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SPACE TESSELLATIONS POLYHEDRAL SCULPTING

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Abstract: *At the Institute for Art and Design, a subunit of the Department of Architecture at TU Wien, every year, a non-mandatory artistic project is organized, open for Master Students (5 ECTS points). I will report on the development and the outcomes of this assignment, a research and design project in the realm of sculpting based on polyhedral aggregations, which appeared to be a fruitful assignment for the basic design education of young architects. We discovered an interesting field of formal research that expanded the student's eyes for spatial relationships, for the world of polyhedra and diverse transformation methods. The results of this highly intuitive experiment were overwhelming, creating many opportunities for related design and research assignments in this field. Tessellations and polyhedra should be integrated in architectural curricula worldwide because they offer anchor points to master shapes or spaces. Great benefits can be reaped from such assignments to understand structures in a more subtle and profound way than the common, well-known rectangular approaches.*

Keywords: Architectural Education; Polyhedra; Sculpting.

INTRODUCTION

Space Tessellations is the general title of a design and research project that I initiated in Vienna in 2017 with students of architecture to enhance their spatial acuities by introducing them to the world of tessellations and polyhedra. It became also the main title of the book *space tessellations – experimenting with parquet deformations* (Hoeydonck *et al.*, 2022). Tessellations, tilings, or parquets traditionally have been a field of experimentation for architects, designers, artisans, and artists. They are 2-dimensional arrangements of geometrical forms on surfaces (floors, walls, ceilings) to enhance the appearance of a space or a building. Tessellation is, for me, more pleasing to the ear as a tiling or parquet – it also has this hidden but important notion of relation or connection - it describes the more sophisticated intertwines of geometrical forms, like those we know from Islamic Design. Etymologically derived from *tessera* (Latin) - meaning a cube or a die with numbers on all six sides - and from the Ancient Greek word téssares, meaning "four" (a small tile or mosaic), representing the square, whereby the cube, from an isometric point of view, represents a hexagon or a spatial composition of squares. The etymology of the word *tessellation* reveals this reciprocal relationship between 2D and 3D. In more mathematical terms, tessellation means the covering of a flat surface or the tiling of a plane using one or more geometric shapes, with no overlaps and no gaps. A tessellation of space without gaps and overlaps is called a space-filling or honeycomb. The space tessellation project is about connecting the yet unconnected, about making new relationships between geometrical forms, be it in 2D or 3D, preferably in an experimental setup with students. I wanted *Polyhedral sculpting* to be free from the space-filling requirements of previous experiments. The idea behind this assignment was to experiment with - for this purpose - selected polyhedra and consider them as a set of *building blocks*, to arrange and aggregate them to a *Gestalt*, an appealing composition expressing, in an abstract way, an idea, a feeling, a figure, a gesture, an animal, a robot etc., to then build these models in scale 1:5 to human scale, and in a next step, to build them in scale 1:1 to study how they - in both scales - interact in different setups.

POLYHEDRAL SCULPTING: PROCESS, METHODS, OUTCOMES.

In a first lecture I gave the students an overview of 2D tessellations and their relationship with the five Platonic solids, the thirteen Archimedean solids, the thirteen Catalan solids and the ninety-two Johnson solids. During this lecture, paper models of these 123 (5+13+13+92) polyhedra were presented to the students. Their immediate presence as a shape in space and their haptic qualities (all built with different materials) led to discussions on how we would build our models, including which materials were best suited for the two scales, and whether to also employ digital constructions. The first weeks of the assignment were devoted to building the potentially relevant (to this assignment) digital and paper models of the 123 solids to make the students familiar with them. I also encouraged constructing duals: by connecting the middle points of a polygon, a new, sometimes unexpected polyhedron appeared. Some students even constructed duals of duals. We searched for instructive tutorials on how to model these polyhedra digitally (Viana, website, 2019). To facilitate building these models we used the Japanese paper craft software *Pepakura Design*, which automatically makes 2D nets after importing the 3D digital model. After three weeks we had a fine set of building blocks and our collection continuously expanded. A compilation of the most used building blocks is shown in Figure 1. The students used Rhino, Sketch-up, ArchiCAD and AutoCAD, but we easily brought together the building blocks of all students in one file (as STL-files or DWG-files). This gathered file was shared via the student server so the students could start to experiment with aggregations in search for *Gestalt*.

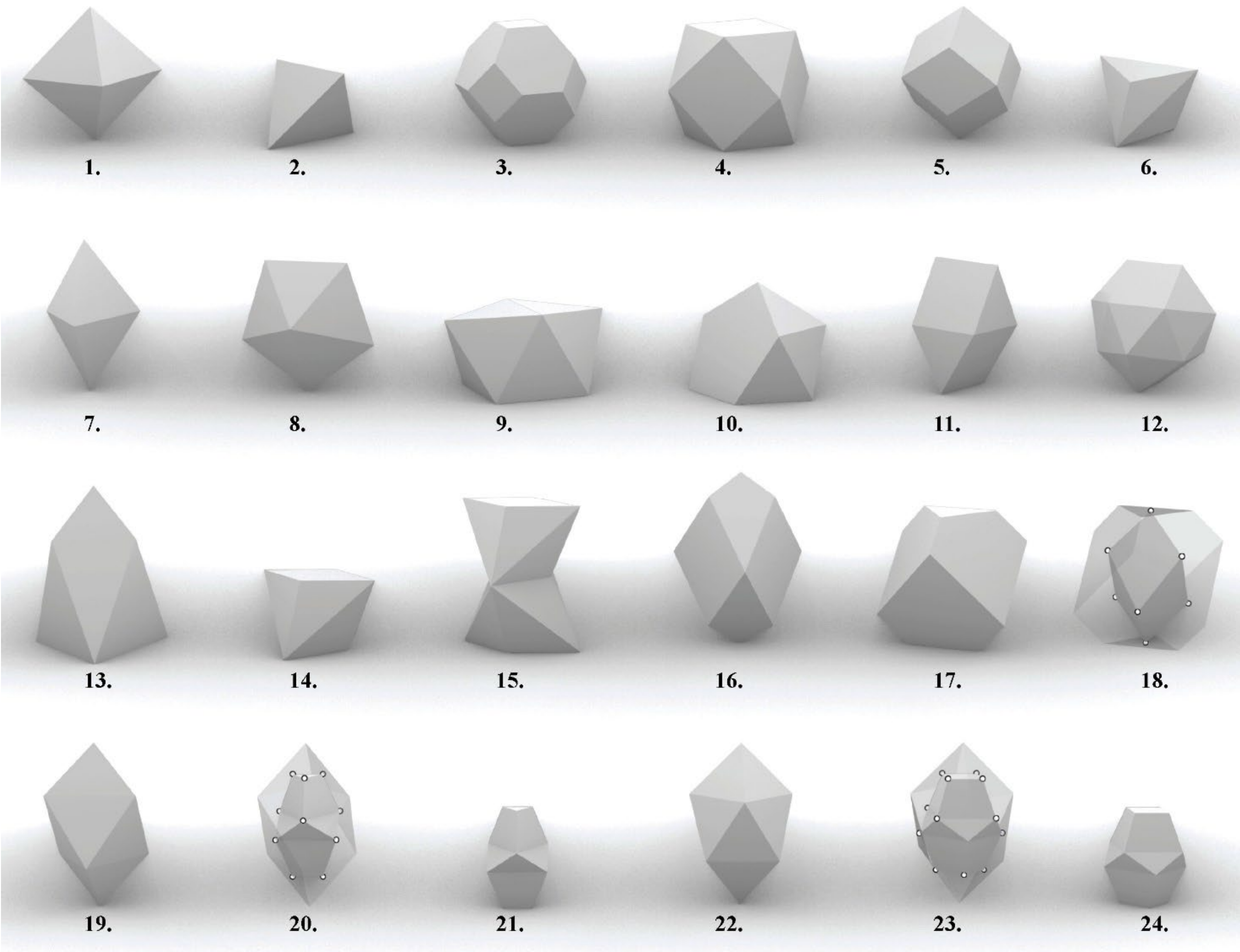

Figure 1 Compilation of building blocks: Octahedron (1), Tetrahedron (2), Truncated octahedron (3), Cuboctahedron (4), Rhombic dodecahedron (5), Triakis tetrahedron (6), Johnson solid nr. 12 = J12 = Triangular bipyramid (7), J13 = Pentagonal bipyramid (8), J50 = Biaugmented triangular prism (9), J63 = Tridiminished icosahedron (10), J26 = Gyrobifastigium (11), J85 = Snub square antiprism (12), Great sethahedron (13), Ten-of-diamonds dodecahedron (14), Rhombic bowtie (15), Herschel's Enneahedron (16), Dürer's solid Melancholia I (17), Dürer's solid with its dual inscribed (18), Dual of Dürer's solid (19), Dual of the dual of Dürer's solid inscribed (20), Dual of the dual of Dürer's solid (21), J17 = Gyroelongated square bipyramid (22), Dual of J17 inscribed in J17 (23), Dual of J17 (24). Note the similarity between Nr. 21 and Nr. 24, but top and bottom are respectively a triangle and a square. The duals and duals of duals always retain symmetry properties inherent to the original form, this fractalisation can be upscaled again to aggregate with the original solids. Drawing by Veronika Amann.

Simultaneously the students had to research for sculptors, architects and designers that use polyhedra in their work. We met once a week in four groups, one hour per group of six students. The evening before, all students had to send me a PDF documenting their research and the digital and analog models that were made in order to be able to discuss the results the next morning. While many sculptors, designers and architects work with solids, strangely, the topic of polyhedra was new for most of my students. Since all 123 solids are based on regular polygons and most of them can be easily connected, our design and research questions were to especially look for solids, which, in aggregation, resulted in an appealing *Gestalt*. A fruitful method for our purposes was to select polyhedra with not too many faces having *asymmetric* properties able to shift directions and bring movement, a twist or tension into an aggregation. The composition had to be appealing and dynamic from all viewpoints. The Johnson solids J12, J13, J17, J26, J50, J63, J85 and J90 have these qualities and were a perfect addition to the more *symmetric* building blocks that were selected (for example Nr. 1-6 in Figure 1). Norman Johnson's paper, however, is a typical example of a mathematician's approach, filled with formulas and lists, and as such is not very inspiring for a designer, but without Johnson's research many of these polyhedra would, perhaps, not even be known (Johnson, 1966). We did, unfortunately, not have the time to explore all of the Johnson solids and it is obvious that a different selection of building blocks leads to totally other results. It also soon became clear that aggregations of around six to ten polyhedral was sufficient – if they were combined in a clever way - to have a result having some kind of *Gestalt.* Variations of promising sets of building blocks were encouraged in a search for the most pleasing combinations. Only a few students came to satisfying results very fast, presenting many solutions at once. This was a clear sign that they had selected a *compatible* set of building blocks. Our approach to compose, aggregate and stack was highly intuitive, virtual (CAD) and visual, no mathematics needed, as the forms were all at our immediate disposal. We only had to scale them to common edge lengths so that triangles could dock to triangles, etc. After seven weeks, most students understood and succeeded with the task. Because of our group conversations, the students were able to judge their compositions for themselves and to develop a feeling for *gestalt*. To fine-tune these first results, I gave a lecture on the ten transformation methods (Williams, 1972, pp. 203-256): vertex motion, fold, reciprocation, truncation, rotation-translation, augmentation-deletion, distortion, dissection, and symmetry integration. The vertex motion and truncation operations were the easiest and most applied. They allow one to subtly, or not so subtly, get rid of annoying symmetries or repetitions, to bring a slight portion of dissonance into the stacking, or to enhance expressions already inherent in the composition. At the beginning of 2022, the scaled 1:5 versions of the models were submitted. These models were produced, by preference, in white cardboard, and served as a test for the final human scale model. Another important goal of the assignment was to have a final result that would feel like a group project in the sense that all the individual results were original designs resulting from a personal quest, while at the same time the assignment was about the resulting cumulative effect of these compositions – based on a shared set of building blocks - when staged in different settings and scales. What happens to the space in between and to the spatial figure-ground relationships when the individual sculptures start to socialize, by positioning them in a dense or lesser dense way? Can we experience their common genealogy in some way? Is there a best distance of interaction between them? In most sculpture parks the distance between the works is rather remote because the sculptures are so different in their formal language, and a dense setting would not bring much extra value because the individual works mostly do not belong to the same formal *family*. This was not the case in our experimental settings. Settings with two compositions but also dense settings with five to ten compositions were tested out with the 1:5 models. These were also intuitive settings – due to the limited time at our disposal in the professional photo studio at our institute (Figure 2). These stagings surely work well as a picture but in the case of many compositions staged in a very dense way, as in Figure 2.4, these narrow distances would not – if staged this way at human scale - allow visitors to walk freely around and study each one of them. This setting however works well as an abstract family picture and one can sense the common genealogy.

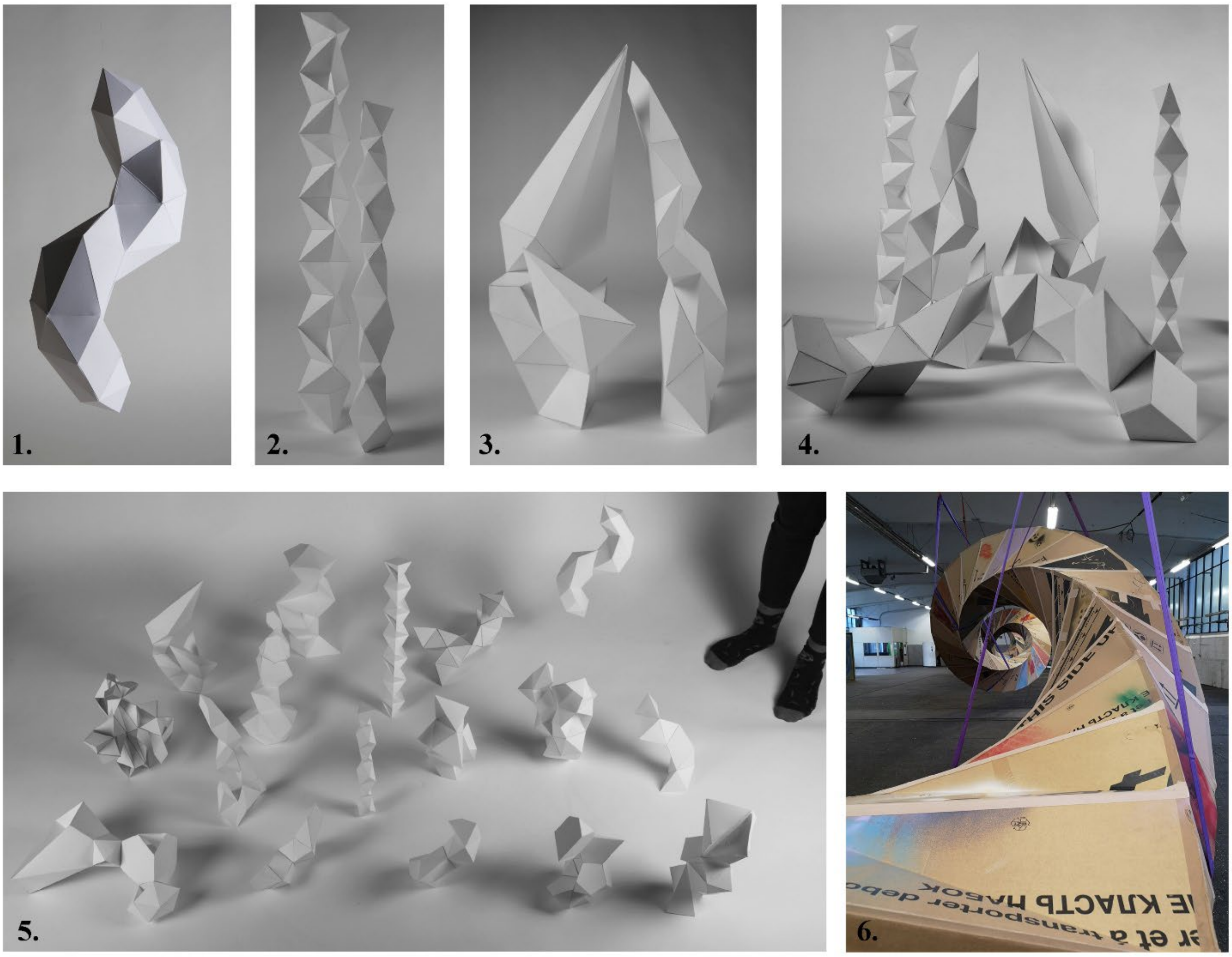

Figure 2 Different setups in scale 1:5 to human scale. 1. Solo: all models being photographed from different perspectives. 2 and 3: bringing together two compositions to see how they relate. 4. Staging more compositions, as in a family portrait. 5. Staging all results together. 6. Peter Sandbichler's installation *Twist*.

For the final materialization as human-scale sculptures we chose recycled corrugated cardboard. This was inspired by the Viennese sculptor Peter Sandbichler, who developed intricate installations with this material. (Thoman, 2021, p. 42). We visited his newest project: a sensational twenty-meter-long helix in cardboard. Peter explained to us in detail how to work with this material and which tools we needed (cutter, long steel ruler, strong tape, preferably in the same colour of the cardboard, hot-glue pistol). The students in Vienna got only four weeks to build their human-size models in cardboard: a material which was freely available in bicycle shops as suggested by Peter

Sandbichler because of its size (1x2m) and stability. After twelve weeks of hard work, the assignment was celebrated with an exhibition which required a new configuration. We decided to put them on three rows of tables, so that the visitors had a good eye contact with them and could easily walk between them. The sculptures were larger than the visitors and dominated the exhibition space. Each sculpture was described in a PDF showing the step-by-step development of each and every composition to allow the visitor to understand the development process (Figure 3).

Figure 3 Human-sized cardboard sculptures at the final exhibition at TU Wien. Picture by the author.

Three students were abroad because of the pandemic, and an alternative assignment had to be found for them. Carlos Gil was stuck at the Canary Islands, I asked him to make digital collages in the impressive sceneries of his home-country, leaving him much freedom which he clearly liked (Figure 4). Andjela Misic and Teodora Radisavcevic, our so-called *team in Belgrado*, got the task to make a group exhibition somewhere on a planet in the universe (Figure 5).

Figure 4 From left to right: A natural rock formation at the Canary Islands, Mai Hong Tran with an aggregation of octahedra, Jelena Devic with an aggregation of triangular bipyramids, Eva Kretzschmar with Herschel's enneahedron, a transformed gyrobifastigium (J26), J17 and the great sethahedron. Rendering by Carlos Juli Gil.

Figure 5 Rendering by Andjela Misic and Teodora Radisavcevic of one of the setups, a group exhibition on another planet, somewhere in the universe.

CONCLUSION

The method of intuitive research and design with an intuitively chosen set of modular building blocks based on well-known and not so well-known polyhedra definitely led to fascinating and beautiful results. The topic of duality led to many unexpected polyhedra. After re-scaling, duals were naturally integrated in the family of building blocks. It is obvious that any other set of chosen building blocks would necessarily lead to very different results. The reason why particular polyhedra were selected and others not, was because these decisions had to be made on the spot: intuitively. This experiment was not set up to directly influence the student's architectural designs, but to offer them more freedom in expression and more confidence when they may want to extend their design beyond the rectangular grid. Architectural education is often based mainly on rectangular grids, the curricula could use some more "crystalline" input. Exploring the fascinating world of aggregated and transformed polyhedra offers exactly that and should be part of architectural education along with introductions to the (neglected) world of tessellations. Both topics are extremely important to future architects in mastering and manipulating shapes and volumes - since spaces are composed out of shaped boundaries. Every step of the process was documented in the obligatory and weekly updated PDF. This documentation is important: it is a treasure trove for me and an inspiration for future publications and other space tessellation assignments based on these first results.

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Werner Van Hoeydonck studied architecture in Ghent (1987-1992) and specialised at the Academy of Fine Arts, Vienna (*Privatissimum* Prof. dr. Otto Antonia Graf on Wagner and Wright, 1993-1996). After several apprenticeships he started his own practice Tek7-architects in Antwerp (2000-2011). In 2012, he returned to Vienna and founded Ornamental Art and Design, a workshop-research-design and art studio focused on patterns and the worldwide history of ornaments. Since 2014 he is a member of Design Austria and exhibited at the Vienna Design Week and other venues. In 2017 he initiated "Space Tessellations", a research and design project to make students aware of the transformational potential of geometrical patterns and polyhedra in architecture and design. In 2019 he took part in the 11th SIS congress and exhibition in Kanazawa, Japan and published his first paper, "William Huff's Parquet Deformations, Three Viennese Experiments". Space tessellations: experimenting with parquet deformations (Birkhäuser, 2022) is Van Hoeydonck's first book.