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Generative Processes:
script based design research in contemporary teaching practice

DESIGN and COMPLEX MORPHOLOGY

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This paper examines the results of an ongoing two year long design research agenda, set up by the department for experimental architecture in Innsbruck.
Students investigated into script based and parametric design research shifting architectural design towards a new digital paradigm. During this time, innovative design processes were iteratively developed, tested, improved and applied in different architectural scales, the urban scale, the building scale and the ergonomic scale. The paper documents and exemplifies the results of this research in the light of the current state of design theory and speculates about their implications for contemporary digital design practice.

Robin Evans once stated that architects "do not build, but merely draw", which constitutes two fundamentally different processes. However, it is interesting to notice that precisely this limitation to the realm of the drawing, in the wake of abstract art which freed the drawing from its purely representational character, has led to the most radical architectural innovations.

The move towards digital design processes and the development of new digital tools and parametric techniques, which are characterized by a high level of interactivity and real-time flow control, subjected the field of architecture to further radical changes.

Additionally the renunciation of linear and binary systems of perception, which for a long time have been dominating our world view, has only recently opened up new areas of scientific research. Rather than seeing the built environment as a number of independent entities, we have now come to understand it as a continuous field of diverse elements, as a spatial organisation that is able to negotiate and interpolate between those elements, which are subjected to the changing forces and currents that guide their use.

As Stan Allen remarks, *"Field conditions move from the one toward the many, from individuals to collectives, from objects to fields." (Allen, 1999: 92)*.

Complex architectural configurations in general and urban structures in particular can be perceived to have an intrinsic networked nature, as they are organized primarily around currents and lines of exchange where people, services, ideas and goods are collected, organised and redistributed in a multitude of directions (for an account of these phenomena see: *de Landa: 2000*). These dynamics can be analysed and described using models from various other scientific disciplines.

In order to expand the repertoire of architectural and urban geometries it is necessary to systematically investigate into what contemporary science can contribute to the fields of architecture and urbanism beyond the well-known classical canon. The appropriation of complex recurring geometric patterns and their underlying mathematical concepts as well as the understanding of emergent, fractal, chaotic or self-optimising systems and their bottom-up logics of development and proliferation will be used to become a source for the experimental development of gradient architectural and urban patterns with high differentiation and different degrees of densities that are able to host a whole range of emergent hybrid spatial conditions.

Like any traditional analogue design process, algorithmic design constitutes a genuinely creative process being – although constructive and goal-oriented – an inherently speculative and non-linear process. By adopting the methodologies and taxonomies of (semi-)scientific research however and by implementing consistent yet highly adaptive processes and logics into an algorithmic and architectural design research carries with it the potential of realizing architectural innovation.

The concepts and logics in question are mostly drawn from the domains of mathematics, physics or biology and include:

Fractal systems: for example L-systems or Mandelbrot systems.
Dynamic systems: for example fluid dynamics or particle systems.
Crystallization systems: for example diffusion limited aggregation.
Self-optimizing systems: for example Voronoi patterns, foams and bubbles.
Geometric systems: for example triangulation systems or self-similar subdivisions.
Behavioural systems: for example flocking or swarming.
Cellular Automata: for example John Conway's Game of Life.
Network theories: for example Frei Otto's path optimizations or Bill Hillier's work on urban networks.

All these systems are to a certain extend characterized by the following properties:
Complexity: the system builds up complexity out of a series of single components. However, their interaction according to a set of simple rules and their initial condition give rise to a high level of complexity.

Emergence: the emergent properties of a system are generated by the recurring iteration and superimposition of interactions of its single components, which add up to the complex state of that system. Consequently, the result of such a non-linear process can – due to its complexity - not be predicted. This is also known as a "bottom-up" process, as opposed to a "top-down" process, in which the overall form is determined first.

Gradient transitions: a field is seen as one continuous organisational unit, which organises and modulates a series of entities, which are subjected to the same set of internal and external rules. As the parameters that drive these sets of rules vary gradually across the field, no binary conditions occur, rather gradient transitions from one state to another.

Coherence: due to their strictly rule-based generative process, resulting field conditions show a high level of coherence, not primarily (or only) in aesthetical terms, but rather in the sense that consistent conceptual and abstract logics necessarily become embedded into the system. A formal or visual coherence needs then to be understood as the result of such a process.

Modulated field conditions: a system is able to create a modulated field of different yet gradually changing densities and/or other properties that are held in a dynamic equilibrium. Emerging and receding patterns (of geometry) resulting from this system are always understood as modulations of an in itself continuous system of changing dependencies, where each modulation becomes an environmental condition (i.e. an agent of change) to their adjacent entities.

In the course of this research process students are asked to take one of these systems from their initial context, investigate their inherent generative potential and apply them in the domains of urbanism and architecture on various scales from an ergonomic object to an urban field. Results are correlated with specific architectural and urban problems in order to propose valid yet innovative architectural solutions.

The systematic exploration and subsequent application of the system's emergent and non-linear behaviour gives rise to the emergence of new and unpredictable design patterns within the design process. At the same time this procedure evades traditional deterministic design approaches, which have mostly been relying on intuition and previous experience and which entirely operate within the presently still predominating design paradigm of modernism [i]. These modes of operation are helpful when trying to replicate already preconceived ideas, but incapable of starting to shift the design processes towards a new paradigm, within which new organisational, typological or formal solutions to existing design problems can be developed [ii]. These solutions are then to be compared to the results of conventional design strategies.

In parametric design and scripted space it appears to be most essential to make use of bottom-up processes and to organize one's work in a continuous feedback loop.
The most compelling aspect of a consistent bottom-up process lies in the exploration of its architectural qualities and exploring its full formal, spatial and organizational potential. Additionally, engineering aspects, such as structural behavior, material dimensions and geometric optimization, can be included into the algorithm and continuously and iteratively readjusted.

Working in a feedback loop and continuously reorganizing and expanding the parametric model, by adding additional information or behavior to an initially simple system, becomes an important issue of any design process, once a basic logic has been defined. Slowly building up a system of high complexity upon a rather simple logic will lead to increasingly elaborated, unpredictable yet controlled results, thus shifting the research focus beyond the point of mere digital representation. Or, as Ali Rahim once stated, *"a great project perceives something that goes beyond its underlying techniques!"*

Hence consistently complying with the clarification of a basic logic, learning to perfectly control it and subsequently enriching it with various content describe significant steps of successfully applying the examined methods.

1) *Do simple things first.*
2) *Learn to do them flawlessly.*
3) *Add new layers of activity over the results of the simple tasks.*
4) *Don't change the simple things.*
5) *Make the new layer work as flawlessly as the simple.*
6) *Repeat, ad infinitum.* *(Kelly, 1995: 41)*

In this sense scripting in architectural or urban design strategies is not limited to the technique of actually writing code, but is rather understood as systematic, rule based mode of operation, in which a process is analyzed and broken down into a series of smaller subsequent steps, that are – with varying parametric values - iteratively and thoroughly applied to all the entities within the field to be structured.

It is considered an important didactic aspect, that each student, according to their specific abilities and ambitions, can set out their own procedural method, working within the paradigm of scripted or parametric systems. Whereas ambitious or advanced students might prefer to write their own code to achieve maximum control over the processes they set up, others rather make us of parametric modeling tools, which are readily included in the software they use, like particle system simulations, fluent dynamics analyses, hair dynamics or the application of force fields or geometric deformation tools that can more easily be applied to any geometric setup. Simple iterative geometric processes can even be accomplished by using a combination of conventional basic CAD techniques like copy/paste/rotate/scale on a generic geometry.
Even analogue explorations can result in a scripted process, such as what we for example would call "making use of a system's material intelligence". Different materials are used to devise different material organizations or physical models, which are analyzed in order to exploit their intrinsic physical and material properties of force distribution or spatial organizations.
To ensure necessary knowledge transfer in this specialized field of research, students are organized in a "vertical studio", meaning that inexperienced and advanced students work together in self organizing teams, complementing each other's individual skills.

All processes in question are evaluated according to their individual capacity to give rise to emergent solutions for specific problems that occurs in their initial scientific domain, but which also bear relevance to an architectural or urbanistic context. As these generic processes in themselves have arguably no capacities to solve problems outside their own domain, they need to be appropriated, enhanced and transferred into the field of architecture.
To this end the intrinsic properties of a generative process are analysed, abstracted and catalogued at first in order to be able to speculate about their potential to solve architectural and urbanistic problems. In a next step students try to understand and describe the process in a mathematical way, allowing them to simulate and reproduce its results in a scripted or parametric process they set up.

When transferring the process to architecture, students develop an architectural model, indicating which contextual internal and external requirements will then determine the values of the parameters that drive the emergence of these configurations.
Like in every field complex field-liken condition, the relations between the different parametric values need to be carefully balanced and varied to achieve a series of possible resulting conditions, which then can be evaluated and optimized in terms of their architectural qualities.
Consequently the main objective is to identify processes, that can be efficiently utilised to purposefully structure, modulate and differentiate architectural and urban fields of varying scale and potentially lead to unpredictable and interesting design results. This is by nature a heuristic and teleological process, in which the qualities of the architectural results depend on the conclusiveness of the initial setup. It is also a genuinely architectural process as its aim is to define and systematically explore a specific design space in order to find an optimised architectural solutions to a certain design problem.
As architecture always encompasses a concurrent series of complex design problems, which require an architectural solution, most scripted systems cannot but produce one aspect of its underlying systematics and logics, which then guide the generation of project-specific geometries and shapes. This architectural layer, which is added onto and connected with the system and which will vary according to the designer's capacities, should be understood as an integral part of the overall design process.

Architectural aspects should not only be implied to the overall system, but also to its sub-systems and root components, as the implementation of tectonic qualities produces architecturally meaningful results. Exposing individual (basic) components to a range of intrinsic and extrinsic forces aims towards making them architecturally valuable, turning them into smarter elements and rising their morphogenetic potential.

Investigating the morphogenetic potential in the end seems one of the most intriguing aspects of algorithms design. The distinct difference between form-generating and form-finding should be clearly understood, as the algorithmic design aims towards the exploitation of its generative capacity rather than merely developing a method of discovering inspiring shapes. A systematic variation of intrinsic and extrinsic forces results in an immense range of possible outcome whereas the range of parametric values determines the capacity of generating unexpected results.

"Only if virtual evolution can be used to explore a space rich enough so that all the possibilities cannot be considered in advance by the designer, only if what results shocks or at least surprises, can genetic algorithms be considered useful visualization tools." (de Landa: 2001: 521)

Thus one of the main goals of the ongoing research is to stimulate the morphogenetic character by favouring the implication of intensive quantities (indivisible values like temperature, pressure and even architectural aspects) over extensive quantities (geometrical values like length, area, and volume). Architectural implications can thus not only be seen in external geometric conditions (relation and interdependency of geometric bodies, e.g. components in relation to their contextual parameters) but also focus on their internal values (exploration of values that are bequeathed from a structural root element to the sub-elements that are proliferated in a field of elements). Essential aspects to be explored are adaptive qualities and high connectivity. The scale of variables is subsequently released from its extensive values in order to achieve unpredicted results. However, the applied tools cannot substitute creative potential but rather produce series of possible outcomes and support direct interaction between designer and design project.

The constitution of diverse architectural layers within the system is either attained due to integration by systematic differentiation of one pivotal system or due to interarticulation of various systems, sub-systems and components.
The first idea makes one system work on multiple functional layers whereas the second implies that various systems complement each other in order to fulfil architectural, structural and functional issues. Both concepts can either result in self-sufficient and solitary forms which have the advantage of actually producing spatially contained volumes or in open and contextually driven structures that are more easily inter-connected with neighbouring entities.

Based on these basic concepts, different modes of operation can be devised, depending on the actual architectural scale, the research is focusing on. These short studio briefs and guidelines are designed to help students to pursue their research goals more systematically.

Urban Scale

A sufficiently large site is selected to allow for the parametric generation of an urban field with gradient densities and to provide enough room to machine urban complexity in general and transformational series in particular.
In a first step students are encouraged to presume that urban geometries - as opposed to smaller-scale architectural geometries like buildings – privilege two out of the three dimensions of space, as the buildings' elevations are always minute, when compared to the entire urban field's dimensions. Therefore, by analysing, understanding and extrapolating those properties and logics of an emergent and self-organising system that organize, structure or generate field conditions of different density each team of students establishes an urban master plan that defines the three primary conditions of any urban field:

Urban massing (The distribution of volume across the site according to the emergent density patterns).
Circulation patterns (The development of a hierarchical yet networked circulation system).
Programmatic use (The distribution of the different uses, functions and programmes that are found in a city).

Based on the organisational properties and the rules of recursive generation of the patterns in use, the task is to generate an urban field condition with a high degree of emergent, unpredictable complexity through an intricate and intrinsic system of order. The main challenge is to machine complexity, which in its final state can still be understood and recognised based on its initial laws of generation. The values for the parameters that guide the emergence of these configurations are derived from analyses of internal (programme, circulation, required distances between potential buildings, …) and external (site conditions, environmental conditions, …) requirements.
The possible volumes of a differentiated urban field can then be read as *swarm formations* of many buildings. According to the changing densities within the generated urban field these buildings form continuously varying formations, whereby:

Every plot of land has inscribed the possibility to hold a building (but not necessarily holds one).
No two buildings are exactly the same.
There are lawful continuities that cohere this multiplicity of buildings (geno-type/phenol-type).

The preliminary results of this process are then worked through by the students, developing an additional architectural layer, which is applied to the entire system alike and operates on top of all the modes of generation that constitute the generative system itself.
In this way entirely different projects might result from similar generative pattern and - when tested - exert varying degrees of urban and architectural qualities and elegance.

Building scale

When changing to building scale, issues are shifted towards more complex three dimensional organizational systems that can be utilized on a relatively smaller scale much more easily and efficiently. As already mentioned the key to successful design research is to build upon elementary logics that are continuously accumulated to subsequently generate new building typologies by implying simple sets of rules. Possible methods can again start with different simple two-dimensional patterns that later on either generate three-dimensional arrangements which themselves are capable of functioning as structural, infrastructural, enveloping or perforation systems or start to establish organizational logics that order the proliferation of elements.
Patterns can be constructed upon geometric logics by scripting sequences as well as by methods of 'analogue computing'. They should in any way contain adaptive potential and high connectivity (soft patterns). Iteration (as in opposition to repetition), variation and continuous differentiation of basic elements are crucial aspects as the driving forces are applied in order to articulate complex architectural systems. Resulting models are expected to be precisely controllable parametric models.

Component / Facade scale

Transferring the design process to the scale of building elements the design process brings up yet another set of potential operations. A further concept that has been explored during the last semesters in the design studio started with manipulating simple geometric shapes by exposing them to scripted mutations in order to achieve relatively smart components. These Manipulations stay on a sub-layer of the base object whereas topological properties stay unaltered in order to attain homogeneous cumulative systems with gradient transitions when modules are subsequently distributed upon building set-ups.

Two strategies can be applied in order to inhabit a field of varying parameters. Following one principle, scripts are used to expose the contextually or functionally derived base objects to a series of iterative, self-similar transformations and thus adapt to specific conditions within previously established arrangements as in an evolutionary process. Following another principle cumulative arrangements are generated by adding distribution logics and therefore differentiating equal base objects according to local contextual transformations.

The student projects presented in this paper are selected from design studio work done at the department for experimental architecture at the Technical University Innsbruck, Austria. Professor: Patrik Schumacher. Teaching assistants: Michael Budig, Markus Malin, Robert Neumayr. http://www.exparch.at

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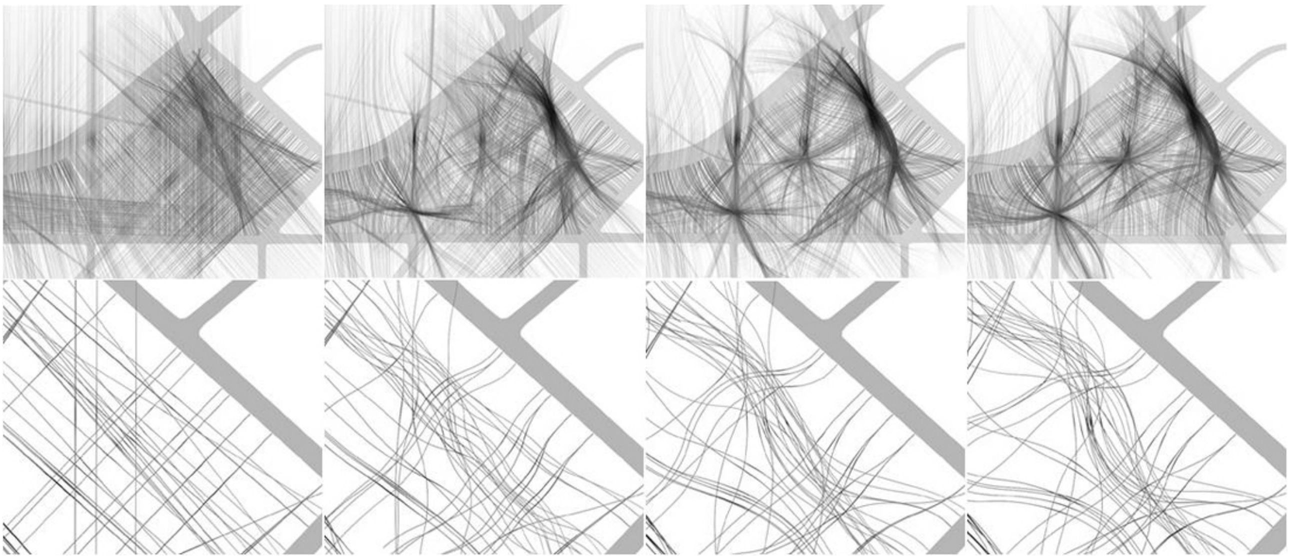
i Research indicates, that arguably all successful intuitive decisions rely on previous experiences which are processed on a subconscious level. Therefore the more experience one has, the better her intuition (Gladwell: 2005).

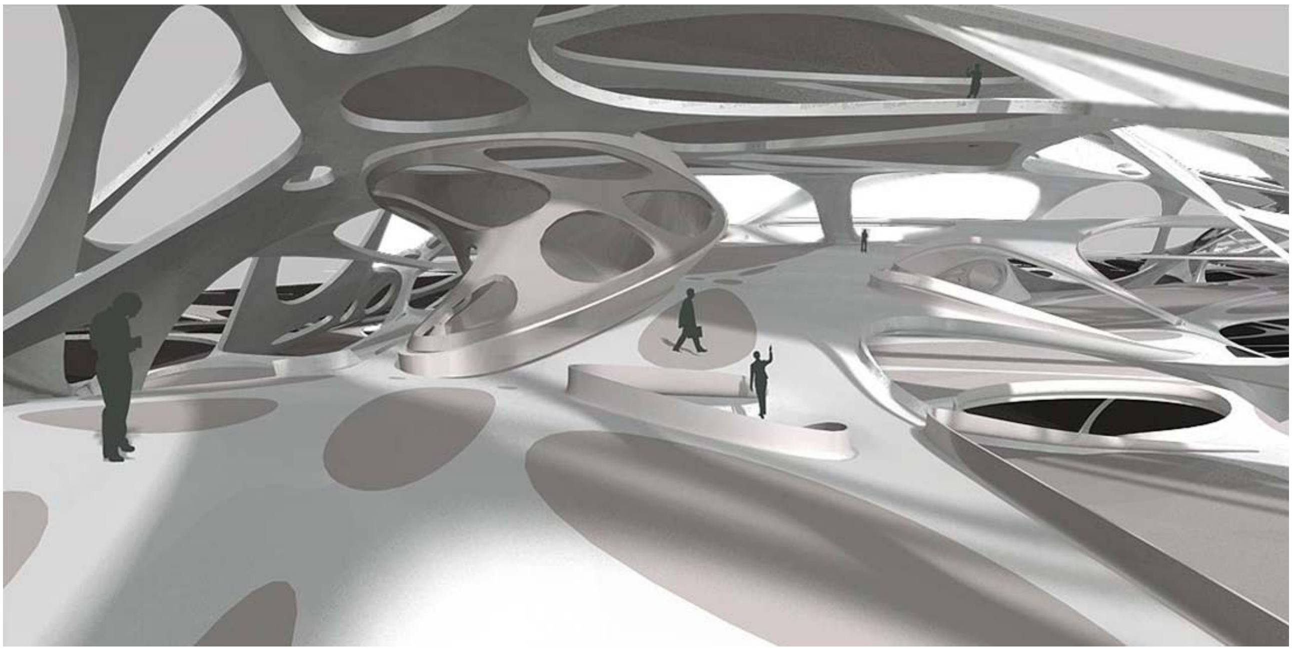
ii The production of knowledge mainly operates within its respective research paradigm developing its own set of tools after once having set its research agenda (Kuhn: 1967). This is also true for architecture, where design methodologies and modes of representation to a large extent foreclose possible design results.

Images:

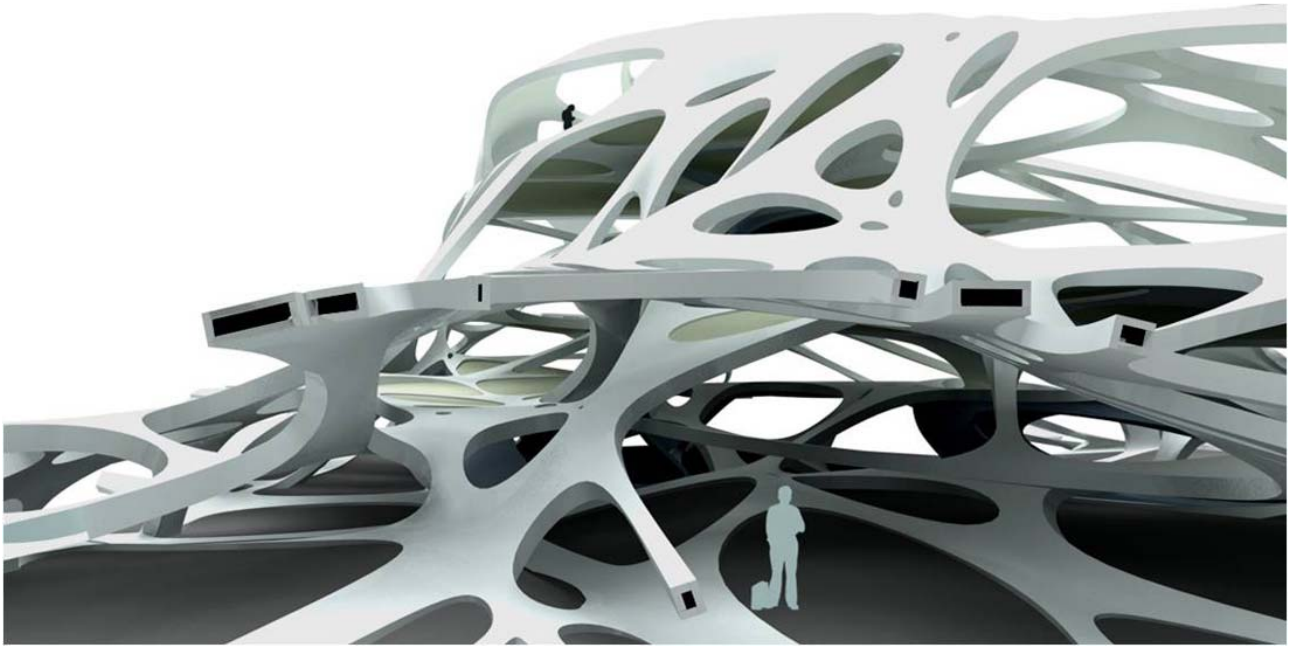


*Moritz Keitel and Christian Precht: along**a**longline*
2dimensional organisational pattern that is adjusted according to contextual parameters

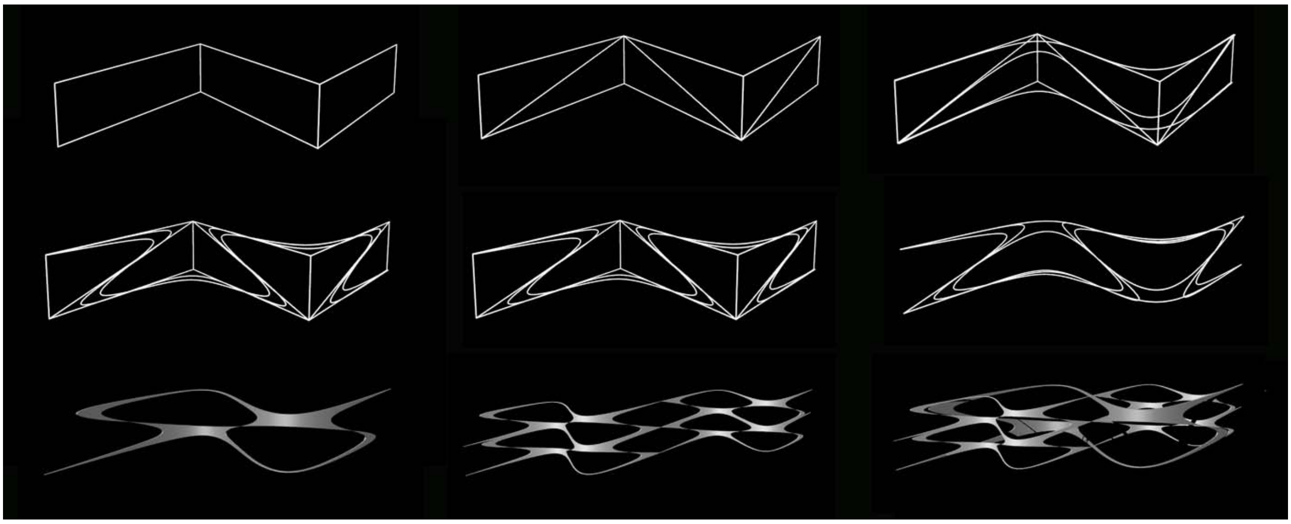
*Moritz Keitel and Christian Precht: along**a**longline*
Transformation of the 2dimensional pattern into a 3dimensional structure



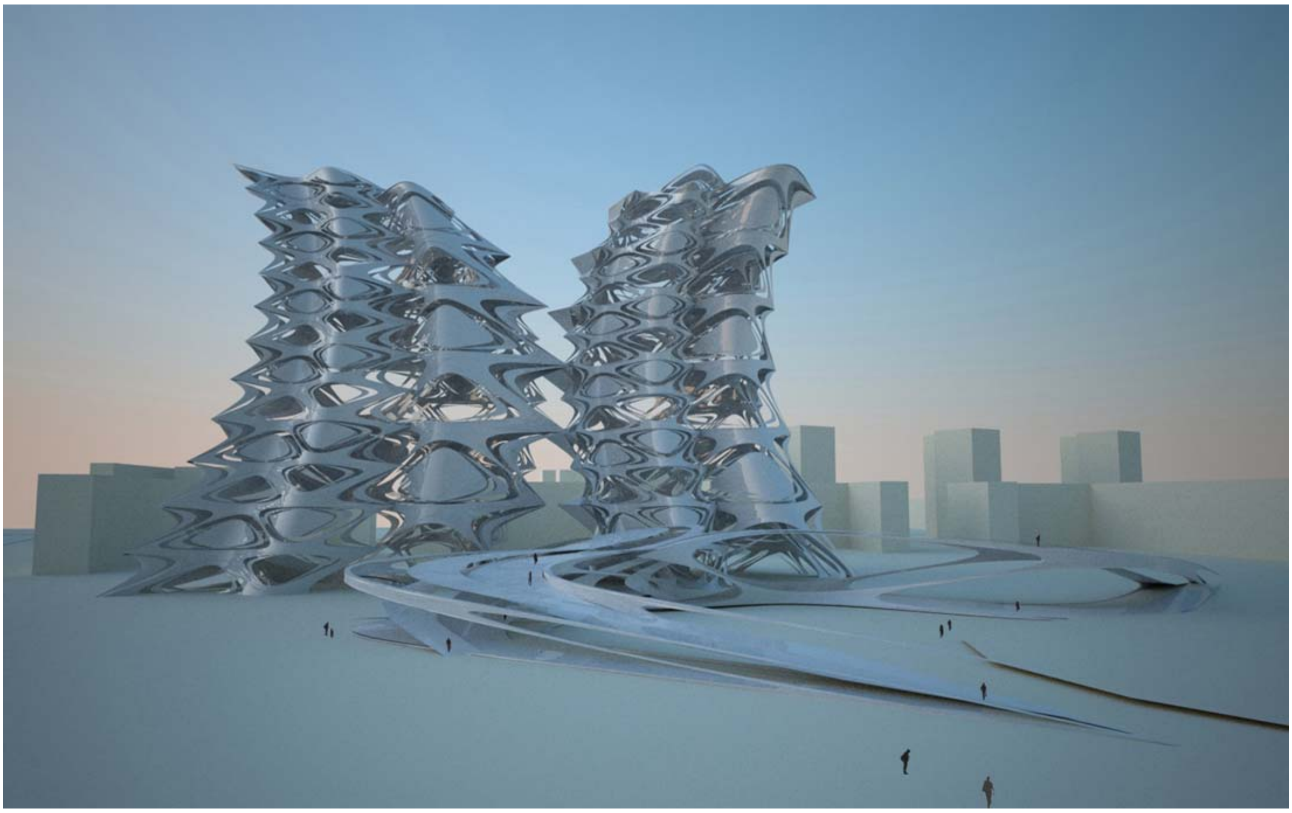
*Moritz Keitel and Christian Precht: along**a**longline*
Interior view



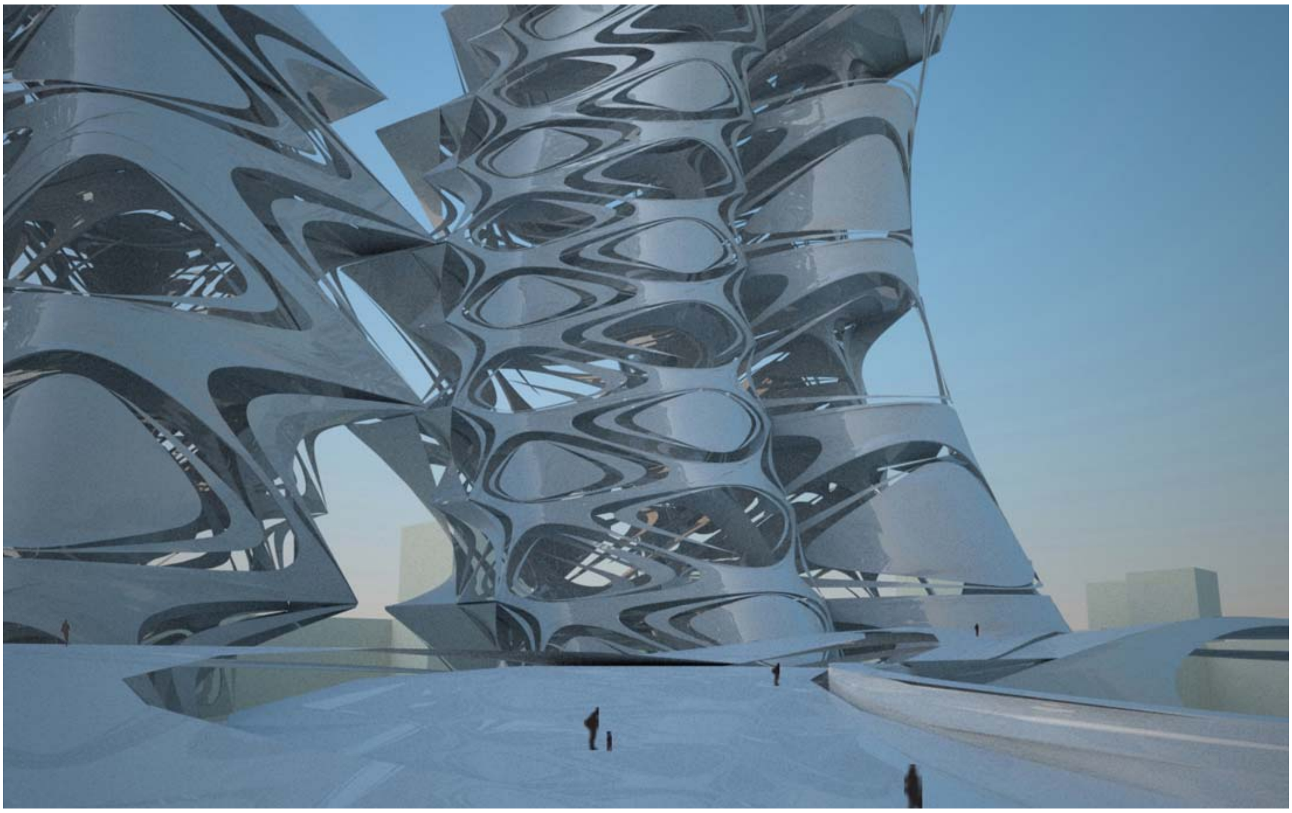
*Moritz Keitel and Christian Precht: along**a**longline*
Sectional perspective



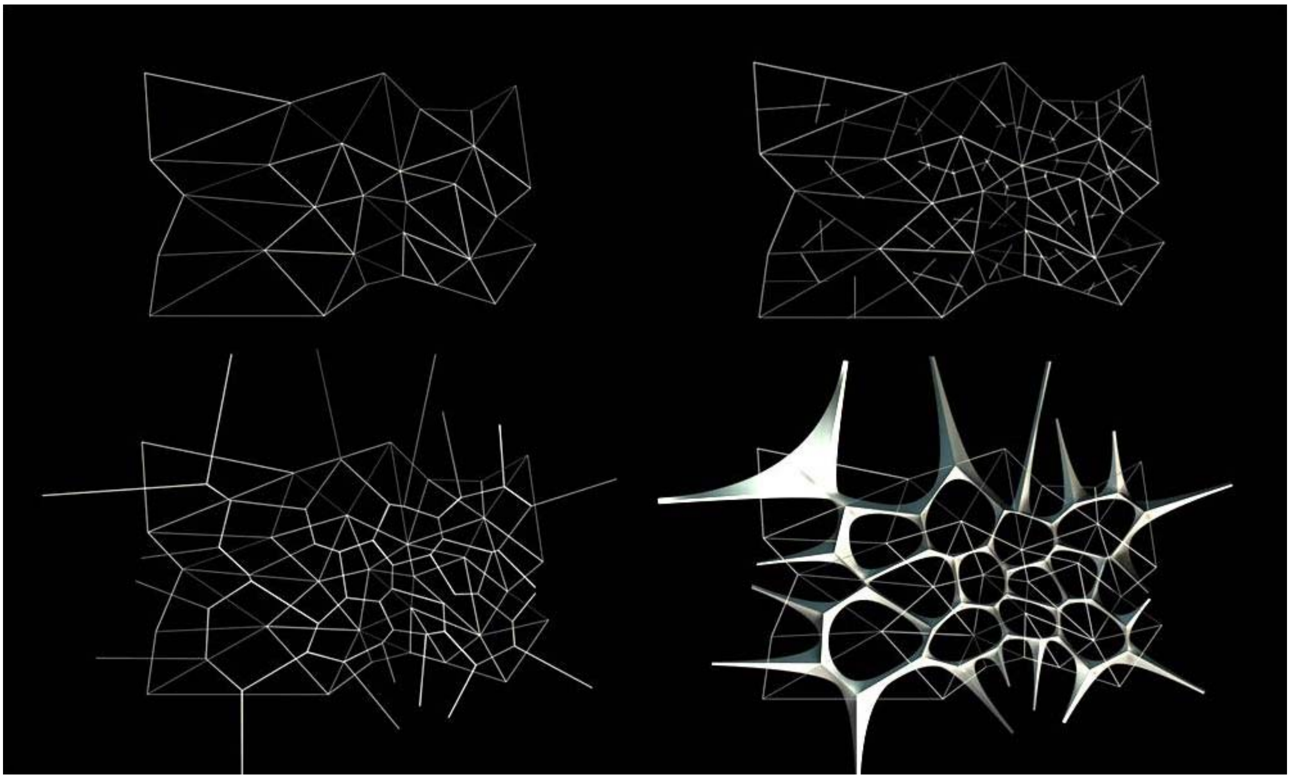
Patricia Bachmayer: line in line
Transformation of a basic geometric principle into a more complex 3dimensional structure



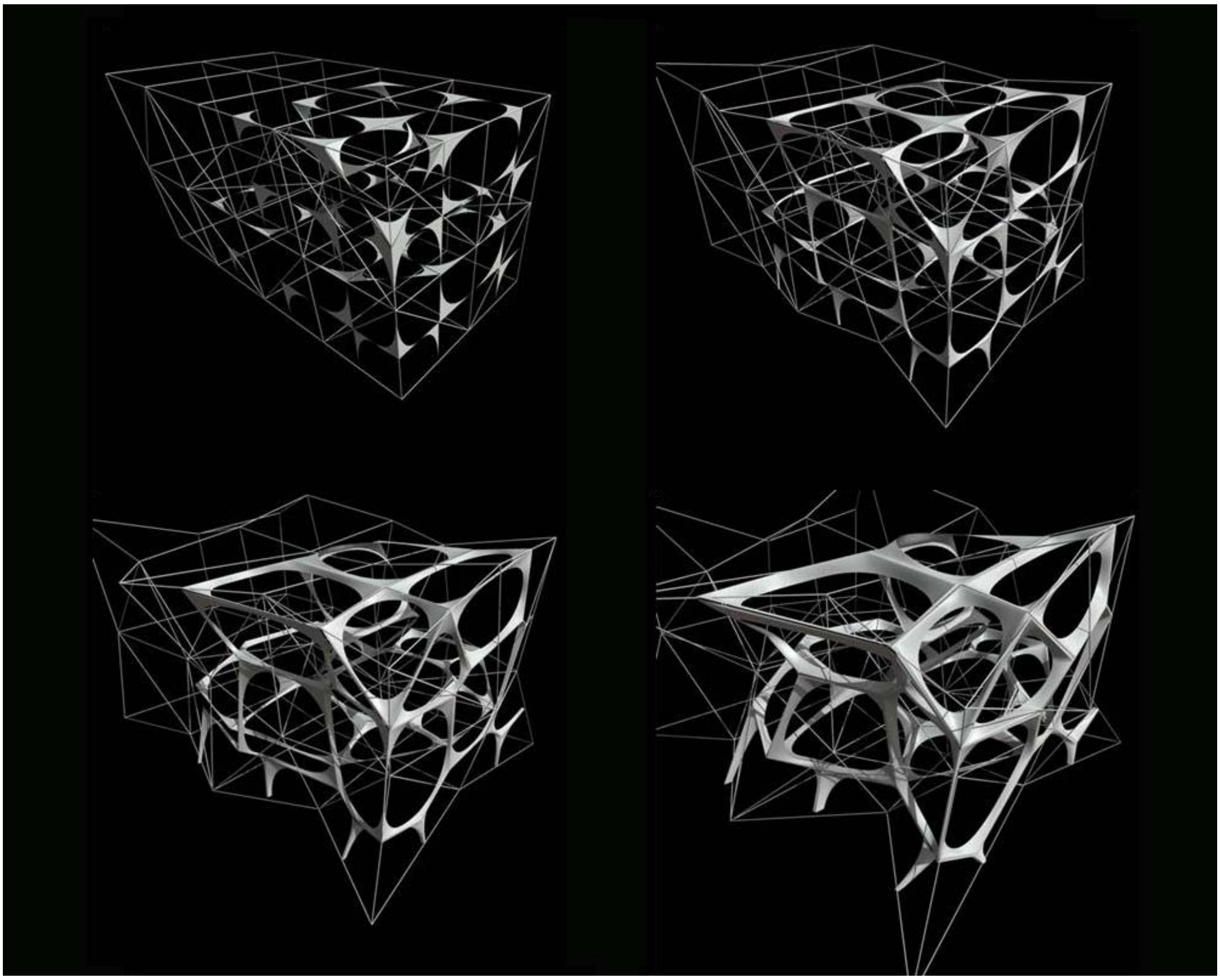
Patricia Bachmayer: line in line
Exterior View



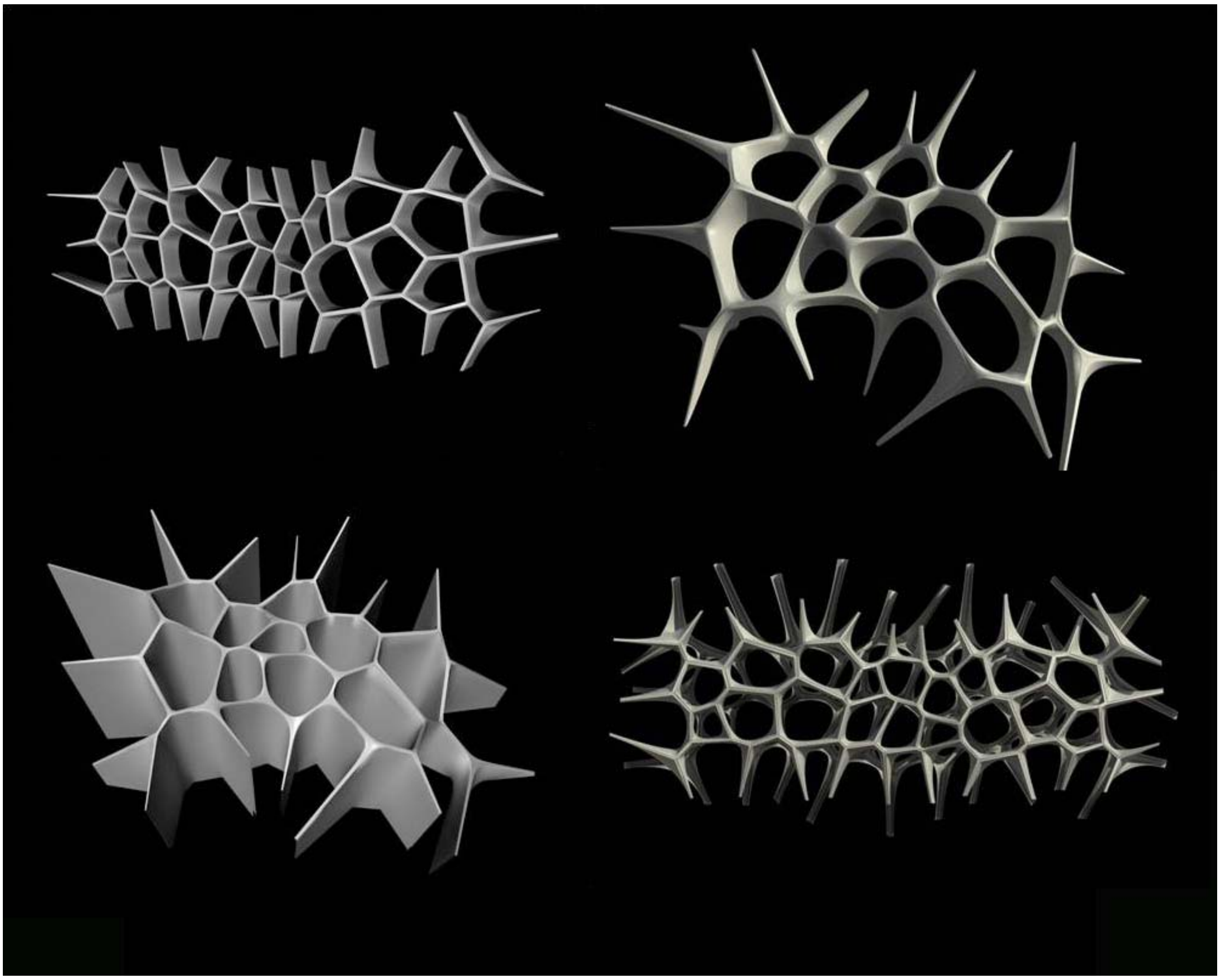
Patricia Bachmayer: line in line
View of the facade structure



Christian Flatscher and Christian Precht: voronoia
2dimensional geometric pattern

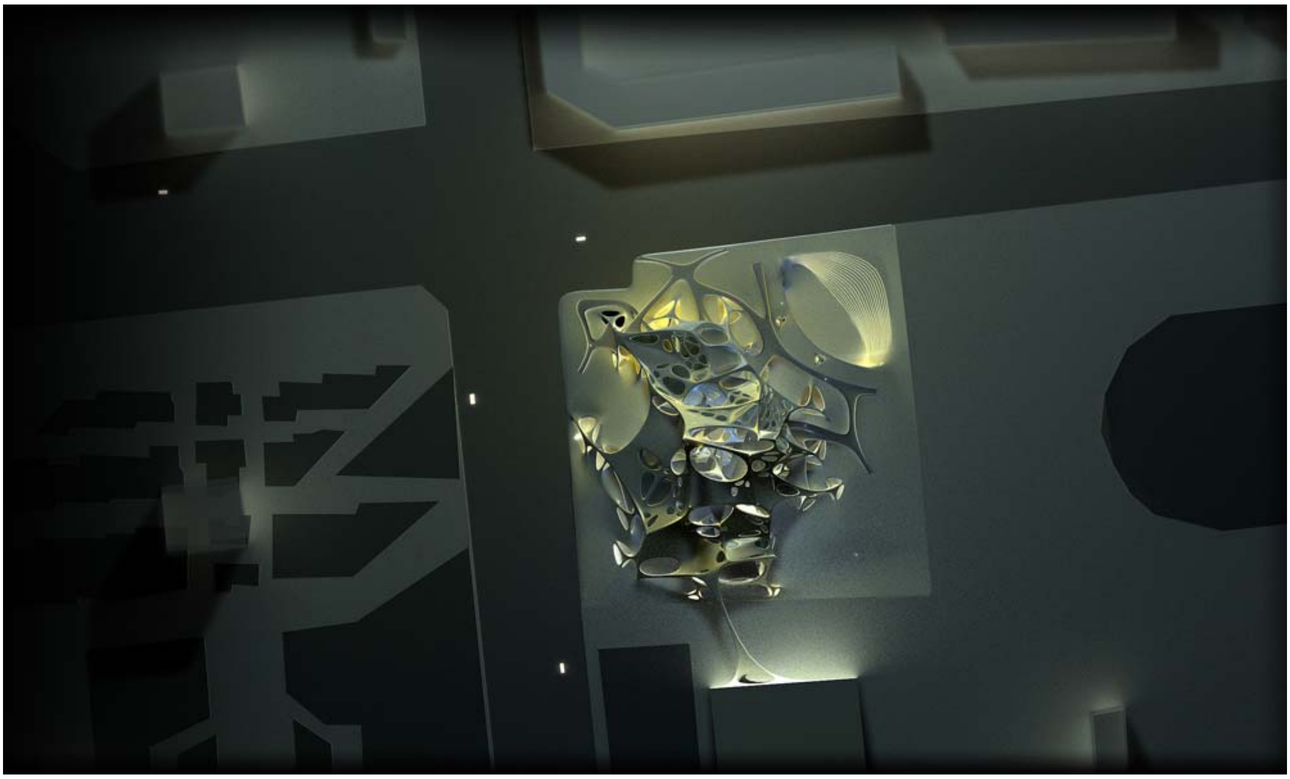


Christian Flatscher and Christian Precht: voronoia
Translation of 2dimensional pattern into a 3dimensional configuration



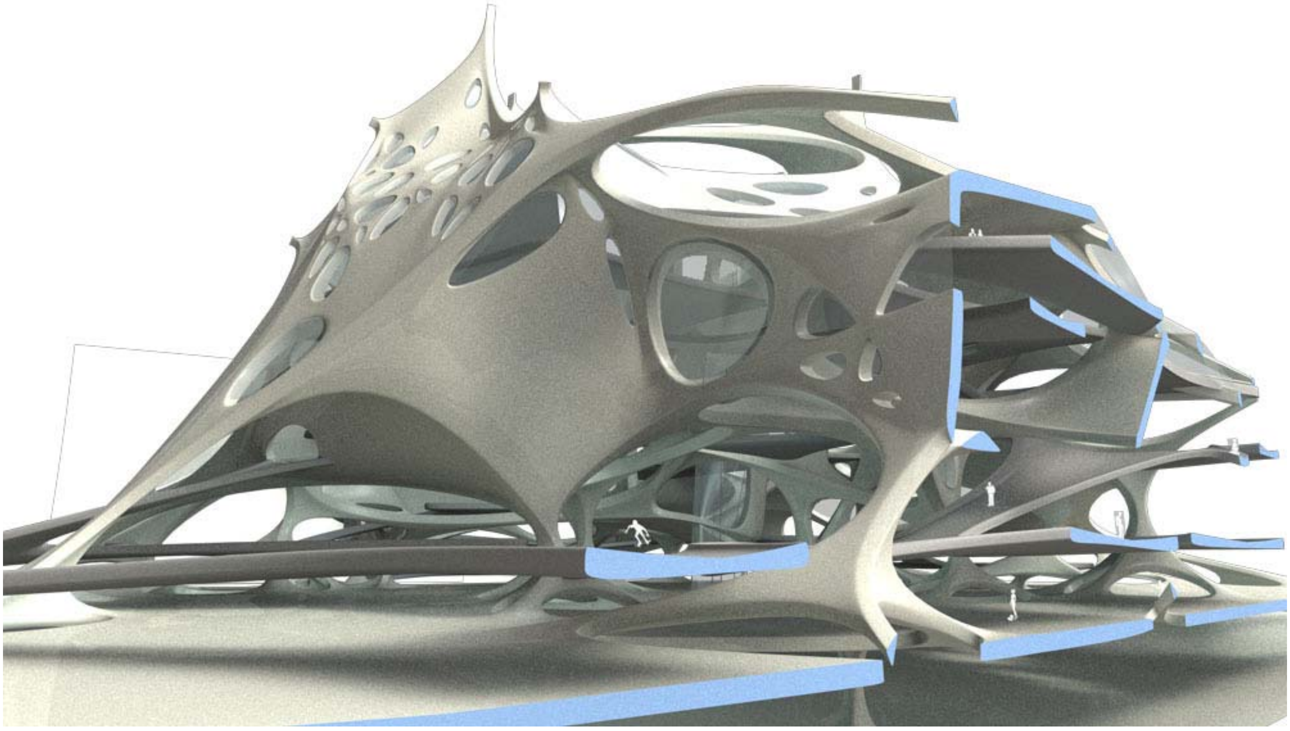
Christian Flatscher and Christian Precht: voronoia
Tessellation studies

Christian Flatscher and Christian Precht: voronoia
Distribution system

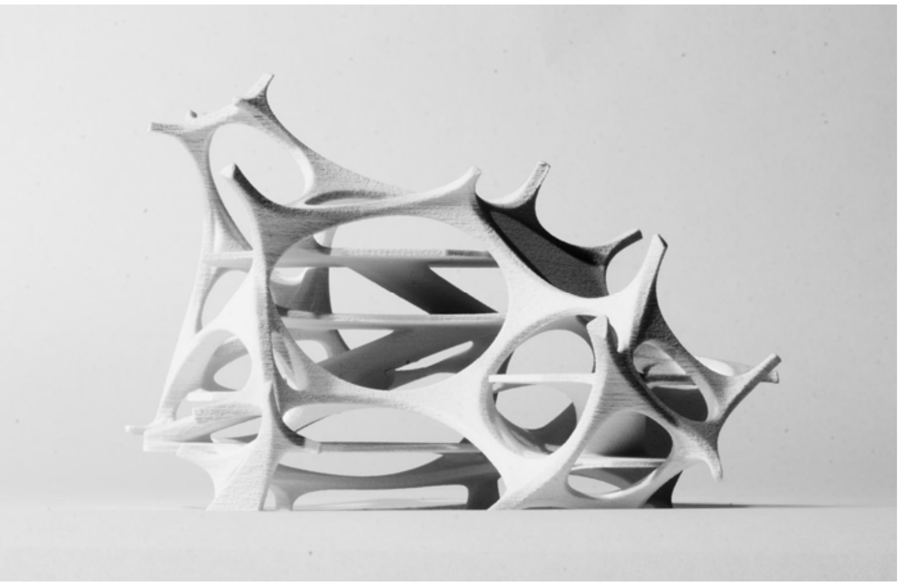


Christian Flatscher and Christian Precht: voronoia
Top view

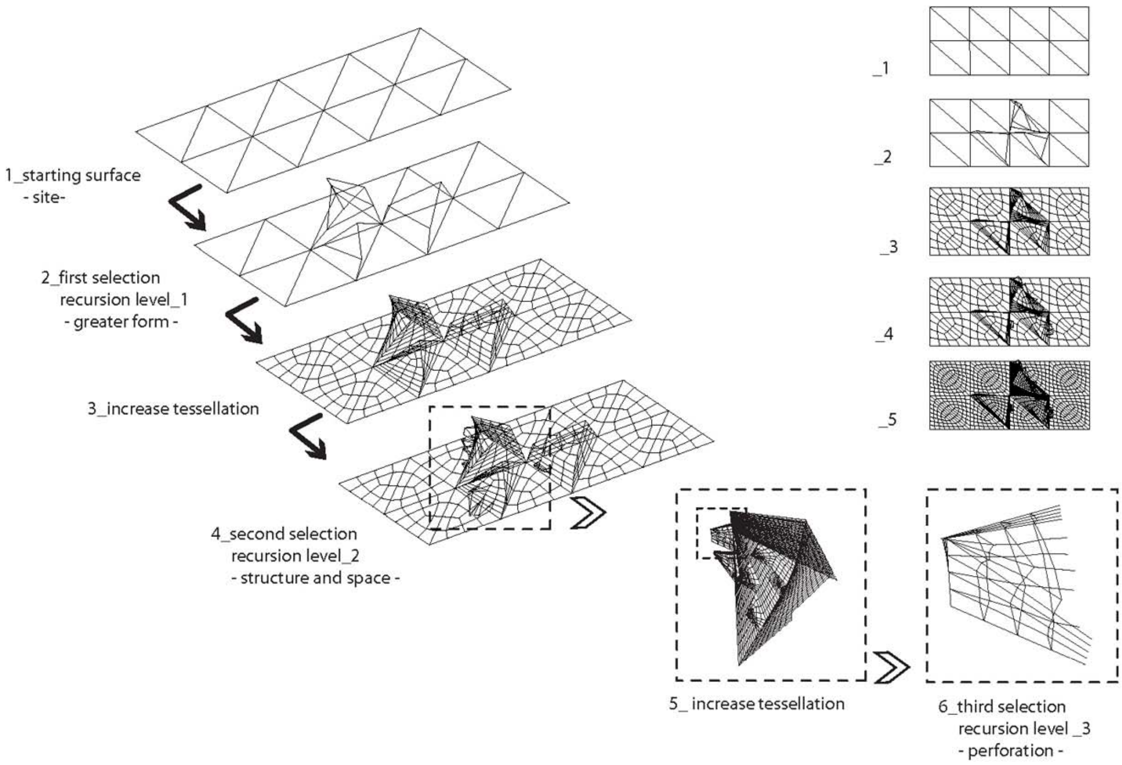
Christian Flatscher and Christian Precht: voronoia
Exterior view



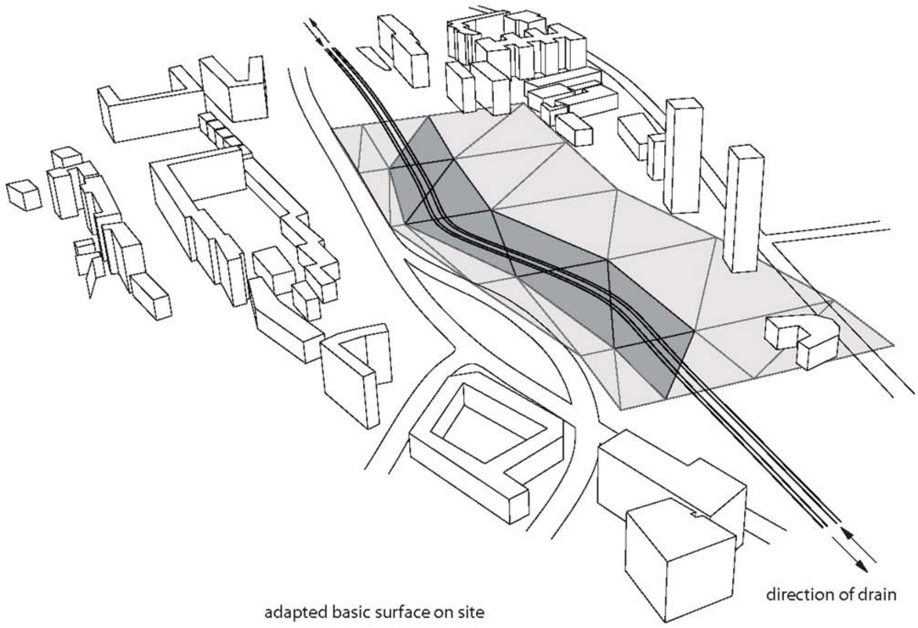
Christian Flatscher and Christian Precht: voronoia
Sectional perspective



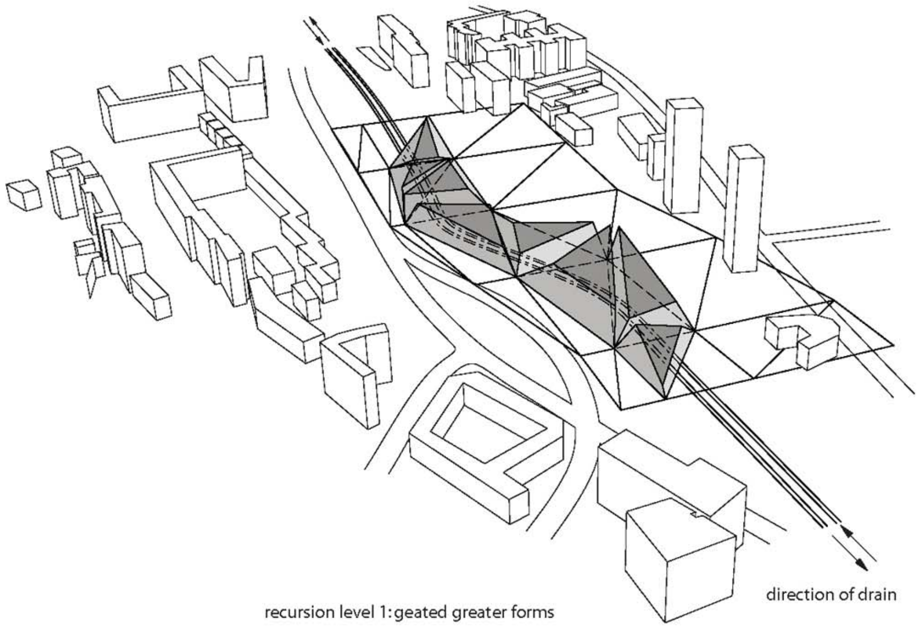
Christian Flatscher and Christian Precht: voronoia
rapid prototyping model



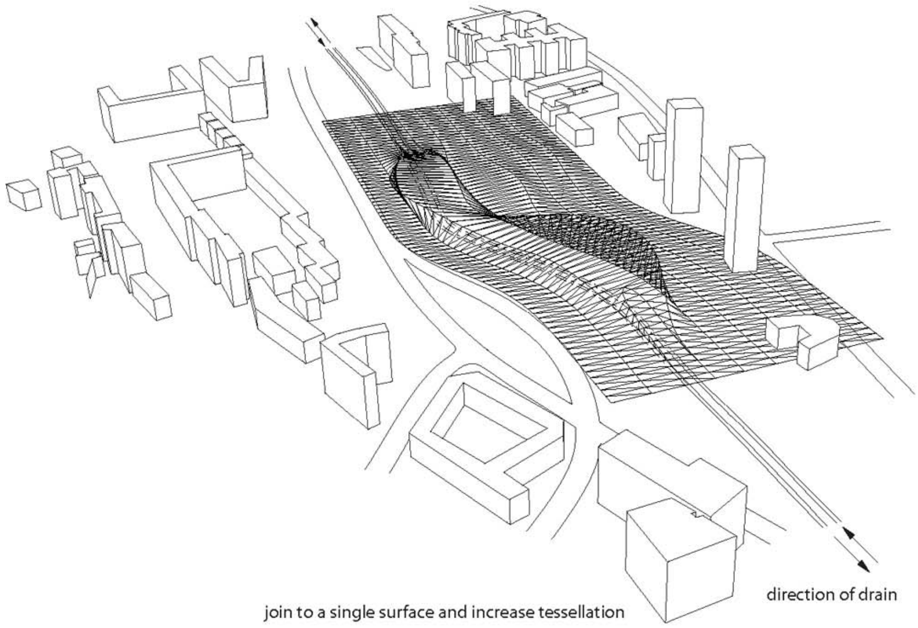
Paul Mandler and David Siebenfoercher: genome144
Recursive iterations – differentiation of a single surface into a complex, multi-layered entity



Paul Mandler and David Siebenfoercher: genome144
Recursive iteration step 01, urban scale



Paul Mandler and David Siebenfoercher: genome144
Recursive iteration step 02, building scale



Paul Mandler and David Siebenfoercher: genome144
Recursive iteration step 03, facade scale

Paul Mandler and David Siebenfoercher: genome144
Exterior view, self similar elements attain various functional properties