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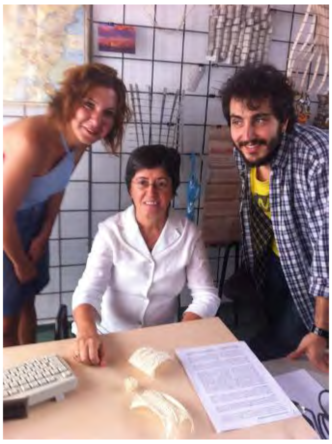
Paper: **AN ALTERNATIVE APPROACH TO STRUCTURAL OPTIMISATION IN GENERATIVE DESIGN**



Topic: Architecture

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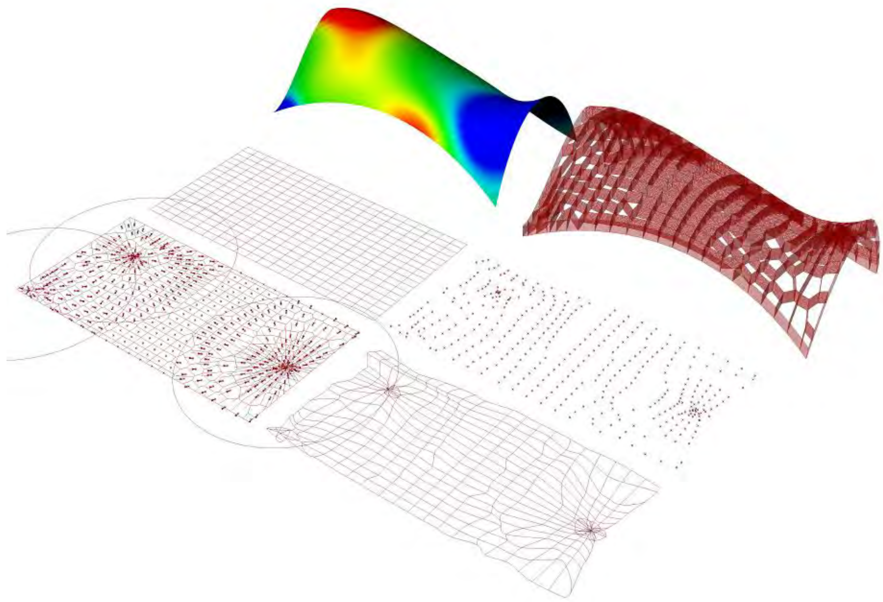
Abstract:
The paper presents a structural optimisation model that proposes alternative methods using generative approaches. Current methods of optimization are defined by three operations, such as modularity, repetition and differentiation. As an appropriate example of these methods, voronoi structure is explored for its potentials for optimization, form finding and structural performance. A voronoi is modular but not repetitive, with potential for a great variety of complex geometries. Using voronoi diagrams, the pattern in architectural design can be formed according to structural performance.

In this paper, a generative algorithm is proposed at initial design phases while designing a structure for a given surface. The structural performance data is converted into geometrical data on the double-curved surface to represent the structural values as an architectural pattern. At initial stages, the surface on which the pattern is formed, is analysed using the finite element methods to obtain values on the surface. Later, according to the data obtained, the surface pattern is generated using a generative algorithm, which is developed in Rhino/Grasshopper software. With the help of this algorithm, it is possible to create multiple solutions meeting the structural performance requirements besides one concrete optimized result. Thus, the proposed work also evokes alternative methods for the design decisions made in the preliminary design phase by means of generative methods.



Images of patterns created with the generative algorithm based on voronoi diagrams

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Keywords:
structural optimization, voronoi diagram, performance based design, form generation.

AN ALTERNATIVE APPROACH TO STRUCTURAL OPTIMISATION IN GENERATIVE DESIGN

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Abstract

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1 Introduction

In the field of engineering, optimisation plays an important role to find the optimum solution. Generally, it refers to maximum or minimum boundaries of solutions to the problems that the designer faces during the problem solving activity. Similarly, the optimisation methods are mainly based on mathematical interpretations and relations related to the defined problem. There are two types of problem solving activity: well and ill defined problems. In well-defined problems, steps to the outcome are clearly defined, whereas in ill-defined problems, the specifications are clearly set. As stated by Eastman, the major distinction between well and ill defined problems is the "assumed availability of a specification process for defining the problem space" (Eastman, 1969: 669) [1]. Thus, optimisation methods are deeply linked with well-defined problems instead of ill-defined problems.

Optimisation is one of the techniques used by engineers to define the solution range set for the problem. However, in the field of architecture, designers deal mostly with ill-defined problems. They predominantly focus on the methods to enrich both the design processes and the outcomes. In that sense, generative methods facilitate the design process by helping the designer to find the optimal solution. Generative methods in which the output is generated by set of rules or an algorithm, and normally by a computer program, named also as tools, are generator for the designer during the design process (Shea, 2005: 254) [2]. Using the implicit capabilities of generative methods, the number of solution sets is increased.

1.1. Deterministic vs. Stochastic Approaches

Deterministic approaches and stochastic approaches are two design methods used during the problem solving process in the ill-defined problems. Similarly, deterministic algorithms are used as exploratory algorithm when there is a clear inside into the nature of variables. Stochastic algorithms are used in problems when there are uncertainties in the elements, the search space or the path for solutions (Barros, et al. 2012) [3]. Thus, the deterministic approach commonly used while stochastic approach has limited use in the architectural design. Deterministic approaches in architectural design leads the designer to arrive to concrete solutions and to produce one exact solution based on the data driven from the parameters. If no change occurs in the parameters, the solution does not change. Thus, randomness has no place in finding the final solution.

As opposed to deterministic approach, the stochastic approach includes randomness. After processing each loop during the generative process of the design, stochastic approach creates diverse outcomes. This probabilistic result is the outcome of the randomness. Thus, stochastic approach helps the designer to use generative methods during the design process for augmenting various solutions.

To better clarify the distinction between deterministic and stochastic approaches, example of a hollow cube is displayed to be filled with intended design geometry (Fig.1). The design of infilling of the cube is based on geometrical rules. In the first approach, defined as the deterministic approach, the designer draws previously constructed and defined product in its mind. Imagining the final product, the designer codes the process in terms of geometrical and mathematical rules. The designer processes and implements the rules of form generation into a computer-based algorithmic model. In the second approach, defined as stochastic approach, the designer does not have to construct the final product in its mind and to code the design product in terms of mathematical and geometrical rules for the whole design process. The designer needs to construct only the behaviours or intelligences of the elements, creating the geometry inside the box. In this approach, design system simulates and processes the elements to create the geometry inside the hollow cube. While comparing the two approaches, we concluded that the deterministic approach brings one solution as opposed to stochastic approach bringing different design outcomes during each execution of the generative system. Thus, the stochastic approach gives the designer divergent design outcome and can be considered much more generative then the approach.

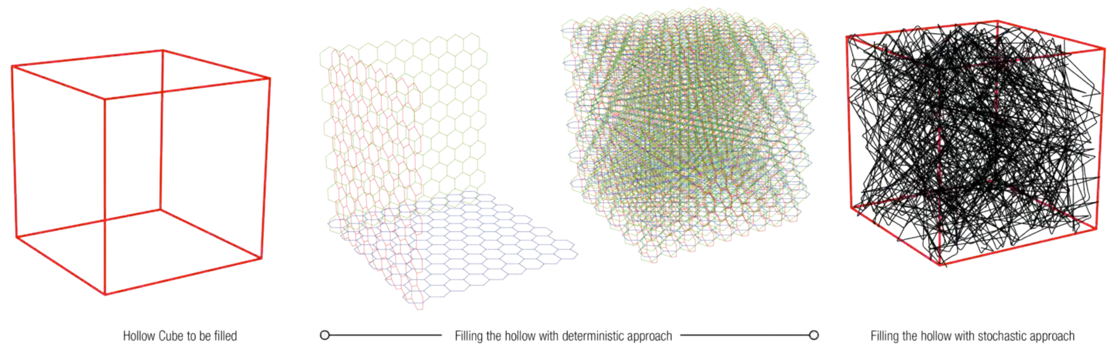


Figure 1 Strategies for the design of an infilling geometry of a cube.

1.2. Paradox between optimisation and generative methods

Optimisation techniques are used to find the optimum single solution to a defined problem. Generative methods are used to create more enriched solution sets during the design process. Optimisation follows the deterministic approaches whereas generative techniques tend to follow stochastic approaches. Thus, the contradiction between these two concepts, optimisation and generative methods should be further examined by defining the optimisation.

2. Optimisation

Optimisation is the search for optimum solutions. During the optimisation process, engineers pick the best solution for the problem regarding the constraints [4]. Optimisation methods help to define the solution domain boundaries by scaling down the solution set range. Moreover, optimisation is a decision-support system for the problem solving process to find proper solution in the solution set domain. Consequently, optimisation methods help to reduce the exploration time within the solution set containing numerous different solutions for specific type of problems.

2.1. Optimisation methods in engineering

Optimisation methods are highly associated with the field of engineering. Engineering deals with well-defined problems, with specifically defined inputs, goals and steps to reach the goal. Facilitating the problem solving process by narrowing down the solution set for specific problem, the methods have become useful and popular in the field of engineering in time. Moreover, the ease of interpretation of optimisation algorithms used for well-defined engineering problems makes the optimisation methods additionally powerful and useful.

2.2. Optimisation methods in architecture

In the contrast to the straightforward interpretation of optimisation algorithms in the field of engineering, the implementations of the optimisation methods in the field of design are complex in nature. The problems faced in architecture are mostly ill-defined; therefore, it is hard to interpret as an algorithm and to search for the solution of problems. Furthermore, the goals and steps for the problem can not be generally interpreted in a mathematical way, due to the nature of the problem. Optimisation methods delineate the design problems by making the solution set narrow down; thus, the optimisation methods might be considered as decision-support system within the design process [5].

3. Alternative Approaches to the Structural Optimisation in Generative Design

As the structural performance has to be optimised, the engineering requirements offer more than one single solution for the problem. At the initial stage of the design process, we proposed an algorithm in order to clarify the dilemma between generative and optimisation methods in structural performance. The proposed algorithm forms patterns along the surface of a structure and gives the designer an optimised relevant solution. This algorithm is based on voronoi polygons, as its cellular formation deforms the surface pattern by optimising the structural performance of the design product.

3.1. Operations

The pattern on the surface formed by the algorithm is defined by three operations: modularisation, repetition and differentiation. These operations, representing the geometric abilities of the pattern, are frameworks of the pattern formed for the structure. Using these operations, pattern can be modified and optimised according to the structural performance.

The first operation, modularisation is widely used for creating cellular formations. Considered as one of the main operations, modularisation is widely associated with grids to explore further geometries. In that sense, grids help to deform geometries of the modular systems, creating more complex and deformed patterns. The second operation, repetition refers to the growth of the system. In a holistic perspective, repetition and growth algorithms lead the system to diverse structural and geometrical solutions. Likewise, repetition overlaps with modularisation and growth of the system. Because of its close relation to the grid system, the growth algorithms have the ability to affect the grid system, which implies the ability to change the whole pattern. Finally the third operation, differentiation makes cells deform based to their locality and place in the system. By the help of the differentiation of intelligence, system meets the performance requirements within a predefined range. This operation helps the pattern to meet the performance requirements and to maximize the performance of the system. Therefore, this operation reduces complexity of the systems in terms of performance requirements and increases the efficiency of the design performance. To conclude with, these operations are the keys elements to reach modified and optimised solutions.

3.2. Technology

In this paper, we chose a pattern type, the voronoi, to optimise a design problem. A voronoi pattern is produced on a double-curved surface as a structural element. Voronoi pattern gives the designer a chance of optimisation within the critical boundaries of structural performance. As displayed below, voronoi pattern is formed and tested for several diverse grid types. The formation of point sets defines end product characteristics of the voronoi pattern. The ability for creating complex patterns of the voronoi pattern is highly associated with the grid formation.

Voronoi pattern behave differently on different grid layouts. For example on a square grid layout, the pattern forms itself as a square. After the deformation, the voronoi generates itself as a deformed pattern. The square cells remain as non-deformed grid while the voronoi patterns are created at deformed areas (Fig.2). Similar result is achieved while the general layout is in a polar or hexagonal form (Fig.3).

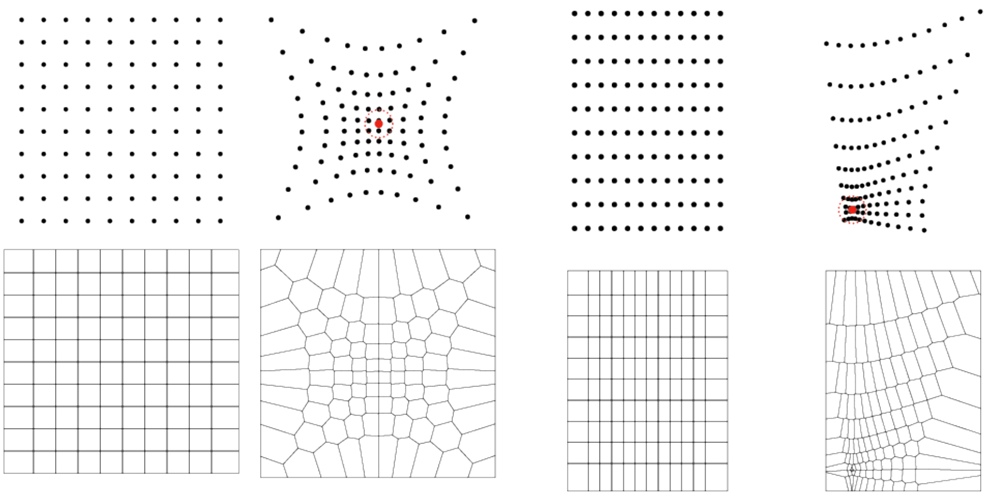


Figure 2 Deformation of the square grid

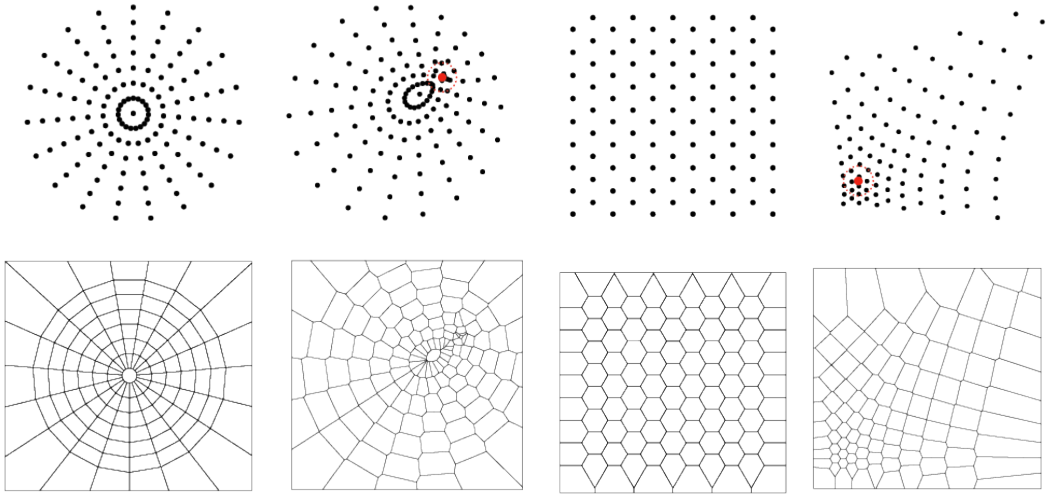
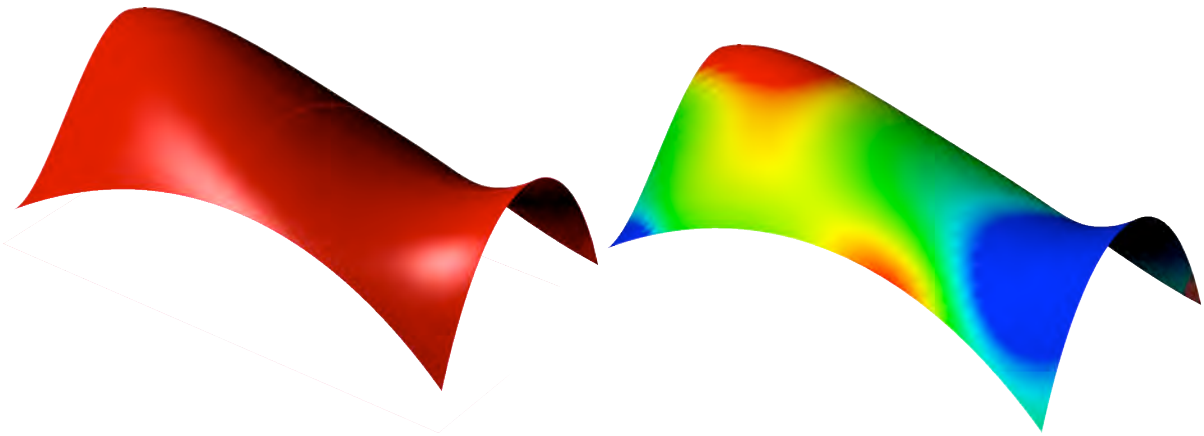
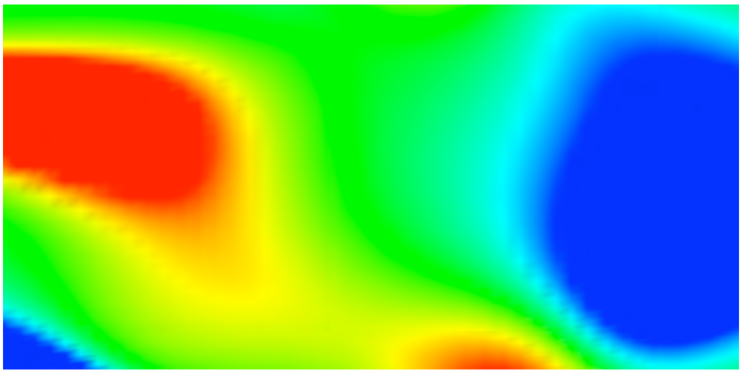


Figure 3 Deformation of the polar and hexagonal form

The model presented in this paper is created using Rhinoceros 3D modelling software, Grasshopper plug-in, finite element method software Elmer. The algorithm is implemented in Grasshopper 8.0.14, a generative modelling environment plug-in for Rhinoceros, 3D modelling software. First, the doubly curved surface, which is the base for the structure, is modelled in Rhinoceros. Second, the surface is analysed under given load conditions, in terms of structural stress by using finite element method software Elmer. The generated stress map defines the local behaviours of the voronoi pattern. Using the stress map, a grid is generated to form the pattern using modularisation and repetition operations.





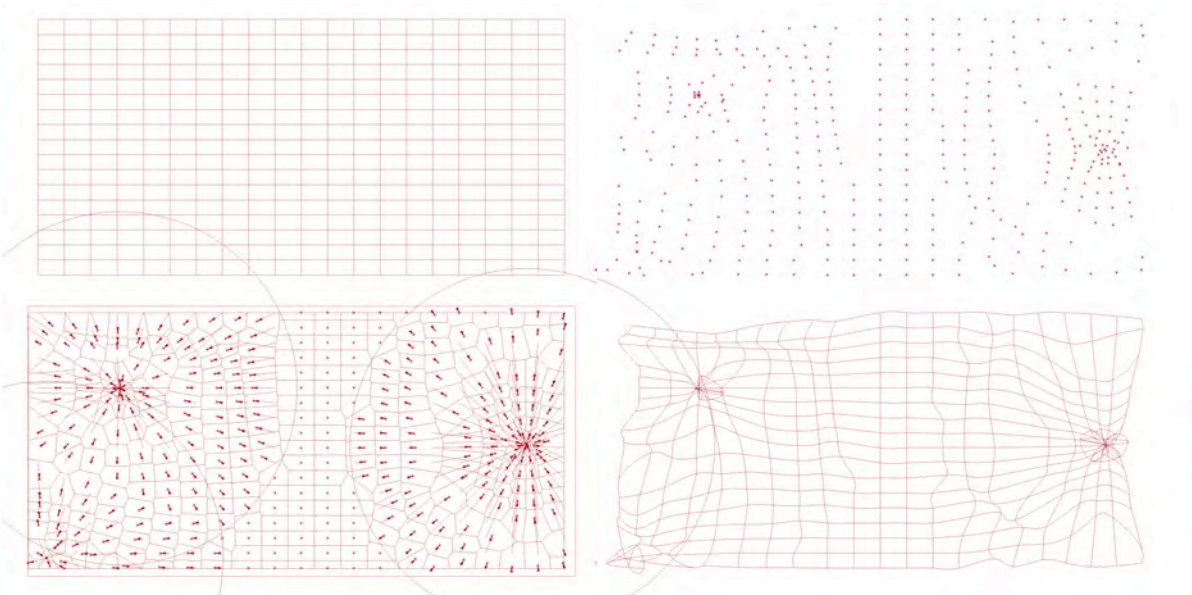


Figure 4 Images from the system: a. Modelled surface, b. Analyzed surface, c. stress map, d. Initial grid, e. deformed point set, f. deformed pattern and the control points, g. final deformed grid.

At this stage, the control points for the extremely stressed regions are significant as they deform the grid and consequently the voronoi pattern.

The control points of extreme regions refer to the deformation on the pattern. By clicking on the effect area, the designer can change the number of control points. This ability gives the designer the flexibility of using alternative optimisation approaches during the design process. At this level, the differentiation operation takes an important role as it forms the pattern relevant to the structural requirements. Differentiation operation both deforms the grid pattern and the point set of the grid (Fig. 5).

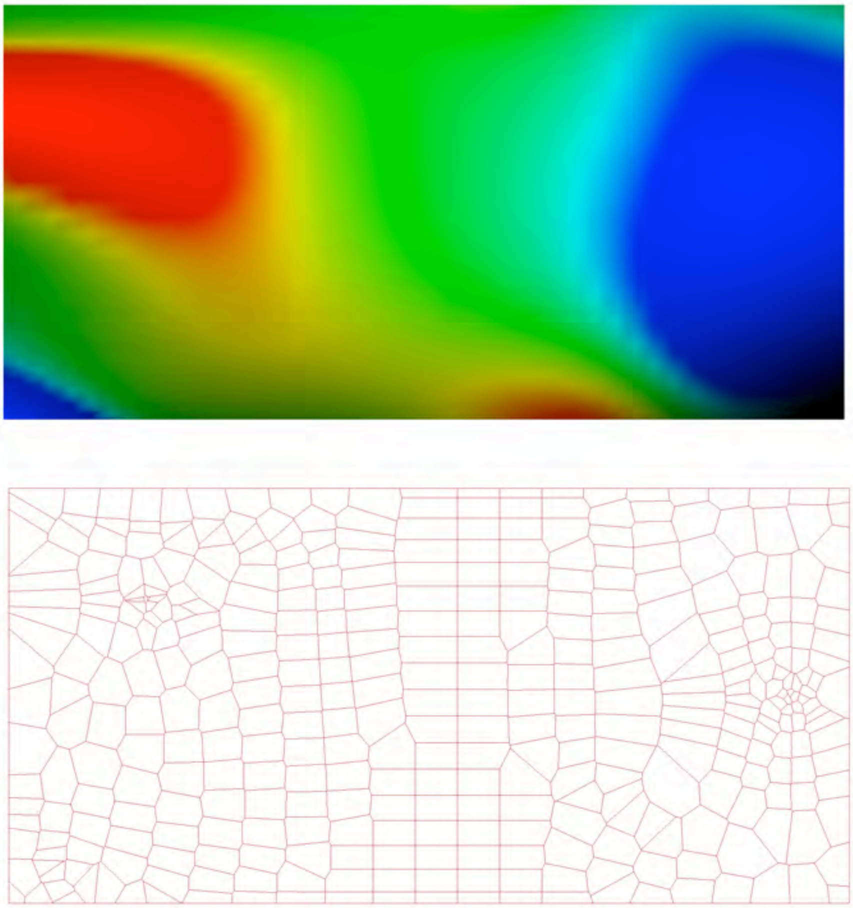


Figure 5 Structural stress map and the optimised voronoi pattern driven

After performing all the operation, the voronoi pattern is formed itself to meet the structural requirements of the system created along the doubly curved surface.

3.3. Tools

The designer is able to perceive the grid, the point set, pattern structural system, and the stress map simultaneously while using the proposed alternative optimisation approach. At initial design stages, the designer is able to form the pattern directly, and other components indirectly. Using the interface, the designer is able to control distribution and density of the control points that direct the deformation of the pattern. Thus, the designer can watch all of the deformations throughout the design production. Using this approach, it is possible to create multiple solutions meeting the structural requirement (Fig. 6).

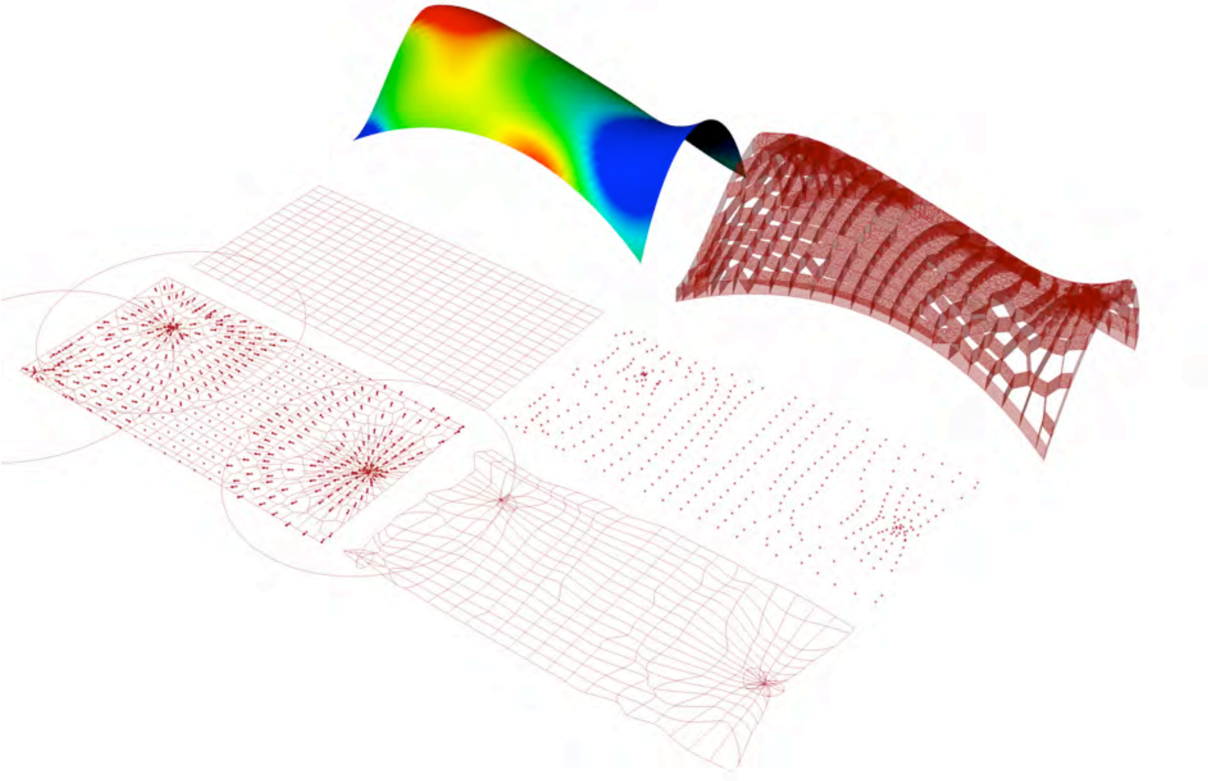


Figure 6 The proposed system

4. Conclusion

The operations that are coined in the paper help to construct the link between geometric and structural topics and help to remove contradiction between optimisation and generative concepts. By merging optimisation and generative concept, the paper demonstrates to extract the implicit structural and geometrical potentials of patterns as structures. Moreover, the proposed alternative optimisation method at the initial stage of the design process offers the designer a decision support system. The solutions generated by the system converge to the optimum solution, which meets the performance requirements. Therefore, the proposed approach reduces the time spent to make the design outcome realistic. Additionally, the proposed approach boosts generative methods by using optimisation methods and makes the design process more performance oriented. To conclude, the designer enriches the solution set around the convergent ones to the optimum solution by the help of the embedded performance intelligence.

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