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Short communication

Frei Otto and the development of gridshells

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ABSTRACT

The innovative architect, Frei Otto, developed the concept of gridshells which could be designed by a funicular modelling method and constructed from an equal mesh net of timber laths bent into the planned shape. In 1970 this technique was used to construct a 9000 m^2 curved roof structure from 5 cm square timber laths. This paper summarises the design and engineering work that went into the construction of this remarkable building.

Mannheim Gridshell

1. Introduction

Frei Otto, who was born in Berlin on 31.05.1925 and died on the 09.03. 2015, was one of the most innovative people working in architecture from 1950 to 1990. He was the son and grandson of stonemasons and sculptors but spent most of his free hours in his youth building model planes and gliders. He was drafted into the German air force towards the end of the second world war and ended up in a prisoner of war camp at Chartres where he was in charge of repairing bridges and buildings without much materials. He returned to Berlin in 1947 and started to study architecture at the technical university.

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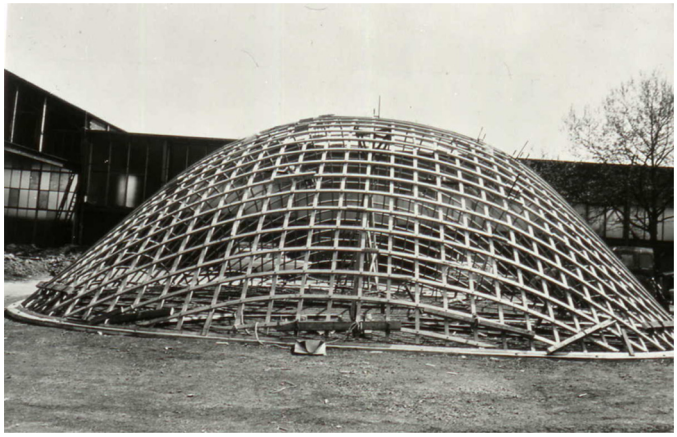

Fig. 1. Trial gridshell structure at Essen.

On an exchange visit to the United States in 1952 he met Eero Sarinen and also, Fred Severud who was working on the Arena for the Raleigh State Fair designed by Matthew Nowicki. This was a large tensioned cable roof supported by a ring beam of two crossed and slanted arches to form a doubly curved surface. This inspired Otto to study tensile structures for his doctorate that was completed in 1953. His interest was expanded by his own experimental work with Peter Stromeyer of the tent making firm of L. Stromeyer & Co. and by further discussions with other engineers such as Walter Bird, David Jawerth, Lev Zetlin. His doctorate thesis plus other work was published in 1962 and 1966 as Tensile Structures Vols. 1 & 2. [1] It was translated into English and published by MIT in 1967 and 1969.

Otto's work with Stromeyer in the late 50s and early 60s was based on using physical formfinding models to define the shape and then in the case of tents develop the fabric cutting patterns. Prestressed tensioned surfaces have to adopt an equilibrium geometry in which the tensile forces in two directions are balanced. The perfect representation of this is a soap film in which the surface tensions are the same in all directions but they are difficult to measure. This forms a "minimal" surface and is a good starting point for a surface tensioned structure. Otto's modelling process would often start with soap film models and then move on to more robust stretch fabric models from which he would develop the fabric patterns using strips of paper.

His work moved up a gear with the design of the cable net tent for the West German pavilion at the Montreal expo in 1967. This was well before the arrival of computer methods and the design work was completed with the making of a large-scale "measuring model" which was used to define the cable lengths as well as measure the tensions in the cables under load. The modelling method defined the construction system as well as the actual geometry.

A trial structure was built for the Montreal tent which had a single mast and contained all the details such as cable cross clamps, connections to boundary cables and a trial eye loop at the mast head. This structure was re-erected at Stuttgart University and became Otto's research centre, The Institut fur Leichte Flachentragwerke (IL), that continued with research and published much of his work which included investigations into natural forms as well as lightweight structures (Figs. 1–14).

2. Work on gridshells

As well as tensile structures, in the late 1950s Otto became interested in light-weight shells which could be formed using the Hookean principle of inverting a hanging net (According to Lisa Jardine, Robert Hooke used this method to show Christopher Wren how the Dome of St Paul's might work [2]). The formfinding method also suggests a construction method using an equal mesh square grid of timber laths or steel rods thin enough to be readily bent into shape. A square grid can be moulded to a doubly curved surface by the deformation of the grid squares into rhombi. Such a structure Otto described as a gridshell (gitterschale).

In 1962 he built, with some students at Berkeley, a trial structure of a dome standing on four points using steel rods. Later that same year he made a trial timber structure at Essen on a15 m × 15 m super-elliptical plan (Fig. 1). Two small auditoria were required within the Montreal Expo 67 tent and these were made using grid shell construction. The meshes were prefabricated in Germany and sent to Canada folded into bundles, where they were opened up and installed on site. The grids were clad with thin plywood sheets to form the enclosures.

3. Initial design for the Mannheim shells

In January 1970 it was decided to hold the Bundesgartenschau 1975 in Mannheim. Carl Mutschler & Partners of Mannheim were selected as architects and Heinz H Eckebrecht of Frankfurt as landscape architect for the Herzogenriedpark. The a multipurpose hall building was to be the central feature arranged alongside a through route and with a restaurant on the