SHAPE OPTIMIZATION THROUGH PARAMETERIC DESIGN METHODS USING CAD SOFTWARE

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ABSTRACT:
THE PRESENT PAPER ANALYZES TWO OPTIMIZATION VARIANTS OF A TRICYCLE METAL FRAME. THE INTEGRATION OF THE PARAMETRIC DESIGN IS TREATED THROUGH THE OPTIMIZATION OF AN EXISTING METAL STRUCTURE BY APPLYING THE VORONOI DIAGRAM AND THE SHAPE GENERATOR.
BOTH VARIANTS ARE BASED ON A FREE CELLULAR FORM THAT ONLY MEETS THE CRITERIA OF FUNCTIONALITY AND PRESELECTED RESISTANCE, THE REMAINDER BEING DEDUCED BY ANALOGY.
THE REQUIREMENT FOR SUCH OPTIMIZATIONS STEMS FROM THE NEED TO ACHIEVE A CONCEPT THAT FULFILLS THE SAME FUNCTIONS AS A PRODUCT DESIGNED USING CLASSICAL DESIGN METHODS, BUT UNLIKE THESE, IT REDUCES THE AMOUNT OF MATERIAL AND IT RESULTS IN BETTER STRENGTH, A PROCESS BY WHICH THE PRODUCT OBTAINS A FINAL ORGANIC FORM.
IN THE FIRST STAGE THE FORCES ACTING ON THE TRICYCLE FRAME WILL BE STUDIED IN ORDER TO GENERATE THE NECESSARY CONDITIONS FOR STABILITY, STRENGTH AND FUNCTIONALITY OF THE WHOLE SYSTEM.
ONCE THESE ARE ESTABLISHED, THE FRAME WILL BE OPTIMIZED BY APPLYING THE VORONOI DIAGRAM AND THE SHAPE GENERATOR USING THE INVENTOR PROGRAM

KEY WORDS: PARAMETRIC DESIGN, VORONOI, SHAPE GENERATOR, INVENTOR

INTRODUCTION

This article presents the steps required to optimize a metal structure by applying the Voronoi and Shape Generator techniques.
These methods of optimizing the shape and the amount of material used are increasingly being applied in the design and construction of different products due to the removal of unnecessary surplus material without affecting the integrity of the product.
In the first stage the forces acting on the tricycle frame will be studied in order to generate the necessary conditions for the stability, strength and functionality of the whole system.

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Once these are established, the framework will be optimized by applying the Voronoi diagram. This will be applied at the level of the individual piece.

A product that is parametrically engineered with a minimal amount of optimized material and distributed in a way that is functional will be a product with a significantly reduced weight with a low production cost and the form it will take will be an organic one.

Two such products optimized by parametric design are a wheelchair for people with disabilities, and a motorcycle frame, both 3D printed, with customized structure on the user's dimensions, offering a much higher degree of comfort than the classic ones, figures 1 and 2 a), b) and figure 3.

Figure 1. Optimization procces through parametric design

a) b)

Figure 2 a), b) Parametric optimized wheelchair

By de-stressing the classical shapes of serial made products, a mathematical formula can be achieved that can provide a mechanically-made organic form without the need for many manual drawings, and the actual construction of the finished product can be accomplished by a robot capable of fulfilling more functions not just one repeatedly as is the case in most factories.

Figure 3. Parametric optimized bike frame

OBJECT OPTIMIZATION THROUGH PARAMETRIC DESIGN METHODS

Modern design methods are increasingly based on the understanding of the nature of the processes and the principles of the automatic organization of biological structures, their

representation being performed by technological methods based on mathematical models, methods used even in contemporary architecture.
Bionic design elements play a very important role in modeling and urban development, ranging from architecture to product design. The development of informational technology has made it possible to create more complex structures inspired by natural forms. The Voronoi diagram had inspiration for surface relaxation, the honeycomb structure or a libelula wing, figure 4 a), b), c).

a) b) c)

Figure 4 a), b), c). Types of biological structures that uses automatic organization

In mathematics, a Voronoi diagram is a partitioning of a plane into regions based on distance to points in a specific subset of the plane. That set of points (called seeds, sites, or generators) is specified beforehand, and for each seed there is a corresponding region consisting of all points closer to that seed than to any other. These regions are called Voronoi cells. The Voronoi diagram of a set of points is dual to its Delaunay triangulation.
As implied by the definition, Voronoi cells can be defined for metrics other than Euclidean, such as the Mahalanobis distance or Manhattan distance. However, in these cases the boundaries of the Voronoi cells may be more complicated than in the Euclidean case, since the equidistant locus for two points may fail to be subspace of codimension 1, even in the 2-dimensional case.
A weighted Voronoi diagram is the one in which the function of a pair of points to define a Voronoi cell is a distance function modified by multiplicative or additive weights assigned to generator points, figure 6. In contrast to the case of Voronoi cells defined using a distance which is a metric, in this case some of the Voronoi cells may be empty. A power diagram is a type of Voronoi diagram defined from a set of circles using the power distance; it can also be thought of as a weighted Voronoi diagram in which a weight defined from the radius of each circle is added to the squared distance from the circle's center.

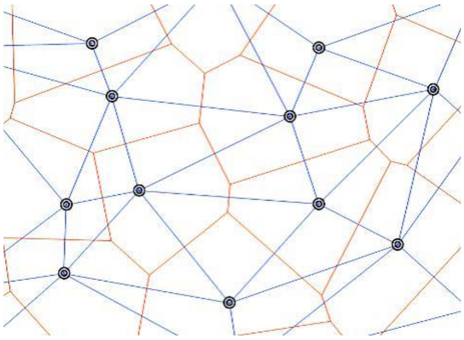


Figure 6. Parametric cells relationship

Parametric design is a process based on an algorithmic thinking model that facilitates the expression of parameters and rules that together can decode or clarify the relationship between the response / result and the originally proposed design.

Essentially, the parametric design is a paradigm in the field of modern creation, in which the relationship between elements is used to model the design of complex geometric elements and structures.
The term "parametric" is usually used in mathematics and refers to the use of certain variables that can solve or constrain the results of an equation.

Currently, the term used in the field of design refers to design calculation systems using analogue models to explore space for design.
All these applications combining clear mathematical formulas and specific constraints in designing a piece or assembly, facilitate the entire design process. Initial data about the total size, the shape of a profile, and then applying one of the two variants - voronoi or parametric design - gives an optimization of superior shape to the classic design methods and implicitly design. Everything starts from the idea of a free form that only the physical conditions imposed by the user have to meet, depending on the requirements that the product has to meet.
Starting from the above examples, the two optimization techniques were applied on the Greeny tricycle, respecting its original form and functionality.

FRAME OPTIMIZATION

The first frame variant was made of a steel profile. The structure of the framework met the initial functionality requirements, but after practical testing of the framework in various situations - rides in the park, distance between home and work, merger with public transport, there were identified problems related to the weight of the product, freedom limitations of handling during use, ergonomic and stability aspects, figure 7.

Due to these negative aspects, the framework was rebuilt into a CAD modeling program and a 1/1 scale physical model was developed to analyze what measures are needed to improve the original concept. Starting from the Greeny prototype, improvement of the framework and the functions were needed taking into account:

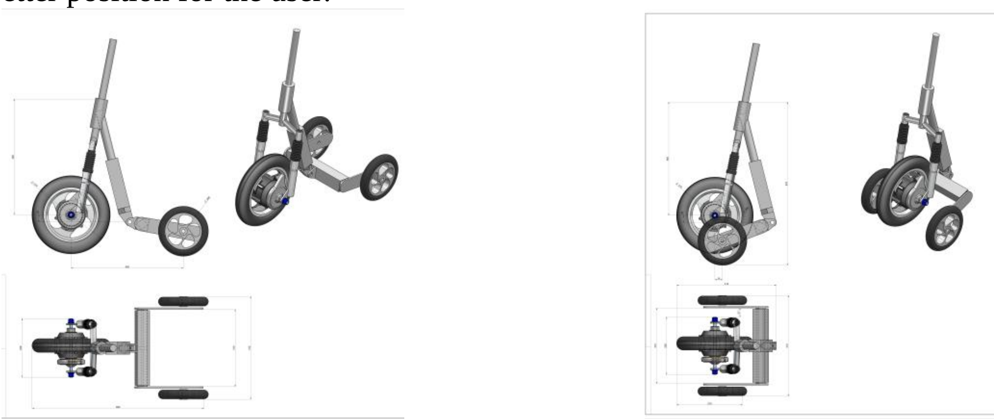
1.Folding style: At the first prototype, folding was done by removing a central spindle linking the top and bottom of the frame, and there is a risk of it being lost during the process, making it impossible for the vehicle to be used later.

2.The angle available for the steering ratio was to small, and the test itself found the need to improve it to provide greater comfort and safety during use;

3.The handlebar required a more ergonomic shape and needed to be easyer to fold (the solution identified at this point is by rotation)

4.An improvement in width is required for better grip stability

5.The tilting angle of the handlebar allows for better handling of the vehicle and a much better position for the user.



a) b)

Figure 7 a), b). First frame prototype, without optimization

Because the shape of the second frame is similar to the Greeny prototype, notable improvements can be seen only in the frame folding process (there are no more parts that needed to be removed and then inserted) and a somewhat greater degree of comfort in use, figure 8.

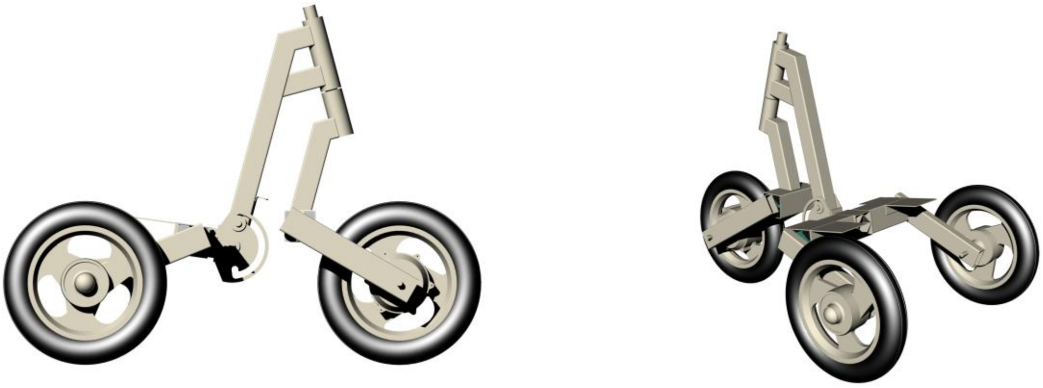
Following the feedback received after testing the two tricycle variants, the following weaknesses were highlighted:

1.The fairly large weight of the tricycle makes it difficult to handle it in folded form;

2.Lack of a seat support to make traveling more comfortable;

3.Rethinking the folding mode to result in a more compact form, thus facilitating its storage in public transport, where space is usually quite limited.

In order to find the best optimization, the design and testing process has resumed. Thus, Voronoi and Shape Generator were chosen to make this frame fit the new requirements, namely: increased stability and reduced weight by reducing the amount of material used to frame the frame.



a) b)

Figure 8 a), b). Improved frame prototype without parametric optimization

DETERMINATION OF FORCES USING FORCE EFECT

In order to study the forces acting on the frame, the ForceEffect program was used. The results thus obtained were used to optimize each part of the assembly - fork, arm, front axle, rear axle, figure 9.

A frame scheme was constructed to delimit fixed and movable areas, welded areas and whole parts, a predetermined weight applied to the whole frame (1000 N) was also applied, then the forces to be taken into account for testing the two optimization options used later.

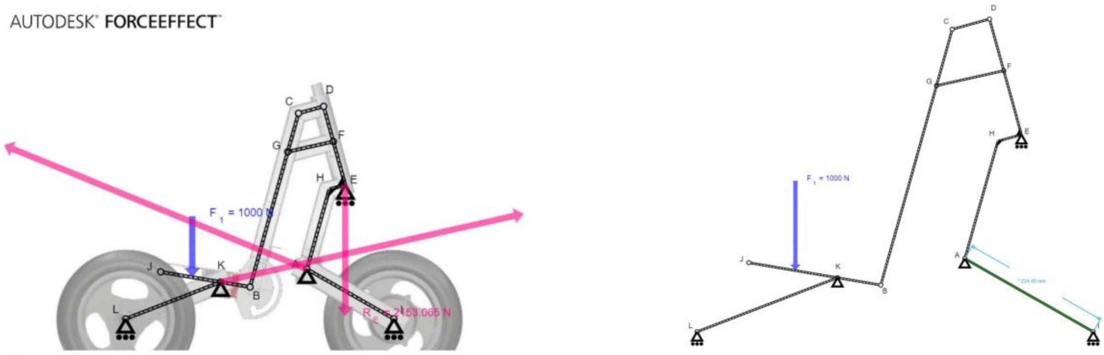


Figure 9. Force effect forces aplied to the frame

FRAME OPTIMIZATION USING THE VORONOI DIAGRAM

For the problems found in balancing the distribution of internal tensions and optimizing the structure, solutions can be found in the forms proposed by nature.

The cells divide the space so that under minimal structural constructive effort for the organism, the equilibrium of the internal stress distributions, the optimization of the flows for different forms of energy transport, the optimization of the path of an information circuit are achieved.

The mathematical models of rational portion of the most commonly used space are the Voronoi solutions and the Delaunay triangulation. The Voronoi diagram has been applied experimentally in various design projects.

In view of these considerations, the framework was optimized using the Voronoi method, thus reducing the amount of material without affecting its resistance. The Rhino program was used with the Grasshopper plug-in, generating a network that selected some criteria to be taken into consideration, given the ratio of previously generated forces, figure 10.

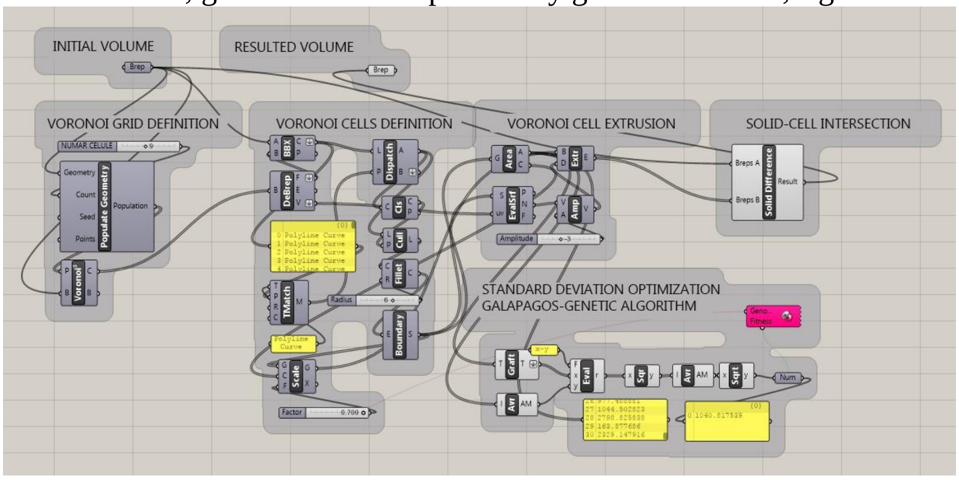


Figure 10. Grasshopper generated network

In this picture is presented the definition used for creating the Voronoi grid and setting the full-empty ratio. Genetic algorithms have been used to produce near-surface cells, figure 11.

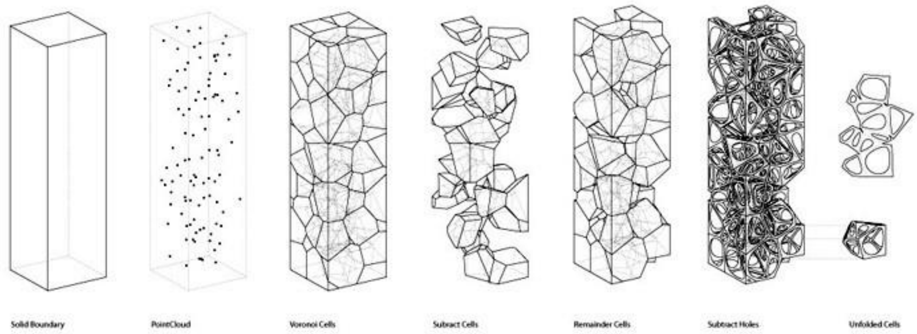


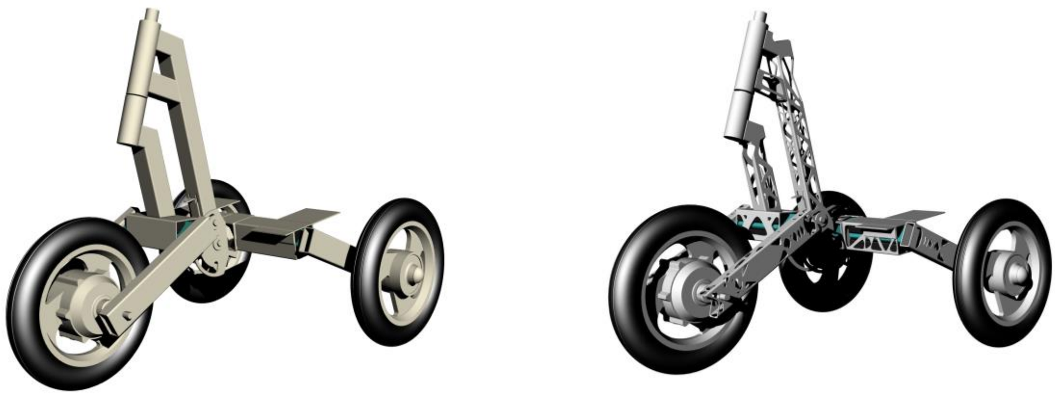
Figure 11. Optimization process for a basic shape

To test a component of the asembly with the applied vortex grid, the component was imported in Inventor, and Force Effect forces were applied to evaluate the strength of the component as exemplified below, figures12, 13, 14.

a) b) c)

Figure 12. Optimization process for a component of the frame

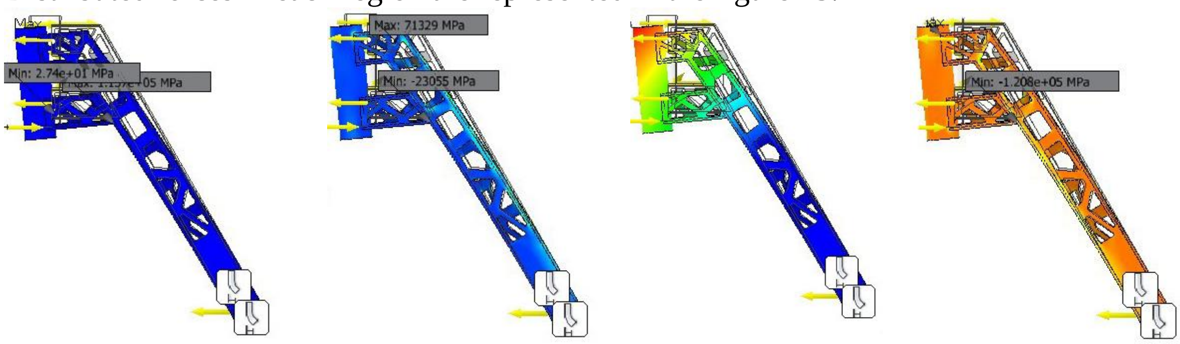
	
a)	b)
Figure 13. Tricicle down tube, a) before optimization, b) after optimization	



a) b)

Figure 14. Tricicle frame before and after optimization

Distributed forces in each region are represented in the figure 15.



a) b) c) d)

Figure 15. Tricicle down tube during the process of optimization (forces aplied)

To apply the Shape Generator, Inventor was used to build the frame and to select the mobile, fixed and distributed forces in Force Effect. Using Shape Generator resulted a mesh that was used as a template to cut the original piece.

CONCLUSION

Following these simulations / tests, using the two optimization methods using parametric design to improve a metal structure can result in an object with superior mechanical and aesthetic characteristics.

Using these optimization processes streamlines design, production, and testing methods, reducing the time needed to perform them more accurately, eliminating the human error in the process.

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