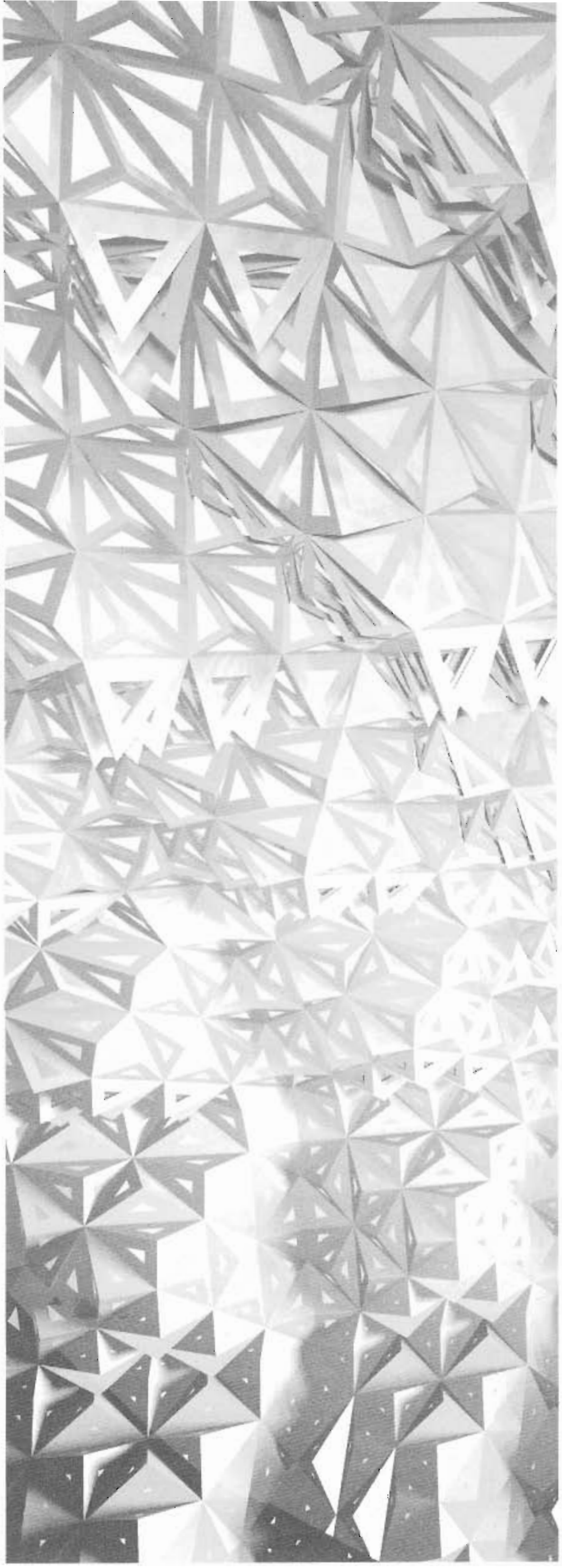

MICHAEL HENSEL AND ACHIM MENGES

MATERIAL SYSTEMS · INTRODUCTI

20 PROTO-ARCHITECTURES, RESEARCH AND DESIGN PROJECTS

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The projects presented here are examples of research into heterogeneous architectures conducted in the AA's Diploma Unit 4 Morpho-Ecologies (ME) programme and in the Generative Proto-Architecture (GPA) visiting studios taught at the Rice School of Architecture and Rotterdam Academy of Architecture and Urban Design. Above all, the work aims at rethinking the discourse of heterogeneous space and architecture as a material practice through intensive research into differentiated material systems and their performative capacities.

In this context the GPA studios focused on basic research, exploring material systems in terms of their potential architectural capacities and applications. Dip4's ME programme went further, by conducting extensive research and producing pilot projects, and by bringing differentiated material systems into contact with specific environments in order to develop their performative capacities and explore the programmatic opportunities of the Morpho-Ecologies approach.

Understanding the importance of digital technology, not as a field of research per se, but rather as a vehicle for notating and instrumentalising the intricate relationship of form, material, structure and ultimately space, all projects commence from in-depth physical modelling experiments and proceed in a bottom-up manner from the development of basic material elements and their arrangement in space and time.

The starting-point for the development of material systems is form-finding, a design method that deploys the self-organisational capacities of materials in relation to extrinsic forces induced for example through the construction process, different loading scenarios or context-specific environmental conditions. At various critical stages the behaviour of the material system undergoes an essential change in response to the increasing size and differentiation of the system across various hierarchical levels of assemblies. At the same time the articulation of the system is informed by an expanding range of performance criteria. The focal point in such a design process is what we define as material systems. These are material assemblies that, in their articulation, embody a geometric and topological logic which is informed by the self-organisational tendencies of material elements, established through form-finding and an inherent logic of manufacturing and assembly, as well as their environmental modulation capacities. In order to become architecture, these material systems must be further informed by context-specific conditions, by strategies of spatial organisation and synthesised structural and environmental performance, and by speculations about emergent social formation and programmatic opportunities.

We have distinguished between three broad categories of material system, though the boundaries between them remain somewhat elusive. These categories are proliferated component systems, globally modulated systems, and aggregate systems.

[i] Proliferated component systems can be developed through Halbzeug (semi-finished product assemblies) or differentiated components. A Halbzeug is a semi-finished product lying between raw material and finished product. Semi-finished products are usually available in larger sizes, e.g. as sheets, rods, hollow rods, profiles, coils, etc., and need to be cut to the required size. The design process unfolds through a differentiation of the rules of assembly within narrow parameters that enable a rigorous proliferation and jointing process informed by internal and external constraints.

A component is a constituent part of a more complex assembly; unlike the Halbzeug, it is a fully defined, finished product. Components can be differentiated and assembled into larger systems in response to inherent material and geometric characteristics and extrinsic parameters.

[ii] A globally modulated system registers local manipulation throughout the entire system. Such a system acquires its articulation through the number and disposition of definition points, which together assert a gradient influence upon the entire system. Globally modulated systems exploit the capacity of materials to settle into a stable configuration resulting from their internal make-up and external forces, which include extrinsic loads as well as the critical location and bearing capacity of control points. They require a different design method than for differentiated assembly systems, since the focus is on a limited number of strategic control points rather than a comprehensive geometric description by a maximum number of points. Membranes are one example of such globally modulated systems.

[iii] An aggregate is formed by the loose combination of many separate units or items. An aggregate system is defined by the specification of the individual aggregate unit, the aggregation process and the external constraints. Aggregate systems are the opposite of assembly systems or composite systems, in that the units are not connected by joints or a binding matrix; nevertheless they are still systems as the interrelations of system constituents can be traced, defined and instrumentalised. Differentiation occurs through the manipulation of the individual aggregate, the aggregation process and external constraints.

The most obvious distinction between the proposed categories is between assemblies of components and aggregates. A system is said to be more than the sum of its parts. Kant's notion of a system demands a specific mode of connection between the system's parts, a linkage (Verknüpfung) that is more than just connection, enabling what Kant defines as 'the synthetic unity of the manifold'. Aggregates by definition do not display such linkages between parts, in fact parts are not connected at all. However, in a wider view aggregates can be understood as part of a larger formative system which can display linkages between causes and effects, between hierarchical multi-scalar feedback relations and hosting environment, much more directly than other material system categories. Extrinsic forces, such as gravity and airflow, shape natural aggregates into formations such as ripples, piles and dunes, which in turn modulate the same forces that have shaped them. Aggregates also interact in highly specific ways with other material assemblies. We have therefore included aggregates and the related formative processes within the scope of our material system research.

Our tentative taxonomy of material systems also takes into account the critical difference of elements or assemblies that are either elastically or plastically deformed. Elasticity refers to the ability of a body to resist a distorting influence or stress and then return to its initial size and shape once the stress is removed. All solids are elastic, but if the applied stress exceeds the elastic limit of a material element, a permanent or plastic deformation results. Both the resistance to stress and the elastic limit depend on the composition of the solid.

Elasticity implies that the elements that configure an assembly are bent, buckled or torqued into shape through the actual assembly procedure. The pre-stressed state of the resulting system can then become instrumental in exploiting the energy stored within the system. Since elastic deformation also remains reversible such systems retain to some extent the capacity for a range of stable states. However, it is important to carefully monitor and account for creep or plastic

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deformation, which arises as a result of long-term exposure to levels of applied load or stress below yield, that is structural collapse. The rate of plastic deformation is a function of the material properties, length of exposure to stress and also temperature. Creep is not necessarily a failure mode, but is instead a damage mechanism. The material strains over time until it finally fails or becomes permanently deformed, thus reducing the amount of energy stored within the system.

Material systems with a high elastic threshold can be conceived as bundles of slender rods that are nevertheless able to transmit load without catastrophic buckling. Elastic structures have been researched extensively by scientists and engineers and from the seventeenth century onwards, producing many useful theories with significant repercussions for civil and mechanical engineering applications. However, mathematical models and tools of sufficient complexity have only recently begun to emerge, informing and being informed by research in, for instance, the discipline of biomechanics. Frei Otto's research and projects have pursued research in this direction using timber in bending (e.g. the Mannheim Multihalle gridshell) or in tension (e.g. the refectory building at Hooke Park, Dorset). Despite their obvious potential, such elastically deformed systems have not found wide application: architects have tended to shy away, cowed by questions of liability and lack of experience. It is precisely for this reason that much of the work presented here investigates ways of better understanding and deploying the behaviour and capacities of such systems.

Membranes are form-active tension systems that also belong to the elastically deformed systems: their shape and extent must be determined as part of the solution through a form-finding process, like the configuration and arrangement of all other elastically deformed systems.

Plastically deformed or pre-shaped systems do not store energy in the way outlined above but often make construction easier by defining the specific morphology of all the constituent parts of the assembly – a process that is critical for the performance of the resultant overall system. This calls for a design process that enables constraints and possibilities of the relevant fabrication technologies to be embedded in the form-generation techniques that determine the particular geometry of all the parts.

Another important aspect is whether the internal make-up of the material at hand is invariant (that is, isotropic) or variant (anisotropic) with respect to direction. The former implies uniformity of physical properties in all directions within the material, for instance equal elasticity in all directions, while the latter implies directional differences and is characteristic of fibrous materials. These material properties determine the behaviour of both element and assembly in a fundamental way. The careful choice of material, with regard to its internal make-up and resultant behaviour, is therefore of central importance to the research presented here. In some cases this may lead to designing the actual makeup of a composite material according to required characteristics and properties. This is where knowledge of biomimetic engineering and material science becomes instrumental.

Overall, the categorisation introduced here may serve as an initial framework. Attempting a more systematic differentiation of the various material systems and pilot projects would do an injustice to their rich scope and their individual goals and focus. Moreover, establishing a unified taxonomy is a very difficult undertaking. Does one begin with the status of the initial element as a semi-finished product or an already defined component? When does the status of an element change from a semi-finished product to a component? Perhaps when the first functional assignment has informed its articulation? If so, this will happen at very different stages of development for each project. Should one organise the work in relation to existing types that the projects seem to adhere to, for example calling a design a proto-gridshell? Such an approach would prematurely channel the designs into particular directions and undermine the possibility of defining systems that are altogether different from those already established. Or should one consider the eventual performance profiles that arise for each project as the means of categorisation? Such an approach would run the risk of either being too general, thus failing to provide a useful taxonomy or, conversely, of leading to an overly specific catalogue of applications. We have therefore opted to outline some important differences and similarities between the systems and give them a loose order without forcing them into a taxonomic straitjacket that could distract from their potential. In doing so, we hope to satisfy the modality of systematic work while avoiding the pitfalls of defining the borders too narrowly.

One shared aspect of the different strands of this material system research is the way in which computer-aided design is instrumentalised. Rather than using representational tools intended for explicit scalar geometric descriptions, the projects employ parametric associative models and digital form-finding methods in a way that is far more immediate in its relation to materialisation, so enabling the designer to orchestrate the system's evolution and proliferation. The geometric rigour of such digital techniques is utilised to integrate manufacturing constraints, assembly logics and material characteristics in the definition of material components. Rather than designing a specific artefact, the focus is on defining, evolving and instrumentalising the behaviour of a material system that becomes increasingly refined and calibrated through the recognition of anticipated and emergent performative capacities across multiple instances of the system. This includes exploring parametric variables to understand the behaviour of a system and deploying this understanding to strategise the performance of the system interacting with context- and time-specific extrinsic influences, such as environmental conditions.

What ultimately binds this research together is the vision and belief of its authors in the potential of architecture as a material practice – a practice that is capable of evolving a heterogeneous, exciting and sustainable built environment with embedded higher-level functionality and higher-level integration between material system and environment.

The following section introduces 20 selected projects that indicate the scope of a much broader and ongoing research.

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