# GEOMETRY AS A SUBSTITUTE FOR STRUCTURAL ANALYSIS IN GENERATIVE DESIGN TOOLS

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**Abstract.** In this paper we argue that purely geometric concepts can be useful for structural analyses in generative design tools. Structural analysis using finite element methods is a non-straightforward task and it is often costly in terms of computation. By relying on geometric criteria it is possible to achieve designs that are structurally sound based on the designer's understanding of the relation between geometry and structure.

## 1.Introduction

Recently, there has been an increased interest in the field of Emergent Design (ED). In ED, generative algorithms are used to create complex artefacts, often inspired by organic growth and form. An important aspect of any design is structural and material properties. Engineers have developed sophisticated methods for analyzing the structure and stability of designs, many based on finite element analysis (FEA). Although ED is still in its infancy and much remains to be done in order to analyze and formalize the existing form generation algorithms, there is also a need to bring ED and FEA closer and allow them to inform each other during the design process.

Performing a FEA is a non-trivial task and the designer must specify a range of parameters in order to set up the specific scenario. Moreover, it is often computationally costly to conduct an FEA and interpreting the result requires some consideration. If one uses a generative design system with an EA component, this computational cost can become significant due to the large number of evaluations required and an impediment for exploration of the design space.

In this paper we discuss how structural analysis can be incorporated in creative design tools (Bentley and O'Reilly 2001). We define a *Creative Design Tool* (CDT) as a tool that includes a generative growth algorithm and/or an evolutionary search algorithm (EA). We will use the design tools Genr8 (Hemberg 2001) and Surface Component System (Jonas 2004) to illustrate these ideas. A complete overview of CDTs is beyond the scope of this paper and a brief survey of CDTs can be found in Hemberg and O'Reilly (2004b).

The main objective of a CDT is to be a creative partner for the designer and to help coming up with new ideas. Thus, we want to give priority to creativity and exploration over structural analysis and optimization.

However, the implication of structural fitness into a CDT is not to be misunderstood as a final, detailed analysis and local optimization of an almost finished design. The ideas which are explored in a CDT are informed by multiple criteria of which structural performance is just one. A designer must also take aesthetic considerations and functional aspects into account.

## 2. Geometric Constraints

We wish to introduce structural analysis in such a way that it does not impede the generative algorithm of the CDT. Our basic idea is to use purely geometric criteria as a substitute for the structural analysis. If the FEA is complicated and costly, it may be useful to have simpler purely geometric evaluation criteria as a complement. We believe that CDTs should be creative, interactive, cooperative and easy to integrate in a design process. In this paper we argue that geometric analysis is useful to achieve this aim as it makes the tool open-ended and easy to integrate in a design process.

Thus, we propose an evaluation process consisting of two stages. The first stage contains only geometric criteria. These are fast and easy to evaluate and they can provide a rough guidance towards structurally sound designs. The second layer includes a complete structural analysis (possibly based on FEA). In order to make the form finding process as efficient as possible, the geometric criteria are evaluated several times in between each FEA.

EAs require a fitness evaluation procedure and the traditional way of assigning fitness in design tools is to have the user evaluate each member of the population. This scheme, called Interactive Evolutionary Computation (IEC) restricts the evolutionary search due to human fatigue (Saito, some year). Parameterized fitness criteria give the user high-level control of the evolutionary search (Hemberg and O'Reilly 2004a). Another important aspect when choosing the fitness criteria is to make sure that they promote multi-parametric search. Our experience indicates that you get the most interesting results if the criteria are chosen in such a way that it is impossible to reach the global optimum by optimizing the different parameters independently. This results in a setting where there are many different ways of obtaining an equally fit surface, which is important since it promotes diversity. It also leads to interesting trade-offs between the different criteria when the designer must deprecate one fitness criteria to improve overall fitness.

In comparison with FEA, structural geometry is independent of a specific context or scenario and arbitrary material properties. The benefit of involving structural criteria through the definition of geometric surface features is that the user is responsible to understand their performance in relation to a specific side and case. To take structural advantage of those criteria the user must have the knowledge of how structural geometry works. For example that folded surfaces are generally stiffer than flat surfaces, if stiffness is required. Geometry is also important since it affects many aspects of the design, not only structural but also environmental and visual etc.

A CDT should allow the user to specify geometric, either as part of the fitness criteria or as other types of constraints that can be more or less restrictive. For example one could use boundary boxes that are either impenetrable or penetrable at a fitness penalty. For fitness criteria, it is in general a good idea to consider some property of the surface and device a numerical measure for that property. The designer is then allowed to set target values for the properties as well as weights that indicate how important the property is (examples can be found in Table 1). Figure 1 shows an example of how geometric fitness criteria can be used to alter structural properties. It is up to the user to make a connection between these criteria and the structural analysis. This is not always a straightforward and trivial task for the designer. However, it is fully in line with our philosophy which is to ``put the user in the loop''. That is, to develop tools that cooperates and interacts with the user rather than monolitically producing artefacts.

## 3. Experience From Using Design Tools at the Architectual Association

In this section, we will relate our experiences of using the scheme outlined in Section 2. The work that has been conducted in the Emergent Design + Technologies group (2004) at the Architectural Association in London shows that it is possible to create interesting designs using the strategy outlined in this paper. Achim Menges of the AA has used Genr8 to conduct experiments (O'Reilly et al. 2004).

In one of his experiments, Menges explores the interaction between a form finding process based on evolutionary dynamics and a computer-aided manufacturing process. The aim of the project was to design a pneumatic strawberry bar (see Figure 1) for the AA's annual project review. Menges formulated a number of fitness criteria that had to be realized through Genr8's fitness function. A complex feedback loop was set up where the three subpopulations were evolved simultaneously. Menges was also able to make good use of the environmental features in Genr8 as he used subsequent surfaces as bounding boxes to help realize the constraints. Part of the analysis was conducted in a dedicated membrane engineering software, EASY. The results of this structural analysis was interpreted by Menges and he used them to modify the parameters for his Genr8 runs.

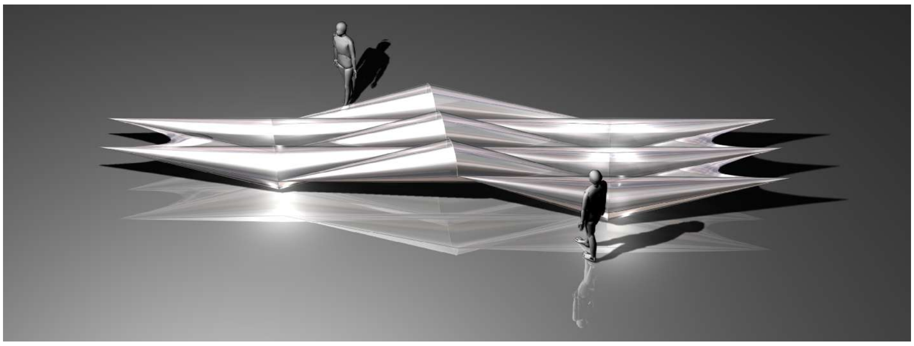

*Figure 1.* A rendered image of a pneumatic strawberry/champagne bar by Achim Menges at the AA, London. When designing the bar, the strategy proposed in this paper was outlined and refined.

Another tool, a Surface Component System (Jonas 2004) developed by Katrin Jonas implements the strategy outlined in this paper in full. The tool uses a genetic algorithm to combine tiles from a predefined set to form surfaces. The set of tiles is shown in Figure 2 and two examples of such surfaces are shown in Figure 3. Part of the tool is implemented as a MEL script for Alias|Wavefront's 3D modeler Maya. The geometric fitness criteria are evaluated inside Maya and they are presented in Table 1. The user must experiment with the target values and the weights of the criteria in order to find suitable values. By inspecting the outcome, the user can learn how to adjust them in order to achieve the desired result for the design task at hand.

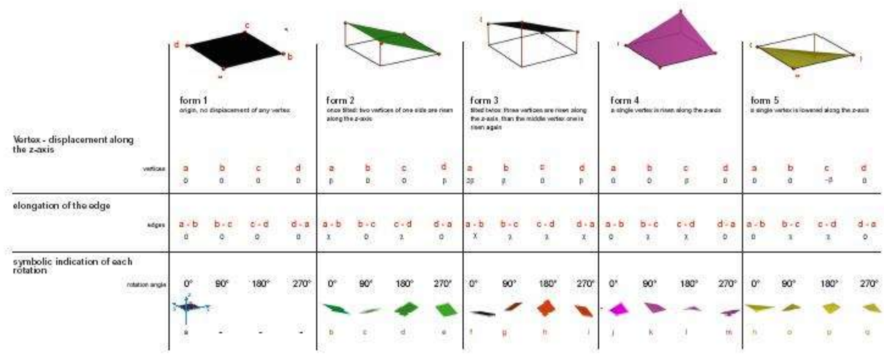


*Figure 2.* The set of 17 tiles that are used in the Surface Component System. There is a set of rules that specify which tiles are allowed be adjacent in order to avoid glitches. It possible to create a situation where the set of allowed tiles becomes empty and in that case a hole is left in the surface.

TABLE 1. The geometric fitness criteria for the Surface Component System. The criteria are fast and easy to compute and they are intuitive for the user. The last criteria is illustrated in Figure 1

| ***Fitness criteria*** | ***Description*** |
|---|---|
| Height | The difference between the highest and the lowest points in the surface. |
| Number of holes | Sometimes it is impossible to select a tile that fits in a location. In those cases, that position becomes empty. |
| Number of support points | How many different points of the surface are at the minimum *z* value. |
| Support point distance | In order to avoid having all the support points clustered in one region, we impose a target distance between all support points. |

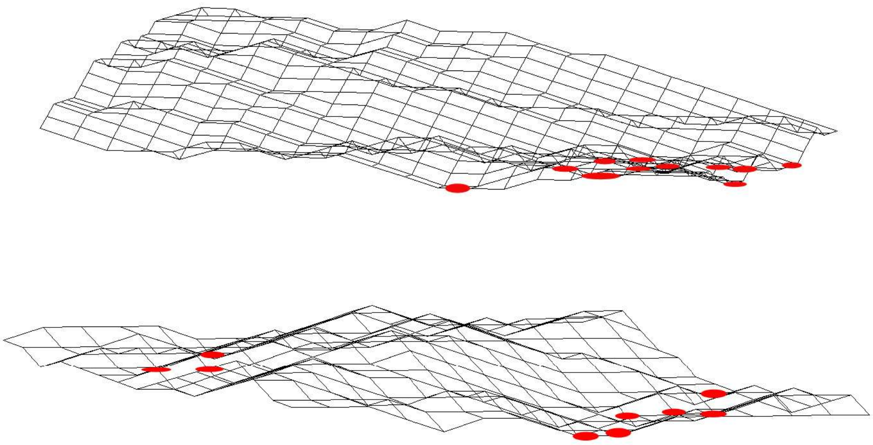

*Figure 3.* The figures show surfaces created with the Surface Component System. In the top figure, there is no selection pressure to have the support points (marked by red dots) separated and the tool finds a solution where all points are clustered in the same region. In the lower figure, a fitness criterion that regulates the distance between the support points has been introduced. It is clear that the new fitness criterion helps create surfaces that are structurally more sound.

After a number of generations, the surfaces are exported to the ANSYS software for further FEA. The output from the ANSYS analysis is a ranking of the surfaces (the fitness of the surfaces can only be stated in relative terms) that can be used to inform the selection process of the evolutionary algorithm. An example of a stress analysis is shown in Figure 3.

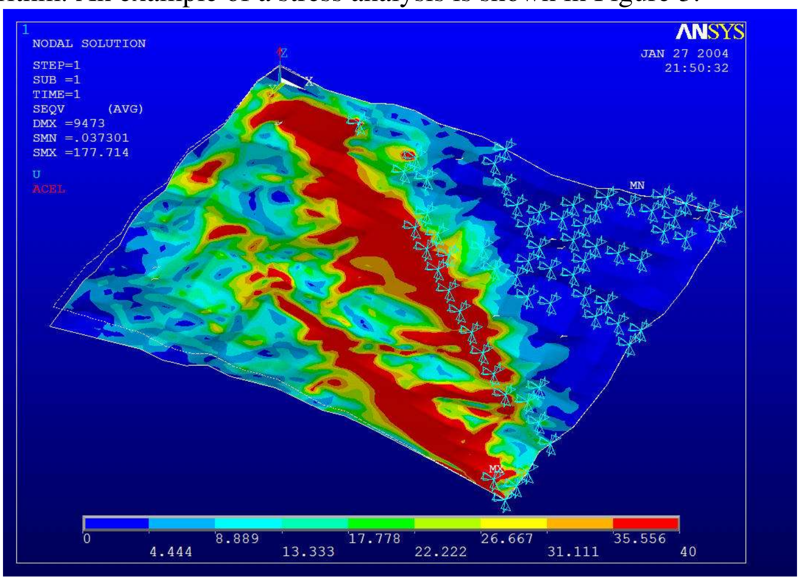


*Figure 3.* The output from a FEA of the stress acting on a surface generated by the Component Surface System. Red indicates areas of high stress penetration.

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