Letter from the Guest Editor: Reciprocal Structures, An Overview

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Abstract Guest editor Alberto Pugnale introduces the theme of and contributors to special issue of the *Nexus Network Journal* dedicated to Reciprocal structures.

Keywords Reciprocal structures · Engineering · Morphology · Structural typology · Design tools

Reciprocal structures and the *Nexus Network Journal* first met in 2003, when a workshop dedicated to the study of Leonardo's lattices took place in Vinci, Italy.¹ The experience was inspired by sketches that Leonardo left on folio 899v of the *Codex Atlanticus*, where reciprocal arrangements of timber beams are illustrated as possible geometrical variations of a curious construction technique. Four domes based upon Leonardo's system were built in full scale, and the event led to the publication of a special issue on the theme in 2008 (*NNJ*, Vol. 10, No. 1).

This story happened before I first approached reciprocity in 2010. I was teaching structures at Aalborg University, in Denmark. Design and optimization of shells and gridshells was the core of my subject, which was conceived for architectural students. For the first year, it was entitled 'Formfindings', for the second edition 'Engineering Architecture'. Everything was about the approach, method and development of technical skills. Inspiration was sought in the characteristics and constraints of typologies. Experimental and numerical design tools were to be mastered first, ideas came after: no rules, no success. Reciprocal structures were

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¹ A short workshop report can be found in Duvernoy 2008.

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close to perfect for my pedagogical needs, and that is why I organized two construction workshops on them.² Through the comprehension of a basic structural principle, students could have been able to transform simple beams into articulated spatial configurations. This was my first experience with reciprocal structures.

Two years of didactics ran parallel with the idea of completing a full literature review on the topic. At that stage, I never expected to deal with such a vast research area for architecture. A few key questions arose rather early. Why are reciprocal structures called by so many different names by different authors, such as ‘reciprocal frames’, ‘nexorades’, ‘mutually supported elements’? What are the reasons for such a terminological inconsistency? What are the dynamics behind the research activity in this field? Reciprocal structures are first of all structures: why is there as yet no consistent study of their mechanical behaviour? They have always been related to timber as the construction material. Is there any reason for that, any promising research activity? If they are intrinsically tri-dimensional because of superimposition joints, why are they mainly designed to appear like simple domes or shells? This is just a sample of the questions which became the spark for writing a first conference paper in 2011 (Pugnale et al. 2011), a short text in which these points were simply highlighted. A more ambitious publication plan was still needed, as well as collecting substantial contributions from an organized research network.

Since the *Nexus Network Journal* had already dealt with reciprocal structures, I decided in 2012 to contact Kim Williams, the editor-in-chief, and propose a new thematic issue on the topic. I was surprised to hear that, with the aim of celebrating the 10-year anniversary from the 2003 workshop on Leonardo’s lattices, a new edition was almost organized. An unexpected coincidence for a rapid agreement: the release of a second special issue of the *Nexus Network Journal* was scheduled too.³

That is briefly the context in which this spring 2014 issue was born. The first article, “Structural Reciprocity: Critical Overview and Promising Research/Design Issues” by Alberto Pugnale and Mario Sassone, is conceived as a theoretical and conceptual introduction to the field of reciprocal structures. The second contribution, “Static and Kinematic Formulation of Planar Reciprocal Assemblies” by Dario Parigi, Mario Sassone, Paolo Napoli and Poul H. Kirkegaard, deals with form-finding and morphogenesis of reciprocal structures by modelling the behaviour of kinematically undetermined configurations. Such theoretical aspects led two of the authors, Dario Parigi and Poul Kirkegaard, to develop a new computational design tool, which is explained in a separate article entitled “The Reciprocalizer: An Agile Design Tool for Reciprocal Structures”. They also built a full scale prototype at Aalborg University and a complementary focus on digital fabrication issues is provided in the article “Design and Fabrication of Free-Form Reciprocal Structures”. A different form-finding tool is described in the contribution ‘A Form-Finding Instrument For Reciprocal Structures’ by Udo

² Two colleagues introduced me to this topic: Mario Sassone, who has been supervising theses and organizing workshops on reciprocal structures since 2005; and Dario Parigi, who has developed his entire academic profile on them. Both collaborated or co-coordinated the workshops in different forms, and I would like to thank them.

³ A great thank you is dedicated to Kim Williams, who placed her trust in my proposal and gave me the possibility to discuss and develop my thoughts.

Thönnissen, where both theoretical and practical aspects of geometry and fabrications are discussed through the experience gained from construction of full scale prototypes. Form-finding of reciprocal structures is also the topic of “An Interactive Computational Design Tool for Large Reciprocal Frame Structures” by Peng Song and Chi-Wing Fu et al., where the authors, using a different approach, present a digital tool to transform 2D patterns of reciprocal grillages into their 3D corresponding versions. Tension between practice and academic research is the core of the contribution “Reciprocal Frame (RF) Structures: Real and Exploratory”, in which Olga Popovic Larsen reflects on real application of reciprocal structures, and compare them with research and teaching experiences. Construction aspects are also discussed in the article “Reciprocal Tree-Like Fractal Structures” by José Sánchez-Sánchez, Felix Escrig and Maria Teresa Rodríguez-León, where a tree-like deployable reciprocal structure is presented. Morphological experiments are provided in three articles. The first, “Three-dimensionality in Reciprocal Structures: Concepts and Generative Rules” by Dario Parigi and Alberto Pugnale, explores the intrinsic tri-dimensionality of reciprocal structures with superimposition of bars. The second, “Reciprocal Systems Based on Planar Elements: Morphology and Design Explorations” by Olivier Baverel and Alberto Pugnale, proposes several reciprocal assemblies made with planar elements instead of conventional beams. The third, “Morphological and Mechanical Investigation of Double-Layer Reciprocal Structures” by Cyril Douthe and Olivier Baverel, investigates double-layer reciprocal configurations aimed at improving the overall mechanical behaviour. Structural aspects of reciprocal grillages were considered for the first by John Wallis, during the period of birth of scientific research. His calculations are described in detail by Guy T. Houlsby in the article “John Wallis and the Numerical Analysis of Reciprocal Structures”.

The discussion of reciprocal structures concludes with a conference report by Kim Williams and João Pedro Xavier of “Leonardo 2013”, the workshop which took place in Geres, Portugal, in June 2013 and was the sequel to the first workshop on Leonardo’s lattices in 2003.

My hope is that this issue will pique the lay reader’s curiosity first. Readers with more expertise can instead reflect on the current state-of-the-art, and find inspiration for the development of future promising research activities for architecture.

A handwritten signature in blue ink, reading 'Alberto Pugnale', with a long, sweeping horizontal line extending to the right.

Alberto Pugnale, Guest editor

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Alberto Pugnale is a lecturer in Architectural design at the University of Melbourne, Australia. In 2007, he won the fifth edition of the IASS HANGAI Prize, related to the study of complex architectural/structural bodies. He has been a assistant professor at Aalborg University, Denmark (2010–2012), and an invited lecturer in France and Italy. At present, he is member of the International Association for Shell and Spatial Structures (IASS) and is a licensed architect in Europe. His research interests are in the computational morphogenesis of free-form structures, reciprocal structures and history of construction.