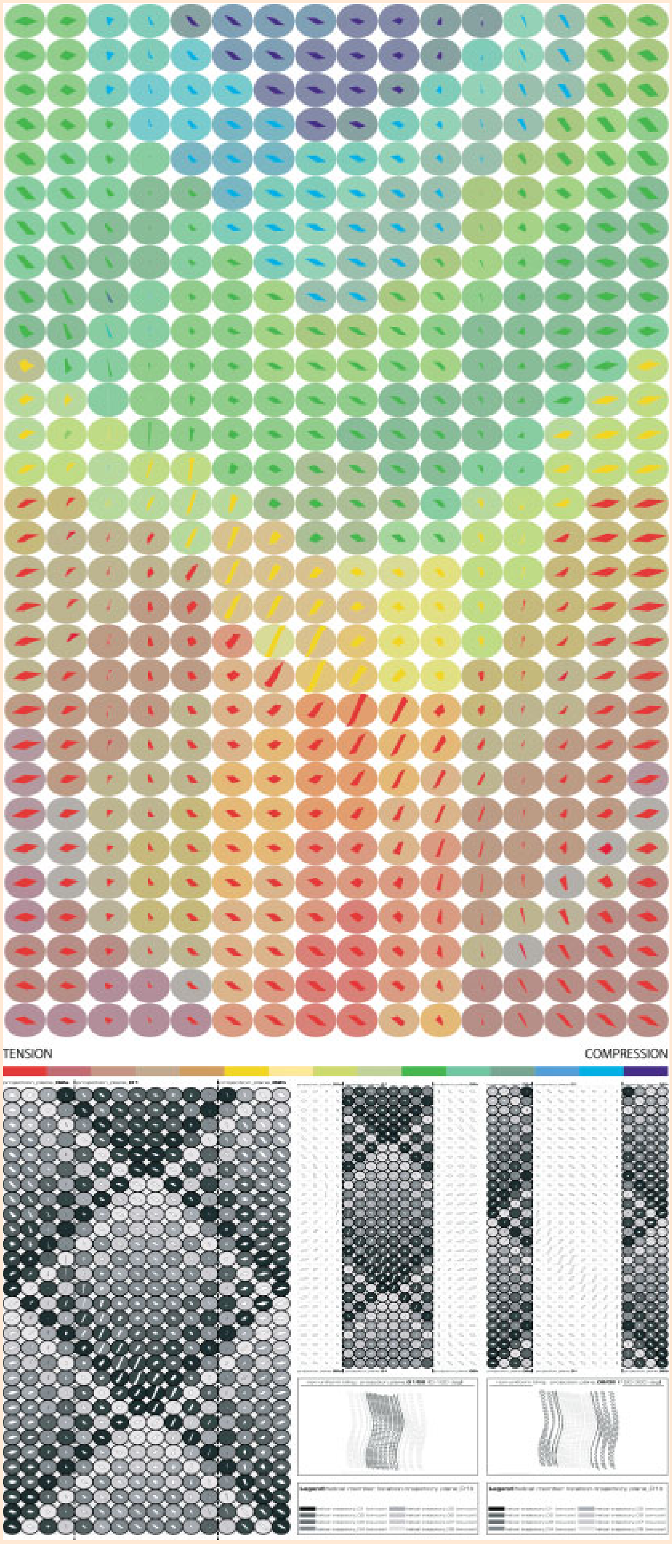
Digital image (two elevation views) of the structural skin developed as a bundled structure. A composite-based system combining the structural strands with additional surface members is articulated to create a structurally differentiated envelope in which force flows are distributed along its entire surface.

overall geometry to detailed local articulation, nor bottom-up, from a defined component or local articulation to the overall system.

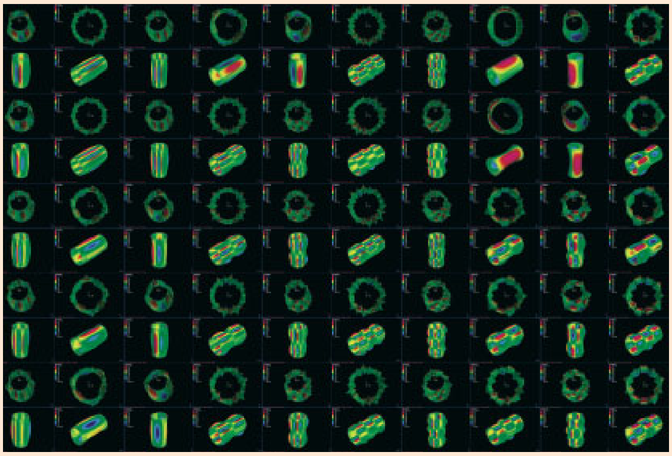
The specific helical arrangement was developed in all relevant system scales simultaneously. In doing so, Bentley Systems' GenerativeComponents, among other software packages, was used to establish a relational geometric logic by which different instances of geometric articulation can more easily be derived though a parametric setup and modification. The evaluation of the structural performance of different geometric articulations integrated physical and digital methods. Scaled physical models were evaluated by applying loads to register the resultant displacement on a local, regional and global system scale. Digital analysis based on the finite element method enabled the determination of stresses and displacement.

An analytical approach was developed that synthesised geometric and structural data, derived from the bending, buckling and torque behaviour of the system. The results of the structural behaviour analysis informed each stage of the iterative design process.

Spatial arrangement and circulatory organisation was evaluated in parallel. Intersecting surfaces that connect the various helical paths result in the formation of spatial pockets. Circulation paths follow the helical arrangement and interconnect spatial pockets. Parametric changes to the system affect the location, size and orientation of spatial pockets towards environmental input, such as daylight and thermal exposure. This was analysed through digital simulation, and informed the iterative design process. In this way, design generation and analysis went hand in hand, with each instance of the project development becoming increasingly informed by context-specific stimuli.



Each of the 480 registered tiles is defined by its geometry, its surface area, and its stress condition across a geometrically idealised map of the unrolled configurations (top). The periodic nonuniform tiling was applied to the skin by projecting the uniform skin elements onto the nonuniform global body. Shades of grey correspond to the relative location of each of the 16 strands comprising the entire volume (bottom).



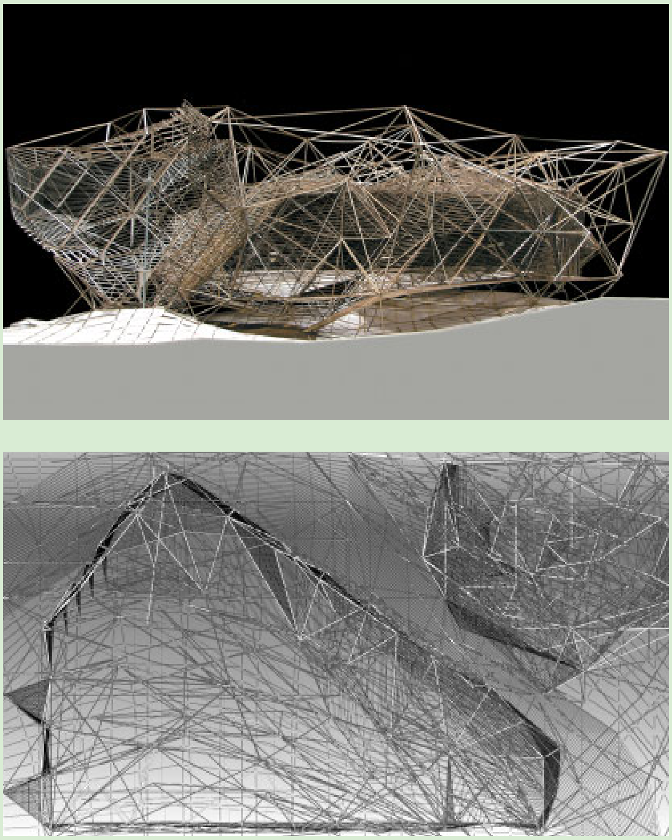
Linear finite element analysis (FEA): static structural analysis of a local cylindrical patch performed in consecutive buckling modes under applied vertical load. The analysis determines the relationship between the mechanical properties of the surface and the load applied. Each mode represents one behavioural instance in the process of load application and is assessed by the nature of the buckling patterns that appear on the surface as a response to a given load case.

OCEAN NORTH, **Jyväskylä Music and Art Centre Phase 02 and 03 Design Study, London, 2004–05**

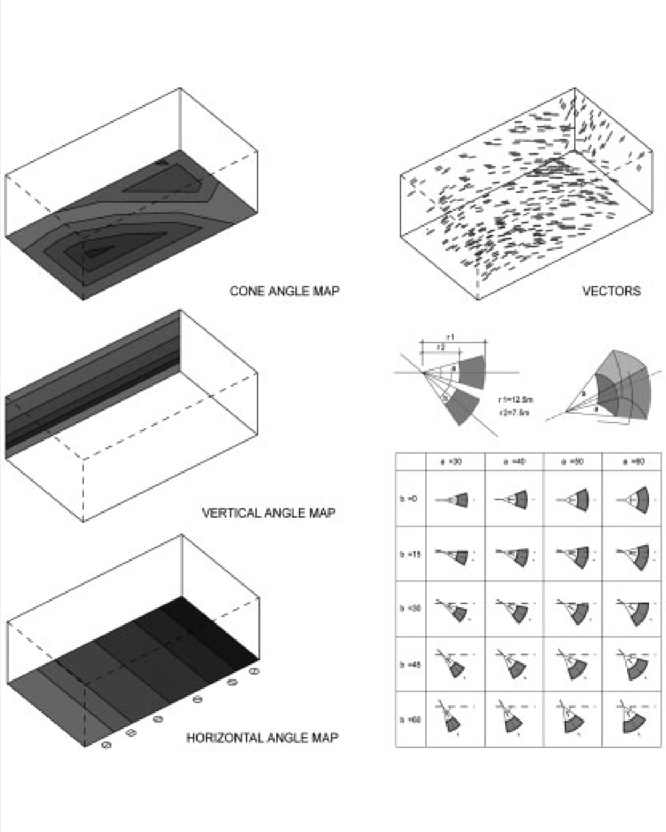
The project aimed for a differentiated event space and an extension of the landscaped town square into an acoustically animated interior landscape that caters for formal symphonic and orchestral events and art exhibitions, as well as for informal cultural activities. The lattice structure and surfaces that articulate the interior provide for ad-hoc stages, and seating and exhibition areas, while creating a dynamically articulated space of acoustic and visual intensities, with the lattices being locally sound-active.[1] This extends acoustic experience beyond the interior of the music hall and rehearsal rooms into the interior landscape of the building volume. The layered envelope consists of a transparent and reflective skin. Exterior and interior light conditions affect the layered gradients of reflection and transparency, which yield the perception of a boundless deep space. Directionality, density and layering of the lattices, and the surfaces and volumes that evolve from it, result in the perception of a locally differentiated yet vast space.

OCEAN NORTH deployed an iterative growth process that articulates the lattices, informed by rules pertaining to i) the location, orientation and density of the struts that make up the lattice systems; ii) structural, sonic and luminous performance requirements; iii) spatial design guidelines. The resulting lattice systems inform the geometries of the terrain, structure and envelopes of primary and secondary spaces and surface areas, circulation pattern and the sound-active system.

The growth process commenced from the definition and distribution of virtual volumes informed by the programmatic requirements of the project brief. A series of gradient maps organised along the *x*, *y* and *z* planes that delimit the growth area for the various lattice systems inform the growth process with performative requirements. Such maps constrain the local search space for each strut of the lattice system in terms of size and search angle. For this project the gradient maps are based on structural performance, as well as the modulation of the luminous and sonic microenvironments of the interstitial space between the outer envelope of the building and the envelopes of the various spaces not to be intersected by the lattice system. Subsequently, a first set of definition points and search rules are defined that distribute and orientate the struts that make



View of model scale 1:75 showing the primary, secondary and tertiary lattice systems without the building envelope (top), and plan view of the centre showing the primary, secondary and tertiary lattice systems and the volumes of the music hall and the rehearsal rooms (bottom).



Diagrams showing the strategic constraints of the growth process, including the local search windows that determine the angles of each strut of the lattice in relation to the connection with the neighbouring struts (right), as well as the gradient maps that allocate search-window constraints to regions within the building envelope (left).

up the primary lattice system in response to the above outlined rule set. From the primary system, a second set of virtual surfaces is derived on which a new set of definition points is defined. In further iterations, secondary and tertiary lattice systems are evolved that define mesh-like enclosures for the required internal volumes, circulation and sound-active systems.

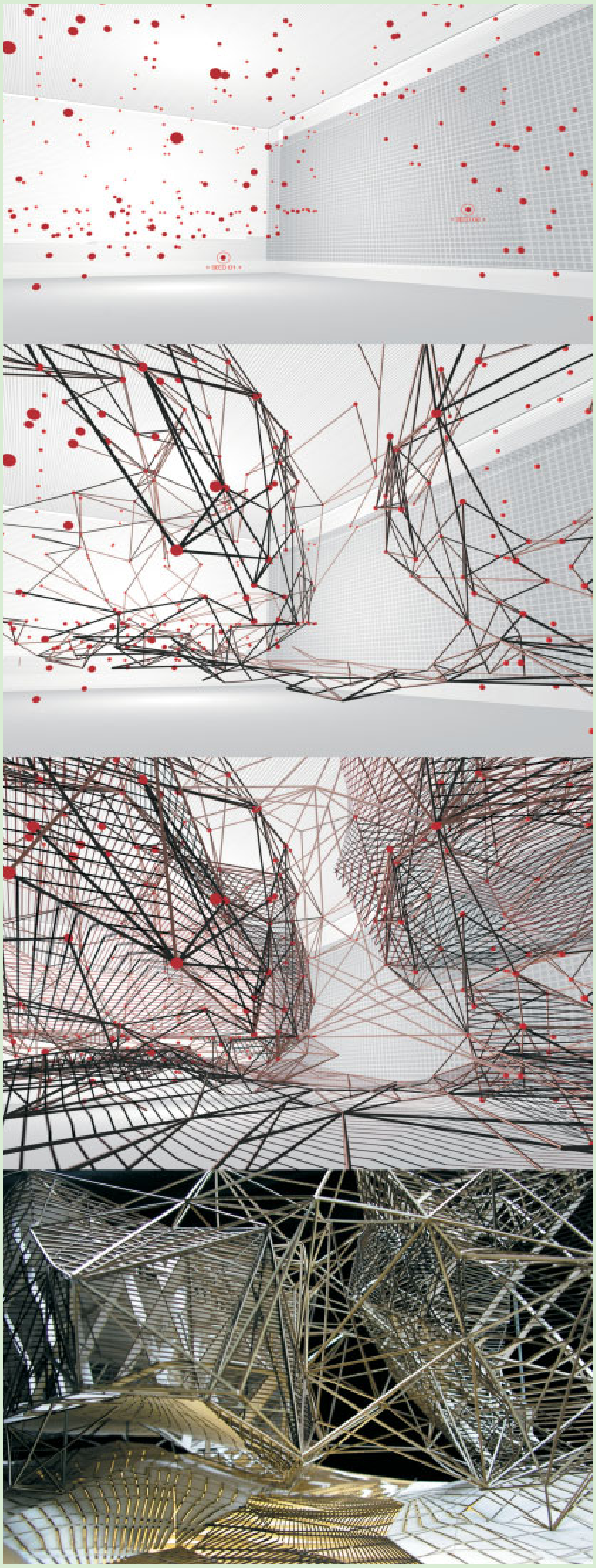
While the iterative growth process is informed by performance requirements, the synergetic impact of the various systems working together needs nevertheless to be analysed in stages. Digital structural and luminous performance analysis was conducted repeatedly in order to evaluate the emerging conditions and synergies between the various systems that make up the project.

From the differential density and angular variation of the lattice systems, and the varied distribution of sound-active elements, evolves a spatial and ambient differentiation of the scheme: a heterogeneous space in which augmented spatial and ambient differentiation provide for choices between microenvironmental conditions that can provide for the time-specific individual requirements of inhabitants.

Note

1. See Natasha Barett's and OCEAN NORTH's Agora project, a sound-active installation in Michael Hensel, 'Digital architectures: Are we ready to compute?', in Neil Leach, David Turnbull and Chris Williams (eds), *Digital Tectonics*, Wiley-Academy (Chichester), 2004, pp 120–6.

Project credits
Phase 01 (1997): Kivi Sotamaa, Johan Bettum, Markus Holmstén and Kim Baumann Larsen with Lasse Wagner, Vesa Oiva, and Hein van Dam.
Phase 02 (2004): Michael Hensel, Achim Menges and Kivi Sotamaa with Hani Fallaha, Shireen Han, Andrew Kudless, Neri Oxman, Nazaneen Roxanne Shafaie, Cordula Stach, Nikolaos Stathopoulos, Mark Tynan and Muchuan Xu.
Phase 03 (2005–06): Michael Hensel and Achim Menges with Nikolaos Stathopoulos.



Morphogenetic growth process. Top to bottom: Distribution of seed and definition points for the struts of the primary lattice system; first growth step of the primary lattice system; growth step defining the secondary lattice system in accordance with the primary system; model view of the same location