PARAMETRIC DESIGN AND STRUCTURAL PERFORMANCES OF A LIGHT METALLIC STRUCTURE

Vlad Andrei RĂDUCANU[1], Laurențiu MOLDOVAN[2], Doina RĂDUCANU[3], Mariana Lucia ANGELESCU[4]*, Ion CINCA[5], Vasile Dănuț COJOCARU[6], Anna NOCIVIN[7], Nicolae ȘERBAN[8]

The paper presents aspects from a multidisciplinary research program to develop an application of free-form type, using smart digital design tools as generative design (GD) and modern manufacturing processes - digital fabrication (DF), by exploiting the deformation properties of conventional metallic materials. At international level, the idea of incorporating the material behavior into generative design is at the beginning, so the paper objective of developing free-form type architectural modules by considering the material properties quantification is a current priority, having direct applicability. The authors investigated curved folded structural elements made of sheet metal, focusing on free-form columns that evoke the classical architectural orders. The structural issues were addressed by implementing both digital and physical load simulation, which in turn influences the process of finding the optimal shape of the object.

Keywords: spatial free-forms, generative design, digital fabrication, deformation properties, sheet metal, light metallic structure.

1. Introduction

Generative design (GD) [1,2,3] is a new class of digital design medium and associated software tools, totally different from conventional CAD and CAE procedures, which can be used as an instrument to obtain spatial free-forms by

[1] Arch., Ph.D, National University of Arts Bucharest, Romania Eng., e-mail: zoster.ar@gmail.com
[2] Eng., Ph.D., Rodax Impex Ltd., Bucharest, Romania, e-mail: rodax@rodax-impex.ro
[3] Prof., Ph.D., Faculty of Materials Science and Engineering, Univ. POLITEHNICA of Bucharest, Romania, e-mail: doina.raducanu@mdef.upb.ro
[4] Assoc. Prof., Ph.D., Eng., Faculty of Materials Science and Engineering, Univ. POLITEHNICA of Bucharest, Romania, e-mail: lucia.angelescu@gmail.com; *corresponding author
[5] Prof., Ph.D., Faculty of Materials Science and Engineering, Univ. POLITEHNICA of Bucharest, Romania, e-mail: ion.cinca@mdef.pub.ro
[6] Prof., Ph.D., Faculty of Materials Science and Engineering, Univ. POLITEHNICA of Bucharest, Romania, e-mail: dan.cojocaru@mdef.pub.ro
[7] Prof., Ph.D., Faculty of Mechanical, Industrial and Maritime Engineering, Univ. OVIDIUS of Constanța, Romania, e-mail: anocivin@univ-ovidius.ro
[8] Lect., Ph.D., Faculty of Materials Science and Engineering, University POLITEHNICA of Bucharest Romania, e-mail: nicolae.serban@mdef.pub.ro

exploiting the deformation properties of conventional metallic materials, in this case the elastic-plastic behavior. By means of parametric settings, the information concerning design becomes a dynamic message; this natural dynamic state causes more design flexibility.

Conventional / old metallic materials can be used to exploit their deformation properties; also, the possibility to recycle these materials or to use them instead recyclable materials, can be taken into consideration. Material can play an active role, emerged by its deformation behavior. The execution of metallic structures with complicated spatial geometries can be done by digital fabrication (DF). The main topic in the evolution of design technology, representing the focal point of construction projects that are based on generative material logic, is finding the balance between material, form and strength.

2. Design of experimental model

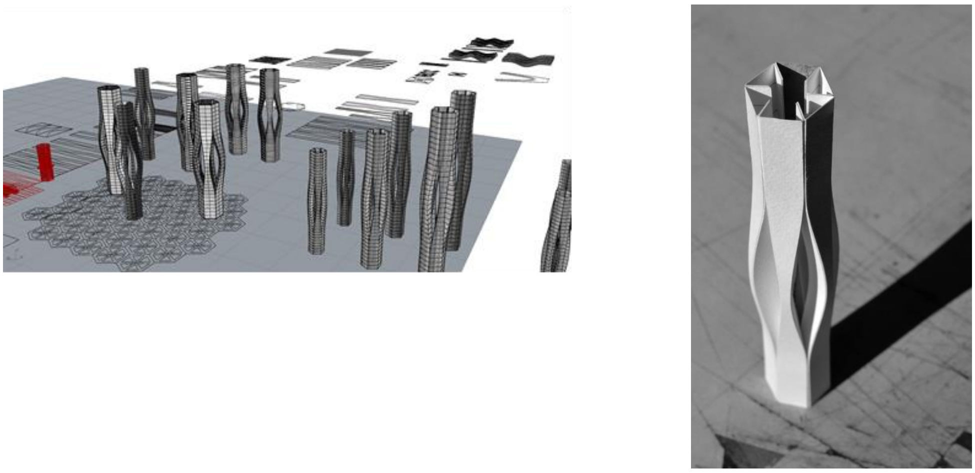
The general purpose of this work was to design a metallic structural element with a three-dimensional free-form having both structural and decorative role, which reinterprets the column idea used in ancient buildings. It was intended that the digital analysis and design to lead not only to an aesthetically item, but also to fulfill its structural function. The purpose was to obtain a curved columnar shape from metal sheets folded by lines that also include curves, which is a new area of current research, called “Curved Crease Folding" [4, 5, 6]. This is possible by generative design approach. By generative design [7, 8, 9], three-dimensional objects are defined through algorithms and mathematical operations. Any geometric ensemble, even complex ones, which involve many constituent components, can be described as a series of processing steps. Associated software packages, such as Grasshopper, facilitate the development of geometric algorithms, significantly easing the design of objects with complex volume [10, 11]. For digital design it was used the Rhinoceros 3D modeling program, augmented by the Grasshopper algorithmic design plug-in.

The main steps of digital simulation of curved folding process are as follows [12]:

- design solution searching by using physical models (usually cardboard made);
- for selected possible models, the development is digitally reproduced in an algorithmic manner, so that defining parameters can be easily modified; cutting-plotters or laser-cutters are used for precise model execution (Fig. 1a);
- the simulation of the folding process is based on the original development interpreted as a rigid origami pattern; the outcome is nevertheless a ruled surface which therefore is developable and has ruling lines; for different configurations of the same development are acting differently oriented ruling lines;

- further analysis: different analysis, be it structural or otherwise, can be applied.

There have been produced several prototypes at model level, as column design proposals (Fig. 1a); the final design has a hexagonal footprint and is pictured in Fig. 1b.



a b

Fig.1.Variety of experimental designs made by algorithmic tools (a) and the final design (b)

The canopy uses a repetitive module that can have different configurations able to describe freeform surfaces (Fig. 1b).

To allow both the geometrical and structural study of the three-dimensional volume, the Rhinoceros 3D modeling program, augmented by the Grasshopper algorithmic design plug-in, has been extended through Kangaroo and Karamba packages for structural simulation.

According to preliminary investigations, it appears that the column may have applications in takeover gravitational loads. The alternative chosen to be developed consisted of six identical strips.

With Kangaroo 1 program there has been tried the use of different forces to simulate the material bending behavior. The first was the Bending Force, which impart a reluctance to change the angle between certain springs, i.e. lines that define the mesh. This force was applied to the ruling lines, but the result was not satisfactory, because it did not bend the median zone (Fig. 2).

A similar result was obtained using Shell Force (Fig. 3). An adequate result has been achieved by implementing an appropriate planarization force (Planarize), which imparts to the quads forming the mesh the tendency not to deviate from planarity (Fig. 4).

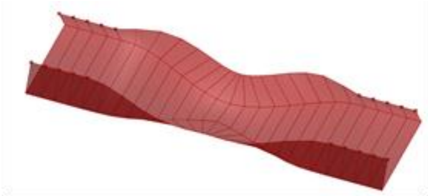


Fig.2. The resulting 3D model with Kangaroo program, using Bending Force.

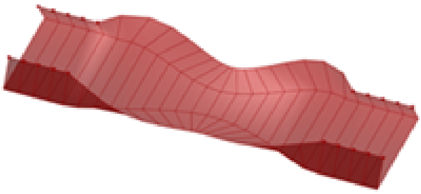


Fig.3. The resulting 3D model with Kangaroo program, using Shell Force.

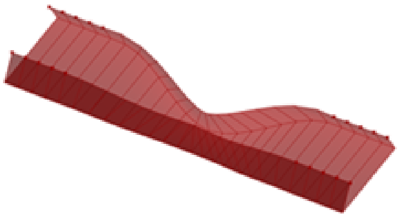


Fig.4. The resulting 3D model with Kangaroo program, using Planarize.

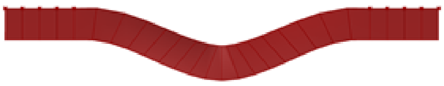


Fig.5. Heads alignment determined by end points fixation.

These variants were based on spatial constraints of some points in the two ends of the strip; the points on the bending lines remained in place, to ensure proper alignment of the heads (Fig.5), and their homologous points on the perimeter were rotated to give the desired angle at the ends.

3. Experimental model execution

Due to quality-cost ratio, to perform the experimental model at 1:3 scale, it was used a stamping steel of Fe360 (CEN-EN)/ A283 (USA ASTM). In this case, higher grade metallic materials are not suitable, due to their anisotropy and pronounced response to cold work [13]. Sheets of 2000 x 1000 x 1 mm, achieving an optimal framing of the column elements on the format, were used.

The coordinates of the architectural model unfold of the column were transferred to the operating program of the punching machine with numerical control (NC). At first, it was chosen the technology of making a groove in the thickness of the material. Several models with varying depths were made, but stamping (bending) did not bring acceptable results. Then it was passed to the punching of circular or oval (elongated) holes, with the axes situated on the bending line (Fig. 6). Circular perforations were made, with different diameters and different steps. Perforations were performed by numerically controlled stamping punches and by dies calibrated for selected nominal diameters.

The next stage was the bending of the elements in accordance with the perforations route. Several methods were used: stamping with articulated grips (knives) manually or electrically powered and stamping with prisms hydraulically powered, numerical control operated.

After stamping, the constituent elements of the column were calibrated and welded. It was used a welding technology with controlled atmosphere, the welding bead being executed in the inner areas, on the reinforcements edge, not to affect the visible surfaces and to provide rigidity to the assembly.

After welding and finishing the outer edges, the corrosion protection was achieved by priming and liquid painting of the experimental model.

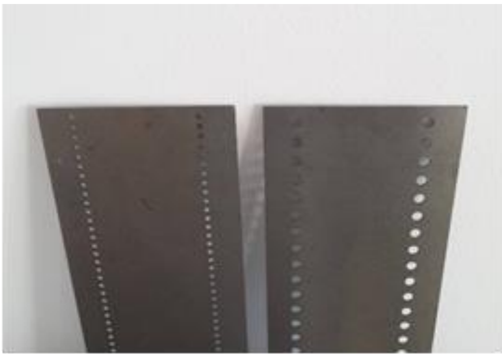


Fig.6. Perforations made on folding lines

Fig.7. Metallic experimental model (punching with oblong perforations)

4. Conclusions

The present work aims at obtaining of a light metallic structure which serves also as a functional element. The use of metal sheets offers the opportunity to obtain volumetric forms with a complex geometry at low cost, while being efficient in terms of structure. To obtain structural performances, the mechanical behaviour of the metallic material in elasto-plastic regime is used.

An algorithmic approach to the design process enables an efficient work, which can explore various solutions in search of the one that best meets the objective. Once defined the algorithm, the input data can be modified, so that instead of a single solution to obtain a family of solutions, for members to respond in their own individual parameters to circumstances to be put into practice (different loads, tri- or bi-axial frame different dimensions, etc.).

The behavior of the material used is valued on the base of the column design. The folding process is digitally simulated, but there is an ongoing dialogue between digital and physical environment, informing each other. It can be reached an automated adjustment solution in response to the real-time results of digital pattern testing. Finally, a method for the practical realization of the structural element is proposed.

Acknowledgement

This work was supported by a grant of the Romanian National Authority for Scientific Research, ANCS – UEFISCDI, project type PCCA, contract no. 316 / 2014.

R E F E R E N C E S

[1] *J. McCormack, A. Dorin, T. Innocent,* Generative Design: a paradigm for design research, in J. Redmond et al. (eds.) Proceedings of Future ground, Design Research Society, Melbourne, 2004;
[2] *Vishal Singh, Ning Gu,* "Towards an integrated generative design framework", Design Studies-Elsevier Ltd, 33, 2012, pp. 185-207 ;
[3] *H. Kloft,* "Structural Engineering in the Digital Age, Digital Real-Blobmeister-First Built Projects", in P.C. Schmal et al. (eds.), Birkhäuser, Boston, 2001, pp.198-205;
[4] *R. Narain,T. Pfaff James, F. O'Brien,* "Folding and Crumpling Adaptive Sheets", ACM Transactions on Graphics, vol.32, no. 4, month 2013, pp. 51:1-51:8;
[5] *L. Zhu, T. Igarashi, J. Mitani,* "Soft Folding, Computer Graphics Forum", vol. 32, no. 7, Proceedings of The 21st Pacific Conference on Computer Graphics and Applications, Oct 7-9, Singapore, Pacific Graphics 2013;
[6] *A. Dias, Levi H. Dudte, L. Mahadevan, C. D. Santangelo,* "Geometric Mechanics of Curved Crease Origami", PRL 109, 114301 (2012), Physical Review Letters 2012, pp. 1-5;
[7] *Rivka Oxman,* Informed tectonics in material-based design, Design Studies 33 (2012), Elsevier Ltd. 2012, pp. 427-455;
[8] *H. Whitehead,* The practice of smart geometry, L. A. Jeffress (ed.), Inside Smart Geometry, New York John Wiley, 2013;
[9] *Vishal Singh, Ning Gu,* "Towards an integrated generative design framework", Design Studies vol. 33, 2012, Elsevier Ltd., pp. 185-207;
[10] *K. Terzidis,* Algoritmic Architecture, ISBN 0-7506-6725-8, Elsevier, 2006;
[11] *** http://www.grasshopper3d.com
[12] *Tachi, T.; Epps, G.,* Designing One-DOF Mechanisms for Architecture by Rationalizing Curved Folding, Proceedings of the International Symposium on Algorithmic Design for Architecture and Urban Design, Algode Tokyo 2011;
[13] *Yu, W.; LaBoube, R.,* Cold-Formed Steel Design Forth Edition, Missouri: John Wiley & Sons. 2010.