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INSTRUMENTAL ROLE OF GEOMETRY IN DESIGN PROCESS OF FOLDED ARCHITECTURAL STRUCTURES - RESEARCH AND EDUCATION

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This paper is related to the fact that geometry can be used as an abstract tool to describe and represent the form and the structure of physical objects. In that respect, the potentials of Origamics as medium of inquiry for structural design in the field of architecture were introduced in the semester project done at course Structural Systems at Belgrade University Faculty of Architecture. Through intensive project period, divided in stages, the objective was to test method, which enabled students to analyze geometrical principles of folded structures in order to apply these principles in the development of new designs.

Introduction. Digital technologies, transfer of knowledge from other disciplines and the re-use of methods and processes from other industries as needed, is demarcating current architectural discourse. In that respect the importance of geometry has been re-emphasized by significant advances in computer aided design and digital fabrication (CAD-CAM). New design approaches that are being developed profoundly change nature and established hierarchies of architectural practice and education. Origami have evolve from being a craft to an interdisciplinary methodology "Origamics" with wide range of applications proving itself as valuable tool to develop various engineering and design solutions. Amazing technical and artistic advancements have been made, largely due to a growing mathematical and computational understanding and analysis of the subject. [2] The potential of folds as an interface to gain cognitive experience on spatial transformations, computational design, form-finding, and as medium of inquiry for structural design in the field of architecture were introduced in the semester project done at course Structural Systems at Belgrade University Faculty of Architecture.

Process. Through intensive project period, the objective was to test methods, which enabled students to analyze geometrical principles of folded structures in order to apply these principles in the development of new designs. In order to strengthen design process the project was divided into three successive stages: analysis, transformation and implementation, where each stage was built upon the results of previous one.

3.1. Analysis. During the first stage geometrical and structural principles were analyzed, by students divided in groups with the task to study different flat-foldable tessellations by making physical and digital models and consider their possible application in the in the context of architectural form. Understanding the mathematical and geometrical pattern relations were essential parts of these studies. Traditionally, origami was designed by trial and error/or heuristic techniques based on the folder's instincts. In the realm of mathematics origami forms can be considered as the mapping of tessellations into 2D and 3D space. In general these tessellations are derived from applying isometric and/or similarity transformations of lines and line shapes in 2D space (paper in traditional studies). In the development of most of these patterns it is possible to say that there is a grammar, consisting of shapes (lines and angles), and "grammar rules" to be followed, mostly the geometry based on Huzita's Axioms, Maekawa's Fundamental Theorems, Muira's Patterns, Kawasaki Theorems. These axioms and theorems have been first converted into successful algorithms by Robert Lang which served as base for development of commercial software. [7]

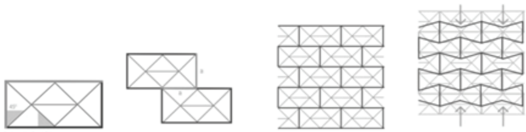

Fig. 1. Generator, String, Creasing Pattern (CP), Folding Pattern (FP)

Form structural studies began with definition of generator (starting block) of divergent patterns. Generators represent fundamental units which form strings and mashes/creasing patterns (CP), when distinct generative rules were applied to it. For selected creasing patterns folding patterns were made. Folding patterns (FP) are diagrams which indicate crest lines (mountain folds), trough lines (valley folds), flat folds (unfolded creases) and control lines. Control line is locus of points or nodes where four or more crease/fold lines meet. It is referred as "control" because it controls the form of the fold with its length and its shape in 3D Euclidean space. By continuing with delineation of generic parameters and generative rules which were apply to starting block different folds were created as a result.

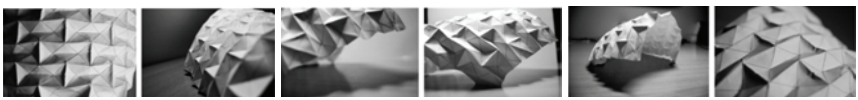

Fig. 2. Folded paper models

3.2. Transformation. In the stage of transformation selected fold tessellation were mapped onto chosen architectural geometry in order to form the geometrical model of space structure. From this phase starts the process of interpretation of folds in the function of architectural geometry. In that respect, and in the purpose of creating a complex family of architectural shapes using folds, classification of underlying geometry types was defined and used as archetypes. Exploration of folds for architectural form-finding and using folds as a primary algorithmic tool, were main objective of this stage.

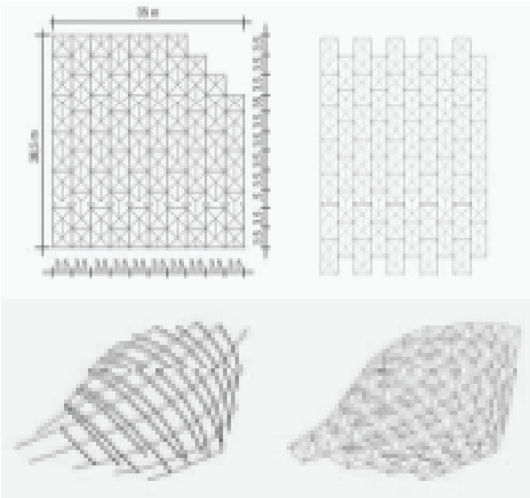

Fig. 3. Mapping selected fold tessellation onto chosen architectural geometry

Mapping of the fold onto selected geometry or defined composition was done by the means of control lines. All geometries could be represented by grids and lines or as wire model. In fact, all CAD packages approximate surfaces and forms in this manner. Fold surfaces can essentially be represented by a grid of control lines that govern them. Each fold has its own unique set of control lines. Control lines define the degrees of freedom (DOF) that fold surfaces geometrically possess, and therefore using control lines as a basis, it is possible to define specific configuration of fold.

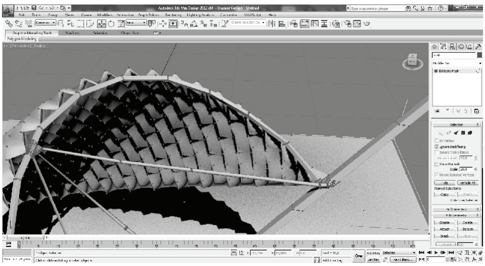

Fig. 4. Generation of digital model of space structure

Studies showed that some folds had more degree of freedom and could fit varied geometries, while others could not, certain folds were ideal for certain forms and not others, though they were all generated using same/or similar starting blocks. Thus, we can state that knowing the properties of the fold's control lines enables recognition and shaping of fold to its natural formal geometry.

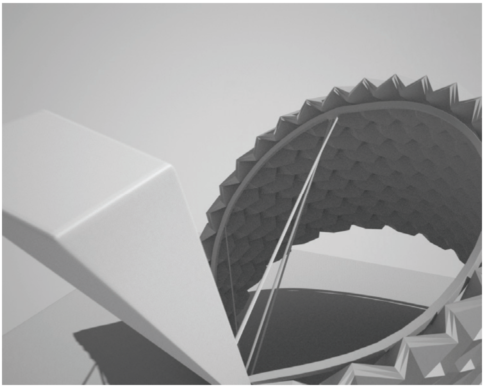

Fig. 5.Model of space structure - render preview

3.3. Implementation. Finally, in the stage of implementation on the basis of model of space structure optimized design solution was elaborated with the consideration of form-structure-function trilogy. Focus was on form-structure and construction-materialization relations and their integration. Beside standard presentation methods used for communication of ideas (plans, sections, elevations, renders), 3D printed physical models were made. By including rapid prototyping in design process holistic approach, in which generative computer techniques in combination with automated fabrication form digital continuum, was achieved. [1]

Fig. 6. 3D Printing (3DP) machine used for production of physical models

In particular case, for model production 3D Printing, sort of additive fabrication, was applied. Additive fabrication is often referred as layered manufacturing, or desktop manufacturing. All additive fabrication technologies share the same principle in that the digital (solid) model is sliced into two-dimensional layers. The information of each layer is then transferred to the processing head of the manufacturing machine and the physical production is generated incrementally by adding material in a layer-by-layer fashion. In 3D Printing (3DP), layer of powder was glued to form objects, or in specific case prototypes of design solutions.

4. Conclusion. Geometry alone may not be the answer to all the problems in architectural design process, but it does play an underlying essential role. Application of geometrical computational methods as guiding design principle enabled for a formal exploration in constrained design conditions and improvement of the structural design process. At the end, as it was anticipated, students become aware of geometry of folds as a source of inspiration, develop new areas of competence with regard to structural design methodology, and exceeded themselves in terms of interesting designs. Our further expectation is that we will build upon our experience with integral design approach and see exciting results in terms of innovative project proposals. In that respect research is left open-ended.

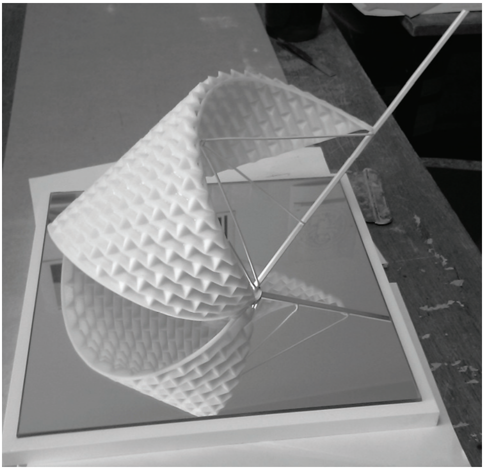

Fig. 7. Finished 3D Printed physical model of a design proposal

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Аннотация

В статье рассматривается тот факт, что геометрия может использоваться в качестве абстрактного инструмента, чтобы описать и представить форму и структуру физических объектов. Соответствующий раздел был введён в курсе «Конструктивные Системы» в Белградском Университете факультета Архитектуры. Была поставлена задача в течение интенсивного проектного периода изучить метод, который даёт возможность студентам анализировать геометрические принципы формообразования сложенных конструкций для того, чтобы применить эти принципы в разработке новых проектов.