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TEACHING PARAMETRICISM AS A STANDARD SKILL FOR ARCHITECTURE

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Abstract. The traditional need for coding to create parametric design has become quite obsolete with the advent of powerful visual programming languages for most becoming architects of the current young generation that are studying all around the world. Parametricism might become one of the standard skills for applicants seeking for a position at architectural design practices. It raises a question – how to implement the parametric knowledge into the workflow of a classical architectural designing approach, and rethinking the way we present these concepts at university level education of architecture.
Additional knowledge of subjects is necessary, for example, about the structural integrity, material tolerance, fabrication optimization, sustainability issues etc. just to name the most frequent areas where lies the highest potential of making mistakes when these new systems are in use. Meanwhile the CAD/CAM paradigm that let architects design straight for fabrication brings new challenge for construction practice.
Parametricism is an excellent platform of research for form finding, as there is very little amount of time needed to recreate significantly different design proposals by changing the variables, as soon as the bigger system of internal relations is set up.

Keywords: CAD/CAM paradigm, coding, intricate systems, parametricism, teaching.

Introduction

Architecture is being one of the slowest forms of art if we consider the time since the early designs are adapted, technically elaborated and proliferated, and finally built. Architectural projects also involve spending significant amount of material resources and energy in order to be built, and it is the responsibility of an architect to make good quality of design that is innovative and contemporary. Research in architecture and the design disciplines must involve experimental design and prototyping, including prototype testing (Schumacher, 2012). Without experimenting, the discipline of architecture is stagnating and basically recompiling and reinventing the previous experiences based on their success and failure. To understand the significance of parametric architecture that has been emerging since last two decades, we have to look and understand the technological background that has brought it to us, both from the aspect of academia and its practical application. This article also reviews a scenario of teaching parametricism for next generation of architects in university degree level education curriculum from the point of view of parametricism being a creative tool in architecture.

1. State of the art of parametricism in academia

Currently parametricism is gaining new insights and popularity and it is positioned as one of the most progressive directions in contemporary architecture. Very often parametric architecture has extravagant shape and form that has a continuous set of included processes being translated from systems into a proliferated material. The Association for Computer Aided Design in Architecture (ACADIA) emphasizes on usage of the digitally driven technologies in architecture to be needed and unavoidable, taking in account the vast effect on the practice, education and research in architecture. Any field needs a healthy attitude and keep its tolerance to the developments, continuously reevaluating questions of inclusion or exclusion, importing or exporting, cooperation and isolation to new ideas, techniques and discipline, new technologies. Within these changes a new discourse emerges and it offers unexpectedly new processes for the field of architectural design. ACADIA also claims that this digital discourse further divides into these categories: digital pedagogy, digital tools, digital production and fabrication, digital visualization, digital projects, digital design, digital

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representation, digital thinking and digital practice (Bermudez & Klinger, 2011). Besides ACADIA there are also many smaller scale and more regional ongoing platforms of discussions covering the subject, for example, the Alvar Aalto Meeting on Contemporary Architecture in Seinäjoki, Finland, held in September 2017, that covers a wide variety of topics and viewpoints reflecting the current state of architecture and technological developments related to construction and the use of buildings. We are more aware than ever that technology and architecture cannot avoid being parameterized, this being also the center point for academia to cover all abovementioned sub-categories of digital discourse. From the academic perspective we could test the outcomes of setting objectives to learn both theory and practice in making experimental parametric projects. That can be obtained by bringing the parametrical architecture to be prioritized as one of the standard skills for future architects.

2. Standard skills for architects in the 21st century

Architect Rem Koolhaas raises the problem that we are not making space but buildings, underlining the trend that many projects are expressing beautiful superficiality, leaving the internal qualities behind. He states: "When we think about space, we have only looked at its containers. As if space itself is invisible, all theory for the production of space is based on an obsessive preoccupation with its opposite: substance and objects, i.e. architecture" (Koolhaas, 2013). Throughout the work of contemporary architects we can observe the will to be original and outstanding, making the preoccupation of Koolhaas more important with vast emergence of parametrically derived architecture that features extreme complexity in terms of its exterior formulations and high-end beauty of sophistication. This may have become the number one reason why students of architecture are willing to apply parametricism to their study projects – built examples in forms of small-scale pavilions and large-scale urban interventions are populating shiny magazine covers and filling up social media. Parametric architecture has been long time seen and communicated as being very experimental, and on the edge of art mixed with vast computation. Leading schools in the field, like Southern California Institute of Architecture (SCI-Arc), Architectural Association School of Architecture in London (AA), Universitat Internacional de Catalunya in Barcelona (UIC) and ETH Zürich amongst many other, have included a wide curriculum of the subject of parametricism in their academic programs for the last two decades. This has been facilitating for the graduated alumni from these schools to spread the popularity of parametricism into significant number of countries around the globe. Many of the pioneers have defended PhD theses in the field and are dedicated to spreading their knowledge in universities as research projects, while others are working in the most prestigious architecture design offices and creating the next masterpieces. One thing is common – the expectations for young architects standard skills have been elevated to complete digital design literacy, including by default the skillset necessary for CAD/CAM application and creation of parametric architecture. Author underlines that in the usage of computer as the main tool for design lies a risk where practice without good support of theoretical knowledge may render the results to be superficial and architectural designs to be made without any relation to the genius loci. The parametric design already does not respect very much the historical background of the older heritage buildings, main reason being totally different formal language and the usage of different and contemporary materials. As parametricism has no link to the classical historical styles, every local situation of design has to be addressed individually and with respect to the surroundings. Whenever possible the parametricism should be cautiously practiced next to buildings with established historical value.

3. Associating the Computer Aided Design with the risk of limited creativity

Architect Vassilis Kourkoutas in his "Parametric Form Finding in Contemporary Architecture: The Simplicity Within the Complexity of Modern Architectural Form" (Kourkoutas, 2012) explains the origins of many parametrical landmark projects that have been created, for example, of using numerous operations applied to curves and other parametric setups that have extremely elementary mathematical iterations or distortions applied to simple geometrical primitives. This sort of simplicity in the design process with the help of computation can be seen a positive feature, thus for many it is still being criticized as being negative and unhealthy for the quality of architecture. Designers can quickly give shape for a sequential progression in two or three dimensions in search for new forms in many techniques, ranging from three-dimensional massing or two-dimensional unrollable developable surfaces as it can be seen in most of the Frank Gehry's undulating facade skins. The layouts for digital manufacturing of the elements or technical assembly drawings are also easy to be mastered once the necessary software is used in correct workflow. In older days before computers became the standard tools the experimentation was often too much time consuming or too difficult. Professor William Mitchell from University of Harvard comments that the professors teaching architecture in the leading schools of architecture are defending the point of view, that this simplicity of experimentation sometimes results in less amount of time being spent for preliminary conceptualization or preparations for many original projects, because students are already aware that little modifications to the digital models can suddenly create an unexpectedly perfect project. Professor Mitchell calls this phenomenon as the window-shopping mode, explaining that sudden forms emerged on the screens of computers can give structure to sudden alternatives that need to be evaluated in the process of project development (Mitchell, 1993). Also many professors teaching architecture admit that projects made with the help of CAD will often look extremely good with a relatively small time invested for their creation. The lack or the deficit in design is being substituted with infinity of solutions. Even though most of the work can be obtained in shorter time, the quantitative pre-digital preliminary research is still indispensable (Cuff, 2001). There are also several observations being made of a "creativity trap" problem facing more often inexperienced designers – that is a situation in which the CAD software is limiting the artistic level and the control of the design with its pre-set tools and object libraries. Advanced 3D modelling power users advise to get acquainted with tutorials and additional plugins to avoid that limitation.

4. Building envelopes and skins

If we take a look at our current architectonic scenery it is obvious that there is concern about experimenting with random forms, also called anomalous forms, according to some treaties. As a result of the architects search for experimenting with new formal solutions and with the appearance of computers and software packages able to shape surfaces, there is a freedom of forms that has not been available until recently. To set some examples, we can point out at ONL (Oosterhuis_Lénárd) and Erick van Egeraat in Holland, Steven Holl in North America and Alejandro Zaera and Farshid Mussavi in Spain (Verdú, 2004). All these pioneers in the field of digital architecture share a common passion for fluid free-flowing forms, which mainly have been obtained with the help of advanced modeling software exploring the dynamics of animated movement in 3D space. Today, more than ever, ground is simply occupied and envelopes have devolved into spatially disengaged thin skins, whether or not formally elaborated, fashionably styled, patterned, or technologically enhanced (Hensel & Turko, 2015). Definitely it is worth elaborating ways of solving integral advanced designs that bind together the concave with convex spaces and solve the abovementioned issue of detached thinking in terms of building volume vs. skin. That is a task to be addressed, as early in the architectural education as possible, so it becomes a part of the digital design routine.

Further in the research author explores defining the scale and size for a set of exercises that would benefit from the creative techniques of CAD/CAM paradigm through collaborating and pre-fixed design methodology and individual materialization inside a bigger intricate system. This is meaning that the internal parts would communicate with the whole system in order to achieve a synthesis or holism. The only way to generate intricacy would be working with the rigors and proportions derived from calculus, thus involving mathematic knowledge, exploring the complex curvatures, variations with incremental change of dimensions, material tolerance and assembly logics for bigger intricate systems.

5. Exercise setup for Morphology 2016

Teaching the basics of parametricism and its application was carried out in an experimental exercise setup in University of Monterrey (UDEM) within subject of Morphology, that is a second semester theoretical class in first year of architectural degree studies. Students come to this class with no preliminary skills in CAD, having taken in the first semester the classes of composition, analytical drawing, descriptive geometry, mathematics and an introductory course to architecture. Morphology is not a studio of architectural design, rather a supplementary course to support the design thinking for the entire study career to come, before students actually take the very first design studio in the third semester. This class is also being part of the new study plan of UDEM that was first carried out in the spring of 2016 with this exercise setup. Morphology covers wide range of theoretical topics from digital modeling to programmed geometries, concentrating on everything that cover basics in geometries of the 3D modeling, various types of surface modeling, designing simple components and their possible aggregations, understanding topologies, parametricism and programmed fabrication. The setup for this exercise was designed to cover all of the learned skills in one technically practical and experimental hands-on design exercise that had to be done in 3 weeks time from concept to a built design object.

Main objective was to solve a complex surface and understand its fabrication constraints, detached from a deeper look to the aspects of the surrounding design environment, while applying only the technical skills of programming and coding through visual programming language (VPL) Grasshopper that is a plug-in running within Rhinoceros 3D modeling software. Grasshopper is great for modeling generative and algorithmic architecture, perform automated transformations and prepare fabrication layout drawings, and perform many more operations in an intuitive way without the need for learning actual coding or scripting. It still involves understanding the logical sequence of parametric operations and their internal relations to succeed and get feasible design results.

Total of 27 students of architecture were given the freedom to conceptualize the desired object that was based on application of knowledge from all of the topics learned throughout the study semester. In the first step a pre-fixed surface was proposed and then split into smaller pieces, each measuring 60x70 cm. The surface shared a common topology that was obtained lofting together four complex contour curves, delivering continuity, undulation and gradual changes within the volumetric setup. From this step onwards all the rest of the exercise was done in an entirely parametric way, learning the basics of cutting the surface to equally distributed longitudinal and lateral slices to create the base for a parametric tool that could help to materialize any complexity of the structure in 1:1 scale (see Figure 1).

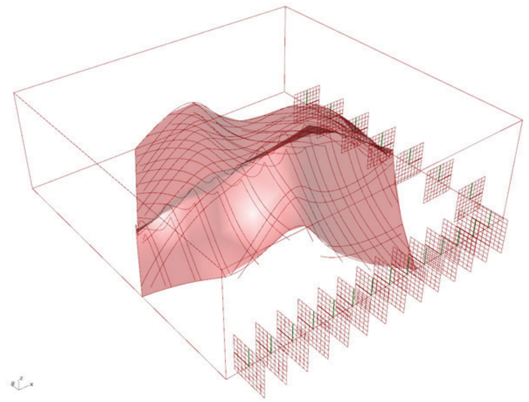

Figure 1. Construction planes are set on x-axis and y-axis to cut any complexity of surfaces into regular contours

Following step was creating a final proposal for the surface to cover the given 11 square meters of wall (540x210 cm) that counted for 3 lines and 9 columns of unique pieces or cells, each designed by individual student and assembled together in a whole setup. Several smaller fragments of the cells were tested for functionality of the parametric system (Figure 2) that by default was slicing the cell orthogonally, followed by an introduction of an irregular rotation angle to the contours in order to see the potential of the same parametric systems behavior in a non-standard situation.

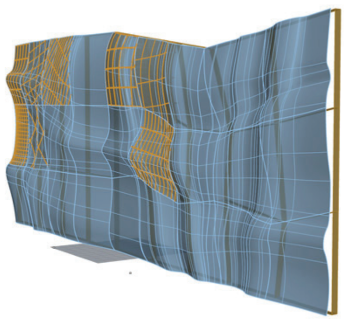

Figure 2. Entire wall panel sized 540x210 cm where several cells have applied the early stage cuts in non-standard angles

Apparently several errors were observed and it needed a custom backup solution. The parametric setup was developed to intersect any x-axis and y-axis oriented contours in their actual physical locations of the crossing points (Figure 3), but as soon as the rotated cells left some contour intersections outside the imaginary orthogonal bounding box of the designed domain – the system malfunctioned and did show unexpected problems in most of the intersections. This is a proof of a fact that parametricism cannot solve simple operations that humans could do intuitively, but once that is setup correctly in an algorithmically correct and logical precision, those systems are facilitating the manual work enormously, saving time and resources of repetitive operations.

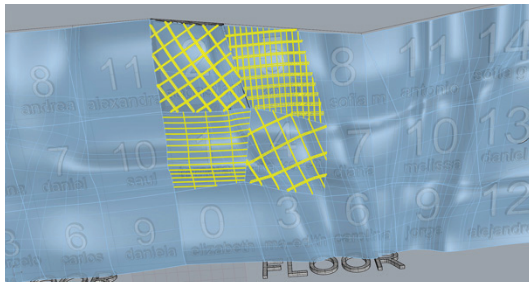

Figure 3. Design for a pre-fixed parametric system that did not fully perform as expected due to its geometrical constraints and the applied mathematical logic of the necessary intersection points

The entire system basically was capable of automating this list of tasks in an absolutely parametric manner:

1) Select the surface.
2) Divide the surface in a selected amount of x and y contours.
3) Choose the height of the intersecting slices of the contours.
4) Choose the material thickness for fabrication (linked to dimensions of necessary intersections to avoid any possible material tolerance errors).
5) Do the necessary intersections with the "Boolean difference" command.
6) Unroll the pieces flat on the surface plane for sending them to the laser cutting.

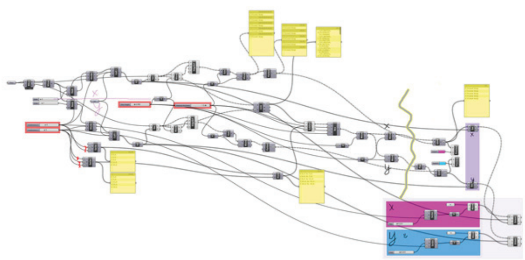

Figure 4. Full Grasshopper definition from selection of the surface to the choice of material thickness and structural dimensions, as well the automated drawing of the contour outlines of all the pieces for laser cutting

For the academic experience the abovementioned Grasshopper definition (Figure 4) was elaborated together with the two groups of students, leaving the actual work of fabrication, assembly and the design decisions of the possible skin (façade) solution for them to finish in any digital or analogue technique that they had learned within the course of the Morphology. At this stage it was also defined that the skin should provide partial transparency of the structural assembly elements, using only opaque materials or perforating solid materials with gradual porosity providing similar performance. In case of the operations done to the material, they had to be designed and executed with digital fabrication tools.

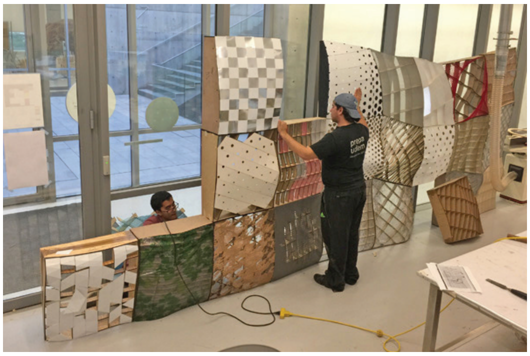

Figure 5. Mounting the cells into the whole installation assembly of the parametric wall

Eleven of the students were capable to come up with the design of the digitally derived skin, while the remaining sixteen students had tried to achieve the assignment setup in a more manual workflow. Most of the students used 3, 6 or 9 mm thick MDF or 5 mm thick plywood for the structure and the box around it, and paper or plastic derived materials for the skin, with some exceptions of textile or metallic meshes. The connection logic was elementary and it involved bolting the details together at the sidewalls of the bounding boxes of the cells.

After all the pieces were mounted together (Figure 5), the installation revealed the whole deliberate look of such an uniform and fragmented design that was able to unite the work of many independent authors and different proliferation strategies (as seen in Figure 6). After further and more constructive review of the final installation one could understand this assignment as a platform for experimenting with parametricism where as well the entire wall could be done in real life situation in just one of the proposed 27 strategies. Such setup could find its place as a separating wall or being a design of an interior decoration, or a fragment in a larger scale in a real buildings façade.

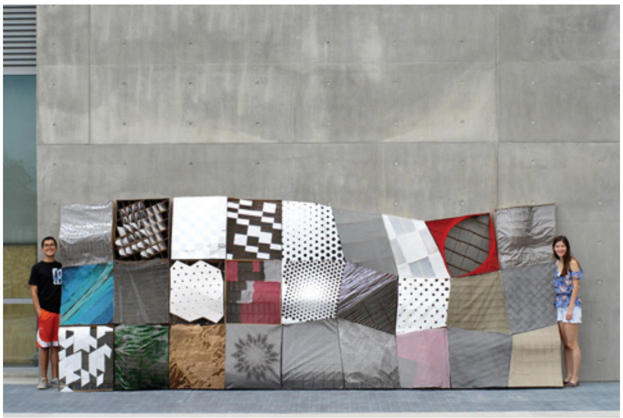

Figure 6. Entire finished parametric wall system prototype in 1:1 scale

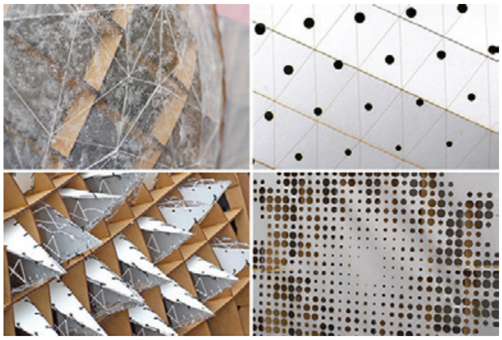

Figure 7. Details revealing different digital strategies for the solutions of the skin that cover shared curvature of the whole installation. From top left: triangulated transparent acrylic covered with silicone, laser perforated and engraved white cardboard, surface faces offset and extruded to acrylic pyramids that are bound together with a tread, laser perforated metallic-coated paper

In this exercise there were separately evaluated these features: the chosen concept and its related research of other similarly built examples, the correctness of the digital file for 3D design and fabrication, the actual built structure quality and assembly, and also the originality of the applied skin strategy. Evaluating in more detail the individual approaches of students who had applied the digital parametric skills also in the design of the skin proves that there are limitless ways to do it. What is initially given for everyone as an equal precondition to cover an element with a parametrically architectural skin, based on what has been learned within 12 weeks of classes both in theoretical and practical application, eventually gives a variety of unexpected procedures and scenarios in its materialization. Applied procedures range from simple triangulation to the mixed use of various perforations and extrusions, all of which have been emerged from the same shared surface isocurves and supported to construction points of non-orthogonal supporting subframe structural ribs (Figure 7). It can be observed that the parametric design has far more patterns of unexpected formal emergence than conventional ways of modern façade techniques, using the very same materials manipulated by digital fabrication craftsmanship.

Every student also left some feedback together with the final presentation, some of it is listed below:

1) It seemed very useful to combine the theory and the practice in a real application.
2) This exercise helped to think outside of the box while getting new ideas of how to design and fabricate objects.
3) You can get inspiration from anything.
4) Ultimately Rhino and Grasshopper are the tools we will be using from now on, that will help us shape our professional future as architects.

Conclusions and future research

In 21st century architectural education it is not about learning one or another particular software but rather about understanding what can be or needs to be done, followed by finding ways to create the appropriate custom tools for solving the problem. It has to be backed with intelligent theoretical knowledge of applying CAD/CAM technologies as creative tools to elaborate complex design issues. This digital design literacy prepares students to integrate advanced workflows into the design studios, giving more freedom for their creative skills. It is not hard to find an open source research that has been involving people from many countries to cooperate on the same subject, where each member is adding or bringing modifications to a predetermined design idea. Rather these designs have to be researched, analyzed and synthesized in real scale experiments to learn the possible implications on the architectural design strategies. The achievements need to be further shared within networks of mind-alike designers, because group work or actual cooperation comes along with higher quality and wider view of feasible solutions. Lot of documenting and analyzing of the obtained results need to be done in order to fully understand what level of profound impact the parametricism will bring for the future architects in practice. The main issues that author found to be concluded in this research are following:

1) The structural integrity has to be part of any membrane or façade solution, resolving the assembly and connection logics of the individual elements.
2) Material tolerance can only be learned in the making, especially in exercises where neighboring components affect local dimensions and create errors in the whole system if they are not being respected.
3) Optimization and automation of the CNC machining time vs. assembly time of the elements can be the deciding factor for choosing on favor of more complex formal explorations. It has to be a priority to achieve better visual effects with less machine operations and therefore lower costs of material usage.
4) Usage of VPL Grasshopper scripts readily available is a powerful design benefit only if these scripts are profoundly understood and adapted to a custom way for individual solutions.
5) Parametric design reveals vast possibilities of new workflows and processes that are non-existent in traditional form finding methods, therefore leaving lots of space for future innovation.
6) The quality of formal languages emerging from parametric architecture raises the discussion of existing artistic values and novelty within the field.
7) Digital design sets new challenges for the construction practice that has historically been depending on the actual labor, as it is now delivered in being fabricated in the highest precision straight from the design files, leaving only the quality of assembly in the hands of construction workers and architects controlling almost the entire process.
8) The digital design literacy has to include parametricism and support it in all of its forms, becoming one of the main driving forces for original formal explorations in the future.

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