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CONFERENCE REPORT

Stereotomy 2.0 and Digital Construction Tools

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Abstract
The event "Stereotomy 2.0 and Digital Construction Tools" was held in New York from April 16th to April 29th, 2018 at the School of Architecture and Design (SoAD) of the New York Institute of Technology. The event included a workshop and an exhibition of the students' work, that was followed by a symposium with international academics and professional speakers. Finally, an exhibition held in the Par Excellence Gallery in New York has shown some of the state-of-the-art research on digital stereotomy through physical models, prototypes and posters.

Introduction

"Stereotomy 2.0 and Digital Construction Tools" is the title of the event that was held in New York from April 16th to April 29th, 2018. The aim of the event was to disseminate theoretical and practical culture related to stereotomic architecture, from its origins in the sixteenth century to the latest design applications. The event, conceived by Prof. Giuseppe Fallacara, was supported and promoted by Prof. Maria Perbellini, Dean of School of Architecture and Design (SoAD) of the New York Institute of Technology (NYIT) and curated with Prof. Christian Pongratz, Interim Dean of School of Interdisciplinary Studies and Education of NYIT, in collaboration with the New York Institute of Technology, New Fundamentals Research Group, Zaha Hadid CoDe and P.art from AKT II. The event included several activities in several locations of the city: a workshop, a symposium and an exhibition. The NYIT supported the whole event as part of its global strategy of research on technological advancements in the field of robotic fabrication techniques applied to architectural design and construction (Nestoras Knoblauch 2018).

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Birkhäuser

The Workshop

The workshop was held from April 16th to April 19th, 2018 at the NYIT School of Architecture and Design, Old Westbury Campus. The workshop was preceded by a competition of ideas, whose prize consisted, in addition to a money award, in the possibility of participating in the workshop itself. The competition of ideas was supported by the School of Architecture and Design, the School of Interdisciplinary Studies and Education, the College of Osteopathic Medicine and the School of Health Professions at New York Institute of Technology and Par Excellence New York gallery and showroom.

The goal of this competition was to design a small bionic pavilion in which stone could be implemented in innovative ways, aiming to rethink design and sustainability from an interdisciplinary systems' standpoint. To achieve this aim, material performance and structural symbiosis driven by biological generative systems were considered, in connection to the latest fabrication and construction technologies. The pavilion concept was developed so that its location and design reinforce the links between various programs of the immediate surrounding schools, as a possible strategy to increase interdisciplinary encounters and holistic discussions on a broader scale. The project will mark a new place on campus to encourage casual meetings during lunch hours and other free times, but also provide a space for outdoor social gatherings.

The workshop was held by tutors coming from Zaha Hadid CoDe (Shajay Bhooshan and Vishu Bhooshan), AKT II p.art (Edoardo Tibuzzi and Lorenzo Greco) and New Fundamentals Research Group (Maurizio Barberio and Micaela Colella). The activities carried out concerned the digital re-design process of the design ideas developed by the students for the competition, from the definition of the structural form to the static analysis and parametric modeling of every component of the pavilion's structure (Fig. 1). In detail, the workflow explained by the tutors is based on the following tools and steps:

- MayaVault: creation of the initial crude mesh of the vault that sets out the surface;

Fig. 1 Pictures taken during the workshop. Photos: Micaela Colella

- MayaVault: smoothing the surface using the Catmull–Clark algorithm;
- MayaVault: form finding of the smooth mesh in order to find its compressive shell;
- Millipede: FEM analysis;
- Rhino/Grasshopper: stereotomic subdivision and voussoirs generation;
- 3Dec: DEM analysis;
- Vray for Rhino: results visualizations.

The winning project of the student Vanessa Rocha was presented during the symposium and at the exhibition Par Excellence. The project consisted of a discrete shell on a triangular plan, composed of thin interlaced panels in fiber-reinforced stone, using Stone Skin technology (Fallacara et al. 2016). The second classified was Arkadiusz Chrobak, the third classified was Santiago Molina and the honourable mention went to Nicole Fatone. The winning projects, afterwards, were the subject of further development and analysis during the workshop.

The Symposium

The symposium "Stereotomy 2.0 and Digital Construction Tools", held on April, the 20th at the 11th Floor Auditorium of the NYIT Manhattan Campus, was introduced with the opening remarks of the Dean of the NYIT School of Architecture and Design's, Maria R. Perbellini. Every contribution was preceded by a brief introduction by the moderator Christian Pongratz.

The first speaker was Giuseppe Fallacara, Associate Professor at Politecnico di Bari and Visiting Professor at NYIT. Through his speech entitled "Towards a Stereotomic Design", Professor Fallacara undertook an explorative journey from the practical and magnificent works of stereotomy of the past to the aesthetic sensibilities enabled by new technological tools, in order to create a new generation of stone architectures. Depicting a number of important archaeological remnants, Fallacara described several historical methods of working with stone and proposed practical means of conceiving and fabricating in stone that are entirely new, by harnessing 3D modeling software and robotic manufacturing tools. His work is enriched by a great number of experimental building projects obtained by taking advantage of state-of-the-art 3D modelling software and digital fabrication technology.

The second speaker was Shajay Bhooshan, Associate at Zaha Hadid Architects in London and Head of Zaha Hadid CoDe, the computational design research group within the office. In the presentation entitled "Stereotomy & Tectonism", he explained that architecture, for the most part, is produced and consumed visually and tectonism is concerned with organising the visible aspects of space to affect and augment the social processes that it houses. According to Bhooshan, this endeavor requires significant resources towards researching and intuitively understanding—visually and geometrically—the harmonious flow of forces through certain 'naturally' curved shapes and the physical production of such shapes. Furthermore, tectonism stylistically heightens the physical aspects of shape—structural, production, environmental etc., making it easier and more natural to be consumed (visually) and understood by the users. For Bhooshan, the aesthetics of tectonism is profoundly compatible with the practice of stereotomy—organizing material layout in relation to the structural action of curved shapes—and inviting the user to recognize what is vital to the space, to the activities to which it was conceived and the interactions it has to offer. Bhooshan's presentation outlined the synergetic and historically continuous relation between Tectonism and Stereotomy.

The third speaker was Edoardo Tibuzzi, Associate Director at AKT II in London and Head of p.art, the computational design research group within the office. In his speech "Structural skins: Fusing Performance and Aesthetics", Tibuzzi asserted that technology and digital innovation have in recent years provided a series of new design tools to the architectural world, which have dramatically morphed the massing of modern buildings. The envelopes that were traditionally constrained to a relatively planar or curved settings, became complex forms, moulded in a digital environment, that push forward the traditional boundaries of engineering, fabrication and performance. This new paradigm generated a dichotomy, from which two solutions became apparent: on the one hand, where the envelope has its own supporting system (often quite complex) that is dropped on the main structural skeleton; and, on the other hand, where the skin is both the supporting system and the envelope at the same time. According to Tibuzzi, in both cases, the challenges posed by those complex geometries required a series of digital tools and workflows to be developed—tools that interwove geometrical form-finding and structural optimisation with fabrication output. At AKT II, the work developed on new digital design-to-fabrication techniques has allowed the use of a building technology that integrates architectural form, structural armature and environmental enclosure in single multi-performative skins. The speaker stated that this technology, successfully tested on a number of built projects, has produced great savings in costs, use of material, energy and labour, offering multiple functionalities within fewer building components.

The fourth speech was held by Maurizio Barberio and Micaela Colella, both Ph.D. Researchers from New Fundamentals Research Group and Adjunct Professors at Politecnico di Bari. In the speech "From Subtractive to Additive Stereotomy", Barberio and Colella referred to the epochal passage between subtractive and additive manufacturing techniques used in the field of digital stereotomy. According to them, Stereotomy, the art and science of cutting solids, is no longer a lost architectural discipline related to a forgotten past, but a very fertile way to reimagine contemporary architecture, thanks to the potential of computational and digital design and fabrication tools. In their hypothesis, if subtractive techniques relate to a digital update of the handcrafted techniques used by centuries in classic stereotomy, additive manufacturing (AM) techniques are opening new scenarios for the discipline. In this sense, the "cuts" are no longer applied on the real matter, but rather on a virtual indefinite space. By using AM and 3D printing, digital stereotomy becomes a way to (re)think the aggregation of matter and architectural elements in a new holistic framework. On the other hand, subtractive techniques can now reach new unimagined performances and expressive potentialities for exploratory design speculations. In this perspective, Barberio and Colella have shown some research outputs in which they have been personally involved during the last few years.

The fifth speaker was Omid Oliyan Torghabehi, a Ph.D. candidate at the Taubman College of Architecture, University of Michigan. In the speech titled "Stereotomy and knowledge-based design", Torghabehi stated that as a unique trait of the human mind, knowledge acquisition is the basis of any creative process. In the context of architectural design, visual representation of the design concept is a way to communicate the underlying knowledge of historical, social, and cultural interactions. Historical construction knowledge, passed down throughout the centuries is a valuable source of significant information about the social and cultural human condition in relation to the built environment. Stereotomy as an artistic translation of geometry into discrete modules, is highly enriched by historical fabrication knowledge, that exists in every step of the creative process, since its geometric conception to its mathematical formulation, further detailing and construction. In this regard, the aesthetics of stereotomy is a representation of the underlying knowledge of material and form in relation to scale and modularity, which, according to Torghabehi, in the practice of stereotomy and inherent connections between stereotomy, geometry and mathematical representation, corresponds to contemporary material-based and knowledge-based practices in design computation. Correspondingly, knowledge-based design aspires to acquire the design knowledge in the form of virtual integration of the performance and fabrication rationale in the process of design. The presentation outlined the connections between the historical practice of stereotomy and knowledge-based design through the lens of digital design and fabrication.

After the precedent speeches, the symposium continued with video presentations from international hosts who were not able to be in person at the event. Among them, Alex Reggiani, a geologist from the Russian company Renca, presented the lecture "Additive Stereotomy: 3D printing with geopolymers" explaining how his company is focusing on the development of innovative products and technologies based on geopolymer binders. Geopolymers are chains or nets of mineral molecules, linked by strong covalent bindings, that can simulate the chemistry of natural rocks. According to Reggiani, geopolymers are inorganic products with superior mechanical properties and "carbon negative" materials able to absorb CO_2 from air through a condensation process, cleaning air from dangerous gases. Reggiani presented an innovative methodology for formulating a geopolymer-based material for the requirements and demands of commercially available powder-based 3D big printers to be used for contemporary stereotomic practice.

The second video presentation was from Vladimir E. Kuznetsov, Lab Head of the Centre for digital fabrication at National University of Science and Technology MISIS in Moscow. His presentation, entitled "Stereotomy: From stone to wood (and plastic)" explained the story of an educational experiment performed at his university's FabLab. According to Kuznetsov, time can turn wood into stone through a natural fossilization process. In this perspective, the transition from wood to stone as the main building material became an important trend in architecture. The transition from an easy-to-handle but short-lived material to a lasting one, capable of preserving its qualities through the centuries, ended approximately between the seventh and sixth centuries B.C. Around that time, ancient masters applied the knowledge inherited from wooden structures and a keen observation of nature to certain procedures regarding the construction of shapes in stone. In particular, the structures resembling trees embodied in the stone (columns resembling trunks, arches resembling tree crowns), passed through the ages and are found in every historical epoch, including our own. Science and the art of stereotomy is now enriched with powerful digital tools for design and fabrication. Kuznetsov states that most FabLabs do not include machines capable of working effectively with stone. In just 2 weeks, a conceptual vision of an art object was turned into a feasible and beautiful structure, designed in consideration of the available material and machine resources, and fabricated just in time thanks to the magic of digital fabrication and coherent teamwork.

The second video presentation was from Bruno Combernoux, Head of the Institut Supérieur de Recherche et Formation aux Métiers de la Pierre (Higher Institute for Research and Training in Stone Trades). His presentation, entitled "Learning Stereotomy: between tradition and innovation" explained the origin of Les Compagnons du Devoir, a French organization of craftsmen and artisans dating from the Middle Ages. According to Combernoux, during that time, the construction activities and art of building were passed on by a handful of masters to their own children, and few perspectives for improvement were left for the workers avid to evolve in their workmanship. Taking advantage of the need of workforce for big building sites of religious buildings in all the territory, workers left their territory in order to gain new knowledge. These first groupings of workers gave rise to the compagnonnage (journeyman movement). The movement got organized so that young people could educate and perfect themselves through many expeditions. When journeymen met each other in different towns, they shared construction skills between them, in order to keep the secrets alive. With the senior's guidance, they learned one science: the geometry of construction. It is the transposition of this art from two dimensions to the three-dimensional empty space by shapes and sliced volumes that later gave birth to stereotomy, a science which, combined with the knowledge of materials, stood (and stands still) as a vector of innovation. Centuries later, and after several political and industrial revolutions, persecutions and infighting to this day, the compagnonnage continues to exist. The apprenticeship of stereotomy is at the core of the Compagnons stonemason's identity. Combernoux stated that nowadays, in order to perpetuate these fundamentals in a constantly changing world where digital conception and production tools are essential, it is necessary to adapt and improve training, so that craftsmen can remain at the heart of creation and of their own professions.

The last speaker was Dustin White, Director of the Fab Lab of the NYIT School of Architecture and Design. He presented "Stereoma" an installation for Stereotomy 2.0 Exhibition. Stereoma is a site-specific gravity formed structure produced as an installation and exhibition design to support the Stereotomy 2.0 exhibition, that includes works from designers and architects investigating the future of stereotomy. The word Stereoma takes influence from the Egyptian translation connoted with a solid structure and embraces the notion of heavens and sky as a vast dome, implied in the significance of the Latin word *firmamentum*, according to the interpretation of Fallacara and Minenna (2014: 16–25). The goal of the installation was to create an immersive and spatial experience using a vaulted or thin atmospheric-like valley (firmament), whose delicacy and ephemeral quality gives the idea of an atmospheric-like filter. The installation is not only a platform for others to work upon, but also a work in itself. Through form-finding software, an optimal hanging shape was engineered to create well-defined zones for each designer and specifically highlight each with circular non-directional forms that allow viewers to circulate and observe the work from multiple standpoints. The manufactured quality of the installation is softened through its porosity and material translucency, and an ephemeral quality of the digitally controlled lighting system that weaves a landscape of colour into the interior of the gallery. This presentation outlines the procedures and production of the creation of Stereoma for the Stereotomy 2.0 exhibition.

The symposium was concluded by a podium group discussion moderated by Christian Pongratz (Fig. 2), and a short presentation by Frederique Mortier d'Aumont of the Par Excellence gallery, the location of the Stereotomy 2.0 Exhibition.

The Exhibition

The exhibition was held in New York at Par Excellence NYC from April 20th to April 29th, 2018. On April the 20th, the curators, Giuseppe Fallacara and Dustin White, asked to talented designers and academics to imagine new applications of the stereotomic principles within the various forms of contemporary architecture (Fig. 3). The projects presented during the exhibition displayed practical and feasible architectural applications. The theme of Stereotomy 2.0 was interpreted in numerous forms by the designers. Most of the projects were new interpretations of vaulted

Fig. 2 The speakers during the final group discussion. Photo: Gotham Fotografia

Fig. 3 Exhibition opening at Par Excellence in New York. Photo: Gotham Fotografia

or domed spaces, while other projects showed new applications of themes such as pavilions, towers, porticos, and walls. Concerning materials, most of the designers selected the stone, foreseeing how to take advantage of the potentialities of the latest CNC and robotic manufacturing techniques. Others designers conceived the use of additive manufacturing procedures to obtain complex blocks in innovative ways. Below are brief descriptions of the projects presented, based on the words of their authors.

Hypar Vault is a research project lead by Giuseppe Fallacara which aims to fabricate stone vaulted structures with near zero waste of material. This is possible using a new type of blocks based on the hyperbolic paraboloid geometry fabricated through wire cutting. Hypar Vault II is the evolution of the prototype of the first Hypar Vault built in 2017, which was a traditional barrel vault (Fallacara and Barberio 2018). Hypar Vault II, designed by Giuseppe Fallacara and Maurizio Barberio, is based on a triangular shape and its form is funicular (Fig. 4). Hypar Vault's parametric morphogenesis is based on the definition of a basic element that tessellates the vault. The block of the vault has a well-defined configuration, in which the basic geometric relationships stand as invariant, since they are fundamental for the fabricability of the project and its overall effectiveness. Unlike a traditional vaulted structure, in which the voussoirs of the various rows are staggered, in the Hypar Vault, the voussoirs are aligned and its areas of contact are very limited. In order to propose the construction system in seismic areas, the static equilibrium of the vault is ensured by the reinforcement of the transversal arches by post-tensioning through a harmonic steel wire rope that passes through the median section of the blocks. The prestressing of the structure occurs due to post-tensioning of steel wire

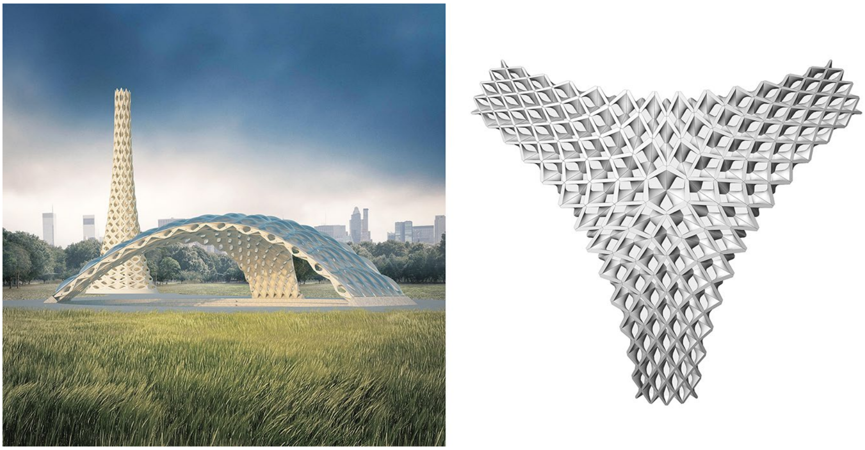

Fig. 4 Hypar Vault II, designed by Giuseppe Fallacara and Maurizio Barberio

ropes which are fixed to the base of the vault. The structure is completed with a special diagonal covering system, consisting of juxtaposed rhomboid-shaped thermoformed polycarbonate modules to ensure the correct rain flow. The whole system has therefore a dual function: to ensure the impermeability of the stone structure from the atmospheric agents, and to improve the matching of the modules, ensuring a better transverse and diagonal connection.

The Anthill Tower, designed by Giuseppe Fallacara, arises from considerations on the conceptual affinity between the logics of stereolithography and stereotomy (Fig. 5). According to the author, the term "stereo", in common to the techniques of

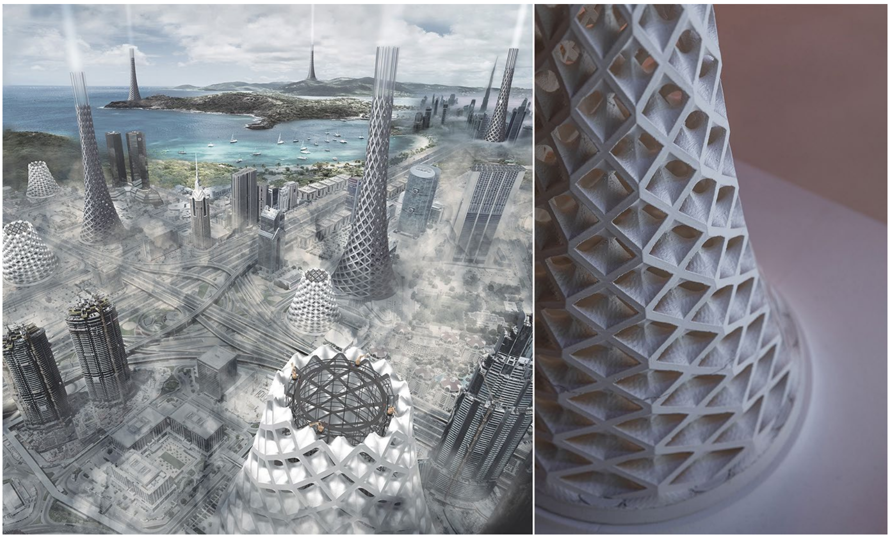

Fig. 5 Anthill Tower, designed by Giuseppe Fallacara. Photo: Gotham Fotografia

stereotomy and stereolithography, indicates the purpose of the resulting technique, namely the creation of solid-volumetric objects, fabricated respectively by removing or adding matter. The two techniques could theoretically be complementary and integrative. Specifically, if stereolithography means, in a broader sense, the technique of additive manufacturing or 3D printing through stratification and solidification of semi-fluid materials composed of a specific mortar, it is useful to consider the salvage of the stone processing waste as an aggregate of the mortar to be used by large 3D printers. The Anthill Tower is a skyscraper inspired by the natural building phenomenon through which insects such as ants are able to build large vertical structures thanks to the sedimentation and stratification of small grains of earth. In the specific case of the Anthill Tower, the incessant and methodical work of the ants is carried out by anthropomorphic robots, coordinated in series, that accomplish the vertical structure by extruding mortar on parallel horizontal layers according to the logic of 3D printing. The particular geometry of the tower, created as a seamless aggregation of giant "hypar blocks", allows the sedimentation of mortar according to the optimized angles of vertical growth, enabling the structure to be "porous and hollow" and therefore liveable like a big anthill. The internal space becomes fluid and dynamic, creating inedited living scenarios. The anthropomorphic landscape of the city thus redefines itself, inspired by nature and the wonderful biological life that surrounds us.

The Armadillo Vault is a vaulted structure designed by the Block Research Group, ODB Engineering and Escobedo Group (Fig. 6), that comprises 399 individually cut limestone pieces, unreinforced and assembled without mortar, spanning 16 m with a minimum thickness of only 5 cm (Rippmann et al. 2016). Its funicular geometry allows it to stand in pure compression, while tension ties equilibrate the whole form. Starting from the same structural and constructional principles as historic stone cathedrals, this sophisticated form emerged from novel computational graphic statics-based design and optimization methods developed by

Fig. 6 Armadillo Vault, designed by Block Research Group, ODB Engineering and Escobedo Group. Photo: Iwan Baan

the project team. The Armadillo Vault was the centrepiece of the “Beyond Bending” exhibition at the 15th International Architecture Exhibition—La Biennale di Venezia, curated by Alejandro Aravena, which was held in Venice, Italy, from May 28 to November 27, 2016. The engineering of the discrete shell employed innovative computational approaches to assess stability under various load conditions. Each stone voussoir was conceived by a predetermined structural logic, given the need for its precise fabrication and assembly, the constraints of a historically protected setting and the limitations on time, budget, and construction. The voussoirs are designed to be planar on the exterior to avoid the need to flip the stones during machining (Rippmann and Block 2018). Their interior sides' doubly curved geometry was obtained through rough cutting. Rather than milling away the excess material left by this process, it was instead hammered off, leaving the resulting grooves as an expressive feature. The shell's dual appearance, scale-like on the outside and softly curving on the inside, is thus a direct materialization of the project's hard constraints. Standing without reinforcement, proportionally as thin as an egg shell, the expressively flowing surface's structure challenges the idea that complex, freeform geometry need to go hand-in-hand with an inefficient and untruthful use of materials.

The Additive Stereotomy project, designed by Maurizio Barberio and Micaela Colella with Diederik Veenendaal (Summum Engineering) represents a novel building system conceived to materialize a vaulted space to be fabricated by means of large scale additive manufacturing techniques (Fig. 7). Its material properties are based on the 3D printing technology provided by Concr3de, a Dutch company that builds large-scale inkjet 3D printers, using a patented inorganic polymer material system to create custom, highly precise stone parts. The main idea of this project was to design a big open space covered by a series of adjacent arches. Under permanent load, the arches are understood as statically independent, in order to form a sort of “false vault”. The use of side-by-side arches allows the creation of a freeform barrel

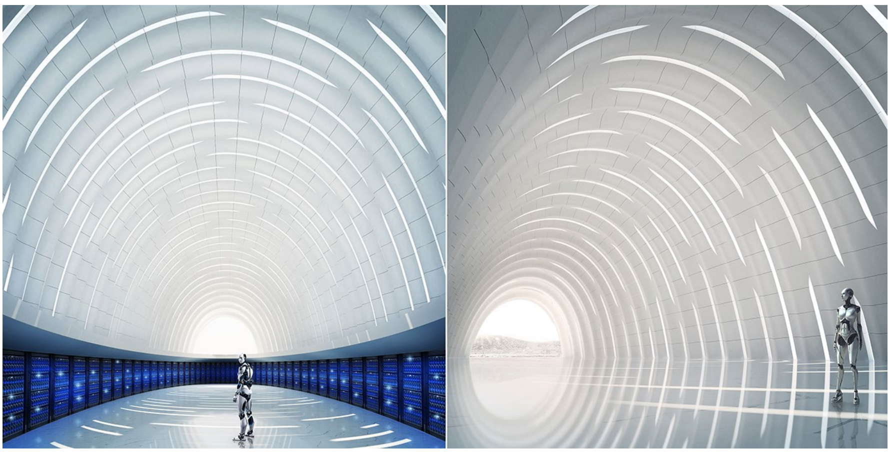

Fig. 7 Additive Stereotomy, designed by Maurizio Barberio and Micaela Colella with Diederik Veenendaal

vault, in which the overall shape of the structure is not conditioned by the static functioning of a traditional vaulted system. In other words, each arch resist through their own weight and prestress loads alone. The arches are divided into voussoirs, each of which have a load bearing core and two variable cantilevered slimmer parts on the sides. The cantilevering side parts can be shaped in such a way as to create differentiated openings to allow natural lighting and, at the same time, insert artificial lighting systems. The project was developed entirely in Grasshopper, with the aim of creating a close synergy between parametric design and computational engineering. Each voussoir is topologically optimized to achieve a volume fraction specific to its position in the arch, in order to achieve constant stress. The entire arch is prestressed by a central tendon that, dealing with live loads, allows the assembly and disassembly of the arch. The prestress disturbs the stress state for a conventional constant stress arch, requiring its shape to be reassessed. Summum Engineering determined the shape of the arches and volume fraction of the voussoirs to achieve constant stress, as well as the amount of prestress to keep them in compression under external load. The first design application of the construction system to be presented is a robotic re-proposal of the project of the famous National Library designed by Boulleé. In this project, the designers have placed servers and supercomputers along the basement instead of books, as contemporary analogues for the preservation of human knowledge.

Plastic Stereotomy, designed by Justin Diles, is a full-scale, mobile interior pavilion built in the Spring of 2015 with the assistance of Kreysler & Associates, the sponsoring fabricator of the international design competition *Plasticity* (Fig. 8). Organized by the Texas Digital Fabrication Alliance (TEX-FAB), the competition challenged participants to determine how state-of-the-art design and fabrication technologies could combine with glass fiber-reinforced plastic (GFRP) composite construction. Selected from a field of 70 entries, this project explores the possibility of reviving close-fitting masonry construction as an alternative to frame-based assemblies (Diles 2018). The project features a self-supporting structural system

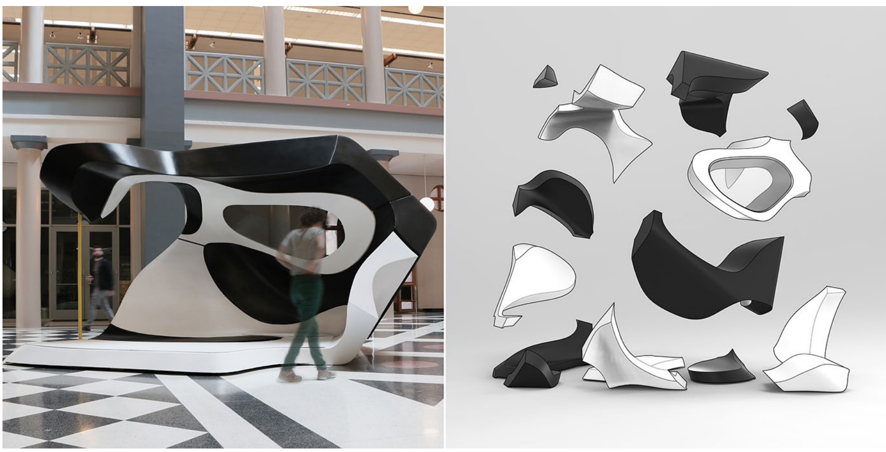

Fig. 8 Plastic Stereotomy, designed by Justin Diles

assembled from massive stereotomic—cut solid—parts, precisely stacked into a complex nested arrangement. Like the large stones used in historic masonry, the elements of the Plasticity Pavilion connect along perimeter surfaces and structural loads are equally distributed from part to part. The black and white patterning was developed by algorithmically deforming a copy of the pavilion's shape until it crossed the original form in an interesting way. The pavilion's parts are made from lightweight EPS foam blocks shaped by a robot and a large-format CNC router. Once cut, the elements are covered with a 1/8″ layer of GFRP. In the composites industry, this method of making parts is known as sandwich panel construction. By varying the thickness of the core material of its sandwich panels, the pavilion develops new relationships between structure, assembly and architectural expression. Through the exploration of the variability made possible with this construction type, the project also suggests that volumetric complexity will be an integral quality of future architecture built from parts made with advanced digital fabrication techniques and high-performance material systems like composites.

The Stereotomic Scherk Vault (Fig. 9), designed by Luca Poian and Nicola Boccadoro with Frederik Ellul (Soluxn Ltd), represents a new structural paradigm resulting from explorations that take advantage of recent advancements in digital fabrication in conjunction with parametric software, renewing a practice historically limited by Euclidian geometry and two-dimensional representation. Inspired by the Abeille and Truchet flat vault systems, the proposal explores innovative uses of stone by understanding the typical capacity and structural span of vaulted masonry formations. The project takes this tectonic principle as a starting point to unravel the structural and spatial potential embodied by a type of minimal surface known as "Scherk" surface, thus achieving a highly efficient distribution of forces (Poian 2017: 8–10). The design consists of a system of CNC routed interlocking stone blocks that conform to the geometry of the Scherk surfaces. This allows seamless and elegant transitions between perpendicular planes, minimizing the amount of material required for construction and producing a self-supported stone structure

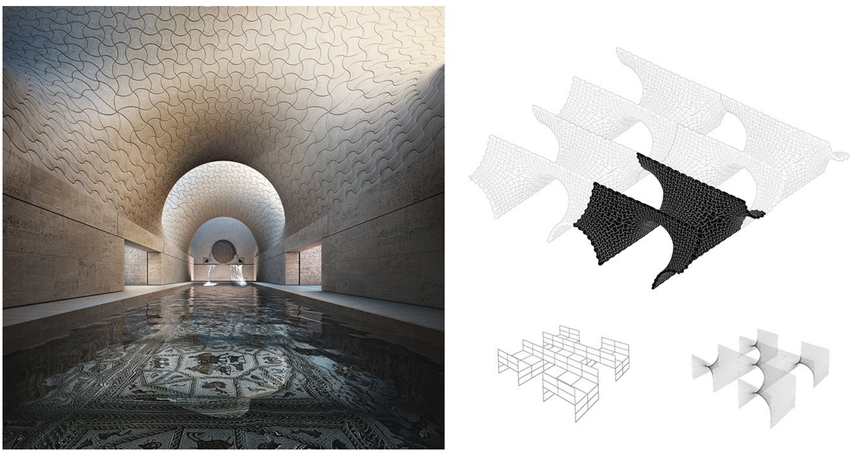

Fig. 9 Stereotomic Scherk Vault, designed by Luca Poian and Nicola Boccadoro with Frederik Ellul

that is both functionally coherent and spatially expressive. Its design reinvents the archetypal interpretation of the vault in a way that results in a new and unexpected architectural language.

The Superellipse Rib Vault, designed by Fabio Tellia, explores the original design of a vault composed by different spatial arches (Fig. 10). Spatial arches were widely described in classical treatises of stereotomy. The design proposed intends to show that computation and digital tools applied to stereotomy do not necessarily create architectures formally distant from the classical shapes which have characterised this discipline over the centuries. Alternatively, they can enrich the traditional lexicon with shapes that have been previously avoided for their complexity and difficulty in the definition of the templates required to cut the stone blocks. In this project, the ribs projections are based on the superellipse, which is a curve first discussed by Gabriel Lamé in 1818 and later used by Piet Hein in many of his designs. The ribs are curving to follow the planar projection of a series of superellipses defined by an incremental parameter. These curves gradually spread from the outer boundary of the vault approximating the configuration of a central rhombus. One complication arises from the fact that the arches are developing in three dimensions: they not only curve on the plan but climb up and down in space to guarantee the static of the whole scheme. The angle between each stone-block was carefully conceived to ensure the stability of the vault. The stone-blocks of the ribs were designed as ruled surfaces to allow production through wire cutting technology. Only the special keystones would require a different production approach. The vault has been subdivided into components to emphasize the rationalization and repetition of identical elements. The transverse arches supporting the ribs are spanning between the corner columns. The keystone from which the ribs are departing is unusually resting in the middle of the transverse arch, dividing the vault in four equal portions made of similar stone blocks.

PentaDome is the result of Roberta Gadaleta's Ph.D. research (Gadaleta 2017) that aims to update the traditional construction of the domed space in cut stone,

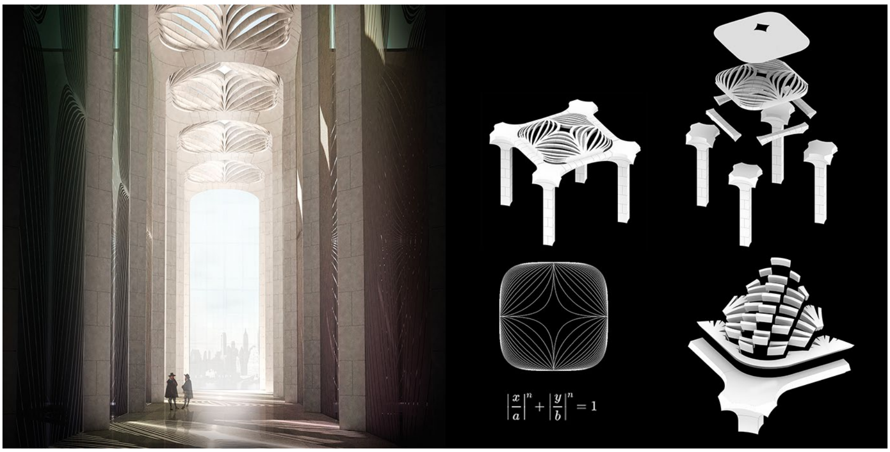

Fig. 10 Superellipse Rib Vault, designed by Fabio Tellia

recognizing, in its organic structural morphology, the advantageous constructive rationalization of the consubstantiality of form, structure and symbol (Fig. 11). Departing from a comparative historical analysis of different bonds of hemispherical domes and a rigorous study of the geometric methods to obtain a structural division of the sphere, this study presents innovative and alternative solutions of bond for a hemispherical stereotomic dome in cut stone, that optimize its construction if compared to traditional methods. This is achieved thanks to the particular structural geometry of the bond, that reduces the number of invariant-ashlars, maintaining their normal dimensions and increasing the diameter of the dome that they outline, respecting static laws and improving aesthetic expressivity (Gadaleta 2018). This result is achieved thanks to infographic software that allows a direct conversion of a three-dimensional model to the rapid prototyping machines and robot that can accomplish it, thus simplifying the production process and achieving the idea of union between project and construction. The innovative bond of the PentaDome is based on a particular geodesic tessellation with fivefold symmetry: the hemispherical calotte is divided according to the spherical regular dodecahedron whose pentagonal faces are subsequently divided into ten triangles by the 5 lines of symmetry of the regular pentagon; each triangular portion is then subdivided according to a structural texture derived from J. Kepler's "Aa" pentagonal tessellation. The design of the repeatable triangular portion and its symmetrical counterpart, according to precise static, geometric, formal and typological requirements interdependent on each other, determine 34 invariant ashlars repeatable on the whole dome.

The Magic Letters, designed by Christian Pongratz e Maria Perbellini, is a proposal for a sculptural and interactive media wall at the Porter Henderson Library (Fig. 12). The idea expressed with this installation is about the essence of reading that remains through time, and formally translates into the eyes' focus on individual letters. The magic letters' concept is an interactive media wall installation that displays words and phrases according to remote digital input through various

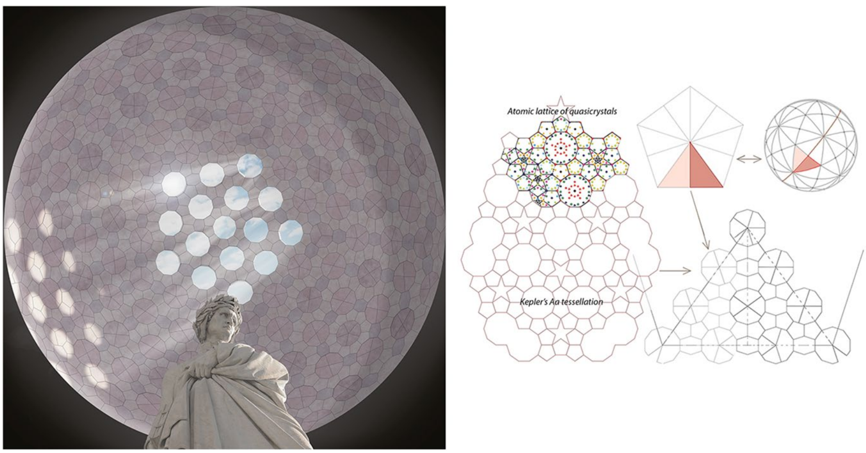

Fig. 11 PentaDome, designed by Roberta Gadaleta

Fig. 12 Magic Letters, designed by Christian Pongratz e Maria Perbellini

networked sources and any kind of mobile devices. The input to the wall may also be used as a learning device by algorithmic computation. Words are composed of many individual discs within the sculptural wall, which contain letters and are illuminated by LEDs. The sculptural design is hierarchically composed of two small individual components which rotate and mirror in order to assemble one single polyhedral shape, the base module. In a subsequent step, several polyhedra join through the specific design of the individual surface geometry and notched inserts that, together, form larger assemblies. The base module successively multiplies into several hundred instantiations across the wall, referring to the notion of information as a scale-less entity, and transforms the actual installation into a process of simply adding small and light modules.

Jim Stevens and Janelle Schmidt, designing Trait #4, questioned the role of drawing in the transition from paper to digital, analyzing this passage from the standpoint of stereotomy (Fig. 13). In the past, according to the authors, the act of drawing was the primary form of communication and touched all aspects of design from conception to construction. Given the rise of parametric modelling and digital fabrication, the architect is able to conceive space and understand the building digitally, before experiencing it physically. Their research project explores the role of drawing using the case study of the 16th century stereotomic drawing method of the trait. A trait drawing employs a floor plan and the surrounding site conditions to circumscribe a perimeter to infill, being the final product a series of section drawings that are consecutively aligned to their position on the plan to create a proverbial “3D model”. However, original trait drawings are flattened representations of this process and their outcomes are indiscernible to outsiders. While attempting to decode the original process, Stevens and Schmidt developed Trait #4 for a parabolic stone vault. Trait #4 has been developed in a parametric workspace to exploit visualization and make subjective decisions about the vault’s form and, at the same time, find the coordinates of the vault’s blocks. The system became a hybrid of traditional

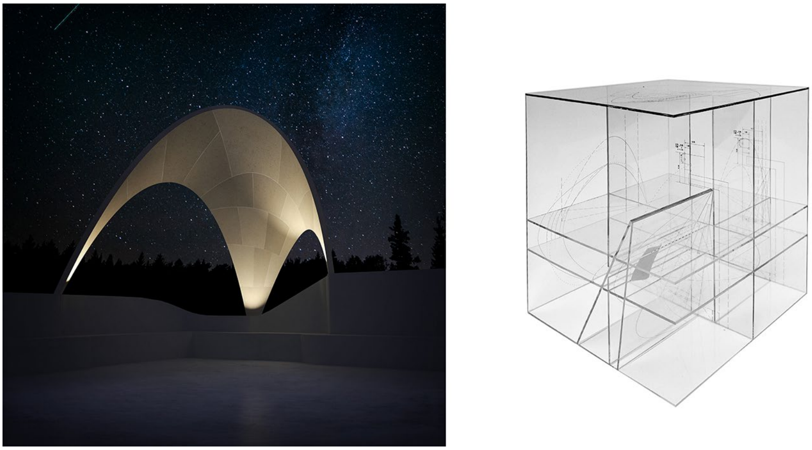

Fig. 13 Trait #4, designed by Jim Stevens and Janelle Schmidt

knowledge and modern tools: 2D drawings were oriented on multiple axes to be solved through projection and rotation within a 3D environment. The exhibition model represents a trait's timeless extraction of constraints to output a three-dimensional map of coordinates that illustrates the value of the drawing's principles and, as such as, the technique of trait géométrique reveals itself as fundamental for 3D modeling, 400 years before the conception of computers.

The exhibition included also three prototypes of stone furniture, one made of massive stone and two made of thin fibre-reinforced stone. This relatively new axis of research applies stereotomic techniques to the world of furniture design, thanks to the latest generation of CNC machines and 3D modeling tools, that allow the creation of complex shapes informed by ergonomic data, optimized by structural analysis software developed in a full parametric environment. Among the three prototypes, "Lapella" by Zaha Hadid Architects, has been designed specifically for this exhibition, as the masterpiece of the whole event.

The first prototype exhibited is Hi-Lo designed by Pongratz Perbellini Architects. Hi-Lo is one of the first free-form stone bench ever developed, and it is part of a series that expanded the Pongratz Perbellini Architects' experimentations on stone surfaces in three dimensions. HI_lo is a playful bench in Vicenza stone (made by Laboratorio Morseletto) with alternative functional areas dedicated to seating and relaxation at different scales, for kids and adults. The design concept of this "surface pattern to 3D structural ornament" is translated into a process of carving and extrapolating form from natural stone surfaces. The stone design is such that these design lines sometimes emerge from the ground and become playful and sometimes develop into parallel undulating seating surfaces and benches to form part of what we term "street atmospheres". The design takes, in those points, inspirations from natural forms and processes which introduce an architecture of experience with smooth tactile stone surfaces. The spatial surface experience is enriched not only by the combination of exceptional forms and materials but through the transmittance of sensations closely connected to the subtly changing color tonalities and the particular light effects that add emotional qualities.

Mobius Sofa, designed by Giuseppe Fallacara with the New Fundamentals Research Group and manufactured by Generelli SA, is inspired by the famous Möbius strip, a surface with only one side and one boundary, materializable as a ruled surface. It was discovered independently by the German mathematicians August Ferdinand Mobius and Johann Benedict Listing in 1858. Möbius Sofa represents a state-of-the-art research into stone materials and manufacturing techniques. The seat is configured as continuous 2 cm thick bands of Perlato di Sicilia, reinforced by a layer of carbon fiber on the back. The bands are made up by assembling a few lightweight pieces manufactured using CNC machinery. Their forms emphasise the enormous unexplored potential of stone as a contemporary material for industrial design.

Lapella continues the Zaha Hadid CoDe (ZH CoDe) investigations in structure and fabrication-aware tectonics by reinterpreting the iconic 1963's lounge chair by Hans J. Wegner. ZH CoDe retains the proportions, scale and reclining from the Danish design whilst deploying contemporary stone tooling and carbon fibre composites to create Lapella (Fig. 14). Forged using precision CNC milling and the application of tailored textiles, it renders visible its constructional design and network of structural forces that flow through its thin-shell skin. Lapella continues ZH CoDe strive to develop design tools that generate geometries expressive of light-weight material utilisation and structural performance. This tectonic approach casts the design of furniture within an architectural perspective—furniture becomes a precursor and human-scale test-bed to the full-scale deployment of novel material and manufacturing technology in an architectural scale. The design combines contemporary and state-of-the-art algorithmic extensions with the historic design techniques usually found in the stone masonry of yesteryear. These stereotomic design techniques recuperate, from the historical tradition, the use of curvature as an elegant form of transmission of weight and forces to the ground along with the organization of the material's layout in relation to such force-flows. The thin, carbon fiber reinforced stone pieces are arranged such that they visually accentuate these

Fig. 14 Lapella, designed by Patrik Schumacher with Zaha Hadid CoDe and AKT II, with New Fundamentals Research Group and Generelli SA. Photos: Giuseppe Fallacara

formative logics between material and forces. The original design was envisaged in steam-bent plywood. They revisit the Wegner chair in polished Palissandro marble procured from Italy. The patented process of manufacture harnesses the compressive properties of stone and the tensile properties of carbon fibre to achieve unparalleled thinness, lightness, and structural performance. In this perspective, AKT II provided material tests and the structural analysis of the chair, while New Fundamentals Research Group supported the fabrication process made by Generelli SA.

Conclusions

The event "Stereotomy 2.0 and Digital Construction Tools" proposed, to an international audience, several ideas for the renewal of stereotomy. Conceptual ideas and built examples based on the "stereotomic design" principles have been fully explained throughout the symposium and during the exhibition thanks to models and posters. The ambition of the whole event was to disseminate the Stereotomy 2.0 fundamentals, in order to become central within the contemporary debate on avant-garde architecture.

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