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Digital Master Builders – Evolutionary Formfinding in the Information Age

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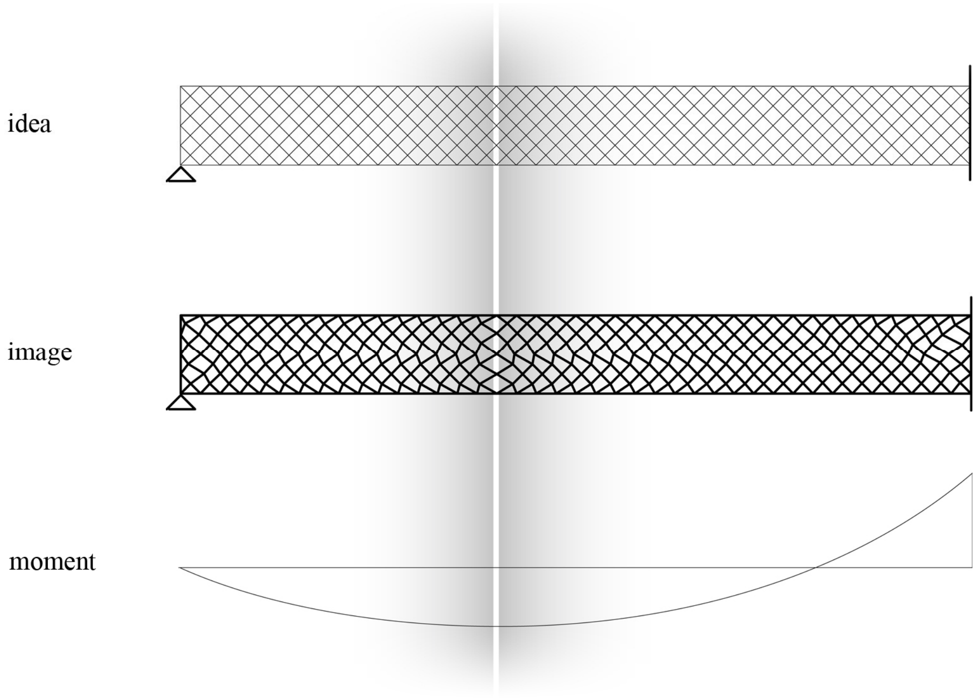
Abstract

This paper explores generative design by means of a Finite Element Analysis (FEA) application that is driven by an evolutionary algorithm as a design tool. Novel technologies enable future designers to create structures that emerge from the gradual integration of the building concept with the physical design aspects.

The modification of geometrical data, whether for buildings, constructions or components, is mostly based on the discrete process of Computer Aided Design (CAD). After being generated, the elaborated computer data represent a defined shape that is neither tangible nor directly evaluative. The potential modifications of complex geometries are often out of imagination and even the experts do not entirely succeed in estimating design changes. Consequently, the design solution often tends towards a geometry being mechanically explainable but not towards an optimum or the design intention. When we comprehend structural design as an interdisciplinary challenge it is most important that we learn to benefit from evolutionary optimization as an integrative (bottom-up) design strategy.

Structural engineers must redefine their strategies that are highly concentrated on mechanical models. The common link combining structural design and architecture could be the pattern. Pattern means on one hand the composition of a physical structure (or data structure respectively) and on the other hand the example or the sample representing a phenotype. The pattern has an enormous potential for the future collaboration between structural design and architecture.

Finite Element Analysis (FEA) applications simulate structures and their physical parameters e.g. stress, deformations, temperatures. Normally, the structure is being optimized in a stepwise collaboration process. The engineers can explore for additional material capacities in any phase of the process. Evolutionary computer algorithms also perform optimization but, generally speaking, neglect geometrical order and therefore remain a one-way street leading towards the best mechanical solution. Evolutionary form-finding combines on one hand an evolutionary algorithm and on the other hand a collaborative design process. Naturally, the order and its regularities, represented through patterns, accelerate and improve evolution. We demonstrate in two additional case studies how evolutionary optimization, representing the natural strategies, could complement geometrical composition, representing the artificial strategies. The fusion of the two strategies into a new experimental way of thinking has an enormous potential. Structural design and architecture should explore and digitally map these strategies into effective design patterns.



Keywords: Evolution, Collaborative Design, Human Computer Interaction (HCI), Parametric Design, Morphology, Emergence, Glass Fiber Reinforced Plastics (GRP) Spatial Structure, Evolutionary Algorithm, Evolution Strategies.

1. Introduction

Architecture is the connection between the shaping of material ("fabrica") and rational conclusion ("ratiocinatio"). Vitruvius gives information about the different building types as well as about machines and mechanics in his treatise "De Architectura" ("Ten Books on Architecture"). Following this tradition architectural education and responsibility include social, economical and natural sciences, mathematics and law. According to Vitruvius each building must exhibit the three qualities of firmness, utility and beauty ("firmitas, uilitas et venustas") [1]. The forecast of firmness ("firmitas") is substantial for each and every building and is consequently a crucial point in all epochs. The master-builders trusted in physical experiments.

After the era of Enlightenment the natural sciences entered a phase of extraordinary progress. While exploring the field of linear algebra the philosopher René Descartes introduced the rationalist view ("je pense, donc je suis", "cogito ergo sum") and created analytic geometry i.e. the fusion of the two disciplines algebra and geometry. The post-rationalist expansions in the domains of science have strongly been interrelated with mechanics from the 17th to the 20th century. The accelerated scientific progress was owed to the theories of famous natural scientists like Newton, Bernoulli and Euler. They have been advanced and followed by many other important scientists who have thoroughly explored the field of mechanics and physics. The master-builders gradually began to rely on mechanical sciences and learned to prevent mechanical failure. The intense cross-links between natural science and mathematics in the 19th century laid the foundations for the engineer profession. Unfortunately, the scientific theories and practices led to various antecedent-consequent design schemes. The engineers, at the very least, altered inventiveness and changed their attitude from a former experiential view to a scientific way of thinking. In the face of modern scientific progress and scientific disciplines like the chaos theory, the complexity theory and biogenetics, the modern structural engineer still tends towards mechanics (statics) of the old school in order to ensure firmness and stability.

In 1960 lightweight structures, once more, forced structural engineers to trust in physical experiments in order to explore novel design strategies. Frei Otto, a German architect and scientist developed design strategies that are strongly related to nature, the famous Form-Finding (Formfindung). More than 30 years later Frei Otto defined „the role of the engineers: It is their role to explore the mechanics of self-adaptation [within this context] because adaptive entities take effect on forces causing configuration, modification and deletion" [2]. Our technical skills still need a lot of improvement in order to fulfill this vision. In future we must learn how mankind could benefit from novel symbiotic design procedures that have the potential to perform an integration process with the environment i.e. the symbiosis of nature, society and human technology.

Symbiotic design procedures are difficult to combine with structural design that roots deeply in mechanical theories. This is a result from the absence of prototyping and product testing in a design discipline where built structures have to go into service quickly after completion. Consumer items, however, are more innovative than buildings because they benefit intensely from product development strategies and interdisciplinary cross-links between product design, science and engineering. Design experiments, substantial product tests, series of prototypes and goal-oriented visualizations gradually advance the future evolution of a product. The term evolution therefore describes on one hand „the process by which different kinds of living organisms are thought to have developed and diversified from earlier forms during the history of the earth“ and on the other hand „the gradual development of something, esp. from a simple to a more complex form“[3]. Structural design should therefore focus not only on aesthetical results but also on the design process.

2. Creative Patterns

The Roman scientist, statesman and philosopher Lucius Annaeus Seneca explains the creation of arts with respect to a sculpture: "All arts is but imitation of nature ('omnibus ars naturae imitatio est'); therefore, let me apply these statements of general principles to the things which have been made by men" [4]. A statue ("statua") has afforded matter ("materia"), which was formed and has had an artist ("artifex") who gave form to the matter. Hence, in the case of the statue, the material was bronze and the cause of the sculpture was the originator ("opifex"). This cause-effect-chain exists for each and every object. The Stoic school of philosophy therefore teaches a deterministic perspective with a strict relationship of cause and effect. The Stoics believe in one cause only. The philosopher Aristotle thinks that the word "cause" can be used in three ways: The first cause is the matter ("materia") itself, without which nothing can be created, the second cause is the originator ("opifex") and the third cause is the form ("forma"), that is given to each artwork e.g. a statue. A forth cause should be added: the objective of the artwork. What is an objective? It could be money, it could be fame or it could be religion if the artist intended to offer his artwork. "To these four Plato adds a fifth cause, - the pattern ("exemplar") which he himself calls the idea ("idea"); for it is this that the artist gazed upon when he created the work that he has decided to carry out. Now it makes no difference whether he has his pattern outside himself, that he may direct his glance on it, or within himself, conceived and placed there by himself'[4]. Seneca further explains that these five causes are not sufficient if we define the term "cause" as the general premise for the creation of an object. Consequently, the creation of an object must be seen as a complex interaction of "countless accessory causes" e.g. time, place or motion. The general "creative cause" lies in the relation between the matter and the creative reason (or the creator respectively).

In this parable Seneca tries to illustrate the Creation of our world on the example of a bronze statue. He proofs that there must be a general cause that we can identify as the Creator, the nature, creative reason or a creative order. The form ("forma") is only what the creator stamps upon his work. "Neither is the pattern a cause, but an indispensable tool of the cause"[4]. The "countless accessory causes" are the design aspects. Their complex interactions are very difficult to control. Many attempts have been made to find a method that is capable of linking the aspects to the design pattern like living nature does. Wilhelm Worringer differentiates two design methods "Abstraction and Empathy" [5] that point at different directions:

1. **Empathy:** The physical recognition of an object and/or small ranges of its construction process yield the design pattern. The design pattern goes often with the appearance of

the object. Biomimetics are an example of this category. A mechanical system (e.g. arch, frame, membrane) can also be the design pattern.

2. **Abstraction:** Concepts or principles are abstracted and serve as a pattern for the design process e.g. evolutionary design, bionics, generative design, parametrical design. The object can appear like the (natural) pattern or even look completely different.

The first design method strongly links architecture and structural design through a common object that is capable of representing the design pattern and the mechanical system simultaneously. The second method is not based on an object representing the shared information of the architect and the structural engineer. Consequently, structural design must define strategies that can react on patterns as a matter of concept or principle because structural design helps to integrate physical laws of nature. The latter aspect should not be seen as a restriction but as a gain for architecture and structural design.

2.1. The Interference of Patterns, Orders and Structure

How can we identify and define design patterns or creative orders? The scientific development in the last 200 years turns out that a substantial theory for the occurrence of orders is difficult to define. Repetitive natural systems e.g. crystallographic orders or human hierarchic systems (e.g. military orders) appear too simple. “Complex patterns generated by interacting rules are more interesting, and raise the possibility of seeing all order as the product of a computable generative process. This could give us a general view of order as any system produced by interacting generative morphological rules” [6].

Since the geometrical rules and the physical design aspects are interdependent, they are both capable of controlling the creative order (structure) of an object. Consequently, the invisible design rules and the visible design aspects reduce disorder (entropy) to the same extent. This process should be realized as the generation of order represented by the design pattern or a structure respectively. Since the morphogenesis interferes between rules and patterns, it reduces entropy and creates a balanced situation.

2.2. The Integration of a Building with Mechanical Aspects

The physical design aspects – especially the ability of carrying high loads – have ever been integrated in building concepts amongst many other design aspects. The non-professional realizes an encyclopedic ornament and a complex structural pattern on historical buildings indicating that the master-builder successfully integrated mechanical aspects e.g. ornamental details on the columns, the arches and the vaults or the studious design of the atlantes and the lintels.

The design of the Catholic Court Church of Dresden (Germany) illustrates the combination of mechanics and geometry. The church tower integrates many columns carrying the roof (Fig. 1) and the heavy church bells. The columns are installed far from the centre and increase the stiffness of the tower. But the physical aspects are even more present in this church tower. All columns are grouped in stories with a limited height what in fact creates additional buckling stiffness in particular because each ceiling works like a diaphragm stiffener. Finally, the stiffness of the tower shaft grows with its diameter in the same degree like the bending stress that continually grows from the roof tip to the foundations of the tower. The architect, Gaetano Chiaveri, combines lightness with strict orders and sequential arrangements. He follows his design pattern very exactly and integrates it with the cylindrical tower and rotation symmetry. Consequently, the structure of the tower parallels cylindrical natural systems with strict orders e.g. the bamboo stem. The structural system of the tower matches to physical laws because its mechanical behavior integrates the same pattern – the bamboo stem (Fig. 2). The tower integrates typical aspects of bamboo although the object "bamboo stem" was definitely not the design pattern of the architect Gaetano Chiaveri. Tower and bamboo are capable of carrying high loads especially if they are exposed to pressure and bending. If we take a closer look on ancient and modern towers we will recognize that many towers of different cultures integrate aspects of bamboo. These structures display aspects of bamboo in their conceptual ideas and in their mechanical behavior. Beside the bamboo pattern we can also identify many other effective mechanical patterns for a tower e.g. stalagmites, trees or bones and tendons.

Fig. 1: The Dresden Court Church
Architect: Gaetano Chiaveri

Fig. 2: The Bamboo pattern

History shows that the master builders have integrated geometrical and mechanical design aspects in buildings and structures over long periods of time. On one hand they followed certainly their professional traditions and on the other hand they integrated their latest experiences. The master-builders have developed structures gradually over long periods of time. The described gradual process follows the principles of evolution. It is therefore comparable with evolution in living nature or, even better, with the directional agricultural breed.

3. An Approach to Evolutionary Algorithms

The process of evolution was the fundamental object of research studies performed by Jean Baptiste Lamarck, Alfred Russel Wallace and Charles Darwin who discovered that fundamental diversification results from small mutations growing slowly step-by-step (gradual evolution). The latter two scientists recognized the theory of natural selection or, more precisely, that favorable functional properties are retained in gradual evolution. „Over all these causes of change, the accumulative action of selection, whether applied methodically and quickly, or unconsciously and slowly, but more efficiently, seems to have been the predominant power“ [7]. All diversification comes through the orderly repetition of the three steps: reproduction, modification and selection. This concept is the only consequential model to explain the diversity of nature. Charles Darwin derived it from agricultural breed. It seems so simple but the interaction of coincidence (modification) and tenacity (selection) is really powerful. Evolutionary progress emerges through the endless repetition of the three steps: reproduction, modification and selection [15].

3.1. Evolution as a Design Driver

Beside the studies of living nature, evolution has been taken as a model for computable algorithms based on mathematical logic. Some researchers presume that evolution was the most effective optimization method. If there had been a better choice, nature would have adopted the better principle (e.g. gradient based optimization). Generally speaking, evolutionary algorithms have been developed by three independent researchers: Lawrence J. Fogel, John H. Holland and Ingo Rechenberg. While Fogel concentrated on artificial intelligence [8], and Holland copied the micro-level of the genetic code [9], the engineer Ingo Rechenberg concentrated on physical optimization. Consequently, Ingo Rechenberg focused on the physical design aspects. In contrast to the natural evolution process that is based on the mutation of genes, represented by the genotype, Ingo Rechenberg’s Evolution Strategies (ES) can be described as an evolutionary process based on the evaluation of physical phenomena and therefore related closely to the phenotypes themselves [10].

Evolution Strategies (ES) are a stochastic search method that fulfills the explored principles of biological evolution. ES are trimmed to yield results that are comparable with the results of natural evolution. One of their biggest advantages is that ES are not gradient-based. Consequently, ES are capable of performing analysis procedures with functions that contain non-linearity, discontinuities or even multi-modality. These problems can cause instabilities with other solution methods e.g. the gradient-method or the Newton-method. Naturally, the ES have a high robustness because they are based on potential solutions that really work and do not rely on suppositions like gradients, derivatives etc.

3.2. Evolutionary Algorithms

We decided to try Evolutionary Strategies in a performance test. It is most important that the algorithm does not stop at a local optimum but continues his search until he identifies the global optimum. Good test functions are topologies with local and global optima e.g. de Jong’s function, Rosenbrock’s valley, Rastrigin’s function. For a better understanding of the multi-dimensional function a 3D-graph illustrates the function in 3D space. Local and global optima z(x,y) can easily be identified (Fig. 3).

The test is performed on a standard processor (2.4 GHz Intel Core Duo) with a standard operating system (Microsoft-Windows XP Pro SP2). We performed the global optimization with a [5/5, 30(10/10, 30)] multi population strategy that contains populations on two levels. The lower level consists of 30 individuals with 10 parents that take all part at recombination – a (10/10,30)-strategy. The upper level consists of 30 populations (containing 30 individuals each) with 5 parent populations taking part at recombination – a [5/5,30( )]-strategy. The Evolutionary Strategies identified the global optimum of 3D Rastrigin's function (n=2) in circa two seconds and the 21D Rastrigin's function (n=20) in less than one minute. Multi population strategies are most efficient because they distribute favorable information on individuals and populations. Consequently, they have more capacities to follow different ways and find the global optimum. The evolutionary process benefits from the distribution of information on individuals and populations. The global quality of the result rises in the same extend as information is distributed on populations and individuals.

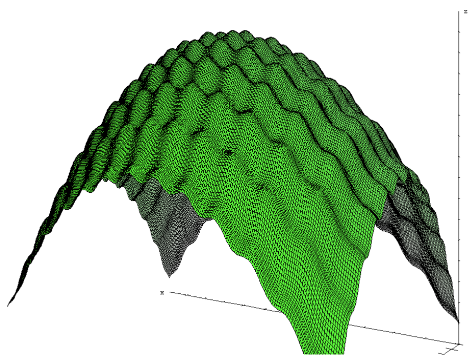


Fig. 3: The 3D Rastrigin's function

4. Evolution in Structural Design

The term „building" includes a vast sphere of activity, e.g. huge artwork, houses, halls, towers, industrial buildings, bridges. The construction is substantive for each and every building. The engineers have explored and developed various strategies in order to analyze mechanical behavior and reconfigure constructions. These strategies aim at opposite directions:

- The simplification of constructions indicates the way leading towards mechanical abstraction and finally a mechanical system (Fig. 4) [11]. The mechanical system is the origin for the calculation process. A proficient engineer tries to discover similar systems that are capable of sustaining the further collaborative design process with the architect. This strategy points "top-down" because it tries to split a mechanical system from the whole building structure.

- The simulation of constructions can display mechanical effects by analysis (e.g. Finite Element Analysis (FEA)[12]) or by experiments (e.g. form-finding [2]). Small modifications improve the mechanical behavior step-by-step. The engineer focuses on the process i.e. the relationships between the performed steps. This strategy points "bottom-up" because it can integrate additional design aspects into the structure.

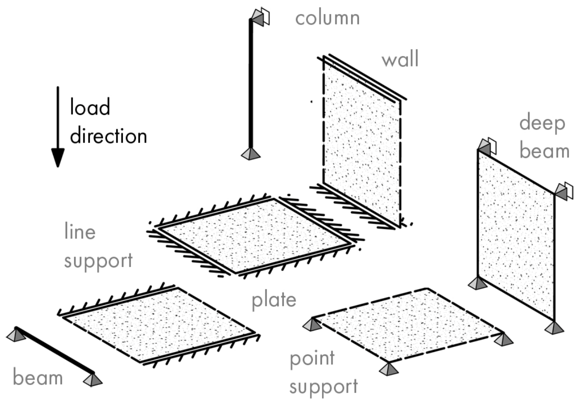


Fig. 4: Structural analysis with mechanical systems

Every building is the result of a collaborative design process that involves many parties e.g. the architect, the engineer, the client, the public in general. Generally speaking, a design aspect can be physical (e.g. extreme dimensions, energy consumption) or it can be mental (e.g. artwork, urbanism, functionality). Normally, architecture unites aspects of both groups that are merged in order to generate one building. Some aspects can be localized more precisely and usually described numerically. Other aspects are not measurable. A collaborative design process tries to merge the different design aspects with the building structure. Buildings are therefore whole objects that unite aspects of form, function and construction.

> *"Whenever a thing comes into being, at that moment it has come to be as a whole; accordingly if you do not reckon unity or wholeness among real things, you have no right to speak of either being or coming-into-being as having any existence." (Plato Sophist. 245d)*

Some buildings are closely related to mechanical systems and we can therefore apply the approved mechanical systems in theories and in practices. Sometimes we identify problems that do apparently not fit for the mechanical systems. We would solve these problems lightly if we were capable of switching from mechanical systems to mechanical experiments. My experiences show that mechanical experiments seem to be an adequate strategy although the experimental design process flows a little bit accidentally and more slowly. Consequently, it would be most effective if we switched back and forth between experiment and mechanical system although complex forms and structures are capable of causing enormous problems of time and costs. In future we must therefore develop better experimental strategies to face the challenges of the 21st century.

4.1. The symbiosis of structural design and natural evolution

Evolutionary algorithms can systematically control and evaluate the performance of experimental design. If the experiment is simulated with a Finite Element Analysis (FEA) application, the Evolutionary Algorithm (EA) can access information via Inter Process Communication (IPC). The common interface can either be provided by the Finite Element Analysis (FEA) application itself or a proper application has to be coded and compiled that integrates the FEA data files and arranges systematically the required information. An open interface and free information design play the key role.

In near future we should learn to integrate small tools (code patterns) with structural design that help us with the performance of repetitive processes [13]. Our repertoire of patterns can serve us with the solution of the bigger problems. Sequences of patterns and executive applications can subsequently be searched and controlled by heuristic search algorithms (e.g. evolutionary algorithms) that help accelerate the design process significantly. The first case study shows how an evolutionary algorithm participated in the free information interchange of a design process and accelerated the integration of the design aspects. The second case study illustrates how an evolutionary algorithm can re-organize complex systems.

4.2. Case Study 1: Integration of a structure with external design aspects

NOX – Lars Spuybroek, an architect in Rotterdam, initiated an interactive public artwork: „Joe and Joey is a robotic sculpture that lies on a large stretch of inaccessible land next to a highway. Passers-by can influence the position of the sculpture by steering the heavy weight inside the structure by means of a simple phone call. By doing so, the center of gravity of the whole subject changes and makes it roll forward or backward.“ [14] Joe and Joey should be built with GRP (glass fiber reinforced plastics) like the other artworks from Lars e.g. the D-tower in Doettinchem in the Netherlands. At the beginning the artwork was pure geometry and based on Lars' experience (Fig. 5). One initial simulation at the beginning clearly showed that the rounded frame alone is not capable of carrying all the loads as a mechanical system. We both wanted to integrate the predefined functions and build "Joe en Joey" physically. Since we wanted to keep the character of "Joe en Joey" the necessary modifications had to follow the design concept and not mechanics. We extracted a 3D wire-frame model and interchanged data in applications like Rhinoceros3D® or AutoCAD® in order to define variants for the evolutionary design phases [15].

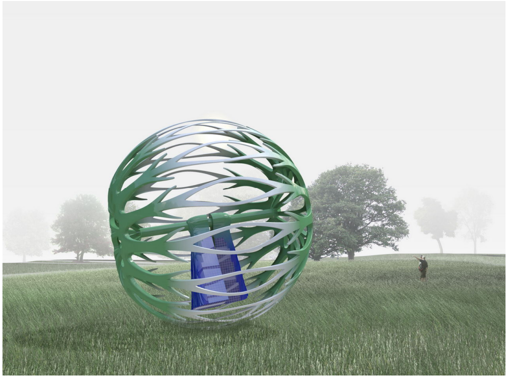


Fig. 5: Joe en Joey (design idea)
Architect: Lars Spuybroek / NOX

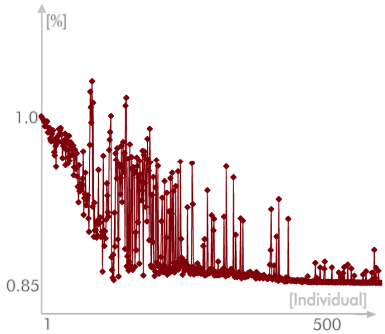


Figure 6: Experimental design steps

The evolutionary algorithm coordinated a huge series of stress tests performed with finite elements in 2nd order theory (Fig. 6). The heuristic search aimed at the lowest weight possible because the costs of GRP structures rise proportionally with the amounts of glass fiber layers being used. The total weight of structure also influences the dimensions of the inner weight that makes the whole structure roll forward and backward. The simulation and the evaluation took into account buckling and failure of the material. The deflections of the structure have been crucial because on one hand usability must be guarantied and on the other hand big deformations cause delamination and breakage.

The structure consists of eight different groups of profiles. One can easily imagine how much trial and error analysis and redefinition of all the profiles is required to take fully advantage of the cross sections and to define the best individual. We applied a (2,10) Evolutionary Strategy i.e. an evolutionary strategy with one population of two parents generating an offspring of 10 individuals. The parents were determined to die because the new parents have been selected from the offspring. The evolutionary algorithm made progress by comparison of the individuals. It can be seen as a heuristic search strategy that is capable of "learning" about the structure. The evolution of 500 individuals, their simulation and selection takes us (or the algorithm respectively) about one day on my laptop computer. It is amazing to see experimental design beign performed so quickly (Fig. 7).

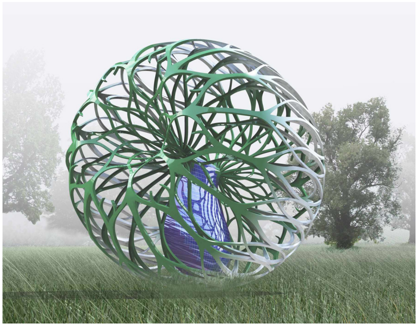


Fig. 7: Joe en Joey (design result)
Architect: Lars Spuybroek

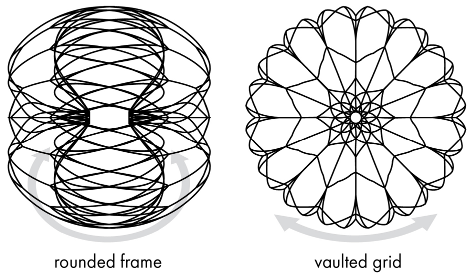


Fig. 8: Force-flow in the GRP structure

Evolutionary Formfinding is the combination of evolutionary and collaborative design phases reducing the weight of the structure by 50% in this approach. On one hand our result reduced the production costs and time but on the other hand it limited the rotating weight to practicable dimensions what made the artwork functional at last. The evolutionary algorithm rearranged the structural pattern in a way that allows a force flow in two perpendicular directions: the rounded frame and the vaulted grid (Fig. 8). The evolutionary algorithm itself gradually carved out and stiffened the vaulted grid. The complex grid structure of Joe and Joey is a direct result from Evolutionary Formfinding combining both evolutionary and collaborative design phases [15].

4.3. Case Study 2: Reorganization of complex pattern structures

The arrangement of highly undetermined structures depends on the organization of the stiffness matrix and the force-flow. Mechanical optimization focuses on the reorganization of cross sections, the structural shape or the structural pattern. Evolutionary Formfinding can control the gestalt mutation and reorganize the pattern what on one hand improves aesthetics and on the other hand increases the effectiveness of the pattern [16]. A regular rhombic pattern defines an effective structure that is often used in historical steel trusses because it can resist high shear forces. It appears regular and the equal elements are arranged harmonically, although the shear force distribution is completely irregular. In this experiment we discovered that the regular rhombic pattern is definitely not the most effective structure for the shear force-flow in a web plate.

We defined our ideal structure as a beam with two different supports: a pin support on the left side and an encastre support on the right side (Fig.10). The evolutionary algorithm coordinated a series of 600 deformation tests performed with finite elements including a nonlinear stress-strain-relation of the structural steel. Since we wanted to increase the stiffness of the whole girder the heuristic search aimed at the lowest deformation. The v. Mises stresses had to be limited within a range that is defined by the yield strength of the structural steel. Since we intended to influence the nodal coordinates, the geometry is defined as variable data.

Consequently, we added geometrical limitations to the standard mechanical definitions on that an FEA simulation is based. The nodes in the FEA model have been parameterized and their allowable movements have been limited within a defined area. Gestalt mutation is based on a defined geometrical arrangement with strict geometrical orders that can be displayed by matrices. The Matrices provide strong cross-links between geometry and mechanics that organize the structural data i.e. the process of sorting information. Since all 277 nodes change their positions in the plane of the web, only a heuristic search strategy, like an evolutionary algorithm, is capable of reorganizing the pattern structure in an acceptable period of time. Evolutionary Formfinding defines an optimum gestalt based on the complex evaluation of a series of experiments. The evolutionary algorithm gains experience with the number of FEA simulations being performed i.e. an ability to learn about the mechanical behavior of the irregular stress distribution in the structure (Fig. 9).

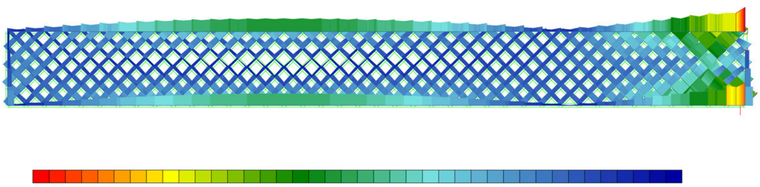


Fig. 9: FEA-simulation of the stress distribution (v. Mises stresses)

We applied the (2,10) Evolution Strategy once again. It turned out that the progress depends more on the effectiveness of information transfer than on the chosen evolutionary algorithm. The structural reorganization reduced the deformations by 10% although it seems even more important to me that we increased the relationship between the structural pattern and the force-flow (Fig. 10). We are really looking forward to integrating this strategy in our future design collaborations on complex pattern structures.

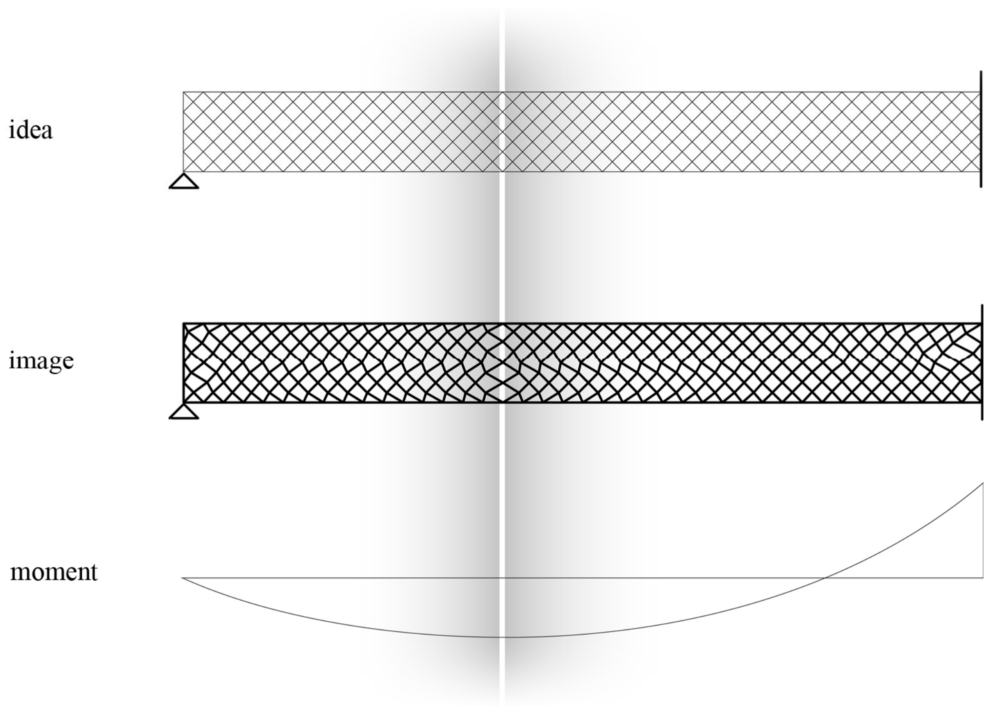


Fig. 10: The structural pattern indicates the force flow

5. Conclusion

The "reemergence of the master builders" is a design trend that has been analyzed by Branko Kolarevic. In contemporary circumstances, the master builder is someone who is fully involved in the making of a building, where the making means design, production and construction in an almost mediaeval fashion." [17] Branko Kolarevic initiated a discussion about the relation between the complexity of forms and the situation of the architects who are drawn back into being fully involved in the making. Generally speaking, an intricate design process requires building practice. The solution seems simple: On one hand the architects and engineers bridge the gap between design and construction and, on the other hand, contracting organizations engage seriously in design practice. But architecture cannot easily model on the consumer industry that unites design and production in one company. Such a mediaeval design process would cause enormous problems and could risk the reputation of the planners' profession. New design strategies must be defined in order to redefine and strengthen the planners' profession.

Future planners must concentrate on professional collaborations, the workflow and especially on information management. The strict role allocation between engineer and architect is deeply rooted in the worldview of the 19th century. The mediaeval master builder paradigm aims even further backwards. Future design evolution should focus on the process because a process with special consultants is more effective than one omniscient “master-builder”. The planners should therefore concentrate on collaboration and optimize innovative tools and technologies in order to activate additional physical capacity with an adequate consumption of material, energy and time. Either formational interaction creates additional capacity e.g. the stretched skins on a skeleton [17] or informational interaction supports a differentiation e.g. the simulation with finite elements that help activate additional capacity through optimized collaboration processes [15]. Architecture can benefit a lot in near future if the experimental strategies of the ancient master builders were digitally mapped and gradually integrated in our engineer-architect-model through simulation. Future architecture must explore and digitally map the natural processes and the ancient design strategies into effective design patterns.

About the author

Julia Stratil studied civil engineering at Universität Stuttgart and collaborative design projects have always been part of her studies. While being educated she improved her skills as a Student Assistant with Prof. Werner Sobek in Stuttgart and in his office where, after her Diploma, she has worked for 4 years. Then she returned to University in order to concentrate on her PhD and student education. For 2 years she has taught at TU Berlin (Berlin University of Technical Sciences) as Assistant Professor in deputyship. Now she teaches at Universität Kassel as Assistant Professor for Structural Design with Prof. Manfred Grohmann. She intends to find a common platform for architects and engineers. Her projects unite esthetics and the effectiveness of structural consultancy (consuplan.de). She likes nature, canoeing, skiing and sailing.

Fig. 11: The structural pattern indicates the force flow

References

[1] Vitruvius: Des Marcus Vitruvius Pollio Baukunst, erster Band, übersetzt von August Rode, Leipzig, 1796.

[2] Otto, F. and Rasch B.: *Finding Form – Towards an Architecture of the Minimal.* Stuttgart, 1995.

[3] Oxford University Press: *New Oxford American Dictionary (NOAD)*, 2nd edition, New York, 2005.

[4] Seneca, L.A.: *Ad Lucilium Epistulae Morales,* with an English translation by Richard M. Gummere. London, New York, 1925. (first published in the year 65)

[5] Worringer, W.: *Abstraktion und Einfühlung.* München, 1908.

[6] Alexander, C.: *The Nature of Order, Book One: The Phenomenon of Life,* Berkeley, 2002.

[7] Darwin C.: *The Origin of Species, by Means of Natural Selection.* New York and London, 1860.

[8] Fogel L.J., Owens A.J. and Walsh M.J.: *Artificial Intelligence through Simulated Evolution*. New York, 1966.

[9] Holland J.H.: *Adaption in Natural and Artificial Systems.* Cambridge, 1992.

[10] Rechenberg, I.: *Evolutionsstrategie '94 – Werkstatt Bionik und Evolutionstechnik, Band 1.* Stuttgart, 1994.

[11] Engel H.: *Tragsysteme - Structure Systems.* Stuttgart, 1967.

[12] Cook R.D., Malkus D.S., Plesha M.E et al.: *Concepts and Applications of Finite Element Analysis.* New York, 1997.

[13] Coenders J., Approximating complex shapes with intelligent structures: embedded design intelligence in systems for the early phases of design. *Journal of the International Association for Shell and Spatial Structures*, 2006; **47.**

[14] Spuybroek L. – NOX, in URL: *www.noxarch.com* (accessed: 01/24/2009). *Joe en Joey*, Spuybroek L. (ed.), Rotterdam, 2009.

[15] Stratil J., Evolutionary Formfinding – Conceptual Integration of Patterns and Physical Aspects, *Design Principles and Practices: An International Journal*, Melbourne, 2009; **3**.

[16] Stratil J., Evolutionary Formfinding – Symmetry as a Medium of Integration, Symmetry of Forms and Structures (ISIS Symmetry), An Interdisciplinary Conference, Wroclaw and Cracow, 2009.

[17] Kolarevic B.: *Architecture in the Digital Age – Design and Manufacturing.* New York, 2003.

[18] Stratil J.: *Interaktive Membrankonstruktionen.* Diploma Thesis at Universität Stuttgart: 2001.

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[Fig. 5] Spuybroek, L./NOX (Rotterdam) in URL: www.nox-art-architecture.com (accessed 05/15/2009)

[Fig. 7] Spuybroek, L./NOX (Rotterdam) in URL: www.nox-art-architecture.com (accessed 05/15/2009)