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Computational Morphogenesis and Digital Manufacturing for Temporary Architecture for Music[1]

Sergio Pone, Bianca Parenti

Abstract
This research project deals with "Architecture for outdoor chamber music" and it is linked with the paradigm of complex projects for simple constructions: custom-made digital tools, generated through a process of computational morphogenesis, are used to design a high-performances acoustic chamber; once achieved a suitable solution and the related construction drawings, the design information can turn into construction information by means of digital manufacturing. The annual experimental phase (since 2012) consists in the construction of a prototype, built during a learning-by-doing workshop for architecture, engineer and scenography students; the scene is built (via simple procedures) to beananalysed through specific acoustic software and eventually put to the test during a week of concerts performed by internationally renowned musicians.

Parole chiave:

PE6-12	Software, operating systems, development methods, languages, algorithms
PE8-10	Production technology, process engineering
PE8-12	Sustainable design (for recycling, for environment, eco-design)
PE8-13	Lightweight construction, textile technology
	Acoustics

Frame of reference

Since 1982 (when the first version of AutoCADwas released), the design processhas switched from analogical to digital tools. «The first commercial mainframes replaced some analysis and statistic functions in big firms and institutions; the first IBM PCs replaced administrative jobs. None of these changed the world» (Anderson, 2013). In the same way, the introduction of desktop, computational and CAD software has not revolutionised Architecture, it has only made the design process faster and more convenient it has been a few years since some buildings began to represent the direct outcome of the digital tools that created them: their shape and, in some examples, their structure would not be conceivable nor manageable with

analogical methods. The new paradigm is related to the equivocal definition of parametric design, whose ambiguity is drawn by its two different meanings resulting from different histories and cultural attitudes in design process. The older and wide-spread one refers to the parameterisation of a rich library of architectural elements; such project consists of components that can be varied anytime, hence allowing the automatic update of adjoining areas, dimensional data, materials, etc. The second one refers to the topological variation of parts of the project (shape, performances, structure and so forth) into a defined domain and, therefore, allows a more complex alteration of the global geometry of the system.
The first group of software has been created to manage all sort of projects, to organise, in a very efficient way, the typical product of a professional firm with its specialised consultants. The second group is used to manage projects with unusual shapes (as well as specific performances, structure and so forth), in which a specific procedure is needed to find an optimal solution; often enough, these projects are published in specialised journals and appreciated for their touch of originality.
This kind of optimisation process belongs to another category of information technology tools, able to add to the second group of parametric software the possibility to generate different solutions modifying the assigned parameters, thus allowing the user to choose the solution that responds the best to one or more performances. This process is named "computational morphogenesis". The main feature of parametric design and computational morphogenesis is that the given instructions do not provide a single outcome but a family of comparable results.
Therefore, the design process becomes more complex and requires the user to become a sort of computer programmer. The difference between the two users of the two different ideas of parametric designis that the first asks the computer to carry out a task programmed by someone else, while the second user has the chance to ask the computer to fulfil a number of tasks, created by himself, with variable inputs generating different solutions. The first one gives commands and gets a solution, the second one sets up an algorithm and achieve a set of solutions. The operator uses digital tools still guided by an analogical mind set, the programmer uses digital tools as a mean of computational thinking. «*Computational thinking* – as said by Jeannette Wing, computer science teacher and considered the mother of the computational thinking - *is the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer – human or machine – can effectively carry out*» (Wing, 2014).
Before the spreading of parametric design, the formulation of the problem and its solution lied in the architect's mind, who drew that solution with a CAD software. With the new tools, the stating of the problems keeps having a completely human matrix, while the computer partly undertakes their solution. This allows to place more complex (not necessarily more difficult) problems, even the ones that the human mind cannot solve because of the huge number of calculations needed.
This process allows the launch of the optimisation processes previously described, modelling forms in a digitally automatic fashion, that do not resemble at all the ones built before. This is a small revolution that considerably changes the way of thinking the project as well as the buildings that this method elicits.
While in the field of design a little revolution is happening to give the digital era its own architecture, another wider revolution calls into question the roots of the global economy. Jeremy Rifkin states that «a new economic system – the collaborative *Commons* – is entering

the world stage. This is the first statement of a new economic paradigm since capitalism and socialism» (Rifkin, 2014). Rifkin's *Commons*, also knew as the *sharing economy*, have the power to substitute the information secrecy - inevitably bringing to patents in the industrial era -with the sharing of ideas and projects, typical of the Global Network. Still at an embryonic stage, new craftsmen, already known as "craftsmen 2.0",cannibble little quotes of market shares from the industrial giants. Internet allows small producers to reach a large audience without the significant investments in advertising dictated by television and press rules, while their offer is often more desirable due to the tiny distance between the production areas and the consumers places, that is the well-known concept of *Food Miles*.

These small economic realities consist of varied, heterogeneous group, from the small producer of artisanal beer, who starts as a joke downloading information (shared by someone else) from the web to make a domestic distillery in his garage, to niche food farming productions, that miraculously survived the impact of the industrialisation/globalisation and are today "adopted" by portals specialised in the promotion of craftsmanship. Part of this group are also the "digital craftsmen", who are named "Makers" by Chris Anderson, long-time editor of the *Wired* magazine. This process is called «*digital manufacturing*, that is – Stefano Micelli explains – the chance to connect the computer design to the production activities» (Micelli, 2016).

This cohesion can happen through «the spreading of new tools for digital manufacturing (3D printers, technologies for laser cutting or new numerical controlled machines) that are increasingly cheaper nowadays. This new generation of technologies for digital manufacturing contributes to a "democratization" of the productive processes, from which artisans, able to develop their know-how and their way to take part in the market, mainly take advantage» (Micelli, 2016): they are "digital craftsmen", indeed.

In this course of events, architecture and the construction industry are a bit late, as in their all history. Only recently it has been felt the need to use digital manufacturing as a consequence of the complexity of the construction; and even more recently the manufacture of building components has in some cases turned down the powerful (but expensive) support of the industries in favour of advanced craftsmen or FabLabs[2] or even is self-managed by the future users of the construction.

This is exactly what happens with Wiki House, a project/program created by Alastair Parvin, who describes: «No expertise of traditional construction is needed (fig. 1). (…) It is the same way in which buildings were built for ages before the Industrial Revolution, in the peasant communities, in which everybody contributed to the building of the granary. (…) All the files of Wiki House are published with *Creative Commons* license, and people all over the world are now downloading, using, modifying, fixing them, and this is unbelievable. We are well aware that Wiki House is a very simple answer, to a very important question, that is that nowadays the cities that grow faster are not cities made of skyscrapers.

They are all, to some extent, built by their citizens» (Parvin, 2013). It is the *sharing process*, once again, this time applied to a procedure that uses a CNC, a milling machine that can cut plywood panels or OSB panels, with cuts that are perpendicular to the face of the panel. Two-dimensional pieces produced in this way are assembled with wedges to create bigger structures, even a small house. Wiki House is designed thanks to the collaboration of the global community; its components are locally produced, with simple and low-cost technologies and assembled at the construction site with simple operations, compatible with the self-construction (fig. 2).

Fig. 1. Wiki House_Building the prototype. Source: http://spacecraft.co.nz/.

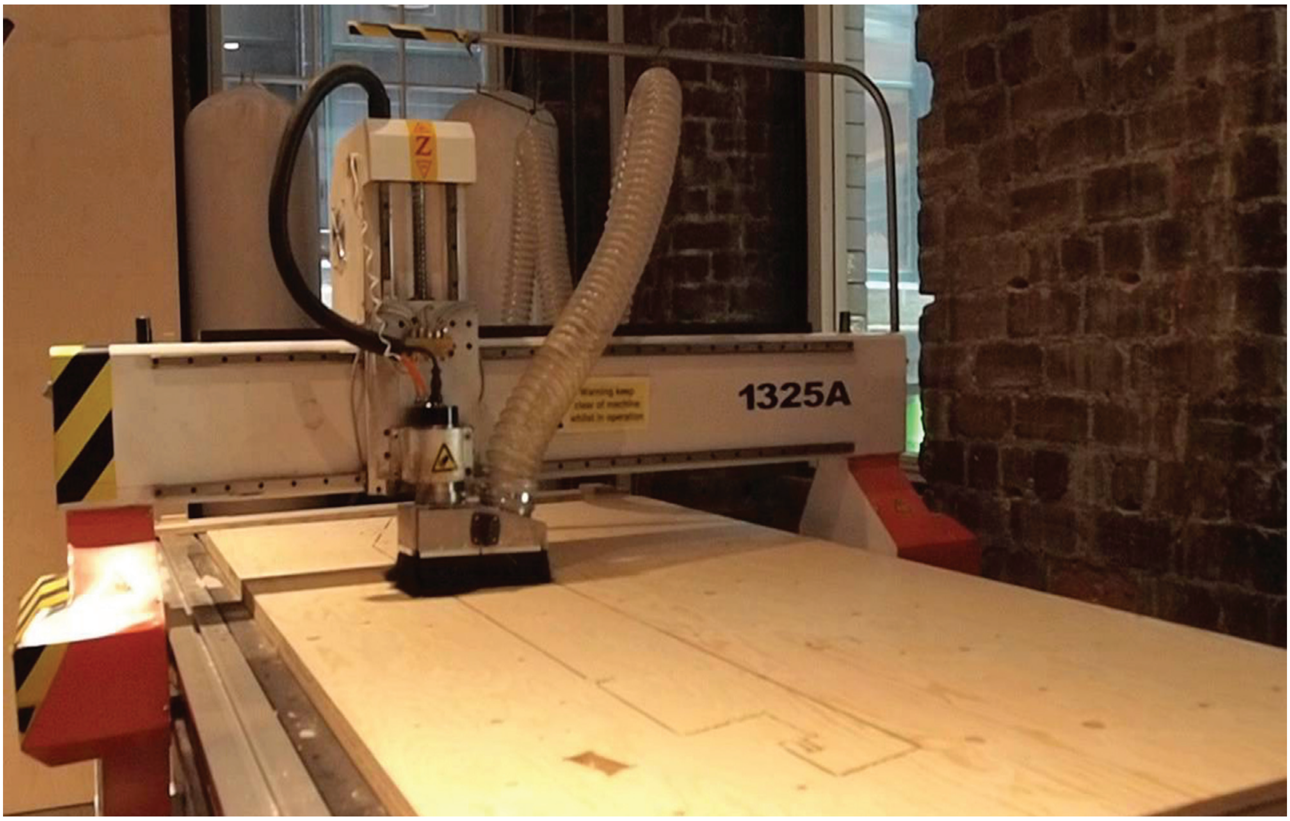

Fig. 2. A CNC machine. Source: https://www.youtube.com/watch?v=sKMNfHBlvh8.

Research project

It has been a few years since an inter-disciplinary team[3] of researchers of the Diarc (Department of Architecture of the University of Naples Federico II)began to study a niche research project, a temporary structures for outdoor chamber music concerts, naturally compatible with the issues discussed above. This group met up for a *Summer School* called *Villa Pennisi in Musica*, held every August in Acireale (Ct), where a workshop for the construction of an acoustic chamber for outdoor concerts and a Masterclasses of internationally renowned musicians, are joined together. For seven days, tutors and students build the chamber while masters and music students build the pieces to be performed during the Festival from day 8th to the 13th. The training program of the Architecture section (*ArchLab*) has always been on the same wavelength of Wiki House program; it is based on a very accurate design, uses sophisticated methods to guarantee a simple construction process and allow self-construction: its slogan can be summarised as *high-tech-design* for *low-tech-construction* (fig. 3).Since 2012, all the editions of the acoustic chamber, named *ReS* (Resonant String shell), have been built at Villa Pennisi and designed during the previous year, to get an even better result. The project comes out from a research process enriched every year with new fields of experimentation, sometimes inspired by the thin literature on the topic, to allow the alteration (massive, in some cases)of the shape, of the structure and of the constructive system of the shell. The fifteen days spent at Villa Pennisi are the trial phase of the research. The experiment is prepared during the first days and tested during the last

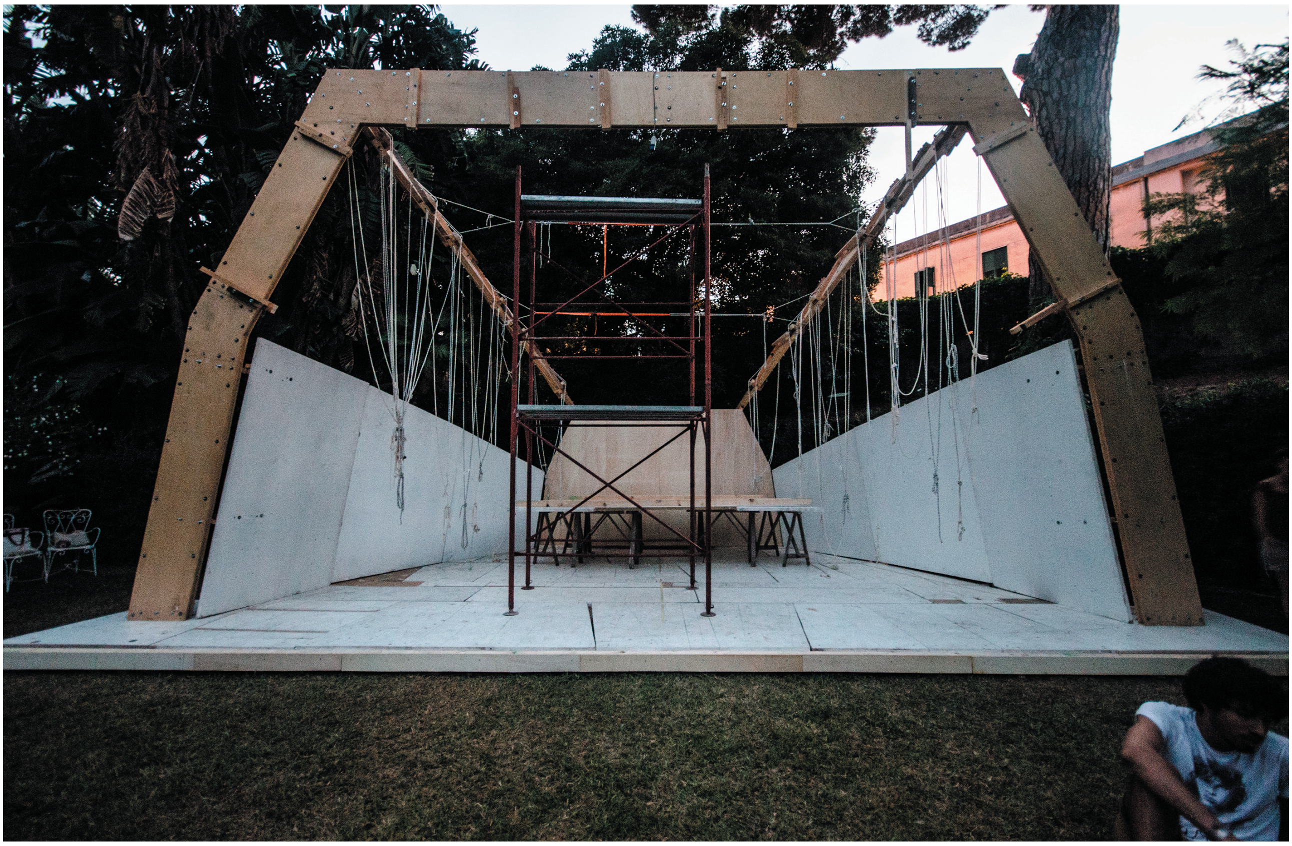

Fig. 3. Structure of ReS 4.1_Workshop_ Villa Pennisi in Musica. Ph. Daniele Lancia.

days of the Summer School according to two available devices: an instrumental one and a perceptive ones, that is the musicians' expertise. ReS is conceived as an actual stage for open-air music concerts and it is made of low-cost materials and elementary techniques; it is reversible and sustainable by its very nature (fig. 4).
The shape of old gramophones inspires its initial concept: in a similar fashion, ReS casts and directs the sound towards the audience thanks to two integrated systems: a truss load-bearing structure, and a set of panels that, given their weight of 20 kg/m^2, reflects the sound towards the audience. This second system represents the very acoustic machine, which in turn is made of four components: the *Main Shell*, responsible for the basic acoustic result, the *Cilia*, a row of adjustable panels, cantilevered towards the audience, responsible for the early reflections to the last row of the audience area, the *Diffusive Bottom*, in charge of the

Fig. 4. ReS 4.1_Concert at Villa Pennisi in Musica. Ph. Sonia Ponzo.

mutual listening of the musicians, and the *Array*, a pattern of smaller panels arranged inside the main shell above the musicians, responsible for the reflection of the high frequencies (fig. 5).
The first two versions of ReS have been designed starting from hypothesis derived from the theoretical expertise of other researchers in this field of outdoor sound diffusion, that is the main reason for creating a research program based on experimental tests, by means of specialist software, on the prototypes, to achieve a more effective knowledge to be used for further developments on the structure. For this reason the first two shells, built during the first two editions of the *Summer School*, were tested by a dodecahedron loudspeaker, an omnidirectional sound source, suitable for this sort of tests, and through a procedure called

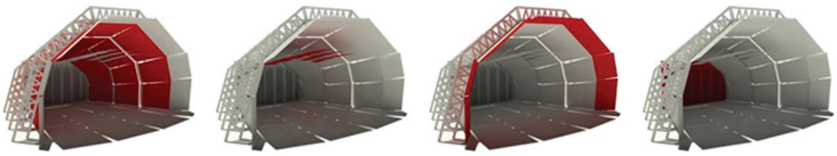

Fig. 5 Acoustic devices of ReS. Ph. Gridshell.it.

Impulse Response, in charge of recording the listening conditions in the audience area, for all the frequencies audible by the human ear (fig. 6).Further survey shave been achieved using questionnaires, filled out by musicians and experts attending the concerts; the results were satisfying and confirmed the instrumental surveys (Pone, Di Rosario, 2013).

For the 2014 edition of *Villa Pennisi in Musica*, the research team began to use the computational morphogenesis to determine the performances of the hanging *array*, together with the rules of the acoustic geometry– especially the *ray-tracing* method –to prefigure the increment of the sound pressure level due to the reflections of the panels towards the audience; these reflections add up the direct sound, making it louder, richer and more pleasant (fig. 7).This device is thought to besensitiveto the performing ensemble of musicians and can vary accordingly.

The *fitness* (target function) of the optimisation process is based on the minimisation of the sum of the audience areas with no reflections and of the sum of the areas reached by two (or more) reflections coming from different panels; the *genome* (variables) of the optimisation process corresponds to the orientation of the rows of the Array panels and their distance from the platform. This tool, running in Grasshopper^{tm}, a Rhinoceros^{tm} plug-in, generates different orientations of the panels and calculates the performance of the device. These solutions are compared through the Galapagos solver to select the shape offering the best performance[4]. A good coverage of the audience area, achieved through different configurations of the Array (set in a different fashion every day, according to the playing ensemble) allows high frequencies to be perceived a little earlier than the others, thus creating a better balance in the ensemble sound. In the previous editions of *Villa Pennisi in Musica*, indeed,a little predominance of mid-low frequencies covered the high ones, causing a less clear sound.

Fig. 6 A dodecahedron loudspeaker and an Ambisonic microphone used for the acoustic measurements of ReS. Ph. Sonia Ponzo.

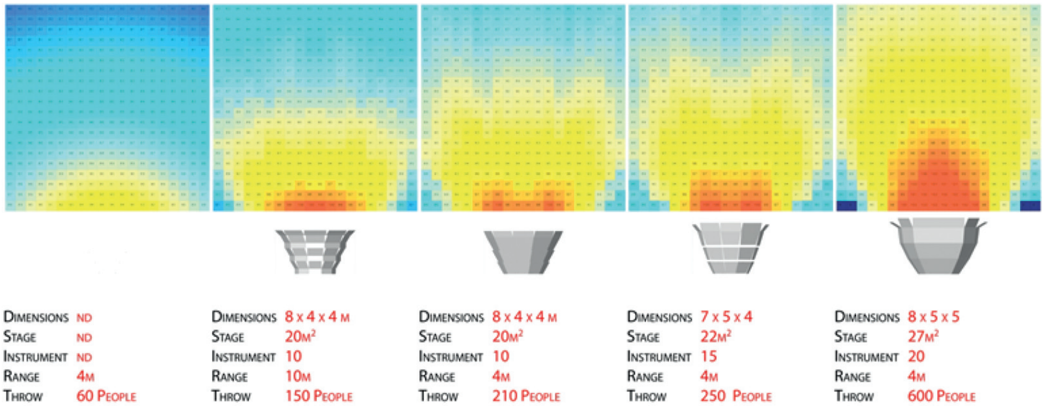

Fig. 7 The diagram shows the "coverage" of the audience area, with first and second order of reflections, in an empty field and with the structures, built from 2012 to 2015. Master's thesis of Lucci G., Mirra G., Pignatelli E.

The 2015 edition saw the convey of the principles described in the first part of this article in the design and construction of a completely new version of the shell. The first prototype of the new version, named ReS 4.0, has been designed through a non-commercial tool developed ad hoc, in the context of a Master Degree Thesis at the Department of Architecture of Naples[5]. This tool uses the *image source* method instead of the *ray-tracing* one; the image source method traces the sound rays back from the viewer's ear (*receiver point*) to the instrument that plays them (*sound source*), both the direct rays and the ones that were reflected once or twice on the panels of the acoustic shell. This procedure, only apparently unusual, makes it possible to take into account only the efficient rays, discarding the ones that do not hit any target. The considerable decrease of the number of rays to be processed allows to use the optimisation tool for all the active elements of the scene: the *main shell*, the *cilia* and the *array*.

This new non-commercial tool, thatuses Rhinoceros and Grasshopper, was created writing a number of commands in Python[tm], in order to reduce the time needed to generate the solutions. The genome of this computational morphogenesis process is the variation of the ratio between the axis of the ellipse circumscribed to the polygonal portals of the structure, the number of segments forming the polygon, the distance between the portals and their number. The fitness is simply the maximisation of the sum of all the SPL values (*Sound Pressure Level*) for each receiver point, without considering the ones that do not reach a set minimum value (Pignatelli, Di Rosario, Colabella, Pone, 2015).

The geometry achieved through this optimisation process generates a decrease of the SPL even at a considerable distance from the stage; therefore, an audience area of 500/600 spectators is covered, thus doubling the maximum audience of 250 people reached with the previous projects. The load-bearing structure of the shell also changed radically; instead of a lattice structure, it features box components. These elements consist of solid wood in the upper and lower part, and of ad hoc plywood panels on the sides. The main structure is made up of three parts: a big arch in the proscenium and two symmetrical ribs forming a "V" silhouette in plan, supported bythe ground in their connection and, on the opposite side by the main arch (fig. 8). The reflective panels are hung to the structure by pre-stressed sailing ropes, which, in the construction phase, constitute a traditional tackle with six pulleys. With this old device (already described by Vitruvius) the reflective panels are pulled up and kept well-placed during the performance.

Fig. 8 The arch and the “ribs” of the structure of ReS 4.0, during the building phase in the courtyard of Palazzo Gravina, Naples. Ph. Sofia Colabella.

Both the lateral panels of the structural elements and the reflective ones are cut by a three axis CNC machine in a process of digital manufacturing (fig. 9). The complex process defining the shape of the shell is directly linked to a similar complex manufacturing system, the enabler of such a thorough construction in a simple fashion, within reasonable budgets. The dimensioning system, that determines the position of each component is directly inferred from the 3D model; therefore, if the components are produced using digital technologies and their assembly is accurate, the final result will be definitely congruent with the project, thus assuring the same predicted performances derived from the exact geometry of the system (fig. 10). The digital manufacturing process simples the use of *File-to-Fabrication* protocol, where the blueprints can communicate with the machine tools that produce the components, without the interference of other software. By using digital technologies, architects take responsibility on construction information -directly derived from design information - and on the full control over the assembly phase. Fully understanding the contents of a complex project and building it as a carpenter represent, for the students, an amazing educational path that is deeply affected by the important changes that the digital tools are operating in the design and construction methods.

ACOUSTIC PANELS

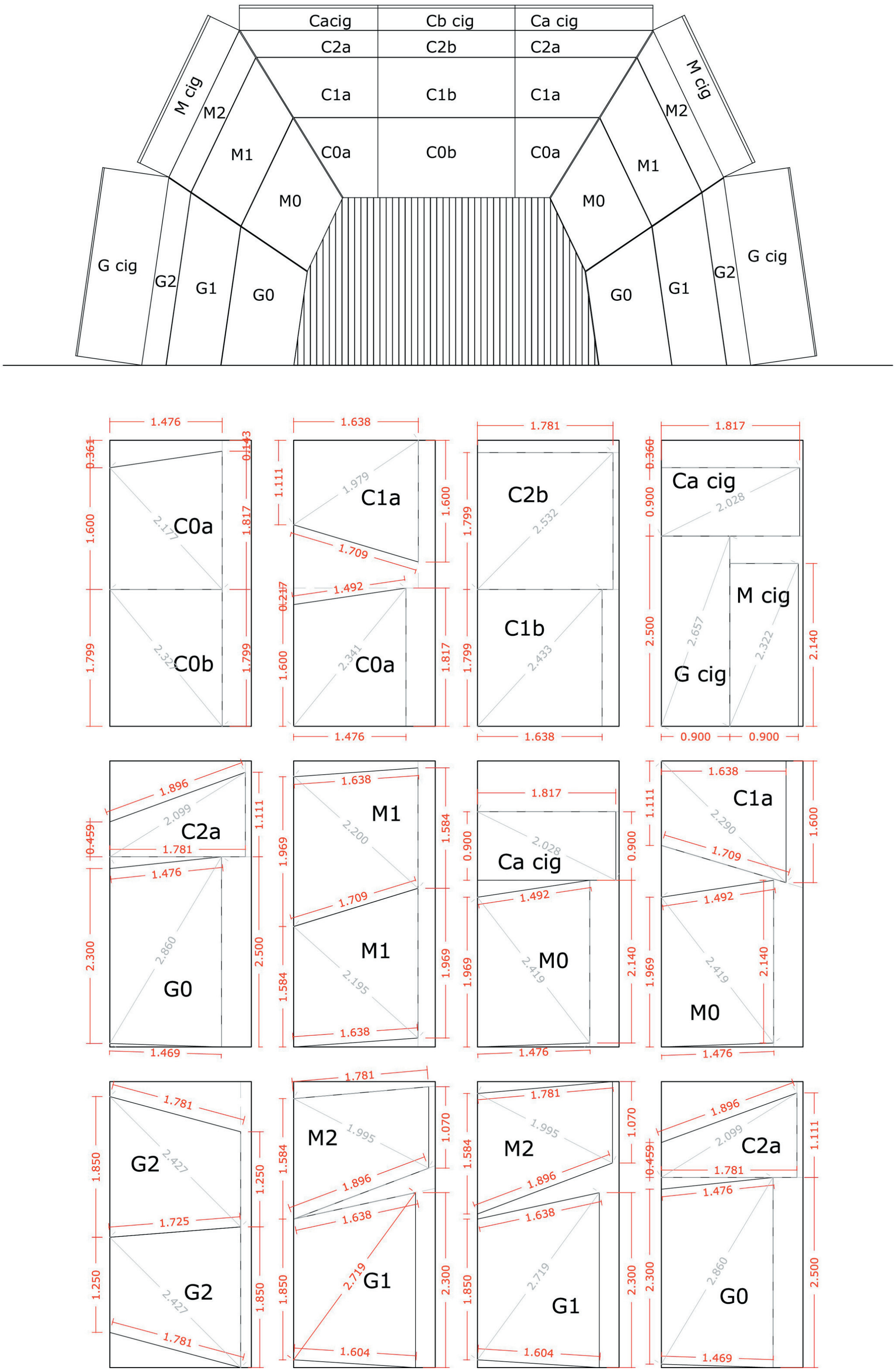

Fig. 9 The nesting of the panels of ReS. Source: Master’s thesis of Lucci G., Mirra G., Pignatelli E.


Fig. 10 The panels of ReS 4.0, before their assembly. Ph. Sofia Colabella.

Notes

1. The first part of this article was written by Sergio Pone, the second one by Bianca Parenti

2. In 2001 at the *Massachusetts Institute of Technology* (MIT), Neil Gershenfeld, director of the *Center for Bits and Atoms (CBA) from 1998, coordinates a course called How to Make (almost) Anything.* Here the first FabLab is born … Gershenfeld explains that this network of laboratories is part of a wider *maker movement*, through which *high-tech/do-it-yourselfers* are democratising the access to the productive systems.

3. The Diarc team is formed by Sergio Pone (coordinator of the ArchLab) and by arch. Sofia Colabella, Ph.D. arch. Bianca Parenti, arch. Daniele Lancia, Davide Ercolano, in collaboration with eng. Serafino Di Rosario, Acoustic Consultant di Buro Happold (London) untill 2015 and with maestro David Romano, second violin section leader in the Orchestra of the Accademia Nazionale of Santa Cecilia (Rome).

4. ReS 3.0, built in 2014, received the Peter Lord Award from the IOA (Institute of Acoustics of UK, London) in 2015, for the best architectural acoustic structure.

5. G. Lucci, G. Mirra, E. Pignatelli*, Computational Morphogenesis and Fabrication of an Acoustic Shell for Outdoor Chamber Music,* master's thesis in Architectural Technology at the University of Naples Federico II, supervisor prof. S. Pone, assistant supervisors prof. A. Pugnale, ing. S. di Rosario, Ph.D. arch. S. Colabella, Ph.D. arch. B. Parenti

The authors

Sergio Pone (Naples, 1958), architect, PhD in Architectural Technology at Politecnico of Milano, is an associate professor at the DiARC (Department of Architecture) of the University of Naples Federico II where he holds the "Construction" studio and the course of "Modeling and Prototyping". His main research topics are wooden innovative technologies (in particular about "active bending"), architecture for music and digital manufacturing. Since 2012 he has been coordinating of "Villa Pennisi in Musica", a Summer School of Architecture, within which he carries out the research on ReS (Resonant String Shell), an acoustic scene for outdoor chamber music concerts, that won the Peter Lord Award conferred by the IOA (Institute of Acoustics of UK), London, 2015. He is the author of *L'idea di struttura*, published by Franco Angeli and of *Gridshell. I gusci a graticcio in legno tra innovazione e sperimentazione*, published by Alinea.

Bianca Parenti (Naples, 1977), architect, PhD in Architectural Technology at the University of Naples Federico II, she is one of the founders of Gridshell.it. Her research is focused on innovative timber structures, architecture for music and structures for the management of solid waste.
Since 2012 she has been teaching construction and architecture in the Summer School of "Villa Pennisi in Musica" within which she participates in the research on ReS (Resonant String Shell), an acoustic scene for outdoor chamber music concerts that won the Peter Lord Award conferred by the IOA (Institute of Acoustics of UK), London, 2015. She is the author of many papers and essays about innovative timber structures and about acoustics in architecture.

Bibliographical references

Anderson C. (2012), *Makers. Il ritorno dei produttori*, tr.it. Rizzoli, Milano, 2013.

Wing J. (2014), "Computational Thinking Benefits Society", in *40th Anniversary Blog of Social Issues in Computing*.

Rifkin J. (2014), "La rivoluzione industriale e il 'futuro a costo 0", in *L'Espresso*, settembre 2014.

Micelli S. (2016), *Fare e innovare. Il nuovo lavoro artigiano*, il Mulino, Bologna, 2016.

Parvin A. (2013), *Architecture for the people, by the people*, Ted talk.

Pone S., Di Rosario S. (2013), "Concordia parvae res crescunt", in atti di *Abitare il Futuro. Abitare il nuovo/abitare di nuovo nei tempi di crisi*, 2° edizione di Abitare il Futuro, Clean, Napoli.

Lucci G., Mirra G., Pignatelli E. (2015), "Computational Morphogenesis and Fabrication of an Acoustic Shell for Outdoor Chamber Music", tesi di laurea in Tecnologia dell'Architettura all'Università di Napoli Federico II, relatore prof. S. Pone, correlatori prof. A. Pugnale, ing. S. di Rosario, Ph.D. arch. S. Colabella, Ph.D. arch. B. Parenti.

Pignatelli E., Di Rosario S., Colabella S., Pone S. (2015), "A wooden acoustic shell for open-air chamber music concert", in *Proceedings of the International Association for Shell and Spatial Structures* (IASS) Future Visions, 17 - 20 August 2015, Amsterdam, The Netherlands.