

ZEBRA – A Heteromodular Origami Technique for Constructing Large-Scale 3D Framework Architectures and Kinematic Linkages from Standard A4 Office Paper

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Abstract

This paper presents a highly heteromodular origami technique, named ZEBRA, for assembling 3D framework structures from elementary struts and connectors folded from uncut sheets of standard A4 office paper [1]. The technique allows the construction of large architectural paper objects, such as truss bridges and towers, on a scale of several meters in all spatial dimensions without using adhesives to connect the elements. The basic set of static elements is complemented by various decorative parts as well as a number of kinematic modules, including levers, bellows, and pivot joints. The kinematic extensions permit the integration of moving parts into static frameworks, ranging from simple mechanisms such as swivel gates to complex multi-bar paper linkages.

In my contribution, I will give an overview of the (steadily growing) set of more than 20 elementary modules, their taxonomy, the corresponding folding procedures, and the fundamental design considerations behind them (Fig. 1). I will show how to connect multiple basic elements to complex cubical truss segments with a lattice size of 21 cm that are capable of bearing considerable compressive, tensile, and shear loads (Fig. 2). These truss segments can be assembled in any number to framework structures of arbitrary size (Fig. 3).

In a vertical stack of cubical truss segments, each stack level is constructed from 40 A4 sheets. Using office paper with a density of 100 g/m^2 to fold the basic elements, the resulting mass density of the truss is 0.25 kg per stack level. For a single cube, a vertical compressive load capacity in excess of 150 N ($> 15 \text{ kg}$) has been determined experimentally. It follows that more than 60 cubes could be stacked to a truss tower with a total height of more than 12 m before the bottom cube would collapse under the tower's own weight.

The kinematic modules have been designed using principles of compliant mechanisms to implement rotational motion capabilities [2]. I will explain their design and demonstrate their performance in exemplary linkage assemblies (Fig. 4).

Finally, I will give an outlook on the range of applications of the ZEBRA technique in university-level engineering courses.

[1] [Online] https://www.flickr.com/people/eckhard_hennig

[2] L. L. Howell, S. P. Magleby, B. M. Olsen, *Handbook of compliant mechanisms*, Chichester: Wiley, 2013

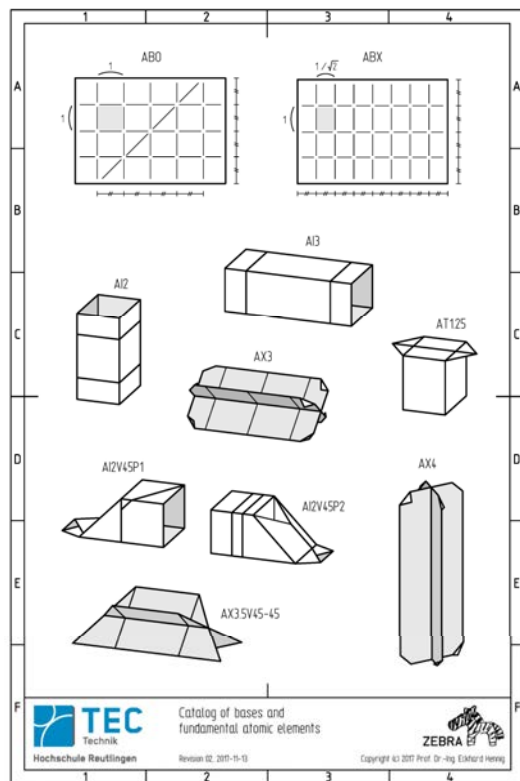


Figure 1: A4 base crease patterns, connectors, and fundamental atomic strut components

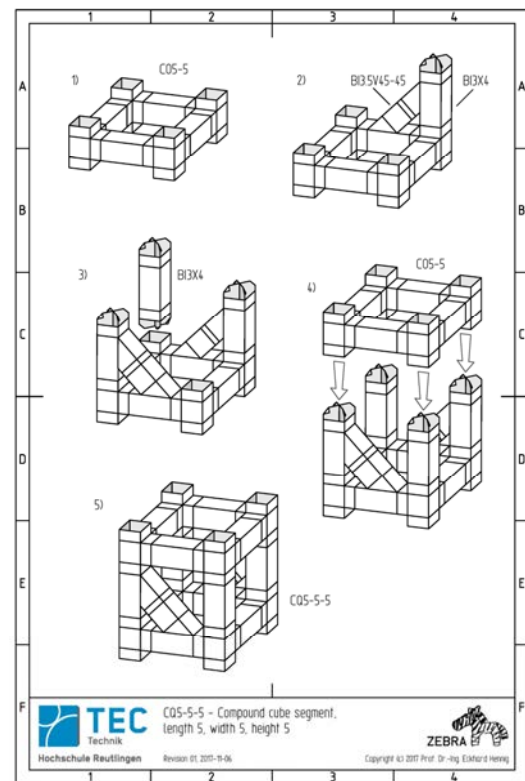


Figure 2: Assembly of a cubical truss segment from static struts and connectors



Figure 3: Truss bridges; **top:** 2 m wide, folded from 700 A4 sheets; **bottom:** 90 cm wide, 150 A4 sheets, carrying a pack of printer paper (3.1 kg)



Figure 4: **top:** compliant pivot joint with 180° free motion range; **bottom:** kinematic linkage demonstrator, folded from 320 A4 sheets