The Tensegrity Arch at TorVergata

A gateway to the university campus and a full-scale experimental facility

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RÉSUMÉ. *On présente un rapport bref sur la conference que l'auteur a donnée à l'occasion du Colloque Lagrange "Tenségrité : Analyse et Projets", qui a eu lieu à la Villa Mondragone, Rome, le 6-8 mai 2001.*

ABSTRACT. *A short account is given of the opening talk given by the author in the occasion of the Colloque Lagrange "Tenségrité: Analyse et Projets", held at Villa Mondragone, Rome, on May 6-8, 2001.*

MOTS-CLÉS : *tenségrité, tours, arcs.*

KEYWORDS: *tensegrity, towers, arches.*

1. Background Information and Antecedents

1.1. *The University of Rome TorVergata*

In Italy, there are about eigthy universities, some very old,[1] many old, and many also brand-new on the time scale of centuries, among which mine, the University of Rome TorVergata, founded less than twenty years ago. Now, while nobody would deny the importance of tradition, excellence can be pursued and achieved also by young academic organisms, as the case of TorVergata vividly demonstrates.

When the first CENSIS Report on the Italian university system was published, in July 2000, TorVergata was ranked, to the surprise of many, fourth over all. One year later, our School of Engineering, which had been ranked sixth in July 2000, was third over thirty-six schools in total, preceded only by the Polytechnic of Milan and by the Polytecnic of Turin, the oldest and most prestigious schools in Italy. The ranking was based on five indicators : productivity, attraction and influence, teaching, research, and international relationships ; on a scale from 66 to 110, TorVergata averaged 92.4 (with a round 110 for research), with Turin at 93.2 and Milan at 99.6.

1.2. *The Primum Movens*

As a manifestation of the emphasis placed on quality and quantity of scientific achievements at TorVergata, our Rector, Professor Alessandro Finazzi Agrò, declared the 23d and 24th of October 2000 the Research Days, and issued that an exhibit with posters and audiovisual devices were organized in those dates at our congress facility, Villa Mondragone, so as to make it possible to everybody to have a quick, exhaustive overview of all the diverse research activities in our university. When I myself was strolling to that purpose through the magnificent halls of the historical Villa Mondragone, to my pleasant surprise, I found Professor Finazzi Agrò standing in front of the poster on tensegrity structures my student A. Micheletti and I had prepared. The Rector's eye had been captured by the shear beauty of the tensegrity concept as realized in the structural examples we had included in the poster, and he was wondering about the concept's implications in interpreting the assembly rules of living organisms, from the molecular to the macroscopic scale [ING 98]. In a matter of minutes, I had promised my Rector to build, in an appropriate location of our "territory",[2] a real tensegrity structure – no toy ! – to serve as both a gateway to our university and a full-scale experimental facility. For a moment, perhaps with the conspirational aid of the location, I felt somehow like a Renaissance architect whose lord had asked to design a new addition to his palaces. But, as soon as I started to realize the entity of the enterprise I had plunged myself in, I got really scared, and begun to look for help.

1. "Universitas Bononiensis antiquissima est orbis occidentalis, ne dicam totius orbis ... nemo dubitet quin primum Bononiae universitas orta sit." da *Rector lectoribus*, htpp ://www.unibo.it.
2. TorVergata's campus, with its 600 hectares of gently rolling lawns just outside the South-East section of Rome's beltway, is one of the largest in Europe.

1.3. *The Choice of the Arch Shape and the TensArT*

The first problem I faced was to choose an appropriate structural type. I knew of no built structures being, strictly speaking, tensegrities, apart for the two beautiful towers erected in Washington, D.C., and the Netherlands by the artist Kenneth Snelson, and, in a less strict sense, the canopy of the Georgia Dome in Atlanta. None of those structures I could possibly think of imitating. However, when discussing my problem with Franco Maceri, an old friend and a colleague in my Department, two useful ideas came up : first, and mostly intriguing, the idea of choosing an arch shape, as a citation and a homage to the greatest contribution to architecture of the Romans ; and, secondly, the idea of choosing the tensegrity theme for a relatively small, but higly qualitative workshop that Maceri, in his fresh capacity of cofounder of the Colloque Lagrange, a French-Italian venture to promote joint academic research in civil engineering, was about to organize together with Professors Michel Frémond (Paris) and René Motro (Montpellier), the latter, by a lucky coincidence, an internationally well-known expert in tensegrity structures.

The occasion of the workshop seemed perfect to bring together a qualified group of researchers, who, as an aside to discussing their latest findings, would orient me in a presumably long, no-map navigation from an intriguing design idea to a built tensegrity arch of monumental proportions. In the mean time, my first priority was to make the design idea precise. I found help with another colleague in my Department, Silvano Stucchi. He and I considered various types of arches (not that examples are rare in Rome !), and their proportions, helped in our search by his former student G. Torrisi and by Micheletti. A Roman arch we found archetypal was Constantine's triumphal arch, as is masterly reproduced by Botticelli in one of his Sistine Chapel frescoes (Fig. 1, left).

Figure 1. *(left) S. Botticelli, "The Punishment of Korah", Sistine Chapel, Rome. (right) A tensegrity arch with the proportions of Constantine's arch*

The fabric of the Constantine's arch is grand, with two lateral smaller arches, powerful springers and a massive crowning attic ; all three arches are round, with the diameter of their fornices and the height of their springers in the classical proportions dictated by taking the golden section of a segment. It was immediately clear to us that it made no sense to reproduce by a tensegrity structure – of minimal weight, traversed by light – anything more than the inner profile of the central arch. But, when Micheletti and Torrisi did that for us (Fig. 1, right), the result simply did not seem right. We then concentrated on the arch as is rendered by the tensegrity concept, that is, as a sign without a surrounding fabric ; and, having quickly discarded a segmental arch, we made it full and round, as the typical Roman arch must be (Fig. 2).

Figure 2. *A rendering of the TorVergata campus, as seen through the Arch*

It remained for Stucchi and I to choose the location. With the recent memories of the encounter Pope John Paul XXVI had had with the youth in August 2000 in the occasion of the Jubilee, we chose the round-about where the Jubilar Door had been built through which His Holiness had passed to enter our campus. And we decided to build an arch with radius of 25 m in the middle of a circular pool, about 60 meters in diameter, so that the arch would reflect in the shallow waters of the pool, composing a huge, full circle. At this point, the general conception of the TorVergata Arch was completed (*vid.* also [MPGS 01]).

It was now time to undertake the technical part of the job, and put together a preliminary design of the Arch. I resorted for guidance and help to my long-standing friend and companion in research Bill Williams, from whom I had first heard about the subtleties in the unusual mechanics of tensegrity structures. Now, it so happens that Williams, a mathematician whose first background is in engineering, has been collaborating for various years on the subject with a colleague of his from Carnegie Mellon University in Pittsburgh, Pennsylvania, Irving J. Oppenheim, who is associated with the Departments of Architecture and of Civil and Environmental Engineering. In a matter of days, Williams and Oppenheim agreed to team with Stucchi, Micheletti, Torrisi, and myself, under the acronym *TensArT*, for Tensegrity Arch Team. Shortly after, our American team-mates produced the document [OW01], which was to serve as a basis for our further developments of the arch project.

2. Concept and Design of a Tensegrity Arch

This is no place, and I have no authority, for an exhaustive account of the tensegrity concept. Suffice it to say that, in civil engineering, a typical tensegrity structure is a spatial truss composed of cables and bars, with exactly one bar and at least three cables in each node, so that the tension members form a connected set of polygonal lines in space, whereas each of the compression members is isolated. In principle, tensegrities are deployable ; they take their equilibrium shape in the set of their *tensegrity placements* and, in that they are form-finding structures, can be regarded as “intelligent" : just as the structures observed in nature at all scales, they seem to find their way to self-assembly “by arranging their parts to minimize energy and mass through continuous tension and local compression" [ING 98].[3] Moreover, typical tensegrities are in a state of prestress before application of the service loads ; the combination of prestress and service loads should never cause any cable to become slack or any bar to become Euler unstable.

To my knowledge, full-scale tensegrity arches have never been built. We have chosen to rely on the stage type used by K. Snelson for his towers, because its mechanics is well understood ; by stage multiplication, a tensegrity structure obtains which is typical in the sense of the above cursory definition. There are 3 bars and 9 cables, 3 vertical and 6 diagonal, in each stage, while two adjacent stages are separated by 6 saddle cables (Fig. 3) ; each stage is inscribed in a cylinder of about 4.5 m in diameter and height ; the arch consists of 25 stages. A geometrically exact method has been conceived by Micheletti, building on some general ideas of Williams, to obtain the arch from a multi-stage Snelson tower made to flex by shortening some cables and lengthening others, in such a way that a continuous path of tensegrity placements is followed ; precisely, the arch is formed by shortening the three “intrados" cables while

3. Living organisms display a rich variety of more complex tensegrity architectures than the one here described, some of which are reminiscent of the architectures proposed for the tensegrity versions of rods, plates, and shells, that is, the other basic shapes of structural mechanics beside the arch.

lengthening of the six remaining “extrados" cables). Tapering of the arch (not shown in Fig. 2) has also been considered.

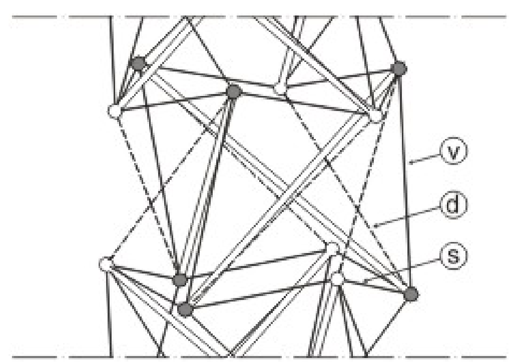

Figure 3. *A stage of a Snelson Tower, with indication of the vertical, diagonal and saddle cables*

Beside being an eye-catching monument, the TorVergata Arch is meant to be a permanent experimental facility, accessible to various research groups in Europe, suitably equipped to gain information about such issues as, among others : design of structural elements (cables, bars, and, chiefly, joints) ; building strategies and tensioning processes ; wind loading (especially, turbulence effects on a cable-bar network) ; vibration damping ; mechanism locking ; failure analysis ; durability and maintenance.

At the moment of this presentation, the service loads have been evaluated, cables and bars proportioned, and both local and global stability checked ; as to joints, many alternatives are currently under study. Our task is not easy, because for tensegrity structures both design principles and design rules have never been systematically formulated and collected (apart of course for [OW01]). But we confidently accept the suggestion of the poet :

“*Caminante, no hay camino.*
Se hace camino al andar."
(A. Machado)

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3. References

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