EFFICIENT GENERATOR OF STRUCTURAL TOPOLOGIES BASED ON IRREGULAR CELLULAR AUTOMATA

B. Bochenek and K. Tajs-Zielińska
Institute of Applied Mechanics, Cracow University of Technology, Cracow, Poland

1. Motivation behind present study

Appearance of efficient and versatile optimization algorithms stimulates fast development within structural topology optimization [1] research area. Utilizing this progress in recent years increasing range of implementation of structural topology optimization especially to practical engineering problems has been observed. One of the most important problems to cope with is to adjust optimization algorithms abilities to high requirements imposed on effectiveness and reliability of structural analysis tools. It is well known that for real structural elements implementation of regular finite element meshes is in many cases inadequate. For example complicated shapes, holes and sharp edges indicate stress concentration, and in order to obtain reliable stress distribution the regions of such intensity should be covered with a more fine mesh. On the other hand to avoid an increase of computational cost one wish to use rough mesh for regions where element concentration is not necessary. As the result, a non-uniform density of elements represented by irregular meshes should be used in order to achieve an accurate solution without excessive increase of number of elements. Since structural analysis is often a part of optimization problem therefore irregular mesh problem arises also for performing design process. Although irregular meshes have been frequently used in structural finite element analysis, implementation of unstructured meshing in topology optimization tasks is not in common use.

2. Irregular Cellular Automata

Recent development of Cellular Automata implementation into optimal design problems has shown that the automaton can be an effective tool for generation of optimal topologies. Nevertheless, the vast majority of results have been obtained to date for regular lattices of cells. The aim of the present paper is to extend the concept of Cellular Automata towards irregular grid of cells related to non-regular mesh of finite elements. Introducing irregular lattice of cells allows to reduce number of design variables without loosing accuracy of results and without excessive increase of number of elements caused by using fine mesh for a whole structure. The implementation of non-uniform cells of Cellular Automaton requires a reformulation of standard local rules, provided for regular lattices. This paper proposes therefore new local update rule dedicated to irregular lattices of cells. The rule incorporates influence of cell sizes on update process. Assuming that a plane structure is considered and quantities A_i and A_{ik} stand for areas of central and neighboring cells, respectively, the update rule takes the following form:

$$(1) \qquad \delta d_i = [\frac{A_i}{A}(-1)^{\alpha_0} + \sum_{k=1}^{N} \frac{A_{ik}}{A}(-1)^{\alpha_k}]m = \tilde{\alpha} m \qquad A = A_i + \sum_{k=1}^{N} A_{ik}$$

The specified values of power α_0 and α_k are transferred to the update rule (1) according to the following relations:

$$(2) \qquad \alpha_0 = \begin{cases} 1 & \text{if} \quad U_i^{(t)} \leq U^* \\ 2 & \text{if} \quad U_i^{(t)} > U^* \end{cases} \qquad \alpha_k = \begin{cases} 1 & \text{if} \quad U_{ik}^{(t)} \leq U^* \\ 2 & \text{if} \quad U_{ik}^{(t)} > U^* \end{cases}$$

The form of rule (1) together with relations (2) guarantee that $-1 \leq \tilde{\alpha} \leq 1$. The above new proposal can be treated as generalization of the original rule [2] extended here towards irregular cell lattice. It is worth underlining that the above rule can be easily extended towards spatial structures. The only modification to make is to replace plane cells areas by spatial cells volumes.

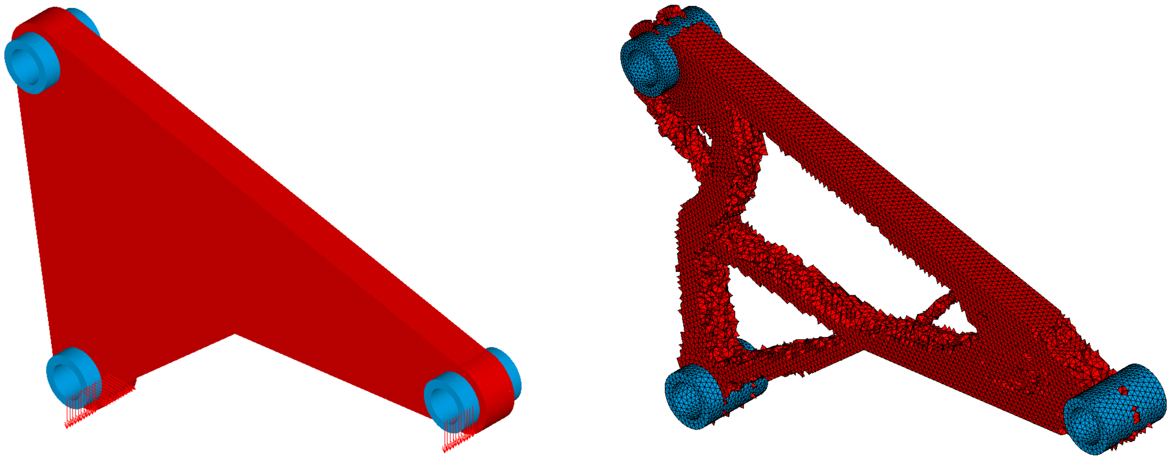

Figure 1. Initial structure (left), obtained topology (right)

3. Generation of minimal compliance topology of 3D structure

Minimal compliance topology of the mechanical part presented in Fig.1 is generated using irregular Cellular Automata algorithm described above. Loads are distributed across a single lines of nodes inside both bottom cylindrical holes, while the inner right area of upper cylinder is supported. Mesh refinement is applied in the region surrounding support of optimized part as indicated by stress concentration. Cylindrical parts (blue coloured regions) are treated as nonoptimized. The irregular mesh that consists of tetrahedral elements/cells has been applied. The minimal compliance topology has been generated for 121769 cells, and the final result is presented in Fig.1. One can investigate that in order to obtain equivalent topology using regular lattice the number of cells should increase to more than 321 thousand elements. That many elements are required to get the same compliance and maximal stress values for final topology as compared with results obtained for irregular lattice.

4. Concluding remarks

The approach presented in this paper demonstrates a significant potential of application to problems which cannot be adequately represented by regular grids. It is not necessary to use a very fine mesh for whole structure therefore number of elements and design variables can be significantly reduced. Although number of cells is limited, because of only local mesh refinement, information about stresses and displacements can still be correct. The use of irregular meshes can be helpful while modelling a domain geometry, accurately specify design loads or supports and compute structure response.

5. References

[1] M.P. Bendsoe and O. Sigmund (2003). *Topology optimization. Theory, methods and applications*. Springer, Berlin Heidelberg New York.

[2] B. Bochenek and K. Tajs-Zielińska (2012). Novel local rules of Cellular Automata applied to topology and size optimization, *Eng. Opt.* **44**, 1, 23-35.