COMPUTATIONAL MORPHOGENESIS

Integral Form Generation and Materialization Processes

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Abstract. Natural morphogenesis, the process of evolutionary development and growth, derives polymorphic systems that obtain their complex form, organisation and versatility from the interaction of system intrinsic material capacities and external environmental influences and forces. One striking aspect of natural morphogenesis is that formation and materialisation processes are always inherently and inseparably related. In stark contrast to these integral development processes of material form, architecture as a material practice is mainly based on design approaches that are characterised by a hierarchical relationship that prioritises the definition and generation of form over its subsequent materialisation.

This paper will present an alternative approach to design that entails unfolding morphological complexity and performative capacity without differentiating between form generation and materialisation processes. Based on an understanding of material systems not as derivatives of standardized building systems and elements but rather as generative drivers in the design process this approach seeks to develop and employ computational techniques and digital fabrication technologies to unfold innate material capacity and specific latent gestalt. Extending the concept of material systems by embedding their material characteristics, geometric behaviour, manufacturing constraints and assembly logics within integral computational models promotes an understanding of form, material and structure not as separate elements, but rather as complex interrelations in polymorphic systems resulting from the response to varied input and environmental influences and derived through the logics and constraints of advanced

manufacturing processes. These processes will be explained along 8 research projects.

1. Introduction

Architecture, as a material practice, attains social, cultural and ecological relevance through the articulation of material arrangements and structures. Thus the way we conceptualize these material interventions and, in this context particularly the technology that enables their construction, presents a fundamental aspect in how we (re)think architecture. Paragraphs immediately following a heading are not indented.

In many ways the progress of computer aided design and manufacturing, or rather the greater availability and affordability of these technologies which have been developed over a number of decades, can be seen in the lineage of other technical advancements. In the history of architecture and construction ground braking technologies have often been initially employed to facilitate projects that were conceived through, and indeed embraced, well established design concepts and construction logics. There is ample evidence of this inertia in design thinking in the context of technological progress. For example the design of the structure and connection details of the first cast iron bridges of late 18th century England were modelled on timber constructions. Similarly the early reinforced concrete structures of the late 19th century mimicked preceding iron and steel frame buildings. In fact almost half a century had to pass between the first patent for reinforced concrete and its significant influence on design through the conceptualisation of its innate material capacities as manifested in Robert Maillart's bridges and the shell structures of various 20th century pioneers such as Franz Dischinger. While these examples of deferred impact refer mainly to advances in material technology one may still trace an interesting parallel to the current employment of computer aided design and manufacturing technologies.

The by now ubiquitous use of CAD-CAM technologies in architecture serves more often than not as the facilitative, and affordable, means to indulge in so called free form architecture as conceived at the end of the last century. Although this may occasionally lead to innovative structures and spatial qualities it is important to recognize that the technology here provides a mere extension of well rehearsed and established design processes. Particularly emblematic for this is the one-dimensional reference to the notion of digital morphogenesis. By now almost a cliché in itself, this term refers to various processes of form generation resulting in shapes that remain elusive to material and construction logics. In foregrounding the geometry of the eventual outcome as the key feature these techniques are quintessentially not dissimilar to more conventional and long established representational techniques for explicit, scalar geometric descriptions. As these notational systems can not integrate means of materialisation, production and construction these crucial aspects need to be subsequently pursued as top-down engineered material solutions. Being essentially about appearance digital morphogenesis dismisses both, the capacity of computational morphogenesis to encode logic, structure and behaviour as well as the underlying principles of natural morphogenesis.

2. Natural and Computational Morphogenesis

Natural morphogenesis, the process of growth and evolutionary development, generates systems that derive complex articulation, specific gestalt and performative capacity through the interaction of system intrinsic material characteristics as well as external stimuli of environmental forces and influences. Thus formation and materialisation are always inherently and inseparably related in natural morphogenesis. Such integral processes of unfolding material gestalt are particularly striking as architecture as a material practice, by contrast, is still mainly based on design approaches that are characterised by a hierarchical relationship that prioritises the definition and generation of form over its subsequent materialisation. This suggests that the latent potential of the technology at stake may unfold from an alternative approach to design, one that derives morphological complexity and performative capacity without differentiating between form generation and materialisation processes.

The underlying logic of computation strongly suggests such an alternative, in which the geometric rigour and simulation capability of computational modelling can be deployed to integrate manufacturing constraints, assembly logics and material characteristics in the definition of material and construction systems. Furthermore the development of versatile analysis tools for structure, thermodynamics, light and acoustics provides for integrating feedback loops of evaluating the system's behaviour in interaction with a simulated environment as generative drivers in the design process. Far beyond the aptitude of representational digital models, which mainly focus on geometry, such computational models describe behaviour rather than shape. This enables the designer to conceive of material and construction systems as the synergetic result of computationally mediating and instrumentalizing the system's intrinsic logics and constraints of making, the system's behaviour and interaction with external forces and environmental influences as well as the performative effects resulting from these interactions. Thus the understanding of material effects extends far beyond the visible effect towards the thermodynamic, acoustic and luminous modulation of the (built) environment. As these modulations, in relation to the material interventions and their construction process, can now be anticipated as actual behaviour rather than textbook principles the design of space, structure and climate becomes inseparable. Crossing a number of disciplinary boundaries the design approach presented here demands that structural and environmental engineering, which has tended to be a question of post-design optimisation, becomes an essential factor in the set up of the design process itself.

3. Computational Morphogenesis and Material Systems

Realizing the potential of computational design and computer controlled fabrication is twofold: Firstly it enables to (re)establish a far more immediate relation to the processes of making and constructing by unfolding innate material capacity and behaviour and secondly, to understand this behaviour always already as a means of creating not only space and structure but also micro-climatic conditions. While the later may have a profound impact on our conception of spatial organisation, which can now be thought of as differentiated macro- and micro climatic conditions providing a heterogeneous habitat for human activities, the former will be the main focus of the following paragraphs. This is due to the fact that a profound architectural speculation would exceed the space given in this article, especially as the research on integral processes of computational morphogenesis and performance evaluation is a substantial field by its own. This basic research entails developing and exploring new modes of integrating design techniques, production technologies and system performance. These modes are by no means similar when developed for different systems but rather differentiate into a wide range of possible material articulations and computational methods. So, while sharing a common objective, a rich palette of different approaches have been explored over the last five years through various research projects of which a cross section will be discussed in this article.

As all research projects to be presented here seek to develop and employ computational techniques and digital fabrication technologies to unfold innate material capacity and specific latent gestalt they all commence from extensive investigations and tests of what we define as material systems. Material systems are considered not so much as derivatives of standardized building systems and elements but rather as generative drivers in the design process. Extending the concept of material systems by embedding their material characteristics, geometric behaviour, manufacturing constraints and assembly logics within an integral computational model promotes an understanding of form, material, structure and behaviour not as separate elements, but rather as complex interrelations. This initially requires disentangling a number of aspects that later on form part of the integral computational set up in which the system evolves.

3.1. MATERIAL SYSTEMS AND COMPUTATION: MATERIAL AND MANUFACTURING CHARACTERISTICS AND CONSTRAINTS

First of all the geometric description of material systems, or rather the notation of particular features of the system's morphology, needs to be established. The geometric definition of the system has to overcome the primacy of shape and related metric, descriptive characteristics. Therefore the designer has to facilitate the set up of a computational model not as a particular gestalt specified through a number of coordinates, but rather as a framework for possible formations affording further differentiation that remains coherent with the behaviour observed and extracted from physical experiments and explorations of the relevant system. This computational framework, which essentially constitutes an open model but will be referred to as 'framework' here due to the ambiguous meaning of 'model' in a design context , is then step by step informed by a series of additional parameters, restrictions and characteristics inferred from material, fabrication and assembly logics and constraints. Principally this includes the specific material and geometric behaviour in formative processes, the size and shape constraints of involved machinery, the procedural logistics of assembly and the sequences of construction. As these aspects vary greatly depending on the set-up and construction of the material system, more detailed explanations will follow in the paragraphs describing specific projects.

However, it may still be interesting to note the significant shift in the way computer aided manufacturing processes are employed in this context. Whereas the nature of CAM enables difference to be achieved, it is currently used mainly as a means of increasing speed and precision in the production of variation. Symptomatic for preserving the facilitative character of manufacturing and its related protocols is the term 'mass customisation'. Flourishing due to the reintroduction of affordable variation 'mass customisation' nevertheless remains an extension of well known and long-established design processes embracing the still dominant hierarchy of prioritised shape-definition and subsequent, purely facilitative manufacture. One needs to be aware that the accomplishment of economically feasible variation through computer controlled production and fabrication, by manufacturers and designers alike, does not by itself lead to strategies of instrumentalizing the versatility of differentiated material systems. Nonetheless, the far-reaching potential of CAM technologies is evident once they turn into one of the defining factors of a design approach seeking the synthesis of form-generation and materialisation processes. At this point the highly specific restrictions and possibilities of manufacturing hardware and controlling software can become generative drivers embedded in the set-up and development of the computational framework.

Generally it can be said that the inclusion of what may be referred to as system-intrinsic characteristics and constraints comprises the first crucial constituent of the computational set-up defined through a series of parameters. The definition of the range in which these parameters can be operated, and yet remain coherent with the material, fabrication and construction constraints, is the critical task for the designer at this stage.

3.2. MATERIAL SYSTEMS AND COMPUTATION: EVALUATION OF STRUCTURAL AND ENVIRONMENTAL PERFORMANCE

The second crucial constituent of the generative computational framework are recurring evaluation cycles that expose the system to embedded analysis tools. Analysis plays a critical role during the entire morphogenetic process, not only in establishing and assessing fitness criteria related to structural and environmental capacity, but also in revealing the system's material and geometric behavioural tendencies. The conditioning relation between constraint and capacity in concert with the feedback between stimuli and response are consequently operative elements within the computational framework. In this way evaluation protocols serve to track both, the coherency of the generative process with the aforementioned system-intrinsic constraints as well as the system's interaction with a simulated environment. Depending on the system's intended environmental modulation capacity the morphogenetic development process needs to recurrently interface with appropriate analysis applications, for example, multi-physics computer fluid dynamics for the investigation of thermodynamic relations or light and acoustic analysis. It seems important to mention though that CFD does always only provide a partial insight as the thermodynamic complexity of the actual environment is far greater than any computational model can handle at this moment in time. Nonetheless, as the main objective here lies not solely in the prediction of precise data but mainly the recognition of behavioural tendencies and patterns the instrumental contributions of such tools are significant.

In parallel to the environmental factors continual structural evaluation informs the development process or even directly interacts with the generation of the system's morphology through processes of evolutionary structural optimisation. Yet in general the notion of single-criteria optimisation is opposed to the underlying principles of morphogenesis. It is imperative to recognize that computational morphogenesis does not at all reproduce a technocratic attitude towards an understanding of efficiency based on a minimal material weight to structural capacity ratio. Nor does it embrace the rationale of what 20th century engineers called “building correctly”. Structural behaviour here rather becomes one agent within the multifaceted integration process. Overall this necessitates a shift in conceptualizing multi-criteria evaluation rather than an efficiency model. Biologists for example, refer to effectiveness as the result of a developmental process comprising of a wide range of criteria. Accordingly the robustness of the resulting systems is as much due to the persistent negotiating of divergent and conflicting requirements as their consequential redundancies.

3.3. MATERIAL SYSTEMS AND COMPUTATION: GROWTH AND EVOLUTIONARY PROCESSES

As of yet two essential elements of a computational framework for morphogenetic processes have been introduced: the parametric set up based on the material system’s intrinsic constraints and the evaluation cycles through which the interaction of individual system instances with external influences and forces are frequently analysed. In other words the possibility of manipulating the system’s articulation in direct relation to understanding the consequential modulation of structural or environmental effects has been established. Therefore the processes that trigger and drive the advancing development of the system are the third critical constituents of the computational framework. Only through these processes the framework is able to operate as they provide the variable input to the defining parameters. This input generates a specific output, one individual instance of the system, leading to the registration and analysis of instance specific structural and environmental effects. Through these effects, basically the way the system modulates the environment, the system’s performative capacity unfolds from feedback cycles of manipulation and evaluation. These processes of driving the development of the system through continual differentiation of its instances can be envisioned in different ways. The most immediate possibility is the direct, top-down intervention of the designer in the parametric manipulation and related assessment cycle. More coherent with the overall concept though are processes based on similar principles as natural morphogenesis. In this respect two kind’s of development processes are of interest here: the growth of the individual instance and the evolution of the system across generations of populations of individual instances. In order to facilitate the former there are different computational growth models that can be implemented, which are all based on two critical factors: on the one hand, the internal dataset or growth rules, the genotyp, and on the other hand the variable gestalt that results from the interaction of the genotype with the environment, the phenotyp. The critical task for the designer is defining the genotype through the aforementioned system-intrinsic constraints. The generation of phenotypic system instances, enabled through seed configurations and repeatedly applied genotypic rewriting rules, happens in direct interaction with the environment. One critical aspect to be considered here, and captured in the computational process, is the profound influence of goal oriented physiological regulation mechanisms, as for example homeostasis, on the growth process.

Each derived instance then forms part of a population and is evaluated with the aforementioned analytical tools. Driven by fitness criteria evolutionary computation, for example through the implementation of genetic algorithms, can then be employed to evolve various generations based on the confluent dynamics of mutation, variation, selection and inheritance.

A continuous mediation of the stochastic evolutionary processes and goal oriented physiological developments at play, or more generally the skilful negotiation between bottom up and top down processes is a central task for the designer. Furthermore, in order to enable genuine morphological differentiation, that is changes in kind and not just in degree, it is of critical importance that the initially established fitness criteria as well as the defining parameter ranges, in fact the entire computational framework, is capable of evolving alongside with the system's development.

4. Research Projects

Before moving on to discussing the deployment of computational morphogenetic processes in the context of different research projects two trite yet common misconceptions may need to be addressed. Firstly, employing such a computational framework challenges the nature of currently established design approaches, yet it does not invoke the retirement of the architect in favour of computation. On the contrary, it highlights the importance of the designer in an alternative role, one that is central to enabling, moderating and influencing truly integral design processes and requires novel abilities and sensitivities. Secondly, despite the fact that the presented design approach requires a serious engagement with technology, as may have become clear from the above description of the involved computational framework, its use is not limited to exotic materials and manufacturing processes. Quite the opposite is demonstrated through the following projects, which are all, in one way or another, based on the above explained computational framework yet utilize mundane materials and by now commonplace fabrication and manufacturing technology. In effect, as the main expenditure consists of the intellectual investment in an alternative conceptualisation of material systems and related computational processes, this design approach flourishes in contexts of limited resources. Here complexity, and related perfomative capacity, unfolds from the continuous evolution and differentiation of initially simple material elements and fabrication procedures.

4.1. PROJECT: METAPATCH (BY JOSEPH KELLNER AND DAVE NEWTON, "GENERATIVE PROTO-ARCHITECTURES" STUDIO, MICHAEL HENSEL AND ACHIM MENGES, RICE SCHOOL OF ARCHITECTURE, HOUSTON, USA, 2004)

An interesting example of a project that starts from a strikingly straightforward element is the "Metapatch" project. Initial experiments indicated the possibility of inducing geometric changes to an element consisting of two rectangular timber patches, which are attached to one another in two opposite corners, by the basic actuation of increasing the distance between the two loose corners through a spacer element. If a larger panel is covered with arrays of these small patches each equipped with two adjustable spacers, in this case simple bolts, the incremental actuation and consequential bending of each individual element led to a cumulative induction of curvature in the larger panel (Fig. 1).

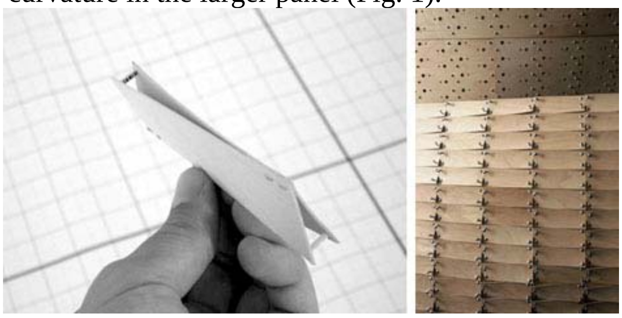

Figure 1. Basic Component (left) and component assembly (right) of Metapatch project

Elaborate physical tests then established the relation of element and patch variables such as size, thickness and fibre orientation, spacer locations, actuation distance and torque, which were encoded in the system's parametric definition. The computational set-up then provided a specific assembly and actuation protocol from which all relevant information for constructing a full scale prototype could be obtained. Consisting of 48 identical patches, 1920 equal elements and 7680 bolts the structure remains to be entirely flat and flexible after the initial assembly. Only through the subsequent actuation of each spacer bolt, guided by the computationally derived data, the structure rises into a stable, self-supporting state that gains considerable stiffness and structural capacity through the resulting convex and concave curvature (Fig. 2). This demonstrates how integral techniques can derive a variable, complex material system made up of amazingly simple, uniform elements.

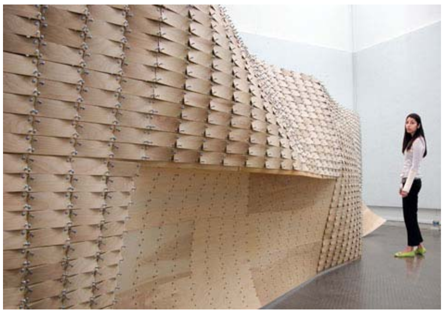

Figure 2. Full scale prototype surface of Metapatch project

4.2. PROJECT: STRIP MORPHOLOGIES (BY DANIEL COLL I CAPDEVILA, DIPLOMA UNIT 4 “MORPHO-ECOLOGIES II” PROGRAMME, MICHAEL HENSEL AND ACHIM MENGES, AA SCHOOL OF ARCHITECTURE, LONDON, UK, 2004-05)

The next project, “Strip Morphologies”, explores another approach to an element assembly. Instead of capacitating the material system through differential actuation of geometrically identical elements, here the system’s constituents differ geometrically yet maintain the same fabrication and assembly logic throughout. Again the starting point of the system’s development is a simple component of three sheet metal strips connected at the short edges. The bending behaviour of the component resulting from the displacement or rotation of one or two edges was examined in a large number of physical tests. Together with the constraints of fabrication, laser cutting from sheet steel, the observed behaviour and related material and geometric limitations were encoded in a computational component defined by parametric relationships. Subsequent processes of algorithmic proliferation evolve a larger system in which each individual component is geometrically differentiated (Fig. 3).

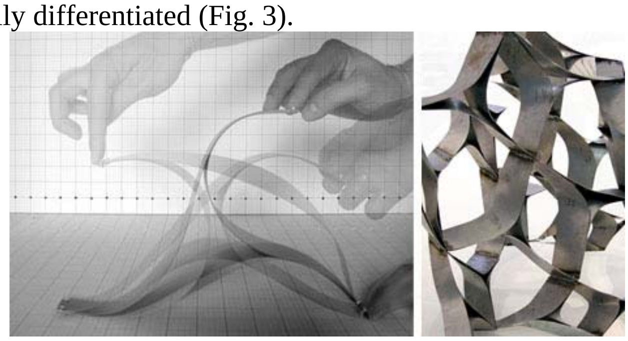

Figure 3. Basic component (left) and full scale welded steel strip assembly (right)

Successive evaluation cycles of testing the system's structural behaviour and interaction with light trigger further differentiation on the 'local' level of the individual component, the 'regional' level of component collectives and the 'global' overall system and related distribution algorithm. In this process of enhancing the system's performative capacities the computational framework ensures that all components remain to be coherent with the underlying fabrication and assembly logic of the basic sheet metal strip. This allows for the immediate manufacturing and construction of a system prototype (Fig. 4).

Figure 4. Prototype structure of Strip Morphologies project

4.3. PROJECT: HONEYCOMB MORPHOLOGIES (BY ANDREW KUDLESS, "EMERGENT TECHNOLOGIES AND DESIGN" MASTER PROGRAM, MICHAEL HENSEL, MICHAEL WEINSTOCK, ACHIM MENGES, AA SCHOOL OF ARCHITECTURE, LONDON, UK, 2003-04)

An interesting variant of strip-based material systems is explored in the "Honeycomb Morphologies" project. This project aimed at advancing honeycomb structures by developing a double layered system in which each cell size, shape, direction and orientation can be different. Unlike in the previous project the performative component, a honeycomb cell, does not directly match the material element, a folded strip of cardboard (Fig. 5).

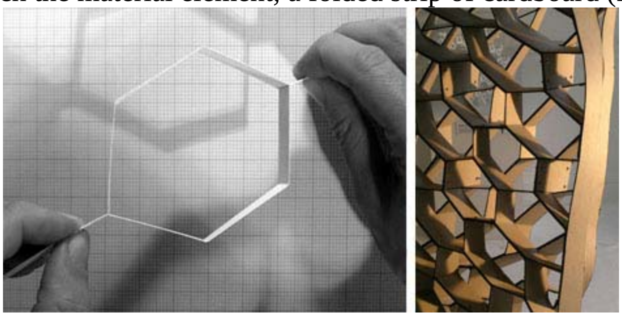

Figure 5. Basic component (left) and full scale component assembly (right)

Starting again from a simple element of two folded cardboard strips a series of linked physical and digital morphological experiments were conducted in order to investigate the interrelation between surface curvature and honeycomb cell structures, the characteristics of the material, such as for example the maximum fold angles of the specific cardboard, and the constraints of the laser cutting process being limited to sheet material of a certain size. These constraints informed the development of a honeycomb deriving growth algorithm that defines the morphology as folded overlapping strips in response to other given design input. The resultant material system, of which a fully differentiated prototype was constructed, shows clearly that innovation in this research does not depend on high-tech material or manufacturing technology Here novelty arises not from singular aspects of the design and construction process but rather from an integral approach that directly relates modes of production and making with computational form generation (Fig. 6).

Figure 6. Full scale prototype structure of Honeycomb Morpholgies project

4.4. PROJECT: 3D-GEWIRKE (BY NICO REINHARDT, "FORM GENERATION AND MATERIALISATION" DEPARTMENT, PROF. ACHIM MENGES, HFG OFFENBACH UNIVERSITY OF ART AND DESIGN, GERMANY, 2006-07)

Whereas the previous projects focused on systems assembled from a large number of elements, the "3D Gewirke-Verbund" project investigated ways of utilizing local form-finding processes to differentiate a larger, continuous material system. Form-finding, as pioneered by Frei Otto, is a design technique that utilises the self-organisation of material systems under the influence of extrinsic forces or manipulations. In other words, material form can be found as the state of equilibrium of internal resistances and external forces. Contrary to most form finding processes, which are concerned with the global morphology of a system, this project aimed at exploring local manipulations. Therefore the notion of component, and the related computational set-up, needed to be extended as it does not correspond directly with a material element as in the previous projects. Here component refers to a specific area undergoing parametric manipulation (Fig. 7).

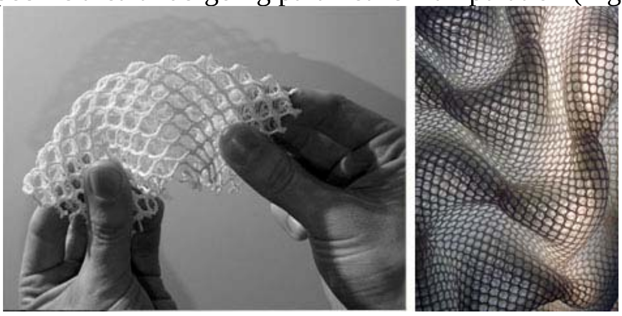

Figure 7. Basic material (left) and manipulation component (right)

The specific manipulation component defines the vectors and distances of gathering particular points on a three dimensional spacer textile. Numerous experiments were conducted exploring the behaviour of local manipulation areas, interdependent manipulation arrays and the resulting overall morphology. This lead to a catalogue of local articulations, applied through simple procedures of point gathering following computationally derived protocols, which enable overall double curvature and considerably increase the structural depth and bending stiffness of the system. In subsequent steps the local manipulations were correlated with larger guiding formwork and a number of full scale prototypes were constructed in order to test the possibility of integrating a similarly form found glass fibre reinforced skin (Fig. 8).

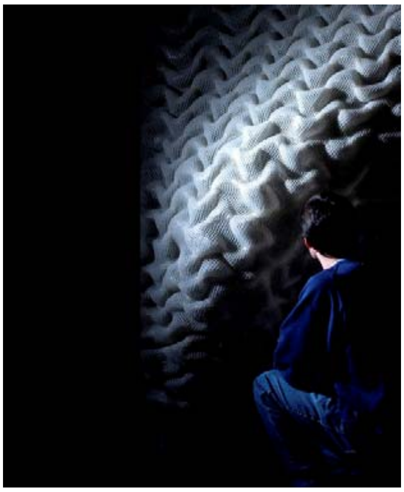

Figure 8. Full scale prototype structure of 3D-Gewirke project

4.5. PROJECT: RESPONSIVE SURFACE STRUCTURE (BY STEFFEN REICHERT, "FORM GENERATION AND MATERIALISATION" DEPARTMENT, PROF. ACHIM MENGES, HFG OFFENBACH UNIVERSITY OF ART AND DESIGN, GERMANY, 2006-07)

The performative capacity of the material systems explained above is revealed and instrumentalized through feedback processes of evolving an increasingly articulated morphology while continually registering and evaluating its interaction with the environment. Due to the inherent dynamics of the environment the modulations effected by a differentiated system are equally dynamic even though the actual structure remains to be a static. A further intensification of the system-environment relation is suggested by another category of material systems, one in which the system actively reacts to environmental changes.

One example is the "Responsive Surface Structure" project which aimed at developing a skin structure capable of adapting its porosity in response to changes in ambient humidity. The project utilises timber's inherent moisture absorbing properties, and particularly the related differential surface expansion, as a means of embedding humidity sensor, actuator and regulating element all in one very simple component.This component consists of a moisture responsive veneer composite element attached to a load bearing, folded substructure (Fig. 9).

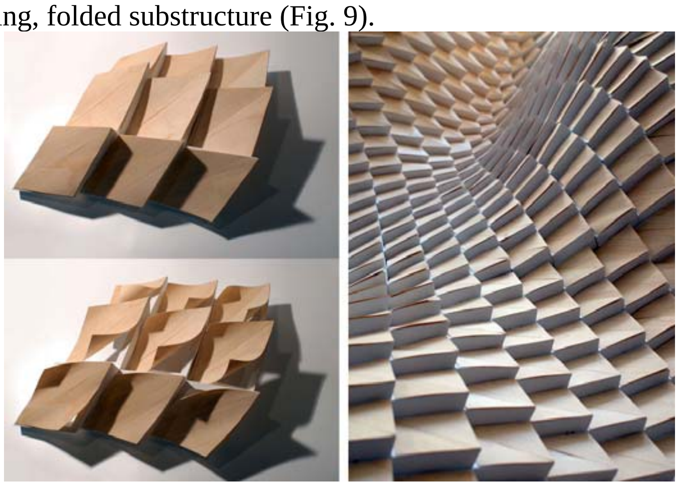

Figure 9. Responsive component (left) and full scale component assembly (right)

Once exposed to a higher level of humidity the veneer composite swells and the consequent expansion triggers a deformation that opens a gap between the substructure and the veneer scales resulting in different degrees of porosity. The local component shape and orientation as well as the mathematically defined surface undulation evolve in continuous feedback with structural evaluation and thermodynamic analysis of the volume, speed and direction of passing air in relation to the system's response time. As the logics of fabrication and assembly had also been encoded in the initial computational set-up the evolved morphology of geometrically variant components could be directly constructed. The resultant material system, which is in one structure and performative skin, provides different degrees of porosity due to local responses innate to the material with no need for other electronic or mechanical devices (Fig. 10).

Figure 10. Functioning full scale prototype of the Responsive Surface Structure Project

4.6. PROJECT: COMPONENT MEMBRANE CANOPY (BY EMERGENT TECHNOLOGIES AND DESIGN MASTER PROGRAM 2006-07, MICHAEL HENSEL, MICHAEL WEINSTOCK, ACHIM MENGES, AA SCHOOL OF ARCHITECTURE, LONDON, UK, 2007)

As evident in the above research projects, a design approach based on material systems promotes a high level of integration of both manufacturing and construction logics as well as performative capacities. Consequently the set-up of a computational framework for evolving a specific design is an involving operation. Thus one critical aspect, mainly to inform further research endeavours and directions, is the viability of this approach beyond a mere research context. This was tested in the "Component Membrane Canopy" project (Fig. 11).

Starting from scratch this canopy structure for a Central London roof terrace needed to be designed, manufactured and constructed in less than 7 weeks within an extremely limited budget. This required a versatile computational set-up providing for rapid design evolution and performative evaluation, automated extraction of all relevant data for fabricating more than 600 different steel components and 150 membranes, detailed planning of the assembly and construction sequence as well as continuous exchange with engineering and technology consultants. This project began with the definition of a component that deploys a hyper parabolic membrane as a load bearing tensile element within a framework of steel members. The proliferation of the component was evolved in feedback with structural evaluation as well as environmental analysis of precipitation, sunlight and wind. The resulting overlapping membrane articulation protects from rain while at the same time remaining porous enough to avoid excessive wind pressure or blocking the view across London’s roofscape. Furthermore the membranes contribute considerable to the stiffness of the overall structure, which acts as a cantilever resting on just three points (Fig. 12).

Figure 11. The Component Membrane Canopy constructed on a London roof terrace

Figure 12. The Component Membrane Canopy structure

4.7. PROJECT: RAFFUNGSKOMPONENTEN-VERBUND (BY ELENA BURGGRAF, "FORM GENERATION AND MATERIALISATION" DEPARTMENT, PROF. ACHIM MENGES, HFG OFFENBACH UNIVERSITY OF ART AND DESIGN, GERMANY, 2006-07)

Two main lineages of material systems have been introduced thus far: One that assumes a specific gestalt through local manipulations of a continuous overall system, as in the "3D Gewirke" project, and another based on element assemblies. What is common to all variants of the later kind is the high level of geometric precision required in defining each element and, in particular, the relation between elements due to the system's morphological differentiation. While the necessary accuracy is afforded by, or rather inherent to, computational processes it still demands additional effort in terms of fabrication and assembly logistics.

An alternative to the geometric precision of highly defined component assemblies is the topological exactitude of systems consisting of elements that "find" their position and alignments. For example, in the "Raffungskomponenten-Verbund" project the basic element is a glass fibre band. By pulling a thread stitched through the band in defined distances a specific loop pattern emerges due to the gathering action (Fig. 13).

Figure 13. Basic component (left) and full scale component assembly (right)

In numerous physical tests the related parameters of band width, length and cut pattern, stitch distance as well as tensile force induced in the gathering process were explored in relation to the resultant component's behaviour of adapting to formwork curvature and, once hardened by resin, structural capacity. As soon as the taxonomy of the observed component behaviour was established this could be related to the principal stress analyses of specific formwork geometry within a computational set up. The relation between local curvature and structural requirements then defines the specific distribution of parametrically varied components. The specific component layout is transferred from the computational realm to the actual formwork via a specially developed projection technique. As the components are laid out in the soft state the alignment of adjacent components providing for subsequent connections happens by itself. Although the initial distribution focuses only on component type and spacing, the application of resin and related adhesive forces, combined with the self forming capacity of the strips, produces a highly defined material system. Material systems consisting of initially loose assemblies pose a considerable challenge not only in terms of developing more advanced computational techniques but especially in terms of rethinking the notion of geometric precision in the design and planning process (Fig. 14).

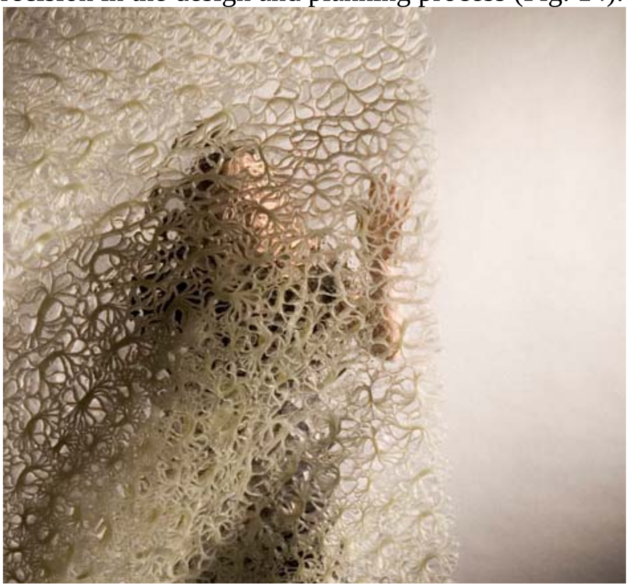

Figure 14. Full scale surface prototype of the Raffungskomponenten-Verbund project

4.8. PROJECT: AGGREGATES (BY ANNE HAWKINS & CATIE NEWELL, “GENERATIVE PROTO-ARCHITECTURES” STUDIO, MICHAEL HENSEL AND ACHIM MENGES, RICE SCHOOL OF ARCHITECTURE, HOUSTON, USA, 2004)

An even more radical departure from established design and construction strategies is suggested by a fourth lineage of research projects investigating aggregates, loosely compacted masses of particles or granules. While an abundance of construction applications of bound aggregates exists, for example concrete and asphalt, research on loose aggregates requires a fundamental rethinking of architectural design and its preoccupation with element assemblies as aggregates are formed not through the connection of elements by joints or a binding matrix, but through loose accumulation of discreet elements. “Aggregates” is a research project exploring the related space making potential and performative capacity. This project started with designing a range of simple to manufacture particle elements (Fig. 15).

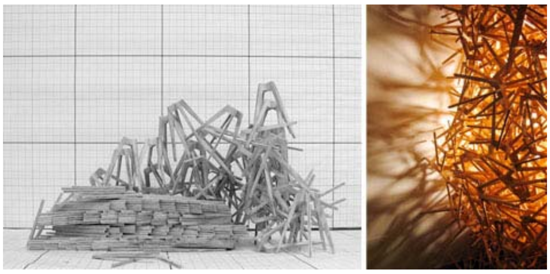

Figure 15. Basic aggregate elements (left) and full scale aggregate structure (right)

A wide range of computational as well as physical tests were conducted to understand the critical parameters such as number of elements, element geometry, pouring speed, pouring height and the degree of friction provided by boundary surface. Subsequently liquefaction, the interesting property of granular systems to display liquid like behaviour despite being composed of solid grains, was employed to test the formation of larger structures utilizing both conventional and inflatable formwork. Through the adjustment of the aforementioned parameters the aggregation tendencies and behaviour can be utilized to create cavernous spaces with multiple stable states, transient spatial conditions and granular, differentially porous thresholds and boundaries. As no aggregate structure can ever be conceived of as finished, this necessitates a critical shift from the precise design of static assemblies towards the recognition of behavioural tendencies and patterns of self-organising and reconfigurable structures (Fig.16).

Figure 16. Full scale aggregate structure prototype

5. Summary

Computational morphogenesis helps to develop a design approach that allows for a much higher level of integration of form generation, materialization and construction as what has been achieved thus far. The related computational processes and computer controlled manufacturing surpass the possibilities of post-rationalization and mass customization that dominate current practice. Due to the nature of basic research the projects and related material systems presented here remain in a proto-architectural state still awaiting their context specific architectural implementation. Nevertheless they challenge the nature and hierarchies of currently established design processes and promote an alternative approach. One that enables architects to exploit the resources of computational design and manufacturing far beyond the creation of exotic shapes subsequently rationalized for constructability and superimposed functions. Rather, it promotes the unfolding of performative capacities and spatial qualities inherent in the material systems we construct while at the same time encouraging a fundamental revision of still prevailing functionalist and mechanical approaches towards sustainable design.

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