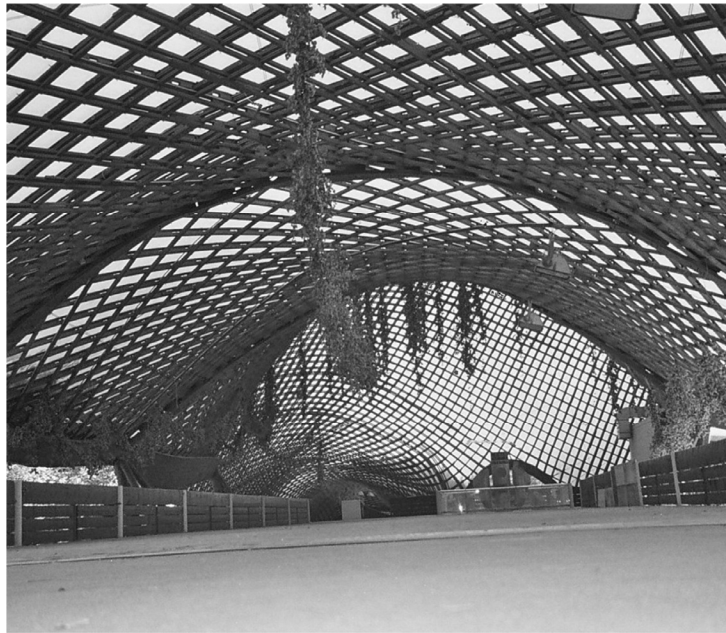
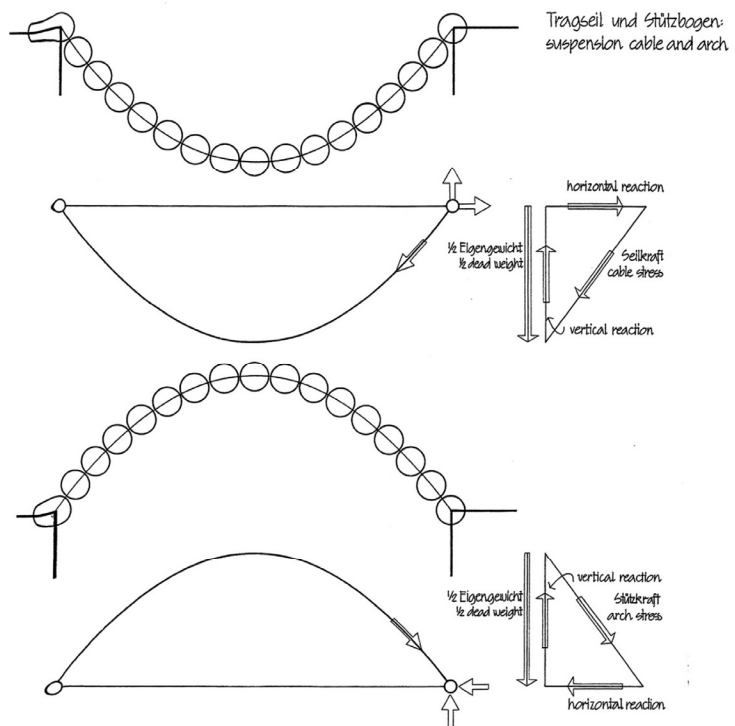


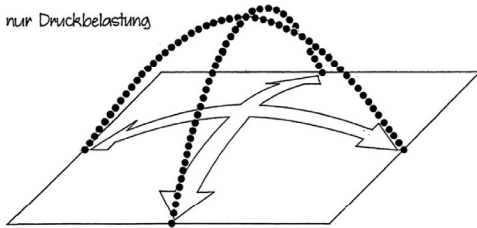
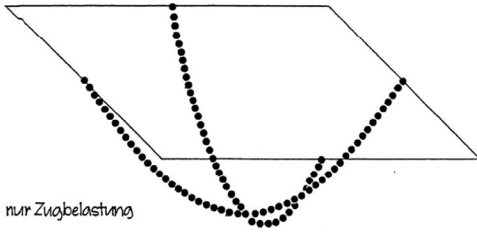
# Grid Shells



## Grid Shells based on catenary nets to minimize flexure

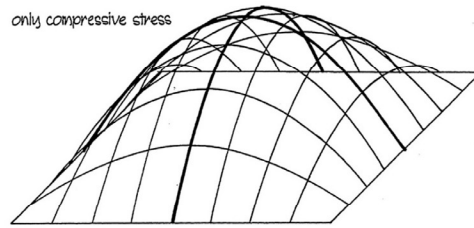
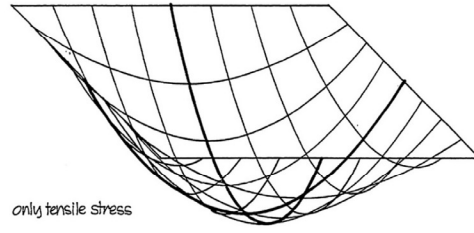


Grundlagen der räumlichen Stützgitter-Systeme  
 Tragemechanik und Tragwerkform als umgekehrtes Hängesystem



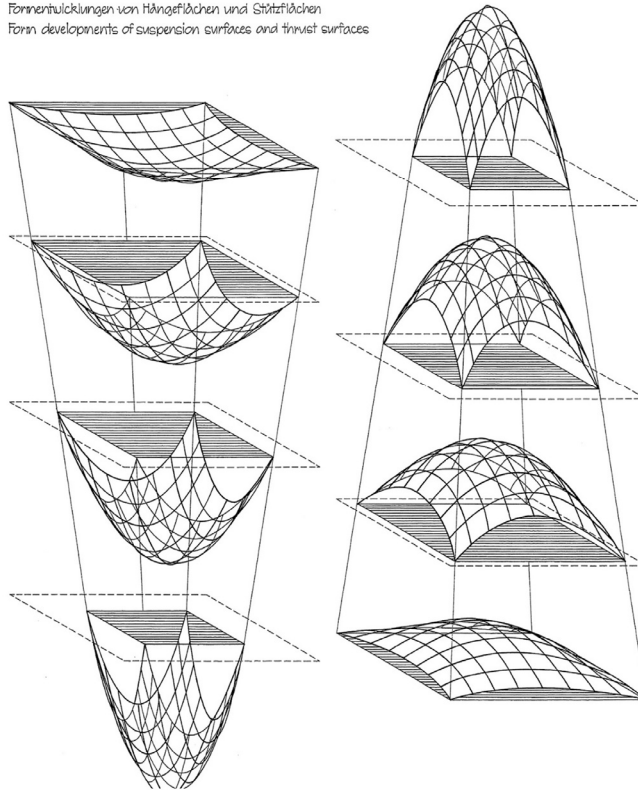
3-dimensionale Lastabtragung und Raumüberspannung durch Kreuzung zweier Stützbögen (bzw. Tragseile) in zwei Achsen  
 3-dimensional load transfer and space spanning through crossing two funicular arches (alternately suspension cables) in two axes

Basics of the 3-dimensional thrust lattice systems  
 Bearing mechanism and structure form as inverted suspension system



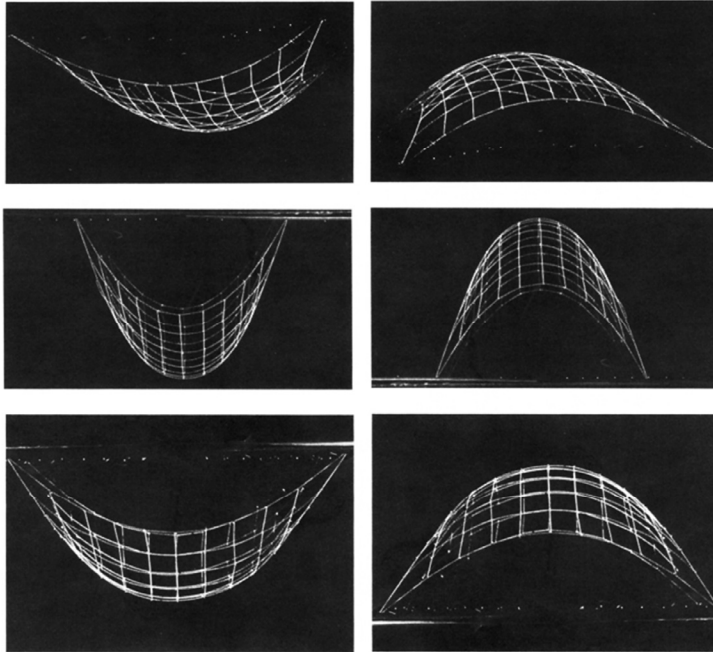
Bildung einer Viereck-Maschenstruktur durch Parallelreihung und gegenseitige Durchdringung der Bogen- (bzw. Hänge-) Linien  
 Formation of a quadrangular mesh pattern through parallel juxtaposition and interpenetration of arch (alternately suspension) lines

Formentwicklungen von Hängeflächen und Stützflächen  
 Form developments of suspension surfaces and thrust surfaces

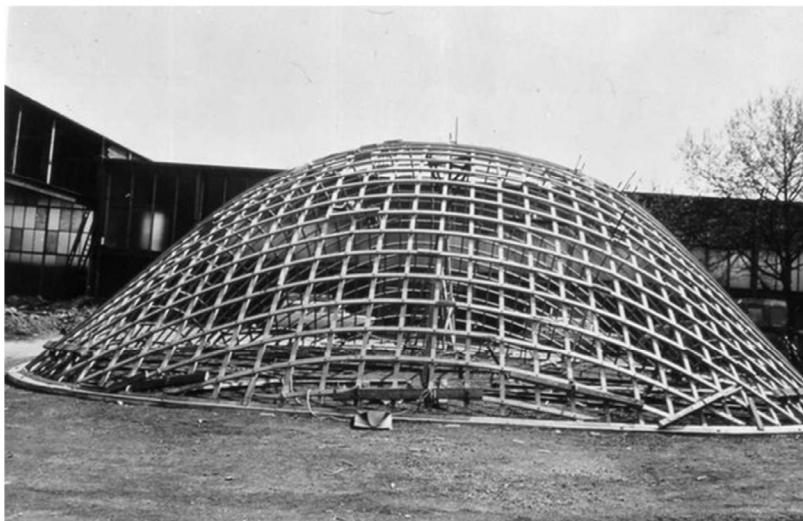


# Grid Shells

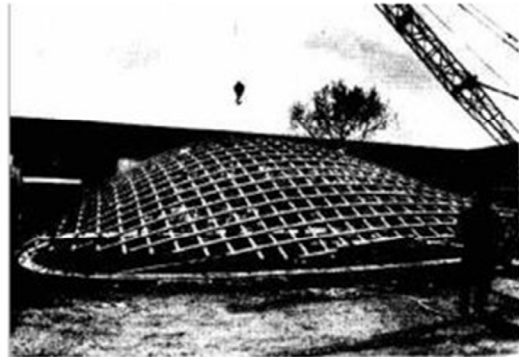
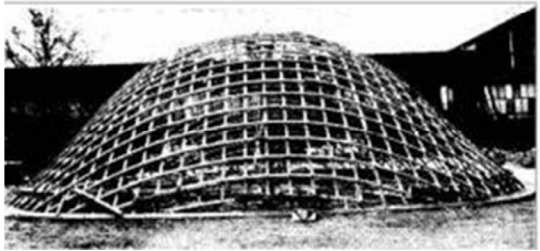
based on catenary nets  
to minimize flexure



early grid shell  
University of Essen  
Frei Otto – 1962  
15m x15m

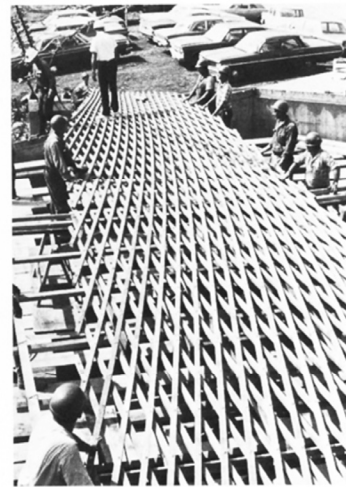
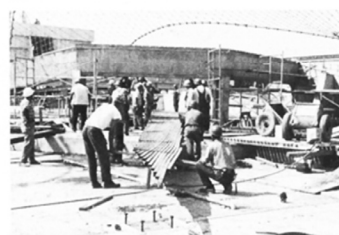
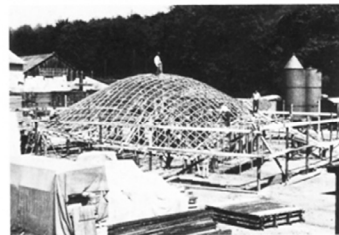
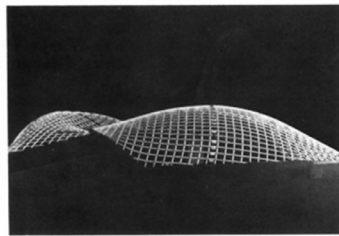


Grid shell  
University of Essen  
Frei Otto - 1962



## Grid Shells

initially straight members  
elastically bent  
deformed grid  
fixed joints to hold form

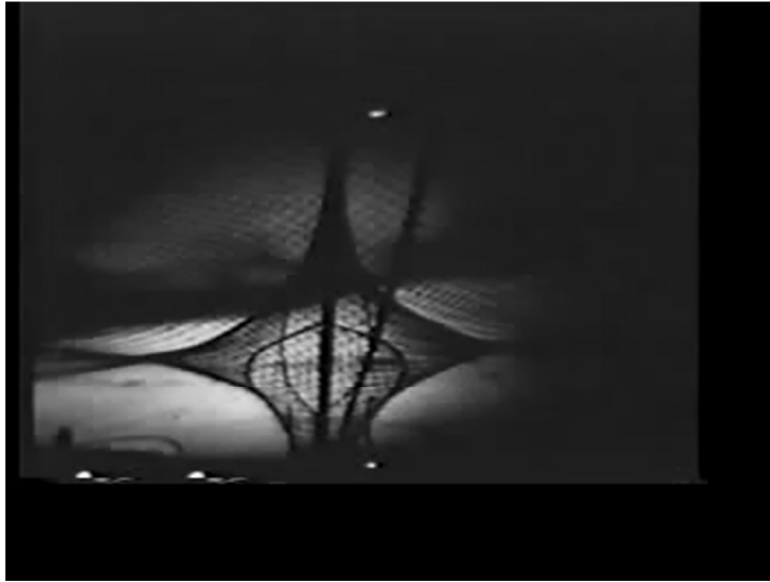


German Pavilion Montreal  
Expo 1967

Frei Otto

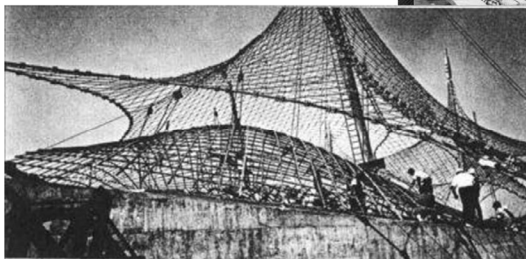


German Pavilion Montreal Expo 1967  
Frei Otto

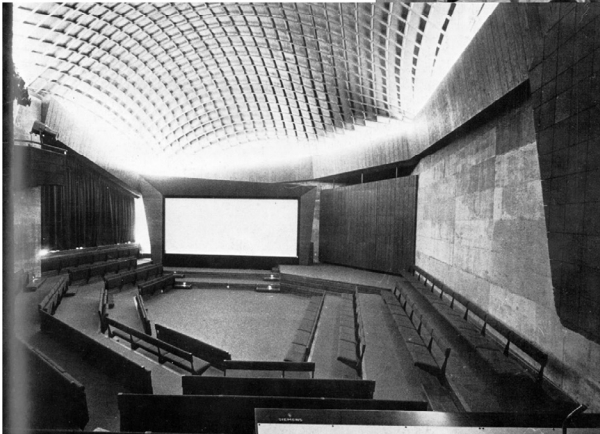


German Pavilion  
Montreal Expo 1967  
Frei Otto

Erection



German Pavilion  
Montreal Expo 1967  
Frei Otto



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Structures II

Slide 11 of 53

## Design with models



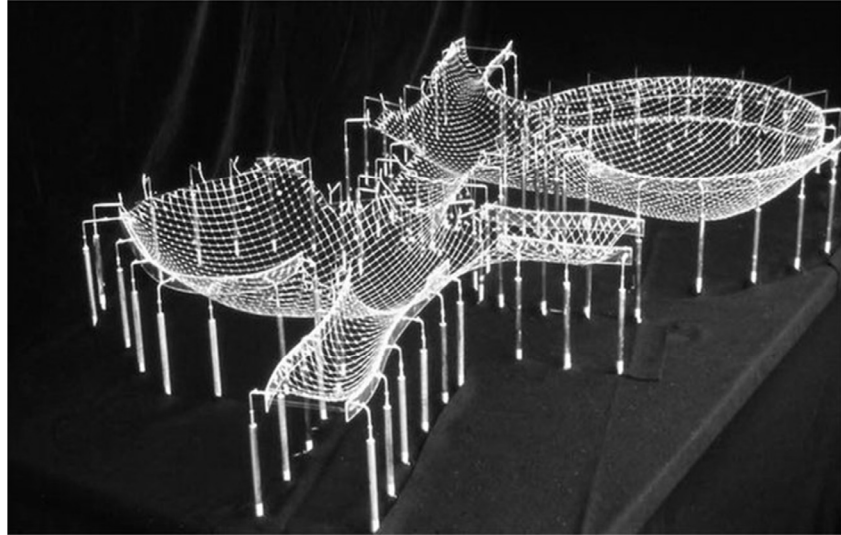
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Structures II

Slide 12 of 53

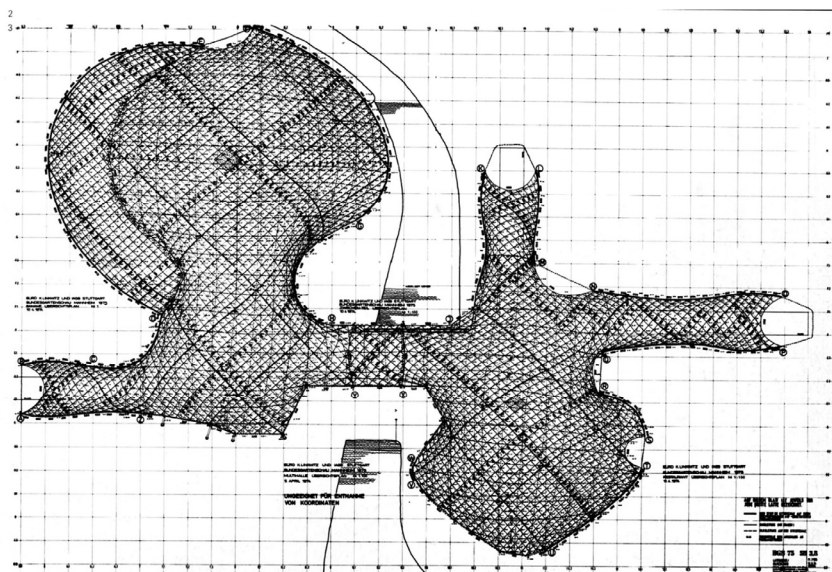
# Multihalle Mannheim

Designed and engineered by Frei Otto and Buro Happold  
Built for the Bundesgartenschau in Mannheim in 1975  
Design and initial analysis with models at IL Stuttgart  
Computer force density analysis by Klaus Linkwitz



# Multihalle Mannheim

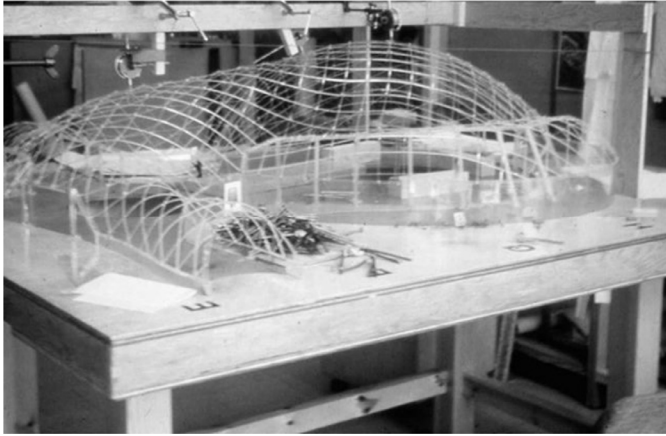
Designed and engineered by Frei Otto and Buro Happold  
Built for the Bundesgartenschau in Mannheim in 1975  
Design and initial analysis with models at IL Stuttgart  
Computer force density analysis by Klaus Linkwitz



# Multihalle Mannheim

testing for shear stiffness

model testing



# Multihalle Mannheim

detail of grid construction



# Multihalle Mannheim

construction



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Structures II

Slide 17 of 53

# Multihalle Mannheim

construction



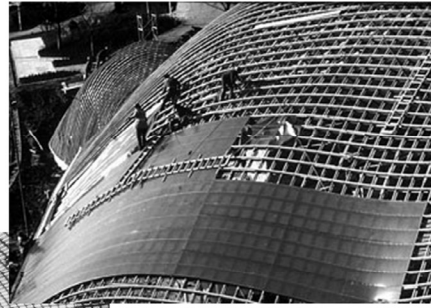
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Structures II

Slide 18 of 53

# Multihalle Mannheim

construction



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Structures II

Slide 19 of 53

# Multihalle Mannheim

load testing



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Structures II

Slide 20 of 53



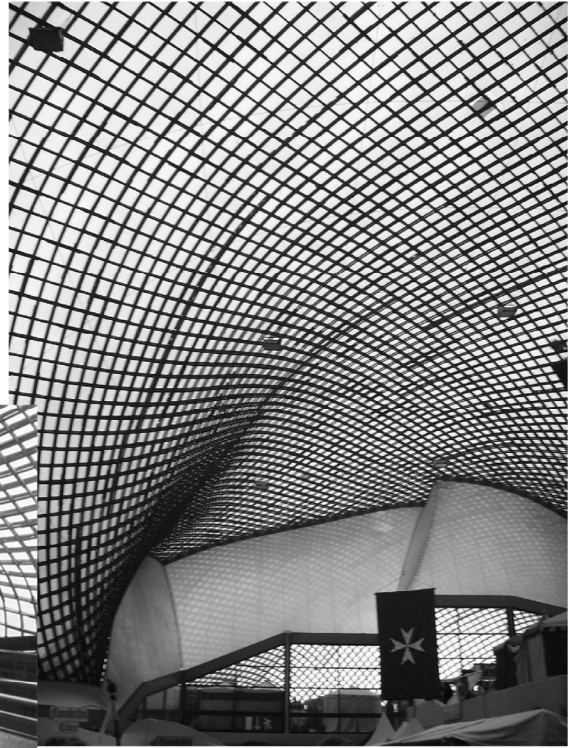
# Multihalle Mannheim

renovation 1981



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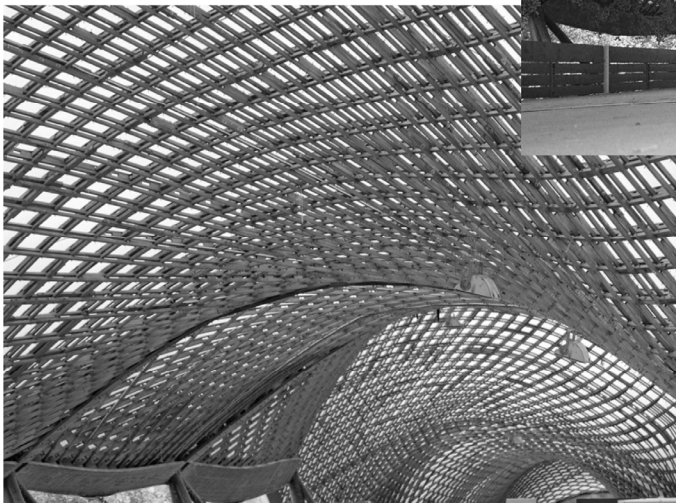
Structures II



Slide 21 of 53

# Multihalle Mannheim

renovation 1981



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Structures II



Slide 22 of 53

# Other Examples

Japanese Pavilion  
Hannover Expo 2000  
Shigeru Ban and Frei Otto



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Structures II

Slide 23 of 53

Japanese Pavilion - Hannover Expo 2000  
Shigeru Ban and Frei Otto



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Structures II

Slide 24 of 53



Weald & Downland Open Air  
Museum – 2002  
Edward Cullinan architects with  
Buro Happold



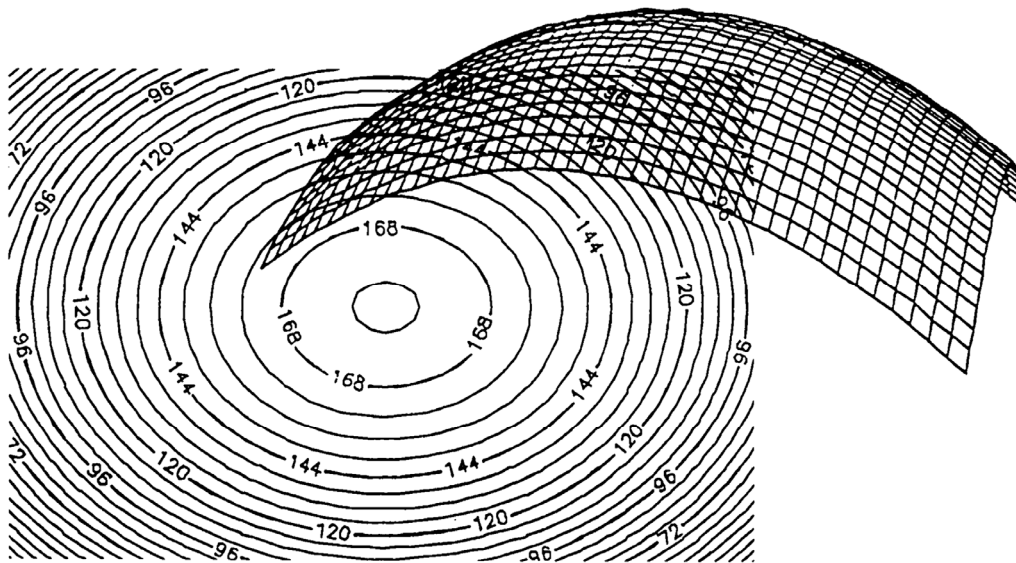
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Structures II

Slide 25 of 53

## Wooden Grid Shell

University of Tennessee - Structural Innovations Lab  
Peter von Bülow, Dr.-Ing.

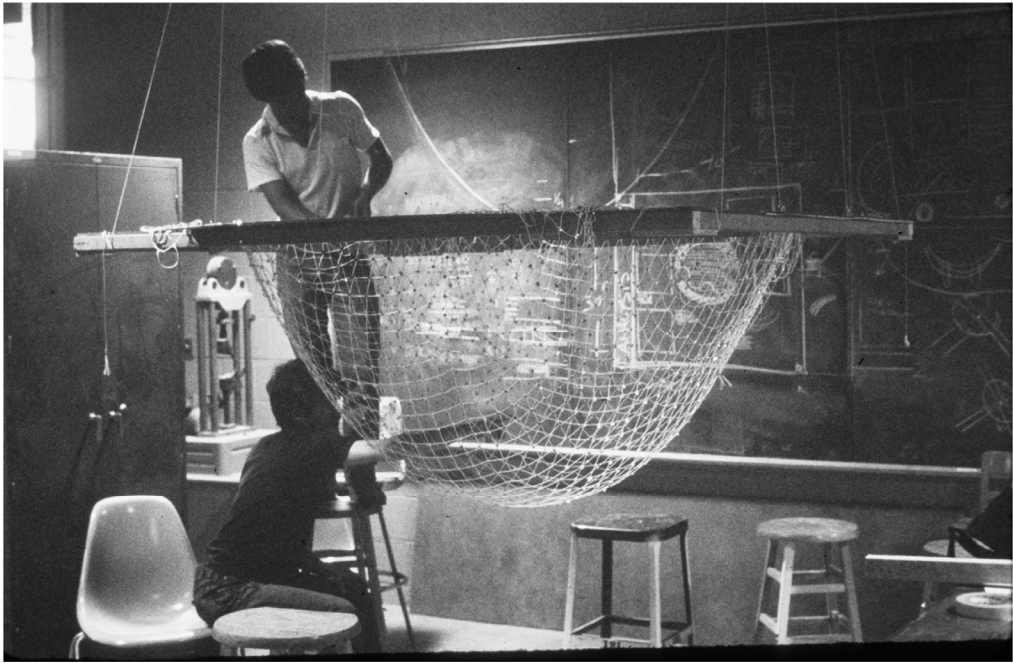


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Structures II

Slide 26 of 53

# Centenary Form Finding Model



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Structures II

Slide 27 of 53

# Construction



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Slide 28 of 53

## Construction



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Structures II

Slide 29 of 53

## Adding bracing



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Structures II

Slide 30 of 53

## completed grid shell

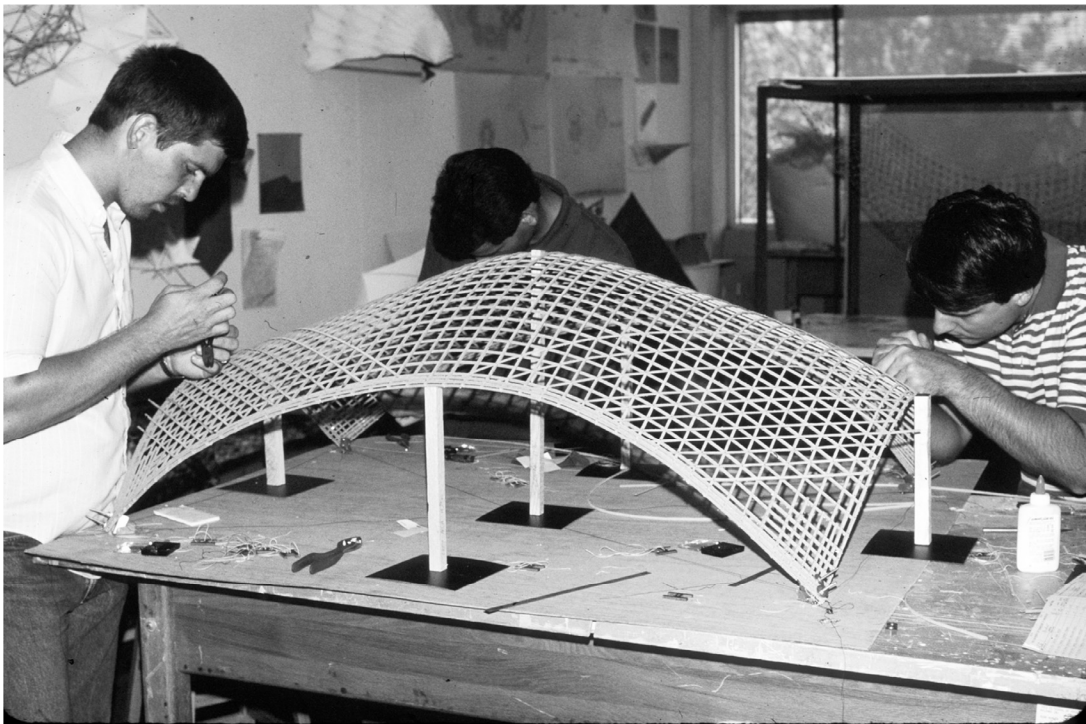


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Structures II

Slide 31 of 53

## structural model

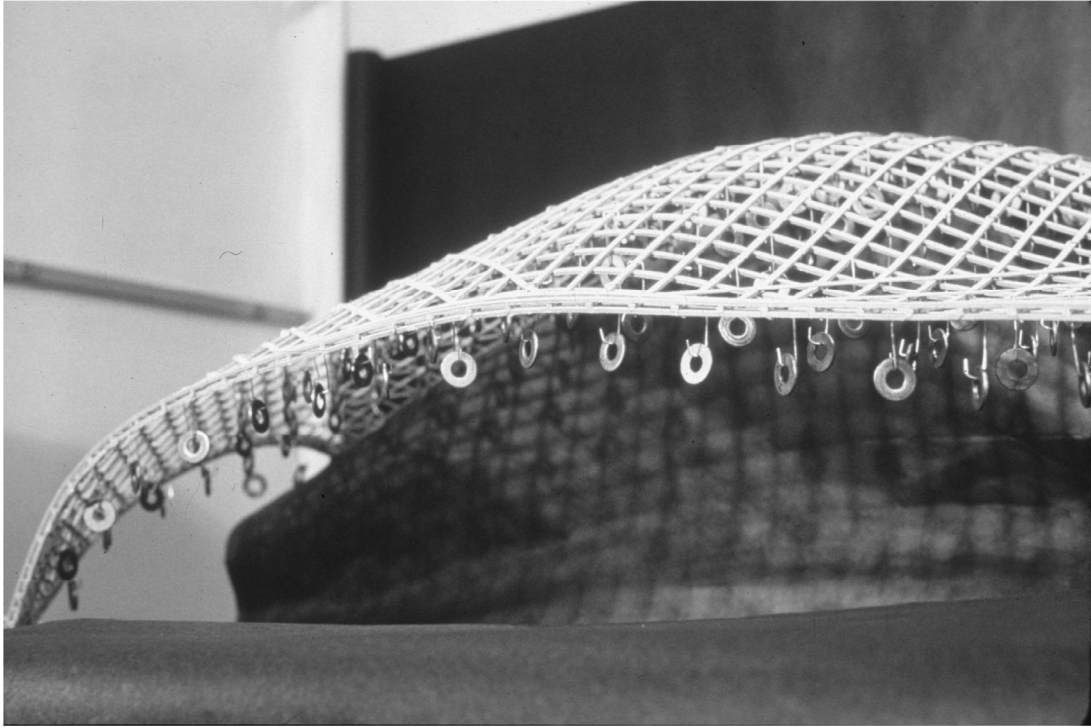


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Structures II

Slide 32 of 53

structural testing

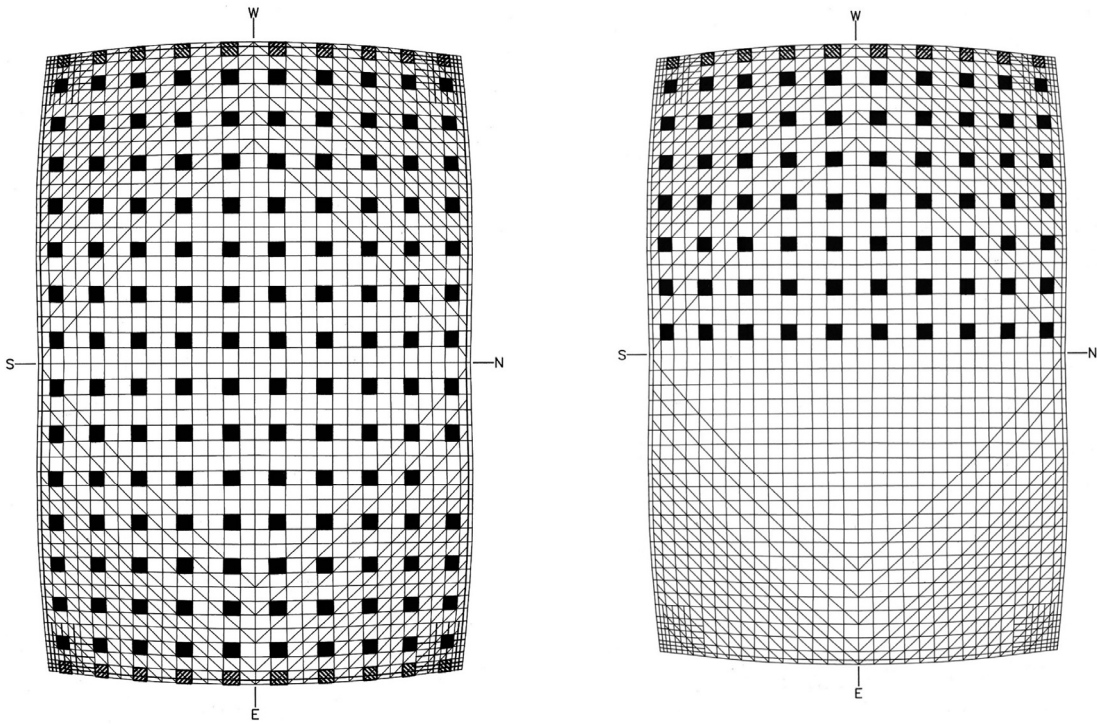


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Structures II

Slide 33 of 53

full scale test



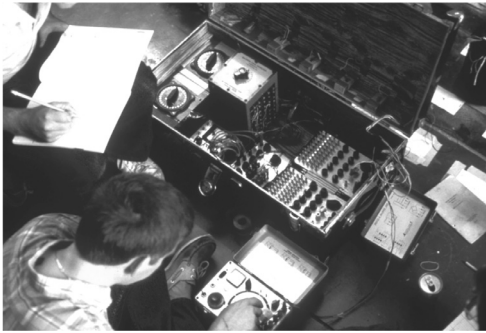
University of Michigan, TCAUP

Structures II

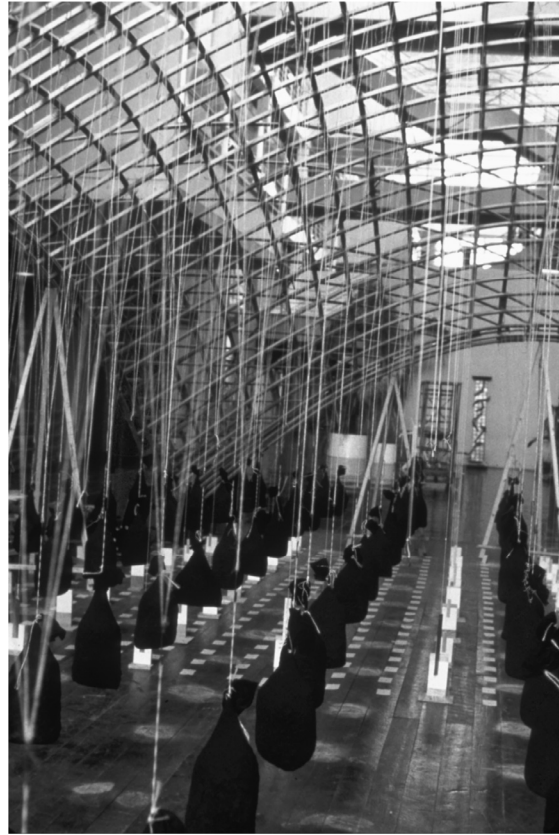
Slide 34 of 53



full scale test



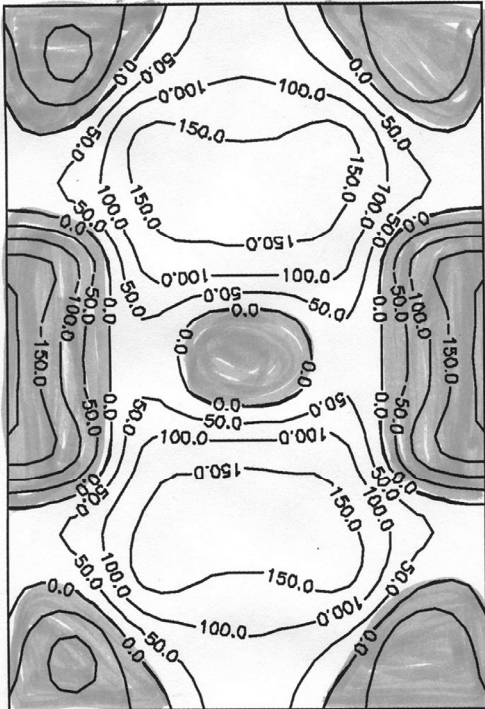
University of Michigan, TCAUP



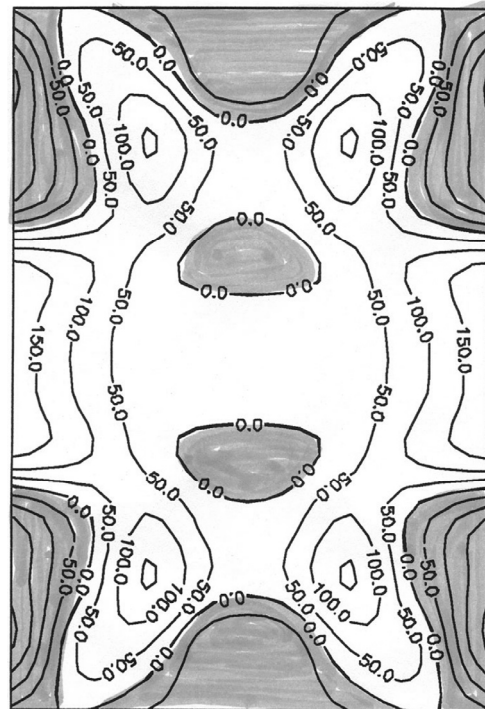
Structures II

Slide 35 of 53

deflection



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Structures II

Slide 36 of 53

## deconstruction



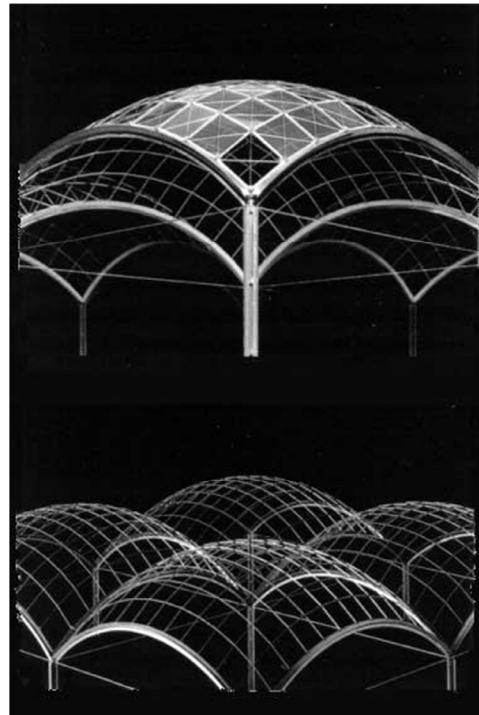
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Structures II

Slide 37 of 53

## Schlaich Bergermann & Partners

Cover for Helsinki train station

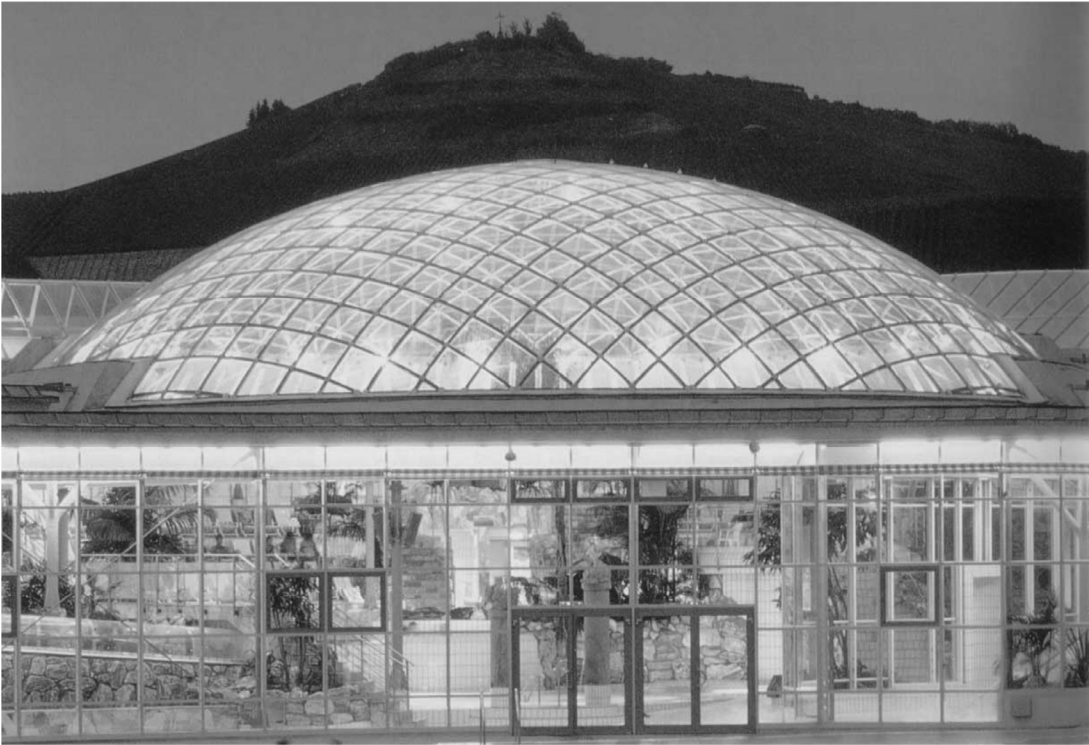


University of Michigan, TCAUP

Structures II

Slide 38 of 53

Schlaich Bergermann & Partners – Neckarsulm Swimming Pool



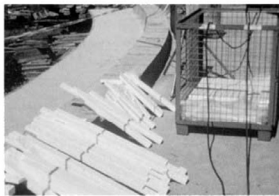
Schlaich Bergermann & Partners  
Neckarsulm, 1989



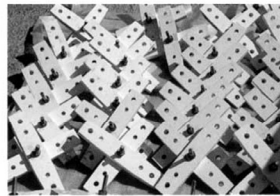


# Schlaich Bergermann & Partners

## Neckarsulm, 1989



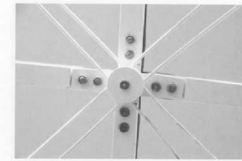
6.14  
The slats



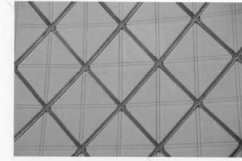
6.15  
The rotatable joints



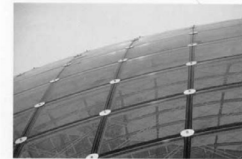
6.16  
Assembly of the grid elements



6.17  
Close-up of the joint assembly  
with diagonal cables installed



6.18  
A segment of the grid showing the double  
pattern formed by the slats and cables



6.19  
A segment of the completed roof  
with the spherically-curved glass panes



6.20  
Water barrels representing  
partial snow load

# Schlaich Bergermann & Partners

## History of Hamburg Museum

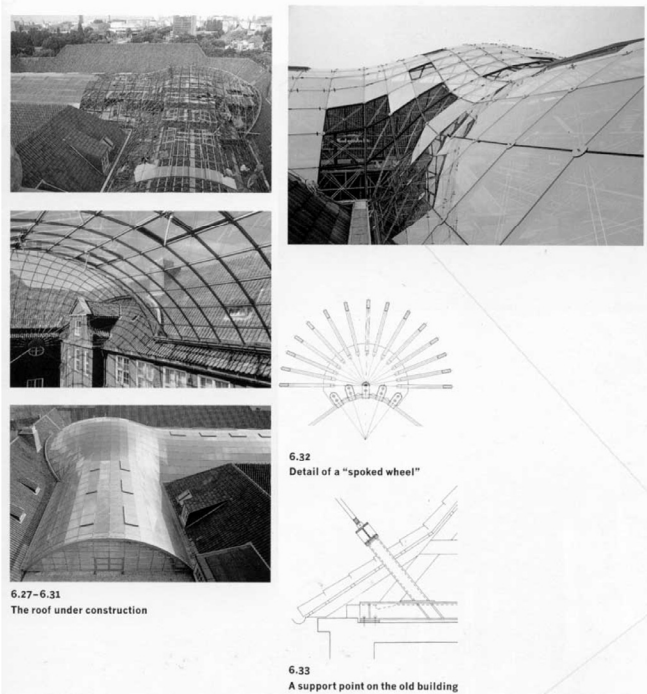


2017 restoration



Schlaich Bergermann & Partners

History of Hamburg Museum

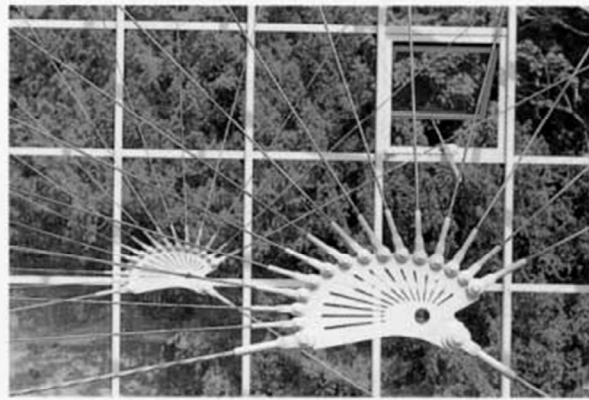


Schlaich Bergermann & Partners – Pool cover for mineral spa, Bad Cannstatt

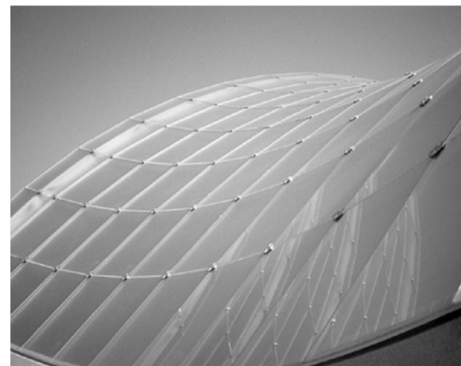




**6.41**  
Connections of the pretensioned cable “spokes” to the “rim”



**6.40**  
The hub connections (see the drawing on the cover of this book)

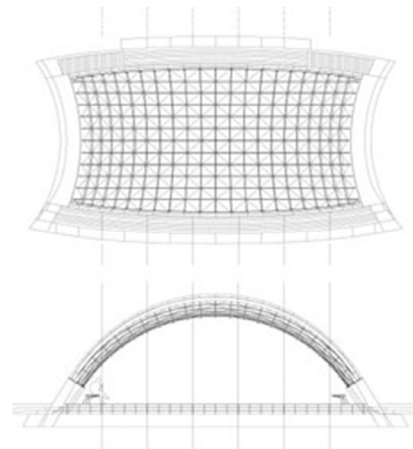


**The Schubert Club Band Shell**

Raspberry Island, St. Paul

Schlaich, Bergermann & Partners with SOM

2000-2002



Schlaich Bergermann & Partners

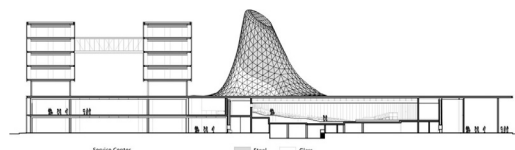
Trade fair, Milan



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Structures II

Slide 47 of 53



Schlaich Bergermann & Partners

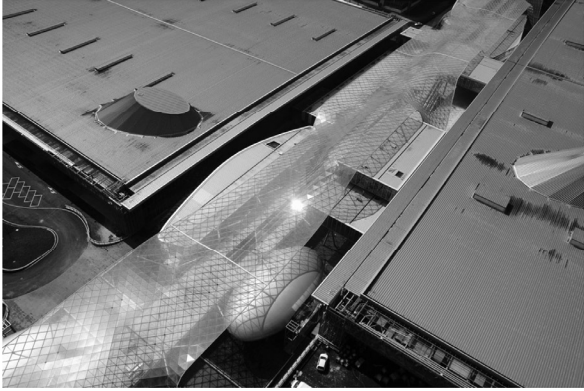
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Structures II

Slide 48 of 53



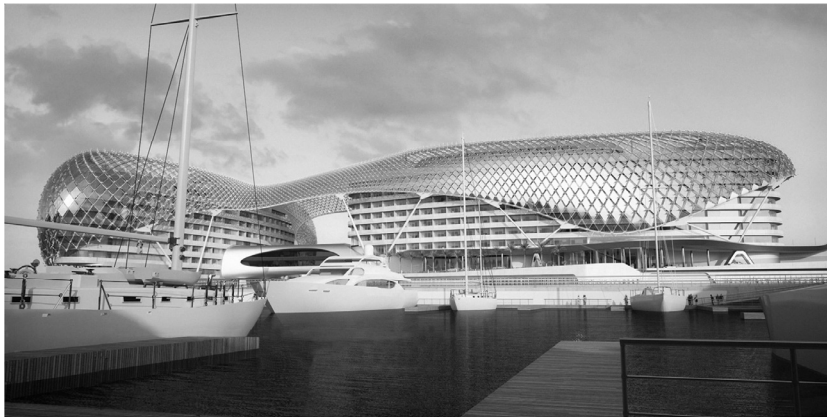




University of Michigan, TCAUP

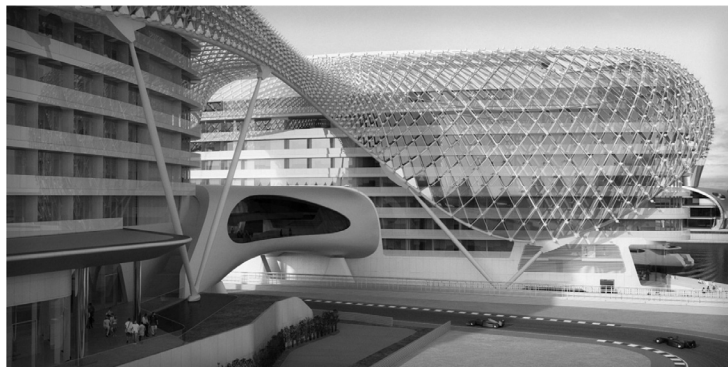
Structures II

Slide 51 of 53



Schlaich Bergemann & Partners

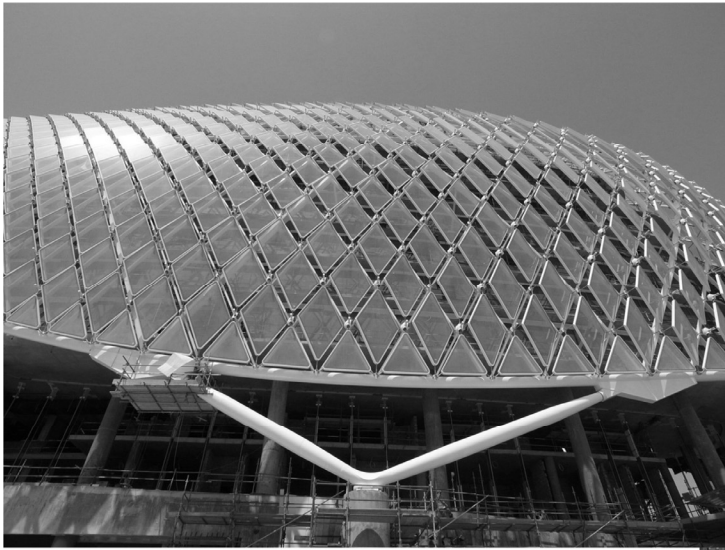
Yas Hotel, Abu Dhabi



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Structures II

Slide 52 of 53



Schlaich Bergermann & Partners

Yas Hotel, Abu Dhabi

