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Form Follows Parameter: Algorithmic-Thinking-Oriented Course for Early-stage Architectural Education

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Abstract

The digital paradigm requires efficient methods of teaching CAAD tools in architecture schools. With the trend of enhancing the design process with parametric methods, linking architecture with other knowledge areas, such as mathematics, is gaining in importance. Equipping future architects with skills in algorithmic thinking is yet another challenge for education. This paper describes the workflow of an early-stage course addressing this challenge, conducted at the Warsaw University of Technology's Faculty of Architecture. The course focuses on the students' ability to construct complex geometric forms in the digital environment by introducing an extensive analytic phase. The students study the geometric foundations of real-world architectural cases and translate them into parametric models. Later, they explore the potential of the generated solutions space. The results compare the course's teaching efficiency with the outcomes of past courses covering similar subjects.

Keywords Algorithmic thinking · Parametric form-finding · Geometric analysis · Felix Candela · Shell structures · Hyperbolic paraboloids

Introduction

Geometric descriptions limit architectural design. Architects create within the scope of the available axiomatic system, which affects the imagination and the ability to communicate architectural ideas. Ultimately, it limits our competence to build. Learning to design in a school of architecture involves learning to integrate

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observations, conclusions and spatial concepts. Gibson (1950) argues that this integration is performed by recording a set of complex conditions and thoughts in a homogeneous, representative model: “upright, motionless as a whole, and unbounded; coloured, textured, shadowed, and illuminated; filled with surfaces, edges, shapes, and interspaces” (199). Models are analysed, assessed, used to experiment and, as a result, provide the premises for making a decision. Intuitively, in the teaching environment it is best to use models that closely resemble the discussed objects. However, the creation of such entities is often difficult, if not impossible, in some areas of professional education.

Duarte (2016: 127–130) points out that—along with traditional technologies—students should be introduced to new technologies, such as parametric modelling, in the early stages of architectural education. He suggests that it enriches their future professional skillset and enables them to adequately select tools and techniques for addressing particular design problems and developing custom, innovative solutions. As noted by Özkar (2017), the effective operation of advanced tools is closely tied to knowledge recognised as computational (or algorithmic) thinking, which allows forging of the design idea into its digital parametric representation. However, Özkar emphasises that learning computational thinking does not necessarily require involving computational devices in the process, but should, instead, concentrate on building specific attitudes and mindsets. This process includes form emergence, however it is not to be interpreted only as a generation of new shapes, but also as an analysis of an already existing examples and its context. Both Duarte and Özkar agree that an understanding of the tools and techniques is required to decide when and why to apply them in a conscious and controlled way.

The ubiquity of computerised processes has widened the gap between traditional clay-type prototyping and CAAD modelling (Duarte et al. 2012: 392–411). The simplicity of the design process, which allows achieving remarkable effects in a sequence of elementary mathematical operations applied to geometrical primitives, has noticeably contributed to the multitude of parametric landmark designs in the contemporary landscape (Kourkoutas 2012). At the same time, while fluency in computer drafting and modelling techniques is considered a standard skill for architects in the twenty-first century, voices in which CAAD is associated with the risk of limited creativity arise (Riekstins 2018). In consequence, inserting courses concerning algorithmic thinking into architectural curricula requires careful consideration and planning. This necessity is further related to the observation that teaching in the discussed area is often driven by individuals—digital practitioners—pursuing their own research and design ambitions rather than an integrated pedagogical agenda (Oxman 2008).

Teaching Methodologies

Teaching traditional descriptive geometry in architectural education is widely discussed in the context of changes in methodology (Banerjee and De Graaf 1996; Williams 1998; Salingaros 1999; Pedemonte 2001; Moran 2002; Jakobsen and Matthiasen 2014). There are two main issues raised whose ambitions are not necessarily contradictory.

The first draws attention to the importance of educating students and developing the design rigour inherent to classical mathematics. The second, in turn, focuses on the need for a stronger contextualisation of mathematics in the architectural curriculum. This second aspect is related to the observation that even students trained in advanced mathematics rarely use skills in their design practice. Some valuable explorations in constructing a theoretical framework for a teaching curriculum solving that issue have been undertaken (Teymer 1996; Consigleri and Consigleri 2003; Maor and Verner 2006).

This research proposes a framework for similar exploration aiming to integrate mathematics and architecture of the digital paradigm. The method presented in this paper is very much in line with the approach to architectural design defined as a three-step process: analysis, synthesis, and evaluation (Alexander 1964). In the context of teaching mathematics, it is postulated to transform these elements into education based on conceptualisation, contextualisation, and manipulation (Consigilieri and Consigilieri 2003). However, since the course refers to architectural geometry generated in the digital environment, including elements of parametric and algorithmic thinking, these elements take on a different meaning, especially contextualisation is understood here as a construction of a system based on formal and spatial information relationships (Ambrose 2009). At the same time, didactics and implementation of parametric tools must be considered in a broader sense than simply changing the tools from traditional to digital ones (Picon 2010). In contrast to conventional CAD and programming methods, parametric design based on VPL, taking into account the possibility of iterative conceptualisation, modification, and refinement (Cross 1982) with a real-time visual confirmation (Schon 1983), allows for intuitive creation of geometry in a digital environment similar to sketching by hand (Yazar 2015).

Due to the dynamics in the development of computational tools, its introduction into the teaching agenda is primarily a bottom-up process, as noted before, resulting mainly from the teacher's own agenda (Oxman 2008). In most cases, elements of parametric design are introduced as a complementary skill set needed in a particular design studio. This includes courses with different scopes, including industrial (Agirbas 2018, 2020), architectural (Iordanova 2007; Iordanova et al. 2009; Schnabel 2013; Headley 2013), and urban design scales (Lima et al. 2020). Some work goes even further, comparing design outcomes of using different parametric design tools (Aish and Hanna 2017).

In the aforementioned research, the algorithmic design thinking is exercised in the context of the architectural design studio. The framework presented in this paper aims to reverse this relationship and refocus teaching outcomes onto building general knowledge on algorithmic design methods and related mathematical concepts. In the proposed teaching methodology, the architecture is exercised in the context of algorithmic thinking, parametric design and mathematics.

Experimental Approach to Algorithmic Thinking in Didactics

As an answer to the evolving expectations towards the young architects' skillset, in 2016 at the Faculty of Architecture at Warsaw University of Technology, an experimental course called Digital Descriptive Geometry (DDG) was introduced.

The course was delivered in the third semester of bachelor studies as a part of the broader CAAD training module. The course's objective was to provide students with the basics of algorithmic thinking and to teach them how to consciously transfer design concepts into digital environments (Ostrowska-Wawryniuk et al. 2017: 425–430).

The course was designed as a project based learning (PBL) experience, delivered over one semester in a form of fifteen weekly classes. The classes included tutorials, workshops and critique sessions. The course was introduced as a compulsory component of the bachelor studies curriculum and, as such, it was delivered to a cohort of approximately 150 students. The students worked on their primary assignments in teams. As pointed out by Duarte (2016), cooperation is a significant factor in gaining familiarisation with new design technologies.

The main focus of the DDG course was on developing design solutions to abstract mathematical problems. Each team was assigned a topic, such as non-Euclidean geometry, conical sections and projective geometry, among others. First, the students searched for the intersection of the given mathematical concept with architectural design by collecting real-world cases that they identified as related to the analysed problem. The aim of this assignment was to understand how the particular geometric aspect may influence the design process on multiple levels: from the concept, to design development, and to eventual construction or fabrication. Afterwards, the students developed their interpretation of the issue by designing a geometric form explaining the chosen aspect of the given mathematical problem. The task was to involve parametric tools in the process in order to digitally generate the form elements, simulate the composition's performance and to support the fabrication with the use of computerised numerical control (CNC) (Fig. 1). In parallel, the students were learning the basics of visual programming in Grasshopper 3D software.

The students developed a variety of original and ambitious concepts. However, it could be observed that transferring these concepts into digital tools turned out to be too difficult for students at this level of architectural education. In many cases, simulating these ideas required knowledge of programming languages such as Python or C#, which was far beyond the scope of the DDG course. This observation revealed the lack of balance between the taught component of the course and the difficulty of the assignment. These findings suggest that the topics the students were working on and the methods of formalising the students' understanding of geometry needed verification. Consequently, a significantly altered teaching method was developed.

Refined Algorithmic Thinking Course Methodology

Mitchell (1996: 25) defines architectural form as "its internal physical structure, as described under some appropriate conceptualisation". He explains that this structure can be described with an intertwined network of parameters applied both to the whole as well as to its parts, while the scope of parametrisation is always defined through conceptualisation of the idea. Pottman et al. (2007) argue that the

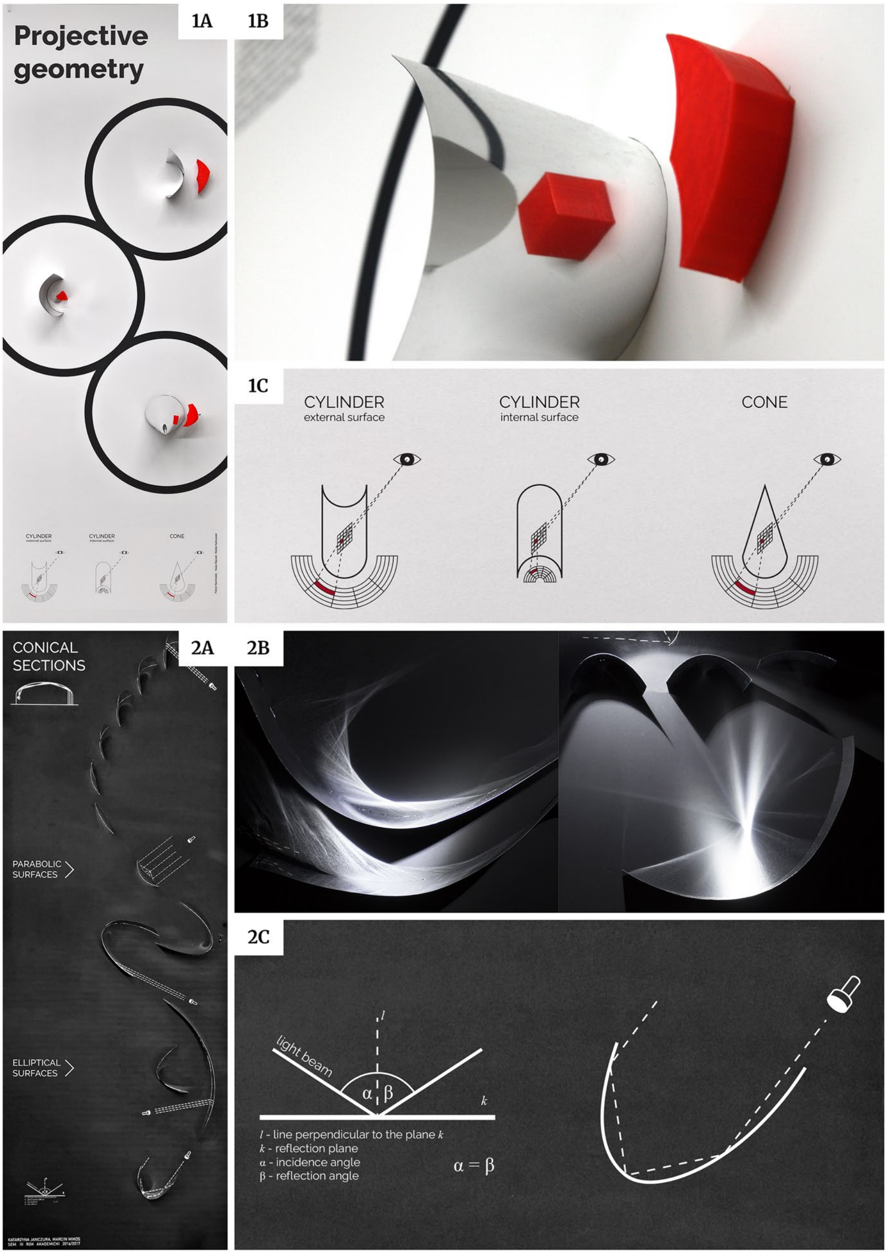

Fig. 1 Examples of students' works from the first edition of the DDG course: **1A** Projective geometry—the authors used anamorphosis to design an installation of deformed solids displayed as regular shapes in the reflection seen from a particular angle; **1B** a closeup view of deformed shapes and their reflection; **1C** a closeup view of the phenomenon explanation (Authors: Wojciech Kalinowski, Patryk Rachwalak, Katarzyna Ślęczek); **2A** Conical sections—the authors studied focusing and dispersing properties of curvatures based on conical sections and proposed a structure of curved panels that demonstrates these properties when lit by a flashlight; **2B** interaction with the structure; **2C** a close up view of the phenomenon explanation (Authors: Katarzyna Janczura, Marcin Mikos)

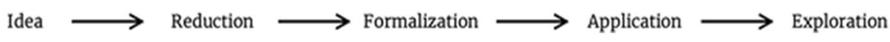

Fig. 2 Representation of design process addressed by the Digital Descriptive Geometry course

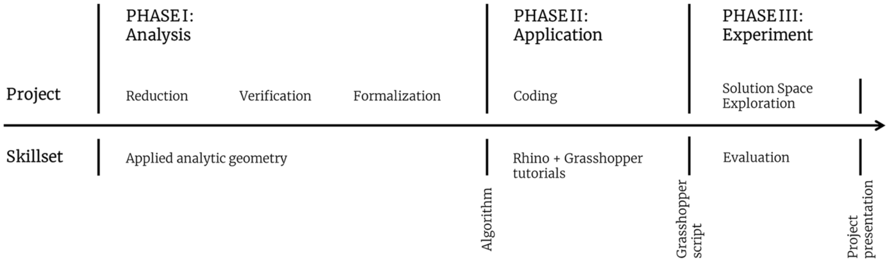

Fig. 3 The DDG course framework showcasing the three project development phases, along with the accompanying theoretical background (skillset) and distinguished milestones (deliverables)

core element of the process of conceptualisation lies in geometry. Understanding its fundamentals is a prerequisite for efficient architectural 3D modelling. According to Hovestadt et al. (2020), the purpose of this process is not only to describe, represent and develop the objects and their attributes, but also to comprehend the space in which they exist and which they create.

The verified DDG methodology aims to integrate these approaches in a structured workflow (Fig. 2) set to equip the students with tools and techniques that allow them to work with architectural forms in the parametric context. The presented method concentrates on acquiring these competences through an in-depth study of real-world architectural cases. The students learn analytic techniques such as geometric reduction, logical analysis and mathematical formalisation. Eventually, they turn an analysed design idea into a formalised concept, which is subsequently forged into an accurate algorithmic solution.

The course workflow is divided into three phases: analytical, applicable, and explorative (Fig. 3). The aim of the analytical phase is to analyse and understand the assigned architectural example; it involves a geometric reduction of the topic building. The task is to identify the form's main elements, such as key shapes, modules, and dimensions (among others). Afterwards, the students put their findings into the form of written instruction. To create the instruction, the students have to translate their findings into the language of mathematics by defining a strict sequence of steps—the algorithm. The aim of the instruction is to allow other readers to recreate the analysed form by following the rules of the algorithm. It is important to emphasise that this first phase is performed without using any computer modelling software.

The second phase is the application of the outcomes of the analysis. Knowing the problem and understanding the mathematics behind it, the students re-generate the form in the digital environment using generative tools. Alongside the coding process, students are introduced to the basics of visual programming using Grasshopper 3D software. Five tutorials covering Grasshopper fundamentals, such as parametric geometry, managing complex data structures, and using dynamic attractors are delivered (Fig. 4). Each tutorial is followed by a workshop during which individual students are given an exercise to solve in Grasshopper. The goal of the workshops is to ground the students' knowledge and help the teachers to identify areas that require further tutoring. The aim of this endeavour is to further develop students' algorithmic skills by confronting them with problems that require developing simple yet unique solutions, instead of memorising predefined procedures. In this manner the students gradually gain both a theoretical background of algorithmic design and a practical expertise (Table 1). Eventually, the students produce Grasshopper definitions that mirror the geometry of the original piece of architecture.

As highlighted by Hovestadt et al. (2020), manipulating (adapting or evolving the objects and their attributes), is an integral part of the design process. Therefore, the third phase is dedicated to experimentation. This exercise is inspired by the research on parametric variations of Palladio's Villa La Rotonda (Park 2008: 145–169). The aim is to experience the advantages of automated form generation which allows one to examine any design space in a short amount of time. The task concerns exploration of the potential offered by the parametric definition prepared in the second phase. The students alter the input parameter values and observe the consequences on the generated form. At the same time, it is intended to increase students' awareness of the importance of rigorous and conscious modification of available parameters. Therefore, the exercise involves defining evaluation criteria allowing students to determine the overly deformed or degenerated solutions.

Case Study—Parametric Candela

The presented course framework was used for the first time in the 2019/2020 academic year. The theme of the initial offering was a virtual reconstruction of the designs of the Spanish and Mexican architect and engineer Felix Candela (1910–1997), whose works were a study material for similar teaching-related exercises in the algorithmisation of the design process (del Blanco Garcia 2018: 581–588; del Blanco Garcia and Garcia Rios 2019: 1577–1585).

Candela is most famous for shell structures featuring hyperbolic paraboloids (*hypars*). His interest in shell structures had developed over time to a point when he became known as the leading practitioner of shell design in the world (Faber 1963).

Fig. 4 The general scope of the Grasshopper tutorials

Table 1 The detailed schedule of the DDG course content delivery

Class	In class	After class
I	Introduction to DDG	Topic selection (random via Moodle)
II	Task#1 initiation	
III	GH1 Tutorial: Introduction to VPL:	Task#1 consultations
	Dataflow design	GH1 Exercise repeat submission (Moodle)
	Data types, parameters, component and connection types	
	GH1 Exercise:	
	Set of arches/vault created on two input curves/architectural case: National Museum of Roman Art, Rafael Moneo	
IV	GH2 Exercise:	Task#1 consultations
	Stairs + balustrade crated on a single input curve	GH2 Exercise repeat submission (Moodle)
V	GH3 Tutorial: Parametric space—Surface subdivision:	Task#1 consultations
	Design space units vs. parametric space	GH3 Exercise repeat submission (Moodle)
	One- and two-dimensional domains	
	Curve/surface subdivision (isotrim) and reparametrisation	
	Curve/surface evaluation at point/parameter	
	GH3 Exercise:	
	Surface subdivision, outlines extrusion to point / architectural case: Esplanade—Theatres on the Bay, DP Architects and Michael Wilford & Partners	
VI	GH4 Exercise:	Task#1 consultations
	Windows + bossage created on a given input surface	GH4 Exercise repeat submission (Moodle)

Table 1 (continued)

Class	In class	After class
VII	GH5 Tutorial: Operations on Data Lists:	Task#1 consultations
	Data lists	GH5 Exercise repeat submission (Moodle)
	Operations (shifting, splitting, reversing, item picking etc.) on lists	
	GH5 Exercise:	
	Paraboloid and hyperboloid based on two lists of points/architectural case: La Sagrada Familia, Antonio Gaudi	
VIII	Task#2 initiation	Task#1 submission (Moodle)
IX	GH6 Tutorial: Multidimensional Data Trees (lists of lists):	Task#2 consultations
	Data trees	GH6 Exercise repeat submission (Moodle)
	Operations (flattening, grafting, simplifying, branch picking etc.) on data trees	
	Transposing one- (flip matrix) and multi-dimensional (path mapper) data matrix	
	GH6 Exercise:	
	Polylines in between flipped data tree of subdivided circles/architectural case: 30 St Mary Axe, Foster and Partners	
X	GH7 Exercise:	Task#2 consultations
	Half-octahedron space frame on a given surface	GH7 Exercise repeat submission (Moodle)
XI	GH8 Tutorial: Mathematical Relations	Task#2 consultations
	Attractors logic	GH8 Exercise repeat submission (Moodle)
	Establishing static and dynamic relationships between various datatypes	
	Remapping data	
	GH8 Exercise:	
	Circle grid with a radius depending on the distance from an attractor geometry/architectural case: Mountain Dwellings, Bjarke Ingles Group	

Table 1 (continued)

Class	In class	After class
XII	GH9 Exercise:	Task#2 consultations
	Wall with bricks rotated by an angle related to the alpha channel of a referenced bitmap/architectural case: Winery Gantenbein, Gramazio & Kohler + Bearth & Deplazes Architekten	GH9 Exercise repeat submission (Moodle)
XIII	Task#3 initiation	Task#2 submission (Moodle)
XIV	Grasshopper test	Task#3 consultations
XV	Grasshopper test (retake)	Task#3 submission (Moodle)

Early in his career, he noticed that the key to understanding luminary structures lies in mathematics. At the same time, instead of following the classical engineering standards, he developed his own calculation methods, treating mathematics as yet another tool for realising bold architectural visions. Most importantly, when working on a design, Candela kept envisioning the structure as a whole: a complex compilation of mathematically intertwined elements where every single calculation directly influences the whole design, an approach which aligns with the principles of contemporary parametric design. Perceived in this way, the works of Candela offer a vast spectrum of complex geometries, a body of case studies suitable for a parametric design-oriented course. For the study cases, fifteen buildings either designed or co-designed by Candela were selected (Table 2).

Each pair of students was given one of the cases in Table 2, which served them as a research subject for the duration of the DDG course.

Following the course workflow, the students began with a mathematical reduction of the given Candela building by identifying the building's basic geometric elements, such as main modules, solids, and surfaces and their hierarchy, as well as the spatial transformations, such as translation and extrusion, required to construct them (Fig. 5). Later, the students formalised their findings into a precise description of the geometry constructing process as a set of discrete mathematical operations. It is essential to point out that each one of Candela's forms could have been formalised in multiple ways. For instance, when describing a hypar, some teams interpreted it as a deformed plane anchored in four points, while others described it with the use

Table 2 List of Candela works selected for the DDG case studies

Case	Design name/Location/Year	Co-author(S)
1	Fernandez Factory/San Bartolo/1950	
2	Cosmic Rays Pavilion/Mexico City/1951	arch. Jorge Gonzalez Reyna
3	Chapel Lomas de Cuernavaca/Cuernavaca/1959	
4	Bacardi Rum Factory/Mexico City/1959	
5	Medalla de la Virgen Milagrosa Church/Mexico City/1953	
6	Ciba Laboratories/Churubusco/1954	arch. Alejandro Prieto
7	Rio's Warehouse/Mexico City/1954	
8	Synagogue/Guatemala/1959	arch. Jorge Montes arch. Carlos Haeussler
9	Lederle Laboratories/Coapa/1955	arch. Alejandro Prieto
10	Signpost/Morelos/1957	arch. Guillermo Rosell arch. Manuel Larrosa
11	Chapel San Vincente de Paul/Coyoacán/1959	arch. Enrique de la Mora arch. Fernando Lopez Carmona
12	Bazaar/Cuernavaca/1958	
13	The Jacaranda Nightclub/Acapulco/1958	arch. Guillermo Shelley arch. Jose Chavez
14	San Antonio de las Huertas Church/Mexico City/1956	arch. Enrique de la Mora arch. Fernando Lopez Carmona
15	Palacio de los Deportes/Mexico City/1968	

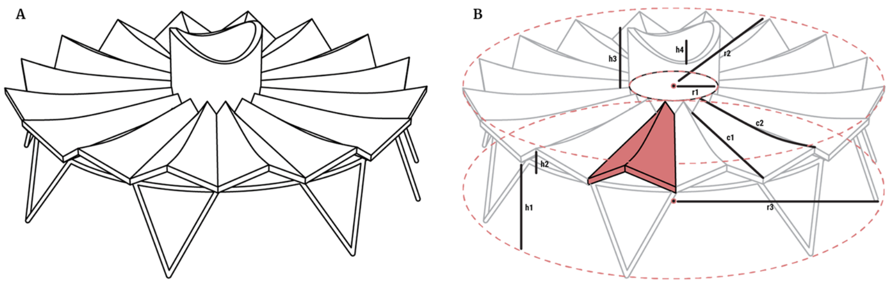

Fig. 5 Geometric reduction on the example of the Bazaar in Lomas de Cuernavaca, in Mexico: **A** basic geometry, **B** identification of main geometric components

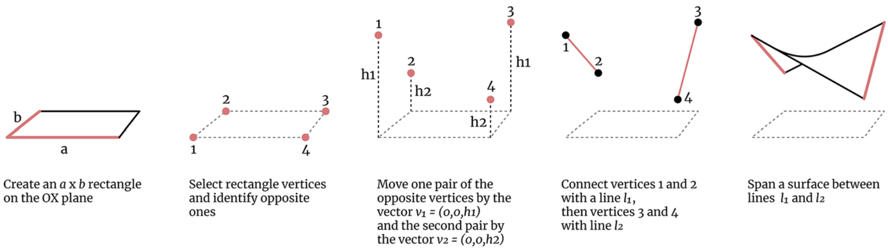

Fig. 6 Example algorithm for creating a hypar as a ruled surface

of its analytic formula—as a parabola swept along another parabola or as a ruled surface. The example procedure of generating a ruled surface between two initially constructed guiding lines is shown in Fig. 6. Additionally, the students identified parameters such as dimensions, proportions, lengths of extrusion, angles of rotation and others that could change the outcome of the operations defined in the preceding steps.

Before concluding the first phase of the project, the students took part in a cross-check session during which they passed their algorithm to another pair—a control group. The control group had to create a drawing based on the submitted procedure. With the procedure steps sometimes being vaguely defined, the students had much space for interpretation. While not knowing the original geometry of the form, each control group was exploiting, bending, and breaking any ambiguities within the given algorithm. The abstracted outcomes of this short workshop revealed the importance of precision, simplicity and clarity in creating algorithms. After this exercise, the students revised their algorithms to leave no room for interpretation. To complete the task, the students compiled their findings in the form of an illustrated infographic describing each step of the process (Fig. 7).

The analytic skillset gained in the first assignment was put to work with the second phase, which involved developing a parametric definition of the analysed Candela building (Fig. 8). The students first translated their algorithms into Grasshopper. All the teams addressed, at the minimum, basic parameters, such as main dimensions and the number of modules, form divisions or tessellations. Some of the teams went further and explored the underlying connections and relationships between the composing elements. Locking the proportions between some of the elements led to the development of definitions where a limited number of variables control the performance of many components of the algorithm (Figs. 9, 10, 11, 12).

The final outcomes revealed that the students who invested more effort into the analytical phase of the project delivered more detailed and more efficiently planned parametric models. These findings suggest a correlation between deepened studies of geometric forms and the ability to express them in an algorithmic process. At the same time, an increased understanding of the algorithm demonstrated that transferring it into a generative tool appeared to be more straightforward.

Discussion and Conclusion

The development of digital tools for architects poses challenges for educators responsible for shaping young architects' professional preparation, and the dynamic nature of this process demands for the evolution of teaching methods. As mentioned earlier, this issue was previously addressed by multiple researchers, however in most cases introducing parametric design is realised as a component of a broader design studio rather than as a distinguished portion of knowledge to be gained. The DDG scenario introduced in this paper presents the latter approach. The aim was to shift the focus from teaching about the tools to teaching about identifying problems and

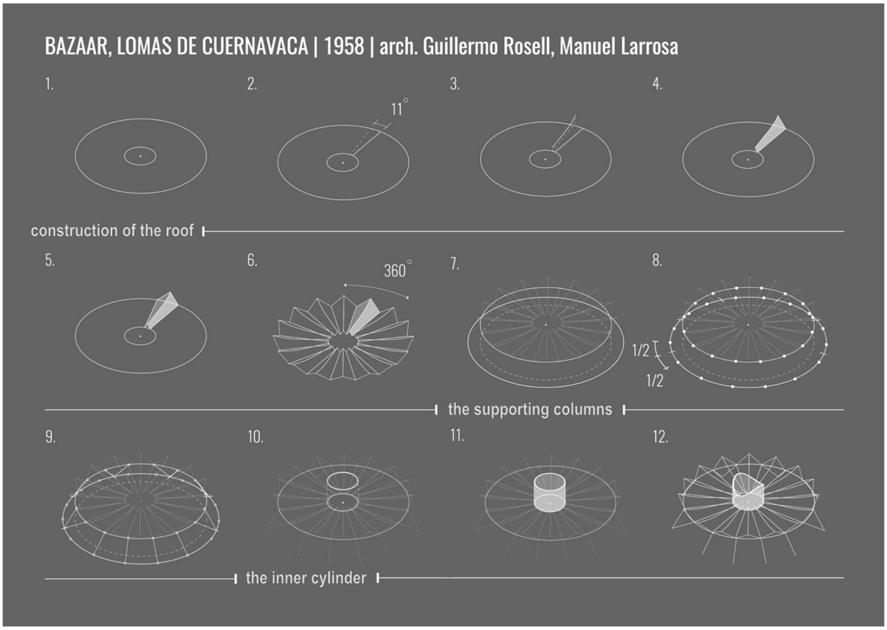

Fig. 7 Example concluding the first phase of the project. Algorithmic interpretation of Bazaar in Lomas de Cuernavaca in Mexico. Authors: Maria Łomiak and Piotr Gontowski

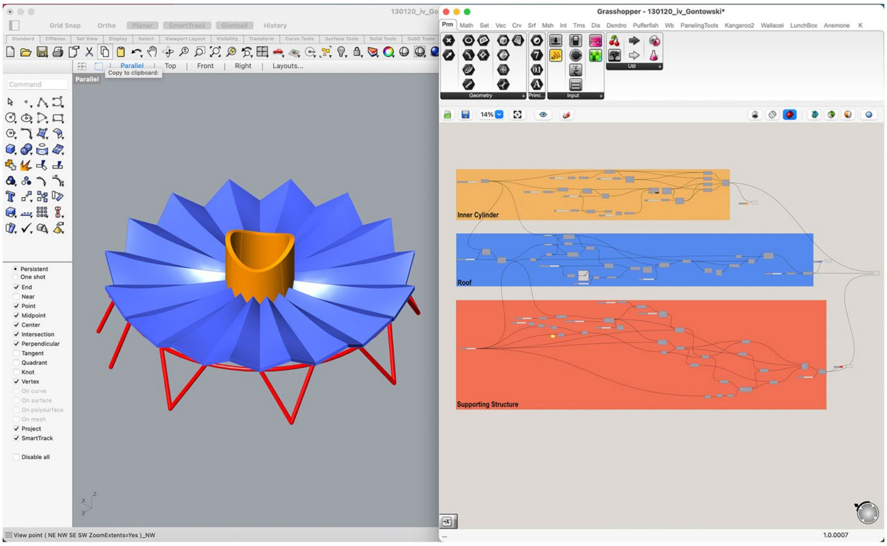

Fig. 8 Parametric definition of Bazaar in Lomas de Cuernavaca in Mexico. The definition allowed to modify the three main components recognised by the authors in the first phase. In orange—position, radius, height, thickness and curvature amplitude of the Inner Cylinder. In blue—diameter, number of creases, curvature, height and thickness of the roof. In red—height, section and dimensions of the Supporting Structure. Authors: Maria Łomiak and Piotr Gontowski

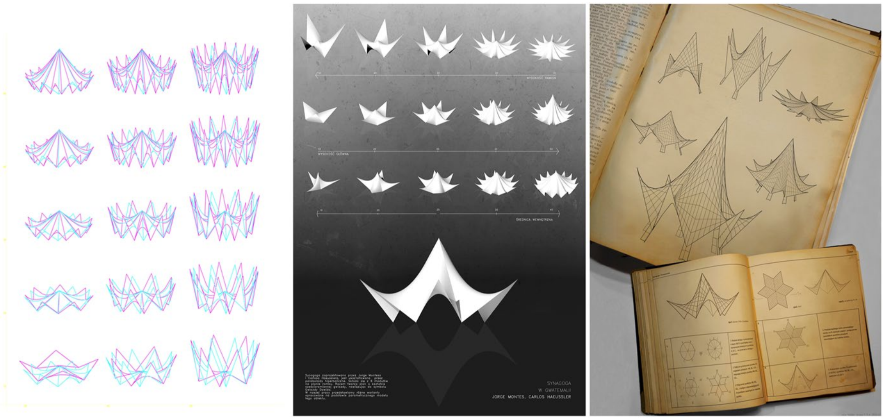

Fig. 9 Example posters showcasing the variations of Synagogue in Guatemala codesigned by Felix Candela, Jorge Montes, and Carlos Haeussler. Authors, from the left: Justyna Krauze and Natalia Cichoń, Karolina Wojenka and Karolina Kuśpiel, Julia Najder

asking the right questions (Fig. 13). Consequently, the course outcomes potentially indicate a better understanding of the algorithmic thinking process among students in comparison to the previous editions.

As a result of the course's insertion in the early stage of architectural education, as postulated by Duarte (2016:127–130), most of the students participating in

Fig. 10 Example posters showcasing the variations of Palacio de los Deportes. Authors, from the left: Gabriela Zielińska and Przemysław Sasin, Agata Subda and Krzysztof Żak, Zuzanna Filipek and Mikołaj Szafrański

the course had no earlier contact with generative tools and had a little experience in architectural design in general. This circumstance inspired introducing the analogous first phase of the course. According to Özkar (2017), such an approach allows the students to focus on the problem rather than on the features available in the computer software. At the same time, the size of the students' cohort revealed the wide variation of students' interest in parametrically supported design. This could be ascertained from the students' level of engagement in the individual tasks. It can be further hypothesised that only a fraction of students will continue to use parametric tools in their future practice. At the same time, as underscored by Özkar (2017), the analogous approach to formulating the problem can be adapted more universally in the design practice, not only when confronted with generative software.

The presented teaching method of algorithmic form-finding proposed in the DDG course appears to be a valid form of knowledge transfer. Operating on existing designs allowed the students to understand algorithmic form-finding as a versatile tool that can be used both in an analytical and a generative way—hence, questioning the superficial understanding of parametricism as an architectural style. At the same time, in comparison to the previous editions of the course, the quality of the solutions delivered by the students along with their ability to explain their intentions in the mathematical language suggest that the phenomenon of a tool controlling an architect can be minimised by adjusting the method of knowledge transfer.

The outcomes of the reformed course revealed that the revised method improved the students' understanding of the principles of algorithm design. These differences were visible, especially during workshops when the students were solving individual assignments. While performing similar tasks, the pass rate has increased by over 50%. A comparable effectiveness was maintained in the subsequent editions, where due to the COVID-19 pandemic all the classes were delivered in an online mode.

The course described in the paper was brought into being to bring architecture adepts closer to computational thinking through the works of Felix Candela. It

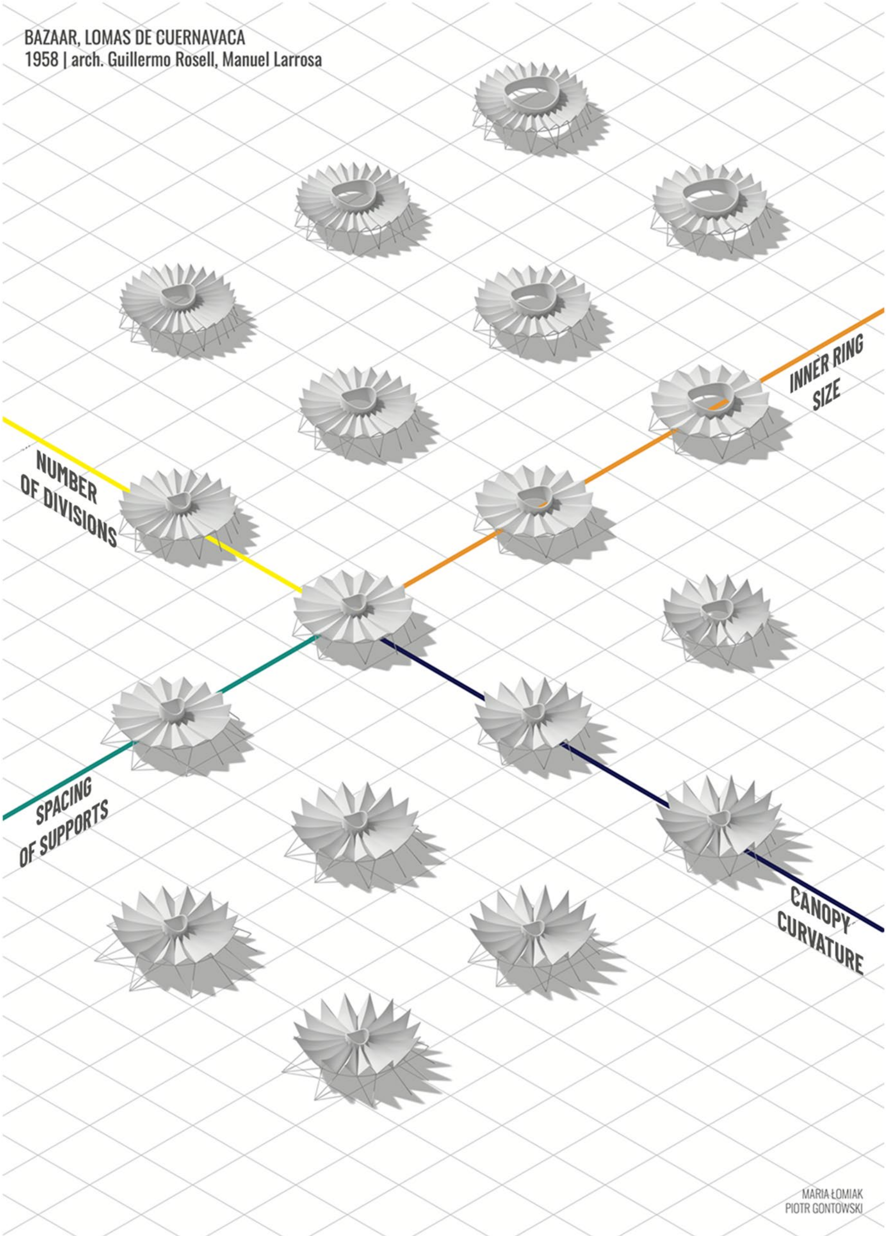

Fig. 11 Variations of Bazaar in Lomas de Cuernavaca in Mexico. The poster presents deformations within acceptable design space. The two crossing axes indicate changes of parameters: number of divisions, canopy curvature, inner ring size and spacing of supports. Authors: Maria Łomiak and Piotr Gontowski

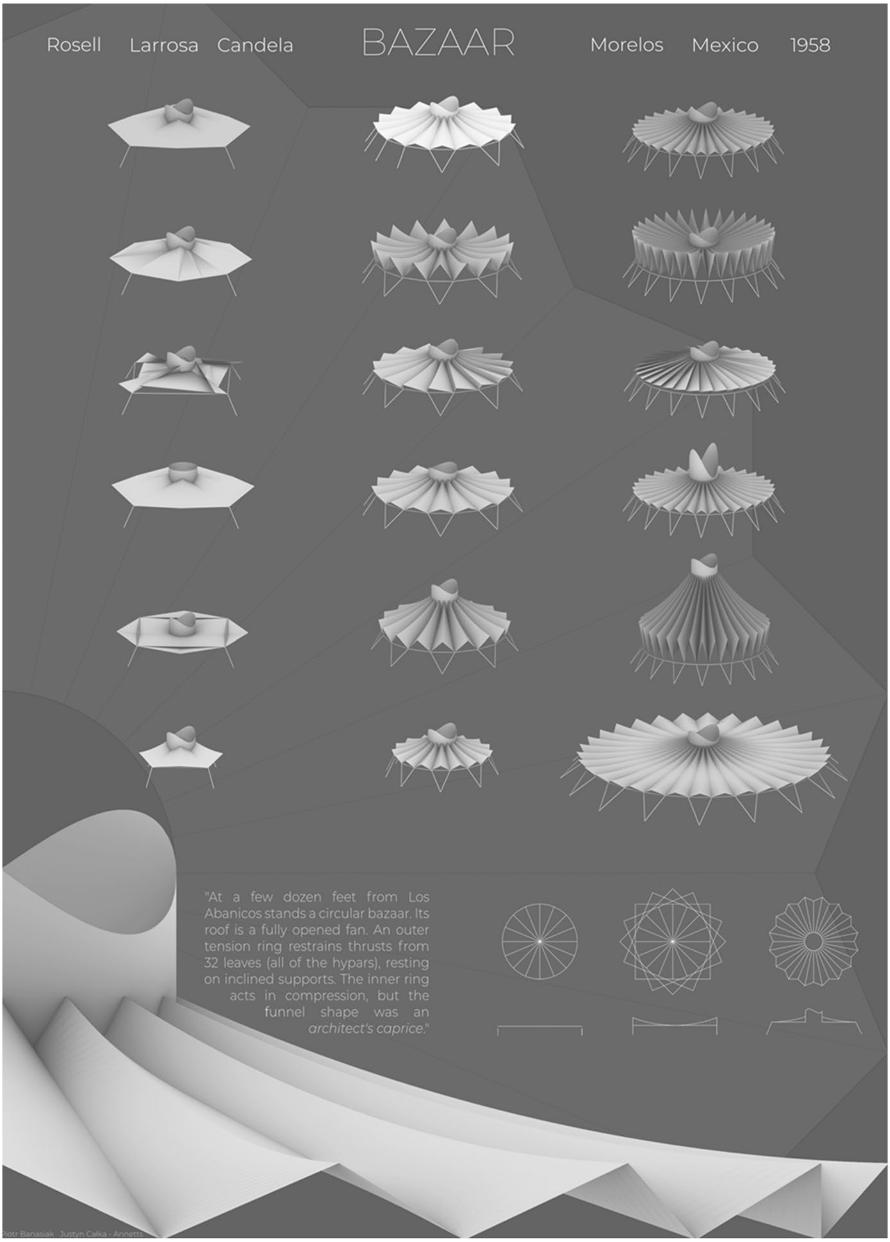

Fig. 12 Variations of Bazaar in Lomas de Cuernavaca in Mexico. Solutions in the left column were identified by the authors as degenerated. Authors: Piotr Banasiak, Justyna Całka-Annetts

is not about simply mapping the appearance of Candela's designs; it is about recognising the spatial idea standing behind them. The study method was based on the creation of ideological and phenomenological models revealing

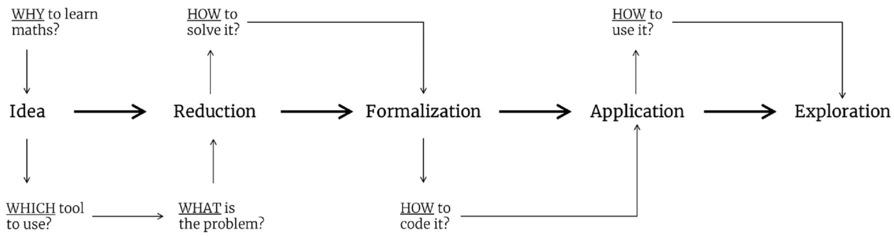

Fig. 13 The enriched design process involving questions to be answered while forming the appropriate design approach

both geometric inspirations and their architectural implementation. From a methodological point of view, these classes—belonging to the topic of teaching geometric techniques—are also a course in the field of history and the theory of architecture. Due to the integration of information in a digital medium, the created models allow students to study form, function, cultural background and architectural craftsmanship simultaneously. Moreover, thanks to parameterisation and automation, these models describe not only the frozen spatial state, but also the dynamics of architectural processes.

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