Integral Computational Design: Synthesizing Computation and Materialisation in Architecture

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Abstract

This paper will present a morphogenetic approach to design computation in architecture that aims at synthesizing computation and materialization in one integral process. Computational design lends itself to such an approach as it is enables employing complex behavior rather than just modeling a particular shape or form. The transition from currently predominant modes of Computer Aided Design (CAD) to Computational Design allows for a significant change of employing the computer's capacity to instrumentalise material behavior in the design process. CAD is very much based on computerized processes of drawing and modeling stemming from established representational techniques in architectural design. In this regard one of the key differences lies in the fact that CAD internalizes the coexistence of form and information, whereas Computational Design externalizes this relation and thus enables the conceptualization of material behavior and related formative processes. In Computational Design form is not defined through a sequence of drawing or modeling procedures but generated through parametric, rule based processes. The ensuing externalization of the interrelation between algorithmic processing of information and resultant form generation permits the systematic distinction between process, information and form. Hence any specific shape can be understood as resulting from the interaction of system-intrinsic information and external influences within a morphogenetic process

Conceiving of computational design processes as morphogenetic enables the systematic integration of material characteristics and constraints. Therefore the complex behavior of material resulting from its internal makeup and structure can constitute an integral aspect of the genotypic datasets from which a specific, phenotypic shape is derived. Obviously this requires both in-depth empirical studies of the microstructure and resultant behavior of the material to be used as well as the development of appropriate computational design techniques. The paper will elaborate the conceptual and technological transition from Computer Aided Design to Computational Design with particular respect to architecture as a material practice. In addition, the paper will present a number of research projects explaining different tasks on developing a morphogenetic approach to computational design.

Keywords: Computer Aided Design, Computational Design, parametric process, morphogenetic process, genotypic dataset.

СОСТАВНОЙ ВЫЧИСЛИТЕЛЬНЫЙ ПРОЕКТ: СИНТЕЗИРОВАНИЕ ВЫЧИСЛЕНИЯ И МАТЕРИАЛИЗАЦИИ В АРХИТЕКТУРЕ

Аннотация

Статья представляет морфогенетический подход к проектным вычислениям в архитектуре, которые стремятся синтезировать вычисления и материализацию в одном интегральном процессе. Вычислительное проектирование предоставляет себя такому подходу, поскольку это дает возможность использования комплексного поведения вместо того, чтобы только моделировать специфическое очертание или форму. Переход от преобладающих в настоящее время способов Автоматизированного проектирования (CAD) к Вычислительному проектированию учитывает существенное изменение использования производительности компьютера к материальному поведению в проектном процессе. Автоматизированное проектирование основано на

компьютеризированных процессах черчения и моделирования установленных представительных методов в архитектурном проектировании. В этом отношении одно из ключевых различий отражается в факте, что автоматизированное проектирование допускает сосуществование формы и информации, тогда как Вычислительное проектирование воплощает это отношение и таким образом позволяет осмысление материального поведения и связанных с этим формирующих процессов. В Вычислительном проектировании форма не определяется последовательностью рисунков или моделированием процедур, но генерируется посредством параметрических процессов, базирующихся на правилах. Следующее воплощение взаимосвязи между алгоритмической обработкой информации и генерированием получающейся в результате формы допускает систематическое различие между процессом, информацией и формой. Следовательно, любая определенная форма может быть понята как результат взаимодействия внутрисистемной информации и внешних влияний в пределах морфогенетического процесса.

Задумывание вычислительных процессов проектирования как морфогенетических дает возможность систематической интеграции материальных характеристик и ограничений. Поэтому сложное поведение материала, следующее из его внутреннего строения и структуры может составить интегральный вид генотипных наборов данных, из которых получается определенная, фенотипичная форма. Очевидно, это требует как всесторонних эмпирических исследований микроструктуры, так и проистекающего поведения используемого материала, а так же развития соответствующих вычислительных методов проектирования. В статье описан концептуальный и технологический переход от Автоматизированного проектирования к Вычислительному проектированию со специфическим уважением к архитектуре как материальной практике. Кроме того, статья представляет ряд научно-исследовательских работ, объясняющих различные задачи развития морфогенетического подхода к вычислительному проектированию.

Ключевые слова: Автоматизированное проектирование, вычислительное проектирование, параметрические процессы, морфогенетические процессы, генотипный набор данных.

1. Introduction

The complicated geometry, expressive forms and elaborate surface articulation of contemporary architecture should not belie the fact that most often the current use of computers in architecture does not yet constitute a significant innovation. Architects merely apply new digital technologies to their projects, which are conceived through long-established design processes. As has often been the case in the development of the discipline, a transitional phase occurs in which the new technologies are primarily used as an extension of conventional practice. In parallel, novel approaches develop which can tap the genuine potential of these technologies – and thus also transform the practice as a whole. We are currently experiencing such a transitional phase. Like the many other ground-breaking technological changes over the course of architectural history whose influence on the processes important to designing was considerably delayed, the computer in current architectural practice is mainly employed as an expedient and efficient aid in processes that are conventional in regards to design methodology. Interestingly, this also applies to a wide variety of approaches that are labelled “digital architecture”.

Architecture as a material practice is predominately based on an approach to design that is characterised by prioritising the elaboration of form over its subsequent materialisation. Since the Renaissance the increasing division between processes of design and making, as proclaimed by Leon Battista Alberti (Grafton, 2002), has led to the age-long development and increasing dependence on representational tools intended for explicit, scalar geometric descriptions that at the same time serve as instructions for the translation from drawing to building. . What is noteworthy is that the drawing as a form of notation is limited to a representation of geometry. Form and information constitute an inseparable entity in a descriptive drawings or representational models. Correspondingly, the designer operates only at the level of the “phenotype”. Designing is consequently a form-defining process. And to this very day, this has not changed fundamentally, not even when CAD was introduced to architectural practice some twenty years ago (becoming pervasive shortly thereafter), and continues, in the form of a large variety of software applications, to be the primary planning tool. These applications are characterized by transferring analogue work methods to the digital realm. Drawing, modelling and calculating techniques that had been used in manual applications were merely imitated by software. While the increased efficiency and precision of such digital tools – as compared to their analogue counterparts – makes it possible to rationalize the planning process and expand upon the architectural formal canon, in most cases it has neither taken a critical look at nor altered the production of buildings – it has simply “computerized” the process (Terzidis, 2006).

Nevertheless, a second approach has developed parallel to this type of computer: computational design. This is based on the concept of an alternative approach to designand planning that takes advantage of the computer’s potential, namely by gathering, processing, and applying complex interactive relationships as the basis for generative algorithmic processes. This is by no means a completely novel phenomenon; it originated in the late 1960s – at the interface of architecture and computer science for example in Nicholas Negroponte’s Architecture Machine Group at MIT or Eric Teicholz’s Laboratory for Computer Graphics at Harvard – and has developed continuously, gaining significance and prevalence in recent years. In contrast to computing, computation refers first and foremost to processing information. It is, in other words, processual and information- based – a computer is not necessarily required. And this brings up another important point: while the design process normally involves executing the design in question on the basis of an analogue or digital representation (be it a sketch, drawing, plan or model), here the focus shifts to developing processes, in the form of algorithms or generative rules, from which a specific result is then brought about through the definition and emphasis on influencing values and parameters. Correspondingly, the designer operates with generative processes, genotypic information and the phenotypic appearance. Designing thereby becomes a form-generating process.

It is important that one common misconception be cleared up: in computational design, the computer does not replace the architect. On the contrary, his or her role is strengthened. The architect is no longer a person who uses digital processes; he or she becomes the person who develops them. The resulting greater degree of integration of a wide variety of influences and requirements in the design process makes it possible for the architect to not only keep up with the increasingly complex demands made on him or her by the clients, technology, and profession as a whole, but to also find opportunities in them.

2. Virtual form and physical materialization

The relationship between virtual and physical is of critical importance to the practice of architecture. Virtuality refers to an entity defined by its characteristics, function or effect. Virtual is not, as is often claimed, the opposite of real – it is physical or material. We are currently contemplating how computational design can be understood not as virtual design – a discrete entity – followed by physical implementation, but as a means to link the two. To recapitulate: just as designs on the drawing board are forgiving, conventional CAD models are not subject to the laws of physics, nor to the constraints of physical properties or structural behaviour. The conceptual overlapping of classical design tools as a result of the depictive character of CAD applications mentioned above makes an immanent separation of form-giving and materialization unavoidable.

Building Information Modelling (BIM) is becoming increasingly widespread and behaves similarly, because the information is obtained from the geometry and not vice versa. In computational design, form is not only determined through a series of drafting or modelling steps, but also attained on the basis of generated, rule-based procedures and scripted links. In contrast to computeraided design, computational design makes the relationship explicit between form and information.

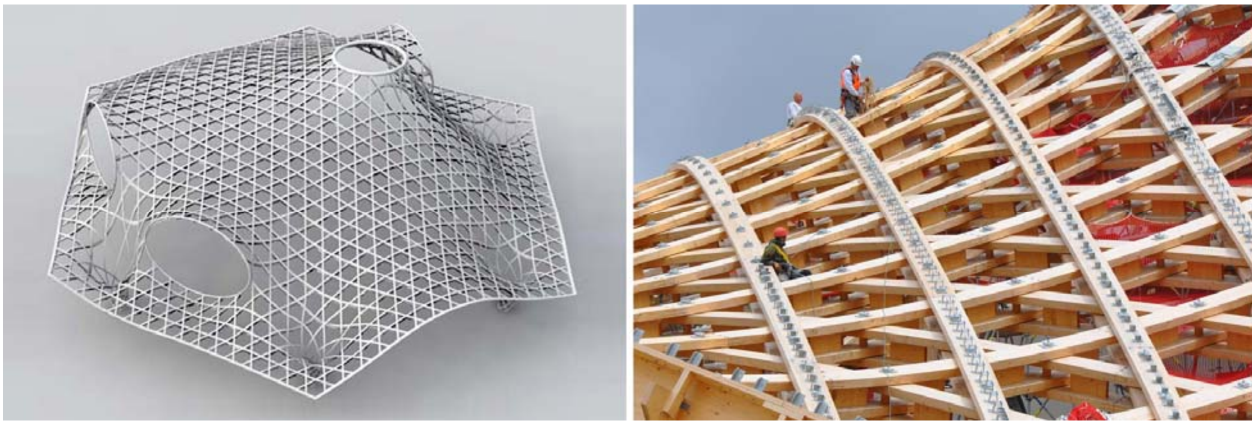
The related discovery of the correlation of algorithmic data attained by compiling and processing informs the form-generating process through the idiosyncrasies and constraints of the materialization. Computational design facilitates comprehending form, material, structure and fabrication as systemic correlations – opening up a realm in which the design can unfold. This reciprocal feedback from the computer model and physical building in the computer-based design process facilitates a new type of synthesis of the formal solution and materialization (Menges, 2008).

Today, those seeking to differentiate the view of how computers are employed are often confronted with the tendency to lump divergent projects together as “digital architecture”. Yet distinguishing among them is of great relevance to the design process. What is meant in concrete terms by the difference between the current state of computerized planning and the perspectival possibilities of computational design? Two built examples may shed more light on the issue: one is often cited as a feat of contemporary technology, the other was completed thirtyfive years ago and inspires us to this very day. The goal is not to evaluate the two, but to identify the different design methodologies – and this allows us to focus on just one aspect of the buildings, namely the design and realization of the roof structures.

2.1 Case Study 01: A hierarchical design approach to form and materialisation

The inspiration for the roof of the Centre Pompidou in Metz – by Shigeru Ban, Jean de Gastines and Ove Arup & Partners – was a straw hat. Correspondingly, the digital form-giving was based on two components: a specified freeform surface with a hexagonal edge and a flat, kagome lattice consisting of triangles and hexagons that is projected onto the free-form surface. The structural grid that was brought about with CAD software led to a complex geometric construct in which every element is uniquely curved in three dimensions. At first, the digital formgiving determined only the roof geometry (Figure 1a). It was not until after the design phase that engineers and specialists for computer-based geometry entered in; they attempted to optimize the design's a priori geometry and make it buildable.

In an automated process, the more than 100 continuous glu-lam girders (arranged in two layers) made up of 1790 segments (classified in three categories: straight, single-curved and double-curved) were fabricated by a computerized numerical control (CNC) joinery machine. Due to the relatively linear flow of data from the architect's CAD model (design phase) to the computer-aided manufacturing in the workshop, despite the impressive efforts and achievements of the engineers seeking to rationalize the process, it was necessary to machine fifty percent of the glu-lam beams in order to attain the required building component geometry. In the next phase, the individual building components making up the complex geometry of the roof were assembled incrementally atop scaffolding on site (Figure 1b).

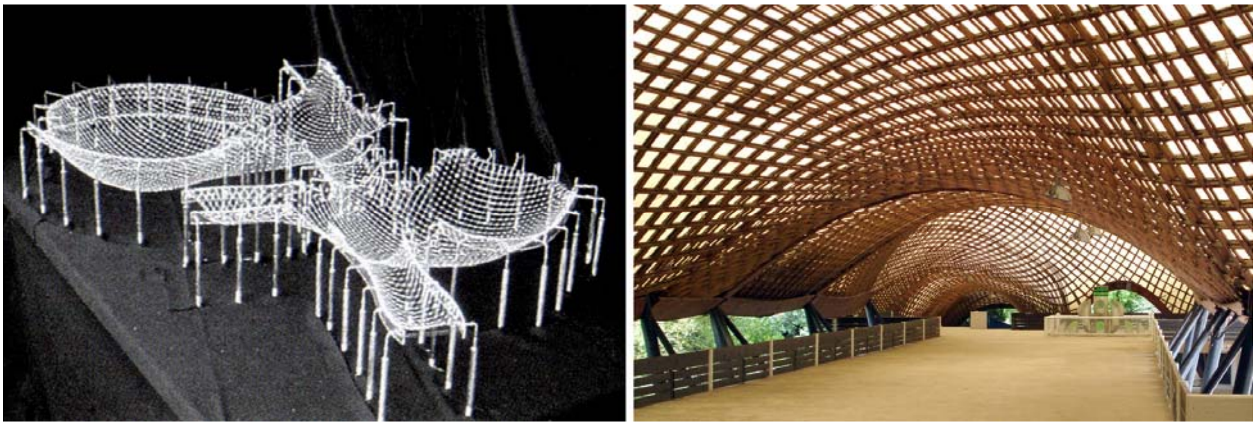


a) b)

Fig. 1(a,b). a) Centre Pompidou Metz geometry model (Shigeru Ban 2005), b) Lattice construction (DesignToProduction, 2009).

2.2 Case Study 02: An integral design approach to formation and materialisation

The second project, the "Multihalle" in Mannheim by Frei Otto, Carlfried Mutschler and Ove Arup and Partners constructed in 1975, which also consists of a double-curved lattice shell, was the result of a form-finding design process. This method is based on two findings: first, the fact that by invertinga tensile hanging form with a uniform mesh, a geometry of shells is attained whose self weight causes no moment of bending (Figure 2a); and second, that such a shell can be attained through the curvature of a lath grid that was, at first, flat (Burkhardt,1978). By changing decisive parameters such as, for example, the cambering and edge definition of the suspended net, the roof takes on a specific structured form. Erecting the shell on site utilizes the flexural behaviour of the lath, which consists of continuous wood members. The lath had merely to be lifted at a number of points and then, through the bending of the wood laths and scissor-like deformation of the mesh, took on the desired shape. By tightening the joint bolts, a shear-resistant connection was attained. At its points of support, the lath was then fastened to the substructure, thereby stabilizing the complex roof form (Figure 2b).



a) b)

Fig. 2(a,b). a) Multihalle form-finding model (Burkhardt 1978), b) Lattice shell.

It is noteworthy that at the Centre Pompidou in Metz, the glu-lam beams, each with a cross section of 140/440 cm, span up to 50 m, while at the Multihalle, with only four layers of lumber and a cross section of 50/50 cm, spans of up to 60 m are achieved. However, the comparison of a singular, quantitative aspect – such as the ratio between load-bearing capacity and mass – is not the focus of this study. The intention is to demonstrate differences in the methodology of approaches to design: one is the digital continuation of the long-standing hierarchy in which form-giving takes precedence to rationalization, and the other is a design process which is informed from the very start and anticipates the possibilities of materialization. Frei Otto's work with lightweight structures is better suited to illuminating our studies – including developing an integrative approach to form-finding and materialization in computational design – than those of the current avant-garde. And it poses no contradiction that in his form-finding processes, rather than utilizing machine computation – using a computer – Otto typically employed material computation, i.e. left the calculation to the forms which come about in the making of a scale model. This refers rather to the real potential of computer-based development from this point on.

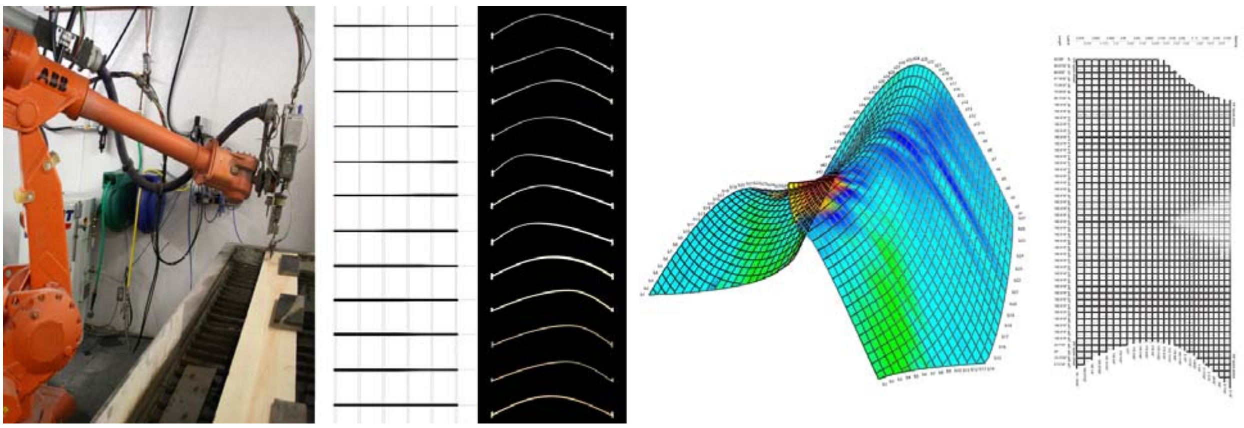
3. Integral Computational Design

Because his research focussed on lightweight construction, Frei Otto's designs typically are oriented towards structural design criteria such as the ratio of mass to load-bearing capacity. Consequently, physical form-finding models are also well suited to this approach, because there is a direct link between the form that was arrived at and its structural behaviour, in that a state of equilibrium comes about of its inherent forces as well as those operative on it as a function of the respective material properties. Today the use of computers makes it possible to significantly expand upon the design criteria. Accordingly, in addition to structural criteria, spatial organization, and building physics, other criteria not related to "forces" also influence the development of the form, which nevertheless always continues to develop in the materialization's scope of possibilities. The decisive difference is that a computer-based generation process following multiple criteria no longer has a single state of equilibrium – it has a number of them. The design process is also fundamentally open. Furthermore, through the degree of freedom in computer controlled fabrication processes it is possible to significantly extend the materialization's scope of possibilities. In contrast to the linear process chain progressing from CAD to CAM, computational design facilitates an information loop of direct feedback between the solution space of computational form generation and the logics and constraints of computer-aided fabrication. The ramifications of such an integral approach to computational design will be explained along two research projects: One focuses on the computational extension of grid-shell design, the other investigates the possibility of utilizing material characteristics to develop a autonomously climate responsive surface structure.

3.1Research Project 1: Wooden lattice structure with robotically fabricated laths of non-uniform cross section and stressed actuator skin

The first research project was developed as part of the Performative Wood Studio (Prof. Achim Menges) by Jian Huang and Minwhan Park at the Harvard Graduate School of Design.

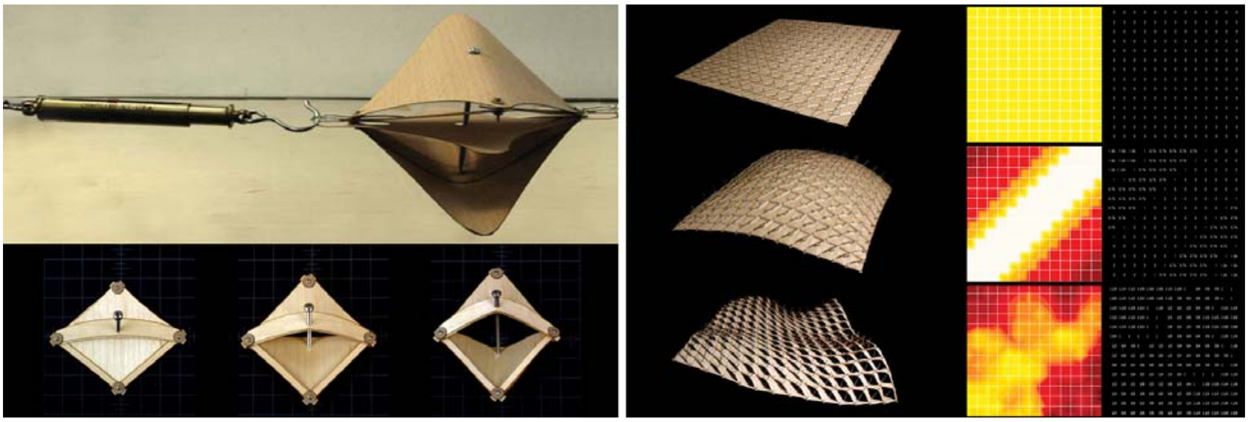
Until today, the geometry of lattice shells derived through form finding processes has been based on the bending behavior of wooden elements with a uniform cross section. The first research objective of this project was to extend the range of possible lattice geometries based on the bending behavior of wooden elements with varying cross-sectional dimensions along their length. Thus, a robotic water jet cutting technique (Figure 3a) was developed, that gradually reduces the cross section of such elements without damage to the perimeter fibres, reducing the risk of splitting during the subsequent bending process. Through the related fabrication variables, each wooden element's stiffness can now be adjusted by locally reducing its structural depth. This differentiation of the cross section allowed building up an entire catalogue of possible bending behavior of the lattice elements (Figure 3b), which was computationally established based on a large number of physical tests. This information was embedded in computational design tool for form-finding the lattice shape (Figure 3c) in relation to the differential bending behavior of its members, which also provides the fabrication data for constructing the initially planar grid (Figure 3d).



a) b) c) d)

Fig. 3(a-d). a) Robotic lath fabrication, b) catalogue of laths' bending behaviour, c) Computational form finding of lattice geometry, d) Flat lattice fabrication data.

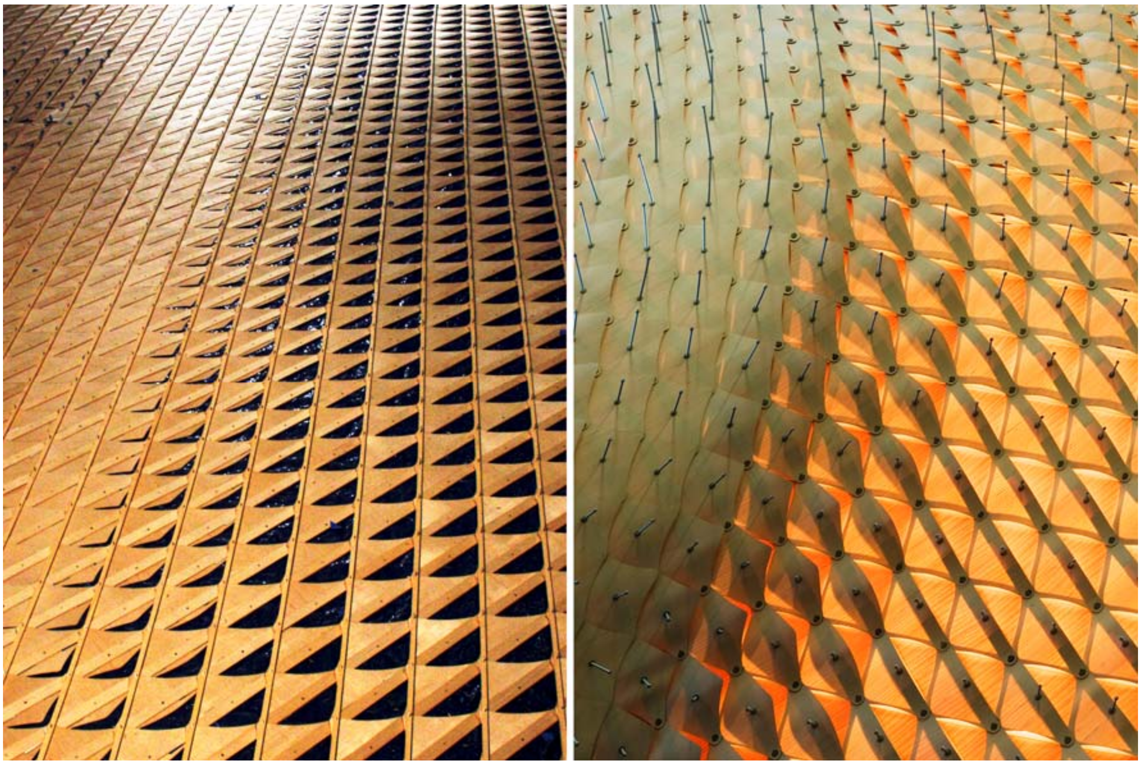
The second research objective of this project was developing an alternative way of erecting such a flat lattice without the need for additional scaffolding or hoists. A stressed wooden skin was developed, which gradually forces the lattice into its structurally stable, double curved state by the local actuation of each skin element A local actuator element was developed consisting of two skin panels with additional diagonal members and a variable spacer bolt that can adjust the diagonal distance of each respective grid field (Figure 4a). Based on detailed studies of the achievable actuation force and related element variables such as size, thickness and fibre orientation, actuator locations and required torque, a computational tool for deriving the related actuation protocol was developed and tested in a full scale prototype (Figure 4b).



a) b)

Fig. 4(a,b). a) Skin actuator elements, b) Computationally derived skin actuation data.

For the prototype construction, the robotically fabricated members with varying cross-section, together with the laser cut skin elements, are assembled as flat lattice (Figure 5a). But once the actuators are adjusted according to the digitally derived protocol the lattice raises into its computationally defined, structurally stable, double curved form. Integrating the critical material characteristics and behavior of wood in the computational design process for both the local stressed skin actuators and the non-uniform bending behavior of elements with locally reduced stiffness allows for a more specific articulation of the lattice geometry. In the resulting structure, the differentiated transparency and articulation of the skin (Figure 5b) registers the embedded forces, which maintain equilibrium in the very thin, non-uniformly bend lattice (Figure 5c).



a) b)

Fig. 5(a,b). a) Flat lattice, b) Actuator skin.

Fig. 5c. Double curved wooden lattice.

3.2 Research Project 2: Humidity Responsive Veneer Surface Structure

The second research project was developed in the Department for Form Generation and Materialisation (Prof. Achim Menges) by Steffen Reichert at HFG Offenbach. It investigates the hygroscopic characteristics of wood and aims at employing the related dimensional changes of wood resulting from changes in relative humidity to construct a climate responsive surface structure.

The fiber saturation point describes the state in which the cell walls of timber are fully saturated with bound water, whereas the cell cavities are emptied of free water. How much of the bound water evaporates and therefore how much shrinkage will occur mainly depends on the relative humidity level of the atmosphere; for example at 100% relative humidity, no bound water is lost while all bound water would be removed at zero relative humidity (Hoadley 2000). The long axis of the cells is more or less parallel to the orientation of the long chain cellulosic structure in the cell walls. Consequently, as water molecules leave and enter the cell walls due to changes in relative humidity, the resulting shrinkage or swelling is mainly perpendicular to the cell walls and does almost not influence their length (Dinwoodie 2000). Thus the main effect of changing bound water content in wood occurs in tangential shrinkage and swelling and the correlated dimensional changes. The anatomical structure of wood causes the main difference between tangential and radial shrinkage and swelling, the later having generally a considerably lower value due to the restraining effect of wood rays, whose long axes are radially oriented (Skaar 1988).

The main focus of this project is utilizing the hygroscopic characteristics of wood in the development of a surface structure capable of adapting its porosity to changing humidity levels. Rather than employing complicated electro-mechanical control devices the project aims at employing the shape change of simple veneer elements triggered by changing bound water content. The gaps opening up between the deformed veneer elements and the substructure locally regulate the structure’s degree of porosity. At any stage in the design process the complex reciprocal modulation of environmental conditions triggering changes in thermodynamic behavior and at the same time affecting the material response to changes in relative humidity need to be considered.

The development process commenced with a series of physical experiments investigating a simple composite veneer element (Figure 6). Critical variables of the key element's parameters, as for example the length-width-thickness ratio in relation to main fiber directionality, were tested for their influence on the element's shape change and response time in changing humidity conditions. Initially rotary cut beech veneer was selected on the base of its high swelling and shrinkage value in the tangential plane. However a number of comparative empirical tests proved that sycamore maple veneer was more suitable due to its considerably lower elastic modulus.

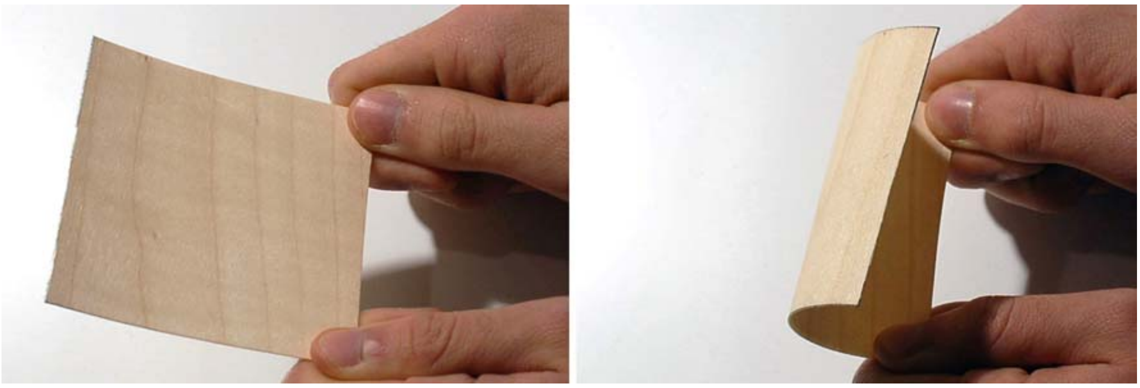
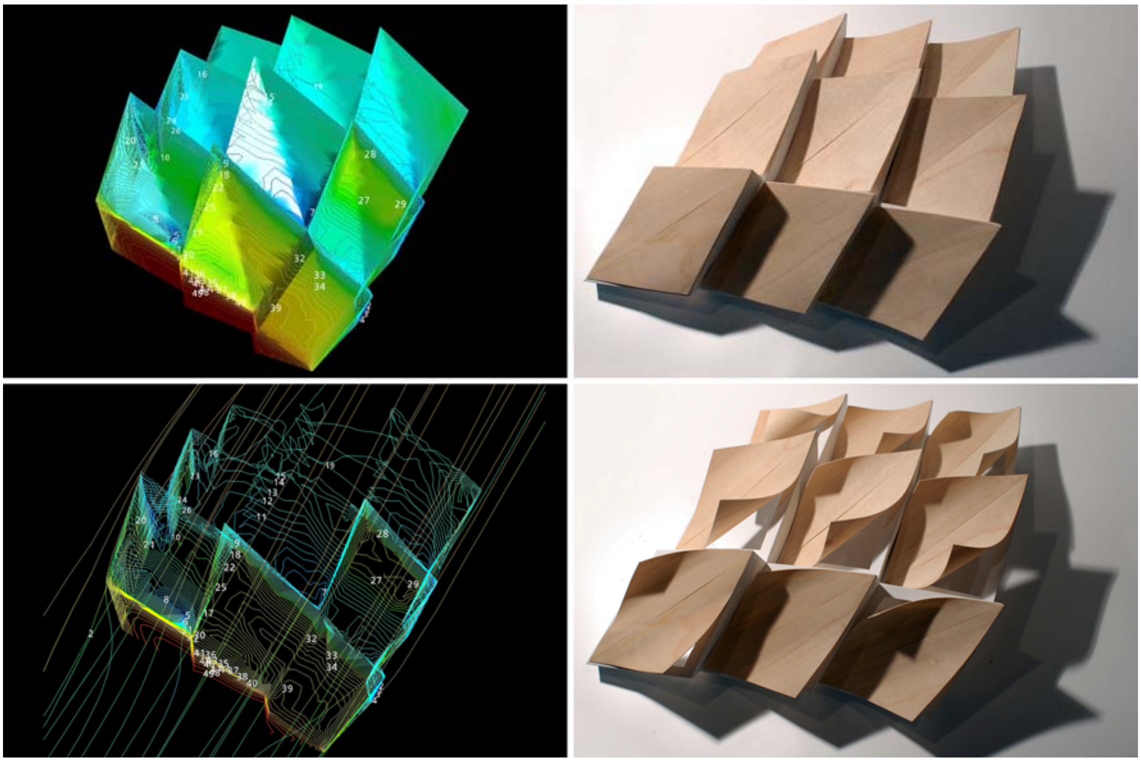


Fig. 6. Composite Veneer Plate Responding to Changes in Relative Humidity.

Following the first series of empirical tests the development of a surface element as the basic constituent of the system commenced. Through iterative computational and physical test models the element is derived as an associative geometric component based on the manufacturing and assembly logics of a larger, multi-component system as well as investigations of the thermodynamic behavior of the element's open and closed state (Figure 7a). The resulting surface component consists of a load-bearing substructure on which two triangular veneer elements are mounted along their long edge. The substructure to which the moisture sensitive elements are attached is developed as a parametrically defined folded structure with planar component-to-component attachment faces. The cut pattern of each component to be constructed from sheet material is automatically generated through the parametric computational model. Similarly the associative model defines the main fiber direction of the element as being parallel to the fixed edge, which is also reflected in the automatically derived cut pattern of each element. The veneer element's shape change perpendicular to the main fiber direction caused by changes in relative humidity results in local surface openings (Figure 7b).



a) b)

Fig. 7(a,b). a) CFD Analysis, b) Components in Closed and Opened State.

An increase of moisture content triggered by a rising level of relative humidity causes the swelling of the veneer elements. Due to the fibrous restrictions of wood anatomy explained above, the elements expand primarily in the tangential plane orthogonal to the grain. This dimensional change causes a shape change and the veneer elements curl up creating an opening for ventilation. A large number of test cycles verified that the movement induced by moisture absorption is fully reversible. Furthermore, the response time is surprisingly short. The shift from closed to fully open state takes less than 20 seconds given a substantial increase in relative humidity.

Instrumentalizing the material's hygroscopic behavior the simple veneer elements are in one sensor, actuator and porosity control element. The developed component enables the construction of a locally controlled, humidity-responsive surface structure, in which each sub-location independently senses changes of local humidity concentrations and reacts by changing the local level of system porosity. The emergent thermodynamic modulation along and across the surface is directly influenced by both the local component geometry as well as the overall system morphology (Figure 8).

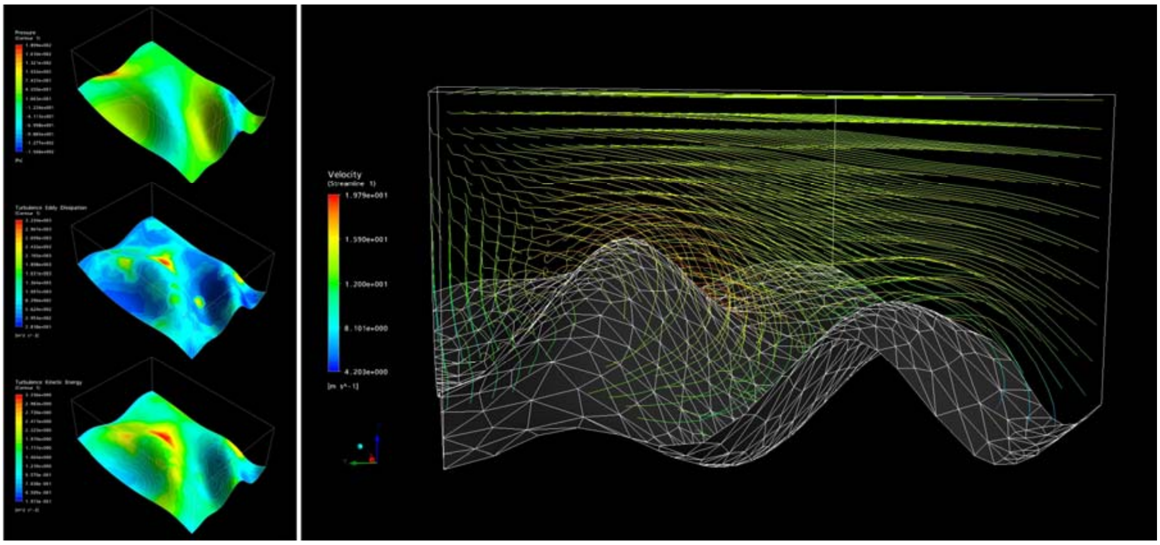


Fig. 8. Iterative CFD Analysis During The Global Surface Evolution.

In order to account for the complex reciprocity of individual component and overall system behavior and related macro- and micro-thermodynamic modulations a feedback based evolutionary computational process is used to prototypically develop a global surface articulation. For this process the surface geometry is mathematically controlled through an equation with a number of variables. Iterative changes to these variables provide a robust yet simple base for the hygromorphic evolution of the surface geometry. This process is driven by the stochastic alteration of the mathematical surface, the subsequent associative component generation and the related Computer Fluid Dynamics analysis of each system instance's behavior. The relevant data is continuously fed back and informs the next system generation. The evolving load-bearing structure's overall curvature orients the responsive veneer elements either towards or away from local airstreams and humidity concentrations. The resultant calibration of overall curvature and local component morphology in different opening states enables a highly specific modulation of airflow and related humidity levels across and along the system.

In order to verify and further inform the developed integral design approach a full scale, functional surface prototype was built from 600 geometrically different components (Figure 9a). Subsequent test cycles confirmed the performative capacity of the responsive surface structure (Figure 9b). Once exposed to changes in relative humidity the veneer composite elements respond by opening or closing components resulting in different degrees of porosity over time and across the surface. Thus the resultant material system is directly responsive to environmental influences with no need for any additional electronic or mechanical control. This demonstrates the high level of integration of form, structure and material capacity enabled by the computational design process (Figure 10).

a) b)

Fig. 9(a,b). a) Functional Prototype, b) with Responsive Veneer Skin.

a) b)

Fig. 10(a,b). a) Functional Full Scale Prototype, b) Close-Up View.

4. Conclusion

The potential of the computer employed in computational design to align multiple influence values, execute a large number of commands and process complex relationships, makes it possible to recognize and explore such differently poled patterns in the design process and to utilize them in an innovative fashion for a performative capacity resulting from the integration of form and materialization. The functional integration that is brought about differs considerably from the approach – still prevalent in the engineering sciences – to optimizing subsystems considered functionally distinct. Computational design is not based on optimizing individual aspects, but on the evolved integration of multiple performative requirements in a generative process. From this, integrative, architectural gradient systems and structures can be brought about that are not dependent on functional classification in subsystems, but rather due to the morphological differentiation within a small number of system levels, cover a complete bandwidth of performative requirements. With respect to individual criteria, such systems consequently exhibit structural redundancy, which makes them decidedly robust in an actual operative overall system. This form of overarching robustness is a further significant characteristic of integrative computational design processes. When we take into consideration that architectural design is always de facto an intervention in an unknown future, the concept of robustness as basic characteristic of systems generated in this manner for the architecture can naturally also take on a significantly expanded meaning.

Differentiation, heterogeneity and robustness thereby also become a component of ecological and economical sustainability. The complex material systems that are developed with such an approach to computational design differ fundamentally from the complicated structures of contemporary architecture. Only the transition from today’s predominant Computer Aided Design to Computational Design represents a significant change in approaching the real potential of the computer and thereby also its design-methodological consequences. The point is that the increasingly exuberant form-making while relying on relatively conventional methods of design leads to an artificial complexity of the geometry and the construction of architecture, which we can observe in many of today’s projects. Whereas the result of a design approach that is truly suited to the potential of the computer is characterized by a reciprocity of material, form and structure, leading to a morphological differentiation´and performativity – an uncomplicated complexity.

Computational design opens up remarkable possibilities for the next generation of architects. Its response to the ever more complex requirements we are faced with is to employ, from the very beginning, an integrative approach to design. Within the narrow path of design constraints, hitherto unthought of possibilities unfold. This approach to design synthesizes virtual constructs and physical structures. It simultaneously enables a genuine interdisciplinary practice and puts architects back at the helm of design, planning and building activity. Computational design not only necessitates learning new technical skills, above all it requires that we rethink tried-and-true conventions rooted at the core of architectural practice. For all of those engaging in practice, research and education, higher level integration in Computational Design presents both an opportunity and a great challenge.

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