Stereotomy, Sustainable Construction and Didactics. Case study: a new Museum for Matera, European Capital of Culture 2019

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ABSTRACT

The paper describes the students' works, which included posters and physical models, were the partial outcomes of the current 3rd year design studio, led by Prof Giuseppe Fallacara and taught with the support of Maurizio Barberio and Micaela Colella, both Ph.D. students at the Polytechnic of Bari. The text illustrate an experimental teaching/learning approach which Giuseppe tested during the design studio. This approach was inspired by the concepts of 'Experiential Learning' and 'Flipped Classroom', consisting in a series of "cooperative classes", where tutors and students interacted and discussed in an absolute spirit of intellectual equality. The goal was to simulate the activity of a large architecture practice, involved in the design of a public building, which generally requires the contribution of a large number of architects and designers. The students were given a brief for a new museum and multipurpose centre in Matera, Italy, which was recently nominated European Capital of Culture 2019. They had to deliver a design proposal, a rapid prototyped model and a short video.

Keywords: *Didactics, Mediterranean architecture, Digital Stereotomy, Sustainable construction, Museum, Matera*

INTRODUCTION

Academic education is crucial for the students, but probably even more important is the influence that the University imparts for the approach of the future professionals, accustoming them to collaborate with other professionals, by sharing responsibilities with all the team members. This input led Giuseppe Fallacara, Associate Professor from the Department of Civil Engineering and Architecture of the Polytechnic of Bari, with the support of his assistants, Maurizio Barberio and Micaela Colella, to experimenting an unusual method of teaching Architectural Design. This stated intention of opening towards the students, has consisted in a series of "cooperative classes", where tutors and students interacted and discussed in an absolute spirit of intellectual equality. In this manner, it was possible to provide the necessary tools, both intellectual and technical, to deal with complex and vast subjects, as those concerning architectural design. The creation of actively participated and collective lectures has allowed to receive immediate feedbacks on learning levels, in order to improve abilities and skills of the whole group in a cooperative way.

DIDACTIC PROJECT AND PHILOSOPHY OF THE COURSE

Since decades, the didactics of the architectural design studios in Italy is basically structured in two parts: lectures and projects reviews. This approach has not changed significantly and each architecture school transmit the knowledge as it deems appropriate, according to the tastes and the cultural background of the teachers. Therefore, each teacher organizes the lectures focusing on the architects who considers his Masters and transmitting its own vision of architecture to his students. This is reflected in the preparation of the students, who often are forced to adapt their own vision to the preferences of the teacher, studying passively and without involvement. The academic course subject of this paper, starting from the current academic year (2015-2016), intends to investigate a new way of teaching architectural design at the University, basing all academic activities on key concepts such as Experiential Learning and Flipped Classroom. The two concepts, born in different moments of the history of pedagogy, have inspired the organization of the Course, which has gradually changed according to the feedbacks received from the students. The objective is to create a learning process in which the student is an active protagonist, encouraged to fully utilize its own resources and skills to the development and reorganization of theories and concepts aimed at achieving a decided goal. The student is then deliberately forced to deal with situations of uncertainty, developing a better adaptation to manage moments of stress. This allows to better develop their problem solving skills through creativity, essential for the future career. The current situation in the labor market, in fact, requires considerable adaptive capacity, where what really matters is the ability to quickly acquire new skills and use them immediately as a new starting point for further developments [1].

The definition of Experiential Learning, of the educational theorist David Kolb [2], was inspired, among others, by the work of John Dewey that in his book "Experience and Education" in 1938 [3], criticizes the traditional teaching, transmitted exclusively through books but without creating the effective involvement of the students who ends up acquiring knowledge often isolated and repetitive. Beside these important concepts, the Course is also inspired by the most recent learning methodology of Flipped Classroom [4], in which it is asked the student to view the didactic resources at home (video tutorials, texts, project references, etc.). Instead, during the workshops, it is asked to apply the knowledge acquired independently to solve the design problems proposed by the teacher, together with the other students and tutors. Thus, the teacher's role results radically changed: his task becomes to guide the students in critical and active processing of the project, encouraging them to face and solve complex tasks.

In order to implement this approach, linking it to the teaching of a complex subject as architectural design, the authors wanted to, as an experiment, to simulate the dynamics of working created inside a big contemporary architecture office, where the projects are being processed in multidisciplinary groups, each responsible for a part of them. The 52 students were divided into 11 groups. The goal was to simulate the activity of a large architecture practice, involved in the design of a public building, which generally requires the contribution of a large number of architects and designers. The students were given a brief for a new museum and multipurpose centre in Matera, Italy, which was recently nominated European Capital of Culture 2019. According to some instructions provided by the official application document [5], together with students, some possible project themes and locations have been found. After a group discussion, the project of a Multipurpose and Museum Centre has been picked as annual theme, because it better suits the philosophy of the Course.

The project: sustainability strategies and functional plan

The application document of Matera 2019 [5] emphasizes the economic and social sustainability of the entire event, especially stating the desire of renovate existing buildings, reactivating repopulation phenomena of the abandoned spaces of the historic center. Whilst considering this statement sacrosanct, we believe that the redevelopment of a city should cover all the municipal area, especially the peripheral and marginal ones, where there are often phenomena of physical and social degradation, with negative effects on the whole urban area, or also provincial or regional for the most extreme cases. For these reasons, we decided to study the possibility of including the new Multipurpose and Museum Centre in a degraded area of the city. After careful analysis, the chosen area has been identified in the suburbs to the north-east of the city, on the edge of the industrial area (Figure 1). Its redevelopment would be strategic for the proximity to very interesting places such as the *Parco della Murgia Materana*, the *Santuario Santa Maria della Palomba,* the *Chiese rupestri* of Matera and the *Parco Scultura La Palomba*.

Figure 3 The project area

In addition, we intend to draw attention on further reflection on the term ‘sustainable’, which has become one of the central issues [6] of the architectural debate and research with climate changes that are afflicting humanity and has increased the awareness of ecological issues, until it becomes almost an abused theme. To conceive something that is not declared sustainable seems impossible nowadays. However, how sustainability is actually a really pursue objective and not just declared? The term sustainable is, in fact, used extensively to indicate technical requirements that provide information about energy-efficient buildings, but that does not really give us any information about the indoor comfort nor the low impact of the building on the environment. Rather, sustainability should be interpreted as a general model of approach to the design and construction of architecture. Thus, the concept of sustainability should also take account of the history of building techniques, the deep knowledge of the characteristic of the materials and how they are used in architectural construction of a particular homogeneous area [7]. In this perspective, we have chosen to work with a local material, the stone, combining tradition and innovation by designing a complex roof made of cut-stone voussoirs, reinforced with stainless steel bands and cables. Therefore, the use of stone to build big roofs typical of complex buildings, is considered by the authors perfectly sustainable and coherent in the

Mediterranean area, where this material is abundantly available and the high temperatures of the summer require the use of structures with high thermal inertia. In addition, the use of stone allows a better visual integration into the landscape Matera, where the entire historic center, protected by UNESCO, consist of stone houses. The elliptical plan of the museum is divided into walls and partitions variously disposed on elliptical geometries, delimiting the various exhibition areas fluidly. Here there are all the functions of the museum, including the ticket office, a restaurant, a café, a garden in the inner courtyard and services. On top of these areas, on a wide low slope ramp are arranged the temporary exhibitions. The idea proposed is the result of the work of a group of architecture students expert in archaeology, after accurate research on the current situation of the museums in the region (Figure 2). It consists of a mutable museum: exhibition will not be a fixed collection owned by the museum, but will temporarily borrow archaeological finds from other museums or their warehouses, organizing temporary exhibitions that will take turns. With this system is possible to show what otherwise would hardly ever be visible, with significant and interesting repercussions from the museological point of view.

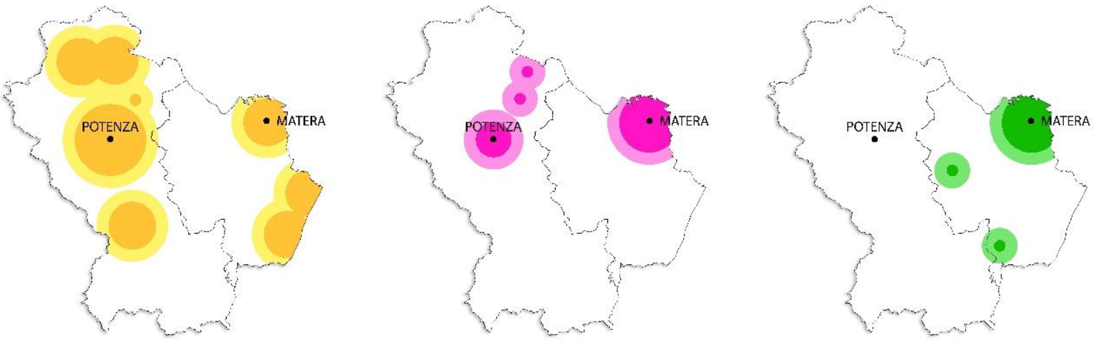


Figure 2 From left to right: quantity of archaeological, artistic and ethnographic museums

Thus, three main areas organize the museum:
- a temporary exhibition, described above;
- an area dedicated to the history of architecture of Basilicata from prehistory to the present day, very marginally dealt with in other museums;
- an underground archaeological museum with a versatile set-up but organized with precise geographical and chronological criteria: the identification of four parallel paths, that represent the historical evolution from prehistoric to Roman cultures along the four major rivers of the Basilicata. It allows the user to follow a path both from the chronological point of view, considering the differences in the same time span between the archaeological findings of the different river valleys, and geographically, considering how the same cultural area has seen evolve its representative artifacts.

The big roof and reinforced stone structural morphologies: from classical stereotomy to contemporary milestones

All the functions of the museum are located under a big elliptical funnel-shaped perforated roof – this was composed by hexagonal elements made of six prismatic blocks, pre-compressed through a metal band (Figure 3). The spatiality generated by the roof is meant to evoke the strong Mediterranean tradition of generating vaulted spaces. The perforated roof allows natural light to let in, while the glazed perimeter triggers a dialogue between the museum interior and the surrounding landscape – this also gives the building a higher permeability that overcomes the functional limits of a conventional museum (Figure 4).

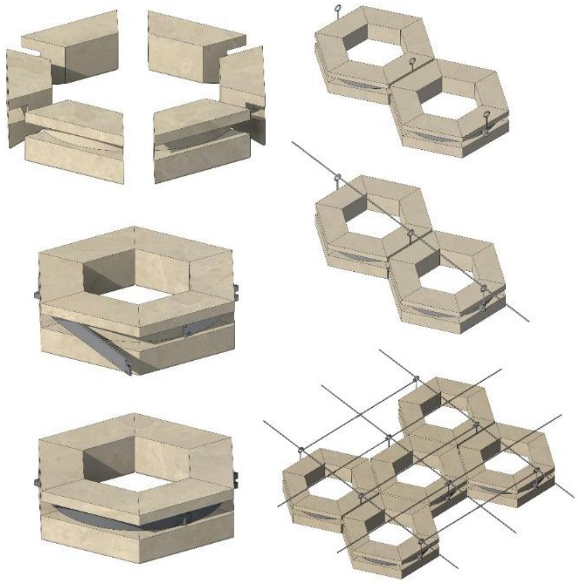


Figure 3 Details of the pre-compression system of the cut-stone blocks

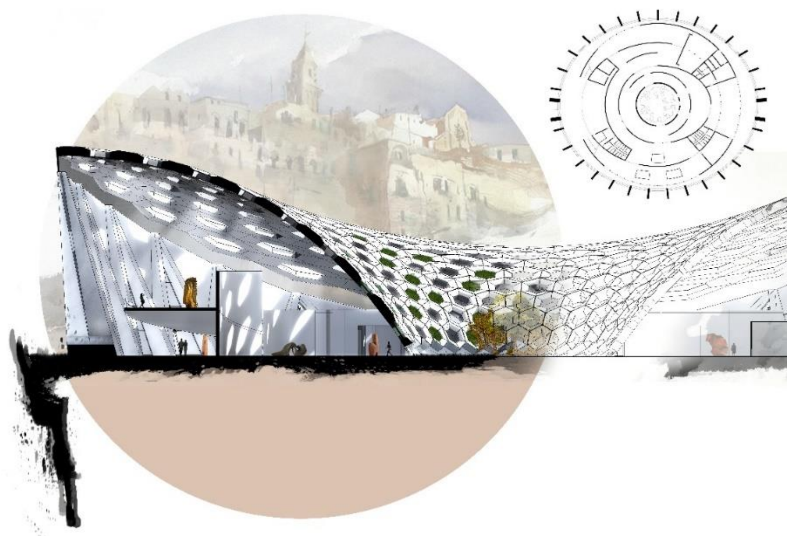
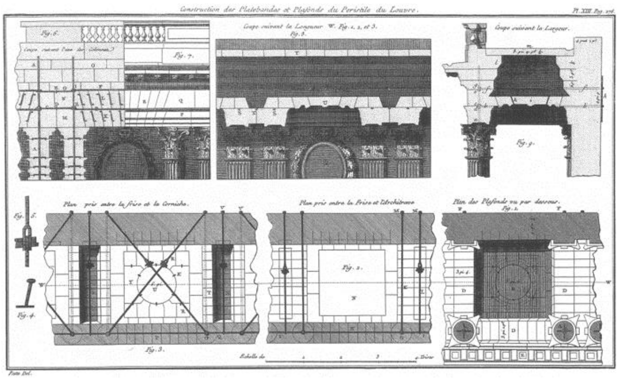
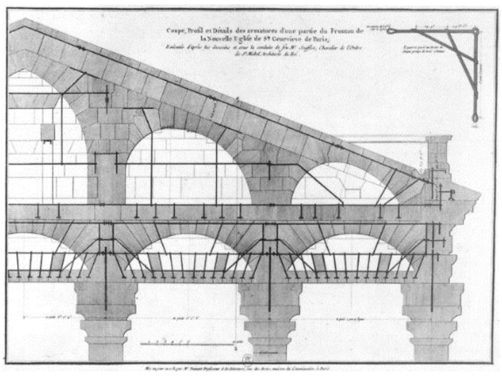


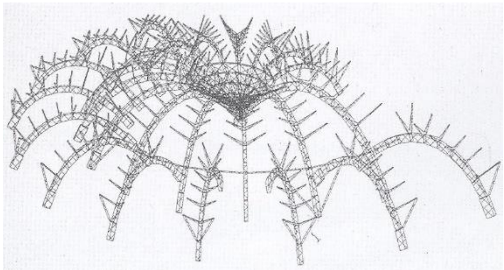
Figure 4 Section and plan of the museum

The interaction between stone and metal, in the Mediterranean area and Europe, has several illustrious predecessors in many stone architecture of the past (Figures 5-6), such as, the jack arches of the Louvre colonnade [8], or the portico of Sainte-Geneviève [9] or, more recently, with the researches of Peter Rice.

Figures 5-6 Left: Louvre colonnade. Right: the portico of Sainte-Geneviève

The most relevant are the Pavilion of the Future, built at Seville for the Universal Exposition 1992 (firm: Mortell, Bohigas and Mackay) and the Padre Pio Pilgrimage Church in San Giovanni Rotondo, Apulia, Italy (firm: Renzo Piano Building Workshop) (Figures 7-8).

Figures 7-8 Left: Pavilion of the Future in Seville. Right: 3D model of the Padre Pio Pilgrimage Church in San Giovanni Rotondo (Photos: Ove Arup and Partners)

These two projects [10], with different strategies, dealing with the possibility of pushing to the limit the structural performance of the stone, through pre-compression techniques with steel cables. The first project is based on the serial aggregation of large arches connected to very tall and slender portals, where all the stone elements are formed by granite composite blocks. The structure is set in compression and stabilized thanks to a complex system of cables and steel struts, according to an expert balance of forces typical of the structures designed by Rice. Even the project designed by Renzo Piano uses large arches arranged in a polar array, made of Apricena stone, and stabilized by prestressing steel cables hidden within blocks. Both projects are based, therefore, on the aggregation of free standing arches in order to build discontinuous structures; Therefore, the design and construction of a real vaulted structure, in reinforced stone, is a research area still unexplored.

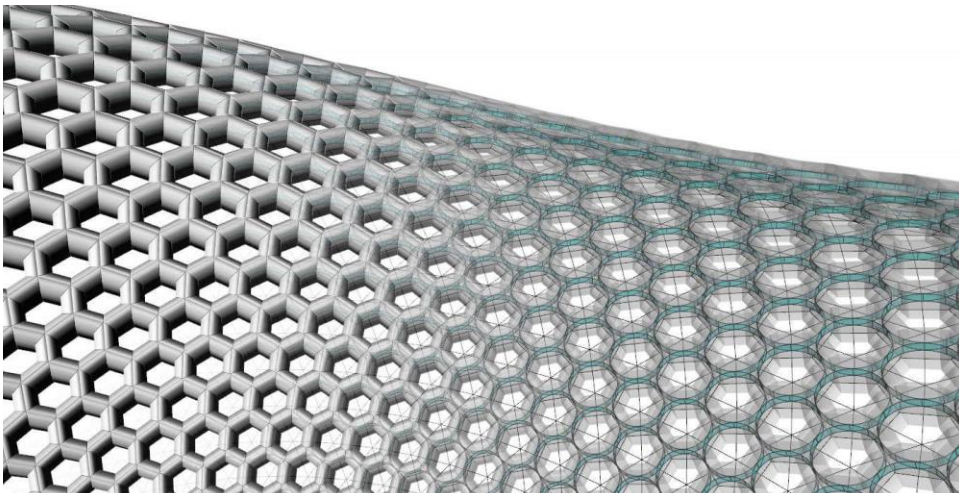
The update of cut-stone vaulted spaces is a research theme that throughout a decade is carried forward by the authors [11]. Stereotomy in the past was regarded as the most appropriate in encouraging students to "build space" and stimulate creativity. The *Ecole des Beaux Arts* and the *Ecole Polytechnique*, representative of the fields of Architecture and Engineering respectively, share from the beginning of the 19th century the common teaching of the subject of stereotomy, although they have specific curricula and teaching programs. In those years, the discipline became the pivotal subject in the first years of education of both the students of the *Ecole des Beaux Arts* and the *Polytechniciéns*. We wonder about the possibility of tying up again the broken thread of the research on stone–cutting construction following in the wake of the discontinued weave of the stereotomic culture, aiming at applying its innate creative momentum in contemporary architecture planning [12].

The big roof: topological vaulted space and parametric digital stereotomy

The vaulted space has always represented the ideal ambit in which to operate the more sophisticated and complex reflections on the construction of architecture. This is particularly true for the stereotomic architecture. The intrinsic quality of the vaulted architecture resides in the immediate ability to define measurable areas, which can serve as the endpoint for the indeterminacy of the outer space. In this case, the curved line that is defining the archivolted systems is the geometrical locus establishing a concavity and a convexity, and consequently a concept of intern and extern, unambiguously. The curved line, with any mathematical complexity, can be designed and built in two basic ways: with a tool that can draw the curved (i.e.: compass, algorithm, etc.), or by bending a straight line. The latter mode is totally attuned to the topologic view. The idea of "potential flexibility" and "manipulation" of the vaulted lithic space is at the basis of the method that is linking topology and stereotomy, and that will be now described. The method is starting from a very simple consideration, that is the observation that most of the vaulted systems can be imagined as a discontinuous structure or masonry wall that has been folded and/or deformed to obtain its geometrical final conformation, with the due simplifications and specifications [13]. According to the topological concept of folding, a sheet of paper lying down and one rolled-up to form a cylindrical surface are equivalent, from a topological point of view. By using some tools (i.e.: 3D Studio Max®) we achieve the final object in an indirect way, and not directly through the canonical modeling that, in the case of complex objects, would involve major difficulties for the three-dimensional modeling. At the start of the design studio, the students were encouraged to experiment with this modeling technique. This exercise proved to be important because the students had to take into account more aspects simultaneously: prefigurative invariant, that is the subdivision capacity in appropriate sections of a vaulted system; technical/geometric invariant, that is the capacity of geometric, punctual definition of an architectural system and of ashlars and its realization. (projective technique and cutting technique); static invariant, that is the capacity of providing static balance of the architectural system of drystone joint (graphic and mechanic static of rigid structures) [12].

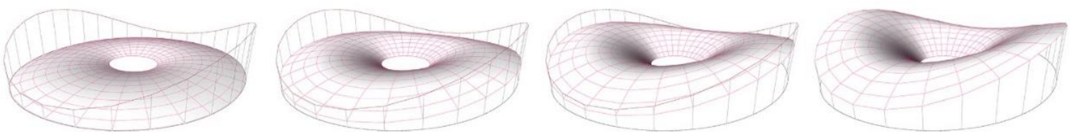
THE BIG ROOF: OPTIMIZATION AND PROTOTYPING PARAMETRIC STRATEGIES

Although topological deformations have a very strong educational and training value, when the surfaces to deform become very complex (free-form surfaces, spherical, etc.), their use is severely limited by the fact that some blocks will result too deformed, making some of these unfit to be prototyped with the current tools for architectural fabrication [14]. For this reason, the tutors has provided a series of introductory lectures to Grasshopper®, a plug-in for Rhinoceros®. Both the deformers of 3D Studio® and Grasshopper® work parametrically but, unlike the first, Grasshopper® allows writing of custom scripts in a very simple way, thanks to an intuitive graphic interface. The lessons were focused to provide some simple tools to manage with a high potential if properly applied. Among these instruments, the attention has been focused on 'Box Morph' and 'Surface Morph' components, generally used to populate whatever surface with 3D or 2D patterns [15]. 'Box Morph' divides surfaces into rectangular prisms (boxes), while 'Surface Morph' allows the tessellation of a surface without discretization, preserving the continuity of the intrados and extrados curvature. However, both components of the plug-in have a limit: they can populate surfaces using exclusively bounding boxes constituted by eight vertices. In the specific case of the museum's roof, the hexagonal tessellation subdivides the surface into hexagonal prisms, containing therefore twelve vertices. The hexagonal tiling was chosen because is known that a hexagonal grid (or honeycomb) is the best way to divide a surface into regions of equal area with the least total perimeter (honeycomb conjecture), as proven in 1999 by mathematician Thomas C. Hales. Even if the double curvature surface chosen for the roof makes impossible the use of hexagons of the same size, this type of tessellation is still very useful, because it avoids the use of a triangular tessellation, not convenient for stone fabrication. Therefore arises the problem of modeling the roof starting from a mesh made up of hexagons using Rhinoceros®. Now, the software (version 5) does not support mesh faces consisting of more than four vertices, i.e. ngons meshes. However, considering that each hexagon consists of six triangles, with the Grasshopper components provided by the add-on 'Mesh +' is possible to populate a triangulated mesh: 'Barycentric Mesh Morph' uses barycentric mapping to morph meshes from reference boundaries to each face of a target mesh, or pair of meshes with identical topologies (Mans, 2015). In our case, this is particularly useful since the perforated roof is formed by blocks bounded exactly inside of the triangular prisms constituting each hexagon. Thus, the problem of parametric generation of the blocks is resolved (Figure 9).



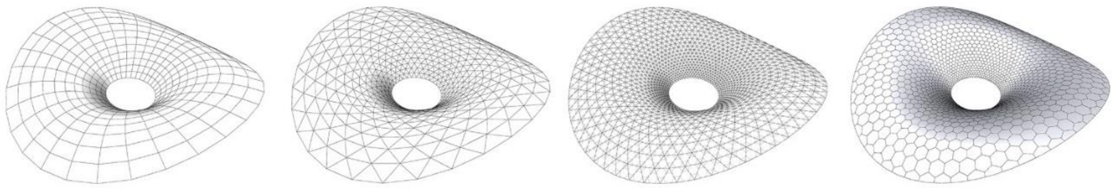
Figures 9 Parametric generation of the cut-stone blocks and metal bands

However, there are still two design problems to address, though not exhaustively: the static and geometric optimization of the base mesh. Also in this case, we wanted to provide students some intuitive tools that they could quickly manage, whose results (although not scientifically exhaustive) should stimulate them to further investigations. For the static optimization it was decided to use the add-on 'Kangaroo Physics' (Piker, 2010), widely known in the computational design field for the simulation tools of physical phenomena, including the digital form-finding, essential for the optimization of the shape of the roof in order to have only compressive stresses (Figure 10).



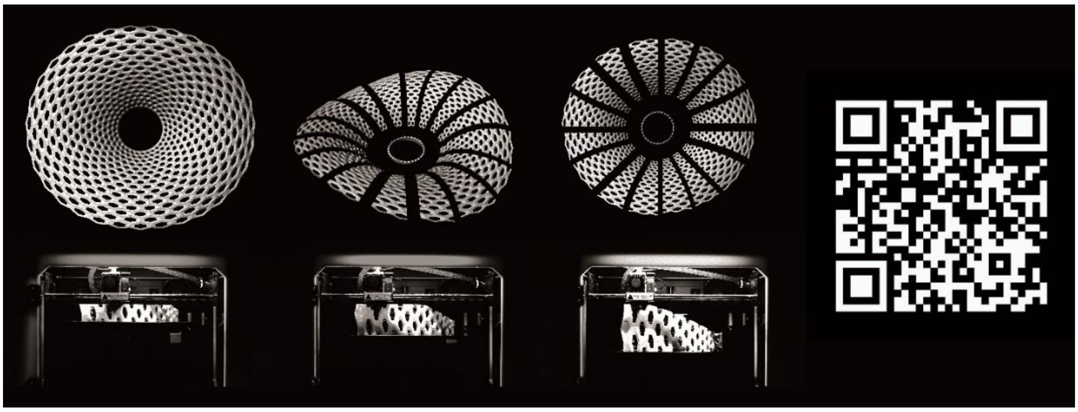
Figures 10 Form-finding process using Kangaroo Physics

For the geometric optimization, in order to obtain a mesh composed by uniform and undistorted hexagons, it has been used the plug-in 'Evolute Tools', developed by the team of Prof. Helmut Pottmann from the Vienna University of Technology. Using the tool, mesh relaxation and ball packing optimization were achieved, a fundamental condition to obtain a hexagonal mesh composed by uniform hexagons. It was possible to extract the polygons constituting the hexagonal tessellation from the corresponding triangulated mesh, using the subdivision method 'Dual with boundary' (Figure 11).



Figures 11 Geometric optimization and tessellation of the roof

The modeling process is completed on Grasshopper®, generating the cut-stone blocks as described before. Afterward, the roof shape has been 3D printed, which allowed students the further checking of the spatial quality of the project. The production of the prototype has requested the accurate planning of the prototyping steps: the students have sliced the three-dimensional model of roof in sixteen pieces, sliced in a way that the printing of additional supports was not necessary (Figure 12).



Figures 12 3D printing process and the QR Code of the video presentation

CONCLUSIONS

We wanted to encourage the students to understand the potential and the limitations of the tools used to pursue an objective, in order to choose the most appropriate strategies for the correct development of their project. The pluridisciplinary typical of the design studios creates the preconditions to address several matters at the same time, from composition to modeling, from geometry to building technology, because all the topics are linked together under the general discipline of architectural design. Moreover, it is believed that stereotomy can still have an important didactic value, because of the intrinsic capacity of this discipline to take into account all of these subjects. Finally, the authors believe that University should not only be the place where the future professionals are educated, but also be a place where students learn the ability to think critically and develop new ideas, being able to search for the theoretical and practical tools best suited to the objectives they have set.

REFERENCES

[1] Vallauri, E. L. (2016) L'università italiana non prepara al lavoro?, March 4, 2016. *Rivista "il Mulino"*. Accessed March 7, 2016.

[2] Kolb, D.A. (1984) *Experiential Learning: experience as the source of Learning and Development*. Prentice Hall, Englewood Cliffs, NJ, USA.

[3] Dewey, J. (1938) *Experience and Education*. Kappa Delta Pi, New York, NY, USA.

[4] Strauss, V. (2012) The flip: Turning a classroom upside down, June 3, 2012. *The Washington Post*.

[5] Matera candidate city European Capital of Culture 2019.

[6] United Nations General Assembly (1987) Report of the World Commission on Environment and Development: Our Common Future. Transmitted to the General Assembly as an Annex to document A/42/427 – Development and International Co-operation: Environment.

[7] D'Amato, C. (2013) The sustainable weight of history. The contribution of digital technologies to the continuity and innovation on masonry architecture. In D'Amato C., Petruccioli, A. (2013) *Australian Lectures*. Gangemi Editore, Rome, Italy.

[8] Patte, P. (1769) *Mémoires sur les Objets les plus importans de l'architecture*. Paris

[9] C.N.M.H.S. (eds.) (1980) *Soufflot et son temps : 1780-1980*. C.N.M.H.S., Paris, France.

[10] Brown, A. (2001) Stone and tension. In Brown, A. (2001) *Peter Rice (Engineer's Contribution to Contemporary Architecture)*, 145-157. Thomas Telford Publishing, London, UK.

[11] Colella, M. (2014) Nuovi fondamenti dello spazio voltato lapideo. In Fallacara G., Stigliano M. (2014) *New Fundamentals of Natural Architecture*. Aracne Editrice, Rome, Italy.

[12] Fallacara G. (2009) Toward a Stereotomic Design: Experimental Constructions and Didactic Experiences. *Proceedings of the Third International Congress on Construction History*, Brandenburg University of Technology Cottbus, Germany.

[13] Fallacara G. (2006) Digital Stereotomy and Topological Transformations. *Proceedings of the Second International Congress on Construction History*, 1, 1075-1092.

[14] Barberio, M. (2014) Nuovi strumenti per la produzione architettonica. In Fallacara G., Stigliano M. (2014) *New Fundamentals of Natural Architecture*. Aracne Editrice, Rome, Italy.

[15] Payne, A., Issa, R. (2009) *Rhino Grasshopper Primer (Second Edition)*.