Architectonic logic of construction on the example the plane elasticity problems solving by the finite element method

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Abstract. The development of architecture, within the process of architectural form making, is based on architectonic logic. From the constructive-physical side, the architectonic logic can be studied by certain methods of elasticity theory, in particular, by the approximate numerical method of finite elements. The article deals with the algorithm of revealing the architectonic logic of eccentricities on the examples of the plane problem solving of elasticity theory. The formal characteristics of the eccentricity logic in connection with the process of form making are considered. The article describes the action of logic within the historical context of the process of architectural form making development, on the example of the constructivists and deconstructionists schools.

1. The problem of studying the architectonic logic

Building structures cannot be of any form. It is impossible to appeal to virtual spaces, because the forms are not independent and expresses a specific spatial function even if their physics absence. Is there exists a form of an independent virtual-world, in isolation from the forms of the real world, for examples, the numbers? It is not supposedly known to science. Along with that, architects would like to have a variety of forms, often devoting their creativity to this task. In the present world, some foundations are necessary to build a real architectural form. So, architects rely entirely on constructors, and in the next step, they lose initiative. But in the process of the physical foundations' structure studying, there was an understanding that they give a general principle of building the form in architectural works – architectonics. The term, apparently, was borrowed from philosophers: in particular, I Kant defined the concept of architectonics as the "art of systems"[1]. Later this feature attracted attention of the architectural community, where the idea of the architectonics phenomenon was used in the description of architecture by Karl Bötticher in 1844 [2]. Thus, K Bötticher introduced a contradiction, which mechanism organizes the entire modern and classic architecture without exaggeration. Architectonics imposes specific physical constraints on the architectural form creation.

Architectural construction process is one of ways to overcome physical limitations in the form creation process. Since the time of Newton's mechanics, common knowledge that construction is possible using numerical methods has become. Nowadays, physical sciences are substantially developed, but still they do not fulfill the task of promoting architectural forms diversity. The difficulty can be identified in the empirical fact that, there is a paradox in the basis of the architectonical logic in the form making process. When an architect aspires to strength, he/she loses diversity; when he/she aspires to diversity, he/she loses strength. The more complex is the spatial connections form of a structural system made in the material, the less optimal and stable it is. Here we refer to the third law of thermodynamics in physics.

In the architecture theory [3 - 5], the problem associated with this difficulty has been considered for a long time and is generally known as "Le Corbusier Binomial"[4], the problem of combining function and form. In the architectonic approach, architectonics, as a kind of organization complex way, unites opposite poles of thought between rational and sensual, function and form, construction [6] and composition [7]. In the classical form, the problem can be formulated as follows:

On one hand, the proponents of the constructive approach base themselves on the possibilities to minimize the material usage through rational optimization calculations, but they loss forms' diversity as an expressive ability of architecture. This gives a rise to the modern architectural-philosophical school of constructivism: V G Sukhov, N Forster, R Piano, S Calatrava, and other architects.

On the other hand, the proponents of the compositional (deconstructive) approach rely on the sensual artistic expression ability of architecture to elevate the latter to art, but they face the need to save materials. This gives a foundation of the deconstructivists' modern architectural school: R Koolhaas, Z Hadid, F Gehry, T Ito, D Libeskind, etc. This school has arisen on the basis of J Derrida's philosophy.

Therefore, a problem of architectonic synthesis in obtaining holistic understanding of architecture arises.

Hypothetically, the solution can be found in the logic of eccentricities. In this case, the logic of eccentricities is a new one as an architectonic approach to constructive design. The architectonic approach is considered as one of the possible ways of force optimal transfer to the foundation. Architectonics is understood as the relation between load and support.

The aim is now to clarify the architectural features of the constructive approach, explaining the mechanism logic of architectural form making at the constructive design level.

2. Identification of the construction architectonic logic

In order to test the hypothesis, we develop a detailed rationale for the eccentricities logic as a search for architectonic axioms, using extremely simple examples from the field of design. The optimization calculation on the classical plane problem basis of elasticity theory [8] with the help of approximate numerical finite element method and the method of topological strength optimization [9] is taken the method of solving the architectonic synthesis' problem. The task of this study is generally considered as optimization. The goal of the optimization calculation is to minimize the structural material used amount. The variable parameter is the geometric shape of the structure. The boundary conditions are the upper limit of mechanical stresses intensity at the boundary, where there is a transition from elastic to large deformations, irreversible or plastic. The equal-stress state is considered as the most optimal one. For the equal-stress state, the material works equally from the standpoint of arising mechanical stresses, which are numerically equal for all points of the working construction. This allows achieving the optimal state of the construction, in terms of saving the material.

In order to perform the calculations, one can use specialized software systems of the CAE class (computer-aided-engineering): ANSYS, Autodesk Revit Structure, Autodesk Inventor, SolidWorks, COSMOS-M GeoStar, NASTRAN, SOFiSTiK, ABAQUS, etc. So, to study the finite element method, the method was additionally implemented by the author at the program level, including the strength topology method [10].

The considered algorithm of the architectonical logic studying also requires the development of specialized terminological tools. We consider the features of the structures (which are nonstandard in the plane problem of the elasticity theory), associated with the eccentricities' analysis, which are a physical characteristic that explains the logic of architectonics as the relation between load and support. This makes non-standard the way of interpreting the considered problem.

In connection with the necessity of analyzing eccentricities, we have changed the axes of the cross-section plane taken in the plane problem of the elasticity theory and selected a new, longitudinal plane of cross-sections (zOy). Where the action of the external load on the considered structures take place from the top down along the z-axis. This allows introducing into the study of plane problems of the eccentricities concept at the level of external and internal force factors, such as the ratio of elementary moments and longitudinal forces acting on the considered surface elements.

The material "Pentelic marble" [11]: modulus of elasticity is (EX) = 35E+003 (N/mm2); shear modulus (GXY) is 15,474 E+003 (N/mm2); density is (DENS) = 2600 (kg / m3); Poisson's ratio is (NUXY) = 0.15;

Consider an algorithm based on the conducted study.

1. The analysis of 64 variants of the window openings forms is performed. As a result, as the most effective ones, we choose the straight, hexagon-shaped and the form of a cavity. The window opening in the form of a cavity, as an opening crack, has the best result in terms of stresses intensity.

2. The calculation of openings on the basis of hexagons and hexahedral structure is made. At the corners of the hexagonal structures there is a high intensity and concentration of stresses. It makes necessary a research using special discontinuous finite element method.

3. We perform a topological analysis of the window opening shape based on the cultivation of the hole. The initial opening, in the topological optimization process, grows into an elongated vertical one. This results in a "colonnaded" structure, where the completion remains uncertain.

4. The search for completion is considered similar to the task of finding the optimal shape of the capitals. In this case, the topological analysis gives an approximation in the direction of the capital shape straightening.

5. The obtained straight form of the capital, as well as the hexagonal version for the openings, gives a high concentration of stresses at the form’s corners. A simple (constructive) rounding allows redistributing internal forces and reducing the intensity of stresses at the corners being rounded. Rounding corners is necessary, and this indicates the effectiveness of the cavity-shaped opening.

6. The subsequent topological analysis of the capitals, as a console, gives a straight-shaped solution.

7. As a result of the console topology, we arrive at the so-called “momentumless console” in Figure 1 (c), working without eccentricities. Topology gives only straight-shaped solutions.

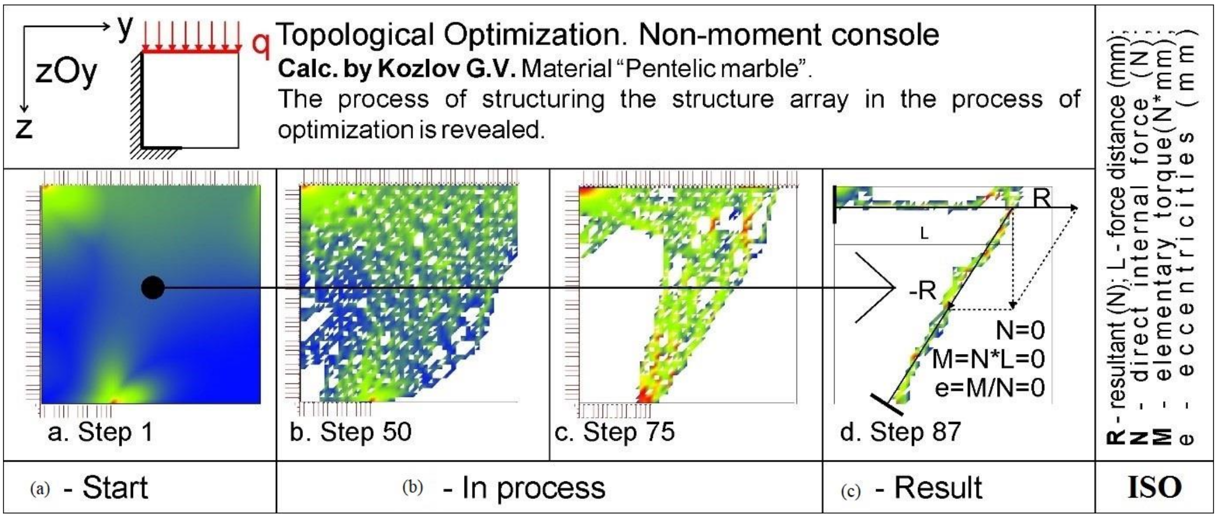

Figure 1. Topological optimization of the console scheme.

8. These results indicate that, in the working process of without eccentricities, an equal stress optimal state can be achieved in Figure 2 (a).

9. The intensity of the tangential stresses increases, and it becomes impossible to achieve the optimal state as the equal stress one, working with eccentricities in figure 2 (b).

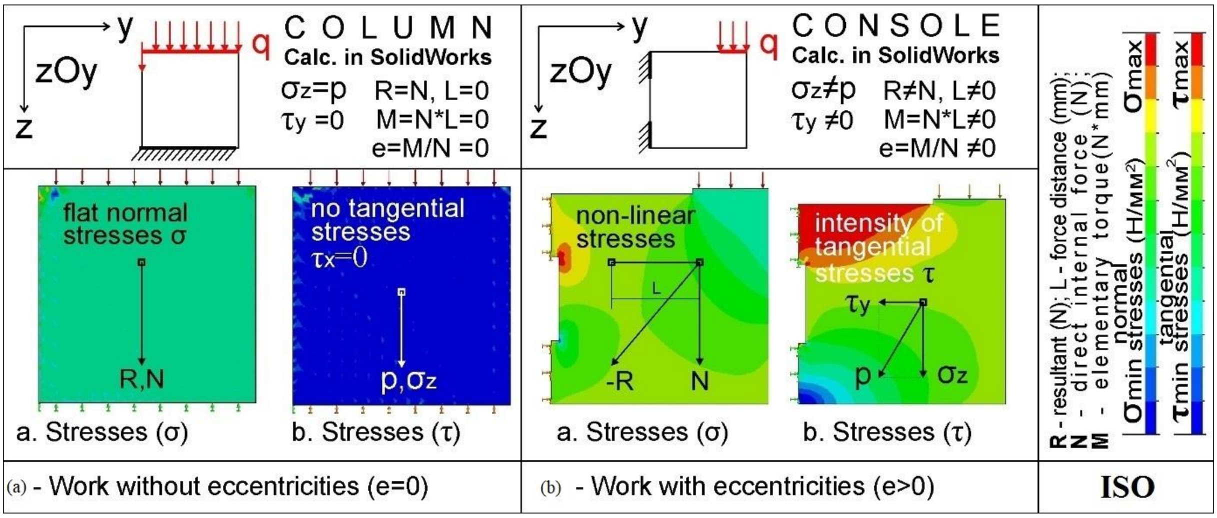

Figure 2. Intensity of tangential stresses.

The considered method of this architectonics empirical study allows describing the internal structural logic of architectonic form, which is responsible for the architectural plasticity formation, articulation and allows identifying a number of design features important for understanding architectonics and its role in the development of architectural form making.

The logic of eccentricities allows describing the design process.

The analysis of eccentricities architectonic logic allows determining the formal features of this logic. Within the logic of eccentricities we can fix the "basic forms" of the architectural design language similar to article [12]: straight (cross) when a solution is certain, and a circle ("circular neighborhood" [13]) when a solution is uncertain. There is a logical unity of basic forms on the borders, because at a point, for indeterminate stresses, there arise indeterminate eccentricity and a state of "dynamic equilibrium"[14] act in architecture too [15]: their strength is to sit still (Isaiah 30:7).

The optimal construction form in the considered conditions is straight and flat. If one desires to develop a form that is different from a straight line, there inevitably arise eccentricities. For any form, the eccentricity is always preserved; even for the straight form, the eccentricity is close to one.

3. Architectonic logic in the style school of form creation process

According to these results, it is possible to establish the simplest logic of form making, which depends on the eccentricities: constructive optimization leads to the form reduction; the reverse process of development, the form construction occurs for the parameters of eccentricities different from zero. From the structural point of view, within the framework of eccentricities' architectonic logic, the process of form making necessary for architecture is a process, which is reverse to the process of optimization in design. The company of the architect N Foster creates projects using the latest design forms, architectonically connected with expressive composition. It is an continuation example of classical architectonics' tradition and its modern rethinking, such as in the "HSBC" bank, for example, where the outer frame is made in a straight structure of "momentless consoles" (work without eccentricities), which makes this design effective. On the contrary, deconstructionists show their readiness, in favor of distinguishing the form, to go beyond the design possibilities, shifting the building as much as possible from its base area (a force moment arises), as R Koolhaas does in his work "De Rotterdam", located in the Netherlands.

4. Conclusion

The obtained results and the revealed features of the constructive approach to the architectonics study can be established empirically, with the help of FEM. Thanks to the considered methods, taking into account these features, it is possible to develop new computer technologies for automated architectonic form making, in particular, for such areas as neotectonics [16] using the adaptive-tectonic method [6].

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