Leonardo 2013, 3-5 June 2013, Perdizes, Portugal

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Published online: 18 March 2014
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Abstract A three-day workshop on the design and construction of reciprocal structures allowed a group of international scholars to experiment with and exchange ideas about dome structures inspired by the designs of Leonardo da Vinci.

Keywords Structural reciprocity · Leonardo da Vinci ·
Leonardo grids · Tensegrity · Spatial structures · Timber constructions

Ten years ago, in 2003, a group of like-minded thinkers gathered in Vinci, Italy, and then in Ponte a Egola, 14 km from Vinci, to discuss Leonardo's thoughts about and ideas for architecture and mathematics. That first meeting consisted of a two-day seminar in the Biblioteca Leonardiana in Vinci, during which each participant presented his or her ideas, followed by the actual construction of four dome structures based upon the system that Leonardo sketched in his *Codex Atlanticus*, which represent what we today call 'reciprocal structures'. The results of that first experience were published in a special issue of the *Nexus Network Journal* entitled "Leonardo da Vinci: Architecture and Mathematics" (*NNJ* vol. 10, no. 1, 2008).

To celebrate the 10-year anniversary of that meeting, another group assembled in beautiful Perdizes, Portugal, near the Gerês hills, for a three-day workshop to take this initiative to the next level. The intention was to build new domes, again using Leonardo's lattices, but pushing his ideas further. The meeting took place 3–5 June 2013. Some of the participants from the 2003 workshop were present, including the

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authors of this conference report, João Pedro Xavier, 2013 workshop host, and Kim Williams, host of the 2003 meeting, workshop leader Rinus Roelofs (Netherlands), Chris Glass (USA) and Biagio Di Carlo (Italy). Joining them were Alberto Pugnale (Australia), Dmitri Kozlov (Russia), Eliana Manuel Pinho (Portugal), Javier Barrallo (Spain), and José Pedro Sousa (Portugal) (see Fig. 1 below).

The plan was to construct reciprocal domes featuring double curvatures and dual layers, including areas of negative curvature, under the supervision of Rinus Roelofs (Fig. 2), who kindly accepted our invitation to ‘command’ the ‘construction site’, as well as other similar structures suggested and directed by other participants.

Sculptor Rinus Roelofs arrived in Perdizes with a van full of small and large elements to use for building models in order to understand the system, and larger elements to build full scale domes. Rinus began his work on reciprocal structures in 1989, when he found that he had independently developed a structural system that was just like the one sketched by Leonardo on fol. 899v of the *Codex Atlanticus*

Fig. 1 Leonardo 2013 workshop participants are looking to the future. Photo: Luis Ruivo

Fig. 2 Workshop leader Rinus Roelofs with Alberto Pugnale and Eliana Manuel Pinho. Photo: Dmitri Kozlov

(Roelofs 2008; Williams 2008). He has worked intensively with the system. The important new development that he presented here was the discovery that if the basic beam units is curved instead of straight, it accentuates the curvature of the dome as a whole (Fig. 3).

Further, the shape of the final dome depends on whether the curve of the basic element is concave or convex; if a combination of concave and convex are used, the dome can assume an undulating shape (Fig. 4). This characteristic allowed us, for example, to build a dome on sloping ground, where the structure appeared to respond to the form of the site in an organic way (Fig. 5).

Fig. 3 Convex and concave curved basic elements used in the dome structures. Photo: Dmitri Kozlov

Fig. 4 The undulating dome structure built with combinations of convex and concave elements. Photo: Dmitri Kozlov

Other structures were built as well. Architect Chris Glass, who had presented the work of Gaudi, the Guastavinos, Buckminster Fuller, Steve Baer, and Kenneth Snelson as Leonardo's successors (Glass 2008), directed the construction a Tensegrity structure that he had prepared for the workshop (Fig. 6).

Biagio Di Carlo, who has worked with rigid tensegrity for a number of years (Di Carlo 2008), used bamboo canes to build a series of Platonic and Archimedean solids (Fig. 7).

Mathematician Eliana Manuel Pinho, who had no prior experience in construction at all, created a modular way of building a dome. Her basic module, easily constructed, consists of seven curved beams, (Fig. 8); four of these modules

Fig. 5 The dome built on a slope. Photo: Dmitri Kozlov

Fig. 6 Architect Christopher Glass and the Tensegrity structure he prepared for construction. Photo: Luis Ruivo

determine a ‘pod’, and the final dome is a combination of pods, in this case four (Figs. 8, 9).

Architect Alberto Pugnale directed the construction of rigid tensegrity structures that he has used in his courses in Aalborg University, Denmark, and at the University of Melbourne, and which showed a remarkable resistance to stress (Fig. 10).

The workshop also included one session for presentations so that participants could introduce themselves and their work, and another one for a general final discussion, where each participant shared the results of their research in this area, and the group as a whole discussed possible developments for studying and building

Fig. 7 Rigid polyhedra structures built by Biagio Di Carlo. Photo: Biagio Di Carlo

Fig. 8 The basic 6-unit module designed by Eliana Manuel Pinho. Photo: Kim Williams

Fig. 9 Eliana Manuel Pinho and the final dome constructed with four modular pods. Photo: Kim Williams

Fig. 10 Alberto Pugnale and his reciprocal structure. Photo: Dmitri Kozlov

these kinds of structures in a pedagogical context with teachers and students of architecture.

There was even an opportunity to present our work to the mayor of Terras de Bouro, Dr. Joaquim Cracel, who generously offered the group a tour of the hills around Geres, and a fine dinner (Fig. 11).

The 2013 workshop was made possible by the generous support of the Faculdade de Arquitectura da Universidade do Porto (FAUP) and its Dean, Prof. Carlos Guimarães, the Centro de Estudos de Arquitectura e Urbanismo (CEMU) and its Dean, Prof. Doutor Rui Póvoas, the city of Terras de Bouro and its Mayor,

Fig. 11 Joao Pedro Xavier explaining reciprocal structures to Mayor Joaquim Cracel. Photo: Dmitri Kozlov

Dr. Joaquim Cracel. We also enjoyed the warm hospitality of Isabel Ruivo and the helping hands of Rosalee Glass, and the photo and film documentation of Luis Ruivo.

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Kim Williams received her degree in Architectural Studies from the University of Texas in Austin, and did her apprenticeship in the offices of Philip Johnson in New York. She became interested in mathematics and architecture while writing *Italian Pavements: Patterns in Space* (Houston: Anchorage Press, 1998) about the role of decorated pavements in the history of Italian architecture. In 1996 she began the international conference series “Nexus: Relationships Between Architecture and Mathematics,” In 1999 she founded the *Nexus Network Journal* to provide a dedicated venue for scholarly research in architecture and mathematics. In 2000 she founded Kim Williams Books, an independent press for books about architecture and mathematics. Her latest book, co-edited with Michael Ostwald, is the two-volume *Architecture and Mathematics from Antiquity to the Future* (Birkhäuser 2014).

João Pedro Xavier an architect and geometry teacher, is Associate Professor in the Faculty of Architecture of the University of Porto (FAUP), where he graduated in 1985 and received a Ph.D. in Architecture in 2005. He worked in Álvaro Siza's office from 1986 to 1999 and, at the same time, he established his own practice as an architect (<http://www.jpx-arq.com>). Xavier has always been interested in the relationship between architecture and geometry, especially perspective. He is the author of

Perspectiva, perspectiva acelerada e contraperspective (FAUP Publicações, 1997) and *Sobre as origens da perspectiva em Portugal* (FAUP Publicações 2006). He published several works and papers on the subject, presented conferences and lectures and taught courses to high school teachers. He was co-director of the Nexus 2010 conference in Porto, and he is a member of the Editorial board of the *Nexus Network Journal*.