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# Design, construction and strengthening of shell structures made by folding

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## Abstract

Modern high performance materials like Textile Reinforced Concrete (TRC) offer new possibilities for the construction of very filigree and lightweight structures. Prefabricated plate elements can be transformed into complex three-dimensional shapes by folding without a laborious construction of curved formworks. In order to exploit the design space within the envisioned technology a method was proposed involving form-finding, simulation of folding process, and production concepts, as well as an assessment of structural performance. Since inspiration for this approach was derived from the ancient art of paper folding origami (ori=folding; gami = paper), we call the method oricreate and its application to concrete oricrete (ori- and con**crete**). By using the design and manufacturing methods, several prototypes of folded plate structures have been realized and tested with sizes up to 2,4 m x 3 m. The design and manufacturing process of folded structures and experimental investigations are described and methods for strengthening proposed.

**Keywords:** form finding, textile reinforced concrete, folded plate structure, concrete shell, folding, light-weight construction, strengthening, prestressing.

## 1 Introduction

The combination of folded plate structures and modern high performance materials like Textile Reinforced Concrete (TRC) offers new possibilities for the construction of very filigree and lightweight structures. Folded plate structures can be built without the need to construct spatial formwork by use of folding techniques inspired by origami. Here the term “folded” does not only denote the final shape of the structure and so the resulting structures can be called “real” folded plate structures.

The basic principle of folding concrete can be seen in Figure 1. A crease is kept below and above the continuous textile reinforcement between the concrete elements, allowing for rotational movement along the crease. The main function of the reinforcement is to act as a hinge during the folding process. After reaching the desired angle, the crease is filled with grout. Several of these creases can be combined to a crease pattern. The kinematic behaviour of these crease patterns can be described by means of mathematical equations derived from theory of rigid origami [1], [2]. In order to effectively support the design and manufacturing of folded structures, the modelling framework oricreate has been formulated and implemented [3]. If the method is applied on concrete, we refer to it as “oricrete”. The name was assembled from ori (Japanese for folding) and con-**crete**. The timeline of prototypes can be seen in Figure 2. It started with the development of small-scale models (a) [4].

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