Digital design and fabrication

Case study: seashell

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Abstract. Computational aspects of architectural design have revolutionized actual process, and have made a new platform for cooperation that spans across all disciplines. The focus of this study is to understand how the seashell form can be applicable in design process of human architectures. Our approach will show the act of choosing an inspirational natural form and its application into the virtual world, then digitalization, transformation, and evaluation of the form that are suitable for human architecture. 3D model generating would be performed by doing the scan of a selected seashell form. Further action would be to import the object as a tool in the Zbrush application, and continued modeling transformations. This phase would include other parameters that need to be integrated during the architectural design process since architecture usually exists in a radically different environment in comparison with the seashell.

Keywords. Complexity; architectural form; generative design; digital design fabrication; rapid prototyping.

INTRODUCTION
Contemporary world is a place of constant change. New technologies are present at every field of human activity. In spite of traditional reluctance that architects have when it comes to new and unknown, most of the architectural community is finally starting to be aware that it needs to except technology, and embrace it as a new source for architectural practice, even from the early stages of the design process. Until recently, typical shapes used by designers have been rectangles, spheres, triangles, squares and cylinders – Euclidean Geometries. As free form shapes no longer are constrained by the traditional drafting and machine tooling, it is now possible to build these shapes as formations with unique details and appearance. In that sense the structures in nature have always been great lessons for human study. Having been in development for several billion of years, only the most successful structural forms have survived. One of the most beautiful, interesting, yet complex natural forms are seashells. The focus of this study is to understand how the seashell form can be applicable to human architectures, not as strict imitation, but as a starting point in generative process of creating architectural forms. Digital methods are used to scan selected seashell form, as well as to suggest a variety of possible architectural forms.

In that sense needs for effective delivery of results within processes of designing, manufacturing,
and other aspects, have significantly improved. Effective use of available resources needs new tools and approaches, which are being developed as a result of rapid movement and advancement in computer technologies, and they directly incorporate computer controlled systems into manufacturing processes. The approach to development of new design has extremely changed, in regard to former design development, and all thanks to important achievements in different computational and manufacturing technology areas. As an addition to CAD/CAM/CAE, technologies of rapid prototyping are being introduced as they significantly reduce time and costs of architecture design. Rapid prototyping have expanded the list of possible Euclidian and non-Euclidian shapes for play by designers. It is one of few clear methods that can help designers effectively build free form shapes for design projects, by producing a prototype. The potential of an effective prototype is acquired information in design that will make full scale production economically, functionally, esthetically feasible.

In this paper, we have introduced a DDF method (Digital Design Fabrication), as a new tool for architects in their conceptual design. The Digital design fabrication method is a two-stage process of working that integrates generative computing and RP into one process. All RP techniques have the same approach. Based on that assumption all RP systems have similar chain of process, containing five steps, which are:

- 3Dmodelling,
- Conversion and data transfer,
- Testing and preparation,
- Fabrication,
- Post processing.

Through a presentation of issues, procedural observations, and research findings, we will present the potential applications of the DDF, drawn from the experiment done with a chosen complex form of a seashell. It will demonstrate a new phase that should be integrated into the process of design. Hopefully, through further computational education and development, it will help architects in generating new ideas for architectural visualization.

ARCHITECTURAL FORMS

Architectural forms can be defined as one of the strongest expressional aspects of architecture. They derive from our definition of space, and have historically gone through many transformations of their physical configuration and semantic codes. Complexity of architectural forms has progressed through time. The concept of complexity came into modern architecture with postmodernism, which is treated as spatial differentiation and diversity, striving for “architecture of complexity and contradictions” (Venturi 1989).

World of forms is a world of proportion, and their relations. Complications within that world are the essence of the complexity of architectural form, which according to Jencks shows the “creativity rich with possibilities”. The complexity of the architectural forms, characteristic of contemporary architectural creations, can be seen as “deconstruction of the
classical concept of space in architecture - introducing fragmentation of form, disorder and randomness, biomorphous geomorphous shapes – seeks original expressions and creating a new grammar which would give a more dynamic, more complex spatial relations. Design of spatial form in contemporary architecture, based on the geometry of complexity and nonlinearity, is enabled by the development of new scientific theories, technological capabilities and by applying computer programs that are based on the theory of complex systems.” (Cahtarevic 2008).

Most complex, proportionally perfect forms can be found in nature, and the nature has always been a place where man has sought inspiration, and translated it into analogies in architecture, science, art, etc., which has been documented since the earliest prehistoric cave drawings.

“Biomimetics, also referred to as bionics, biomimicry, bioinspiration or bioinspired design, can be defined as the implementation of design principles derived from biology… Three distinct levels can be recognized at which patterns can be translated from biology to architecture. The lowest level, and the most obvious, is direct copying of biological objects… The second level of translation is the recognition of patterns in the way problems are solved in biology and engineering....The third level of translation is more closely integrated with current practice in engineering and design. The patterns are more abstract, but are there, in that problems are defined and solved within a closely defined framework based on a large number of published patents.” (Vincent 2009). In our paper the attempt is to make a shift from the first level of biomimicry, by illustrating direct copying of biological objects just as one of many possible ways of jumping further into the conceptual design process, instead of starting from scratch.

SEASHELL FORMS

There are many examples of the use of natural forms, or the phenomena as the basis for architectural geometry. Through history and especially in recent times we have seen a lot of examples of that. Our interest is focused on research how natural forms can be a starting point in generative process of creating architectural forms. “The research has been outlined in a number of mathematical relationships that control the overall geometry of shells.” (Jirapong and Krawczyk 2002). Mathematics is the science of patterns and relationships, which helps us to express ideas. By observation and mathematical definitions we extract new parameters into the mathematical framework, which gives us new rules that we can implement for solving different architectural problems. Architecture, which exists in a radically different environment from the seashell, has other parameters that need to be integrated during the architectural design process. These parameters are in relation with the functional requirements of architectural forms.

Beautiful, natural forms such as seashells have especially been suitable for analysis and applications into digital design process.

Seashells exist in specific natural environment, which has its implications on defining the final shape. Extracting such form from its original environment, and putting it in another context, leads to new condition for designing in accordance with its inputs of new environment. “The abstracting process combines three major components that influence the final result of an architectural form. These components are the seashell geometry properties, seashell structural properties and architectural properties.” (Jirapong and Krawczyk 2002). Using mathematical language selected model of seashell can be described as combination of circles, lines and forms they make by their translations and rotations. Moving on from geometry
to structural properties, as we do further analysis of seashells forms, we can find analogy in how shell geometry responses to any load from outside world by redirecting forces within a very thin section of shell structure along its natural multiple curvatures. All this is why seashell forms are suitable for extraction of principles and their further analysis and application. Never the less, architectural properties that every building has to fulfil in order to produce human architecture, no matter which design principles are used during the design process, the final goal should always be inhabitable architectural forms.

DIGITAL DESIGN FABRICATION
The Digital design fabrication method is a two-stage process of working that integrates generative computing and RP into one process. The term digital design has various meanings and definitions. “Digital design as a method can be generically described as a constructed relationship between information and forms of representation that support design in computational environments.” (Sass and Oxman 2005). Generative design, or generating a 3D model, can be achieved through several methods, by using software systems, mathematical data, reversible engineering, etc...

Software systems, such as Proengineer, Catia, and others, can provide data and representations of the model. Mathematical data, as results of analysis and measurements are used as inputs for generating 3D models. Reversible engineering represents use of digital technologies like 3D scanners, to translate existing physical objects into digital models. “RE aims to automatically generate computer models from existing physical ones. RP aims to create physical model based on computer model, quickly and directly with minimal human assistance.” (Plančak 2004). The implications of rapid prototyping in digital design tend to emphasize the continuousness of design, materialization and construction.

CASE STUDY: SEASHELL
An idea is starting point of each design process, that doesn’t appear in vacuum, it is triggered by inspiration, which can be found everywhere around us. For this case study, inspiration was found in the seashell.

Next step was observation of the seashell complex forms, and development of strategy and concept how to use seashell in future design. Sketch (Figure 3) was used to present the idea, and it became clear very early in the design process that use of ordinary computer skills and software won’t be sufficient for representing the design in full version.

Next phase was defining of all the steps that had to be parts of digital design and defining what we need to do, which softwares we need to use to express our desired design. Algorithmic thinking is
needed in these design approaches. Observing patterns in natural environment, recognising how they act in their natural environment is inevitable, and whether their relationships say something useful for solving the problems.

Illustrations of steps that need to be taken in this kind of approach are shown in algorithm:

1. Scanning “object” by laser scanner 3D Davids laser scanner (“object” will be the start of our concept design)
2. Processing of “cloud of points”, creating 3D model (shape model)
3. Creating solid object by Pro E (Catia)
4. Modifying and making our final design
5. Preprocessing of model for Rapid Prototyping
6. Preparation of 3D model for 3DP process (Z Print)
7. Production of “green” part by 3DP machine (z310+, Z Corporation USA)
8. Post processing of “green” part – production of final product

Generating of 3D model was performed by scanning of selected sea shell. The model was set within camera objective, the laser passed over the model 20 times from different angles. Laser that we used to scan model was contactless David Laserscanner. Since this is a complex form, this type of laser is preferred for scanning in these cases. It should be noted that scanning must be done carefully and slowly in order to collect vast number of dots, which gives us more detailed results. Each recording with a laser can be seen, and should be saved in order to overlap. After recording model from different angles, as we rotated the model around one axis, in the same direction, spanning 360 degrees, we overlapped resulting images in order to generate the model, as basis for our design. Overlap was also made in software program 3DShape Fusion, where we performed the scanning by choosing the ADD button, and choosing the saved surface 1 and surface 2 and then pressing the command ALINE. That way overlapped surfaces dots were identified. After that, we excluded the surface 1, added surface 3, and repeated the same process for surfaces 2 and 3. The same process was continued with two by two surfaces in order to get compact model which had overlapped surfaces, placed on exact position. Once we had done the procedure for all of the 20 surfaces, we turned on and selected all of the surfaces and pressed the button COMBINE. As the result we have a model that consists of all surfaces that we recorded, with dots set to the proper place. Obtained model was saved and the use of other software packages was acquired for detailed model transformation and manipulation. We used GEOMAGIC Studio 10 software. First we had cloud of dots and by using method of triangulation we transformed model into a surface and deleted excess dots. For these actions, we used commands: Point phase, Reduce noise, Uniform Sample, Repair intersections, etc. Relax Boundway. After saving as STL format, model can be further processed in Pro Engineer, or CATIA software. The same software was used for modeling, designing and 3D printing. Working process requests knowledge of software packages, and multidisciplinary approach, which improves final results.

In our work we collaborated with Faculty of Mechanical Engineering in Tuzla that gave us unique opportunity to perform our practical part of our paper in the Faculty lab. After importing the model in ProE, we removed the lower part of the base (plasticine) which we used to fixate seashell during the scanning process.

Special interest architects put on 4th stage of process: modifying and making final design. This stage integrate skills and knowledge about computer software and virtuosity of architect to be able to implement those skills in architecture, as this case shows how to use natural form in exploring new concept of constructing object. It is not just about design in sense of aesthetic, but constructing also. Shape study will allow architect to use natural form in architectural design. The scanned model was imported in 3ds Max software, containing several mesh structures, which needs to be grouped and exported as an .obj file, quad type geometry.
without texture and material library. According to the fact that this is scanned 3D model with about million polygons (982500) it was needed to minimize model up to 80,000 polygons to be able to efficiently manipulate and operate with model. Further action was to import the object as a tool in the Zbrush application. Zbrush application requires work based on pixels (2,5D pixels, which besides having a width and height, also has depth). Zbrush makes specific kind of editing possible, with its own brush tools. This enables development of very complex and precise interventions on the mesh structure of the object, as: configuration modeling, all kind of space transformations, and texture painting on very surface of the object, and upgrading of the object to HD geometry level which later on can be used in context of very refined researches and additional visualizations. Alignment of model was done in Zbrush with smooth brush and after it was exported as an .obj format in 3ds Max in which it was by using prooptimizer minimized up to 76,863 polygons and maid as one unit. Using

Figure 4
The scanning process
Figure 5
Shape study

Figure 6
Final shape option
spline volume was structured and patch area was
done with all smooth shell lines. Rough border was
removed. On the flank opening is performed. Result
of such modifications is a model that could again
be exported as an .obj file, with a possibility of re-
peated importing in any 3D or CAD application.

After defining the final satisfactory design, the
new model is ready for realization in the material
world, as generative design and rapid prototyping
close the cycle of digital design fabrication.

CONCLUSION
Nature has always been an endless source of inspi-
ration for architects. Richness of forms and shapes
prompted our exploration of nature. Earlier in time,
architects had certain constraints, due to lower lev-
els of structure and material technologies. Most of
the forms and shapes, inspired by nature stayed only
in their imagination and on their sketches, only few
brave as Gaudi succeeded in breathing life into his
nature inspired beautiful forms. Architects of today
don’t have those boundaries, and that is provided by
technology advancement and computation. Now, as
the possibilities have no boundaries, and the com-
putation has made abstracting natural forms into ar-
chitecture possible. Complex visualizations and fab-
rications are made by simple computation. It is very
important to stress significance of the link between
future design and use of new technologies, and the
fact that multidisciplinary approach is inevitable. Un-
til recently architects had to be familiar and have at
least basic knowledge in all other engineering disci-
plines, but now contemporary world has introduced
a new aspect that enforces obligatory knowledge of
new software packages, new technologies.

This paper has illustrated the approach to
design that shows all preliminary stages of design
process, and a possible path that can be chosen in
sense of implications of natural forms into the de-
sign, as an initiating generator of architectural form
conceptualization. The case study shows the act of
choosing an inspirational natural form and its ap-
lication into the virtual world, then digitalization,
transformation, evaluation of the forms that are
suitable for human architecture.

In contemporary society, digital design literacy
of architects is expected, as well as constant update
with technology development and growing possi-
bilities of different software packages. By having
that knowledge, architect becomes aware of im-
portance of collaborations and openness to other
disciplines, and of their contributions to architec-
tural design process. Those elements affect the cog-
nition of creativity, understanding the limitations
of technology and building techniques. Overall, it
concludes in liberation of the mind and more crea-
tive designs.

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