Tower Project

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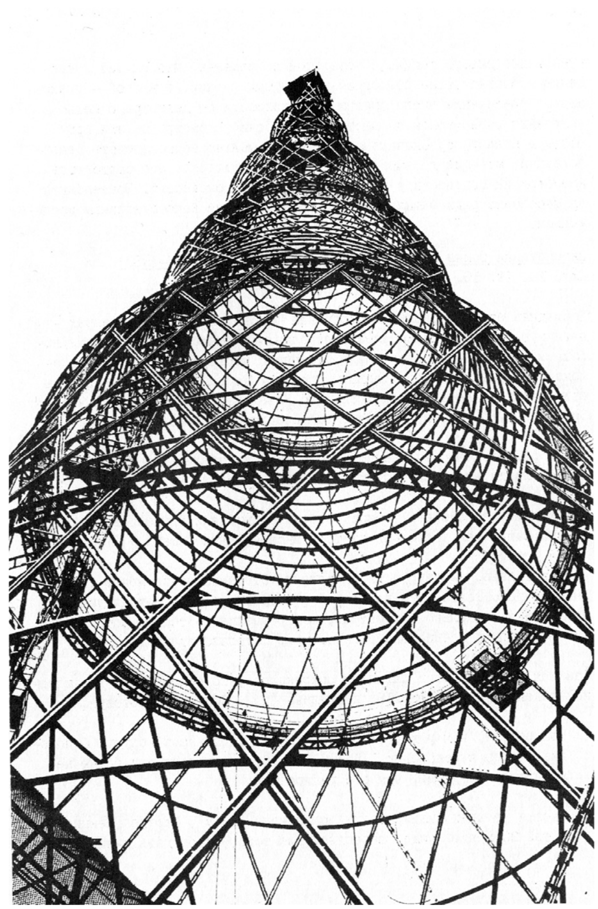
  - Trussed Frames
  - Shukhov



Sollbruchstelle 445 LBS 3.8 oz

Criteria & Procedure

Criteria

- The tower is to be made of wood. Either linear wood (sticks) or wood panels (sheets) can be used. Glue can be used to connect the elements. Gusset plates at the joints are allowed and can also be glued. But **no steel pins** or fasteners may be used.
- Wood: **any species**. **maximum cross-sectional dimension = 1/4".**
- **NO** paper, mylar or plastic or string or dental floss.
- If a member is made by laminating multiple pieces together, the maximum cross-sectional dimension or thickness still cannot exceed 1/4".
- The **height of the tower = 48"**.
- The tower **must hold at least 50 lbs**.
- The entire tower **can weigh no more than 4 oz**.
- The top of the tower must be loadable. The weights will be stacked on top of the tower, but you may optionally use a loose piece of MDF or plywood as a tray under the weights. (It will not be counted in either weight or load)
- Towers will be graded on their low weight, high load-carrying capacity, and the load/weight ratio. The evaluation formula is:

  (4/weight in OZ) + (load in LBS/50) + (load LBS/weight OZ)x1.5
- The score will be normalized to a range of 50 to 100. It is used together with report scores to assess your project (a detailed evaluation form is given separately).

Procedure

1. Develop a structural concept for a tower meeting the above criteria.
2. Analyze the design concept with **either** hand calculations or a computer program (e.g. Dr. Frame)
3. Determine the capacity of the major members and of the overall tower (total capacity in LBS)
4. Estimate your expected score using the formula above.
5. Write the preliminary report.
6. Construct the structural model.
7. Test the model. 5-pound steel bars will be placed on top of the model, until the model fails. (bar size: 1 ½" x 2" x 5 13/16").
8. Produce final report documenting requirements and process. See also score sheet.

Analysis

Use NDS approach

Find load P and stress F'c for each member

Use 1.0 for all factors except C_P

Analysis – the report should include the following:

- **Choose wood type and stress properties**. Either use values below for typical model grade Basswood or use values in the NDS or find test values online. Indicate in the report which values you choose.
- **Determine the cross-sectional area of each member**. Find the axial force P and the allowable stress F'c. The force P can be determined either by a hand calculated truss analysis or as a second order analysis in Dr. Frame or STAAD.Pro. The stress F'c should be found using the NDS equations for C_P and F'c. Other NDS stress adjustment factors (C_D, C_M, C_t, C_F and C_i) can be taken equal to 1.0. Size members based on the predicted load, P and the allowable stress F'c. Target (or predict) some total capacity load for the tower. A minimum of 50 LBS is required. Then size the members based on the force in each member.
- **Predict the total weight of the tower**. Provide a table with each member type showing, length, section and weight for each. Make an estimate of the weight added by glue joints and/or gusset plates. The total weight should be under 4 OZ.
- **Predict Capacity**. Predict the ultimate capacity in pounds that the entire tower can carry based on the actual cross-sections chosen. Produce a utilization table to show for each member type (e.g. main vertical, horizontal tie, diagonal brace) the utilization ratio fc/F'c based on the predicted total capacity load. This ratio should be below 1.0 for all members.
- **Calculate the buckling capacity of the tower as a whole**. This is done by treating the tower as one column loaded at the top, made up in cross section of multiple columns. Show the moment of inertia of the tower cross-section, and use it to calculate the critical buckling load using the Euler equation. An example of this calculation is given in the slides from the class lecture. The ultimate capacity is the lower of the two capacities (critical member or tower as a whole).

$$C_P = \frac{1+(F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1+(F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}} \quad (3.7\text{-}1)$$

where:

F_c^* = reference compression design value parallel to grain multiplied by all applicable adjustment factors except C_P (see 2.3), psi

$$F_{cE} = \frac{0.822\ E_{min}'}{(\ell_e/d)^2}$$

c = 0.8 for sawn lumber

c = 0.85 for round timber poles and piles

c = 0.9 for structural glued laminated timber or structural composite lumber

Analysis	Capacity	Design
$f_c = \frac{P}{A} \le F'_c$	$P = F'_c A$	$A = \frac{P}{F'_c}$

Properties of Basswood:

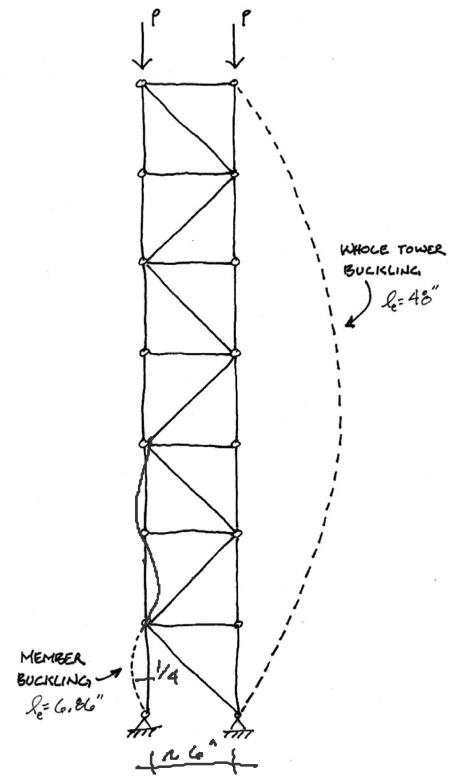
Density (oven dry)	20 pcf *
E (buckling)	1,650,000 psi **
F (Compression ∥ to grain)	4745 psi *
F (Compression ⊥ to grain)	377 psi *
F (Tension ∥ to grain)	4500 psi (estimate)
F (Tension ⊥ to grain)	348 psi *
F (Shear ∥ to grain)	986 psi *
F (Flexure)	5900 psi *

* www.matweb.com
** tested by PvB

Buckling modes

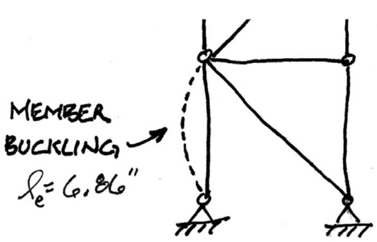
- Member buckling
- Tower buckling

The lesser of the two controls



Buckling modes

Member buckling



$$\ell_e = 6.86''$$

$$\frac{\ell_e}{d} = \frac{6.86}{0.25} = 27.44$$

$$F_c^* = F_c = 4745 \text{ psi}$$

$$F_{cE} = \frac{.822(1650000)}{27.44^2} = 1801 \text{ psi}$$

$$C_p = \frac{1+0.38}{2(.8)} - \sqrt{\left[\frac{1+0.38}{2(.8)}\right]^2 - \frac{0.38}{.8}}$$

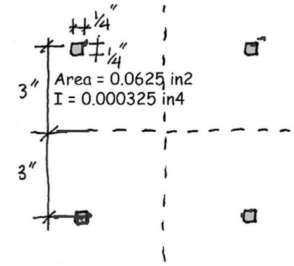
$$C_p = 0.343$$

$$F'_c = 4745(0.343) = 1630 \text{ psi}$$

$$P = F'_c A = 1630(0.0625) = 101 \text{ LBS}$$

Buckling modes

Tower buckling



$$\underline{I} = \Sigma I + \Sigma A d^2$$

$$4\left[\frac{.25(.25)^3}{12}\right] + 4\left[(.25 \times .25)\, 3^2\right]$$

$$I = 0.0013 + 2.25 = \underline{2.251}\ \text{in}^4$$

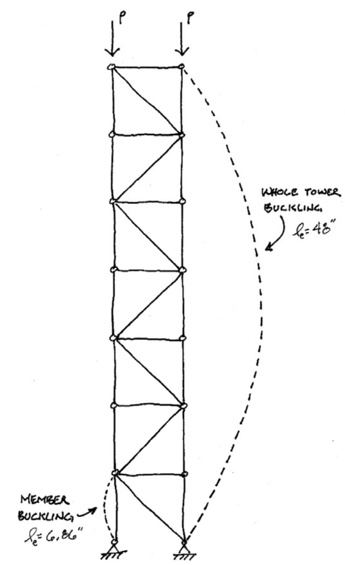
$$\underline{r} = \sqrt{\frac{I}{A}} = \sqrt{\frac{2.251}{0.25}} = 3''$$

$$\frac{K\ell}{r} = \frac{1(48)}{3} = 16$$

$$P_{cr} = \frac{\pi^2 I E}{(K\ell/r)^2} = \frac{\pi^2(2.251)(1650000)}{16^2}$$

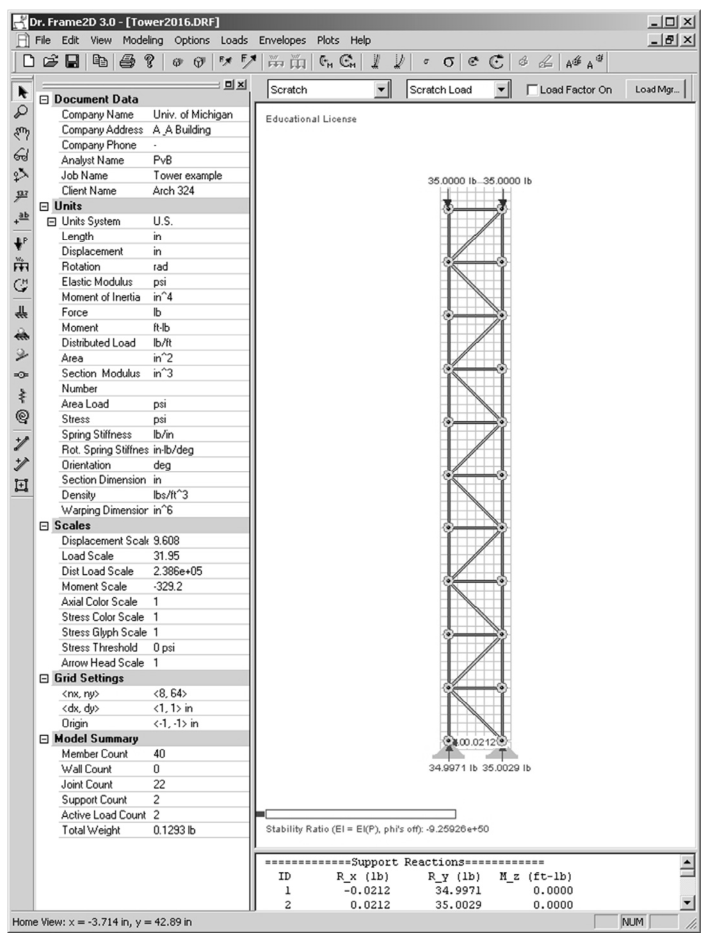
$$P_{cr} = \underline{143{,}275}\ \text{LBS}$$

$$P_{cr}/4 = 35\,818\ \#/\text{STICK}$$



Dr. Frame 2D

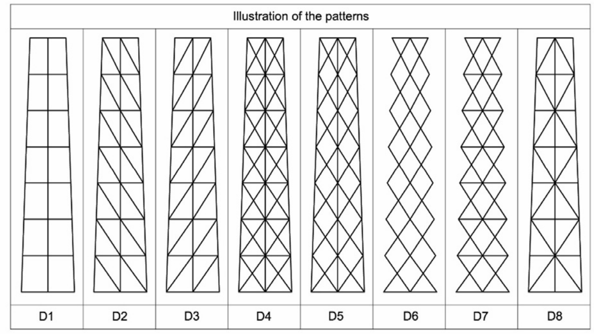
- Material properties
  - Provided test values
  - NDS
  - Other (online)
- Member dimensions
  - Use actual dimensions
- Connections
  - Use pinned connections
- Second order analysis

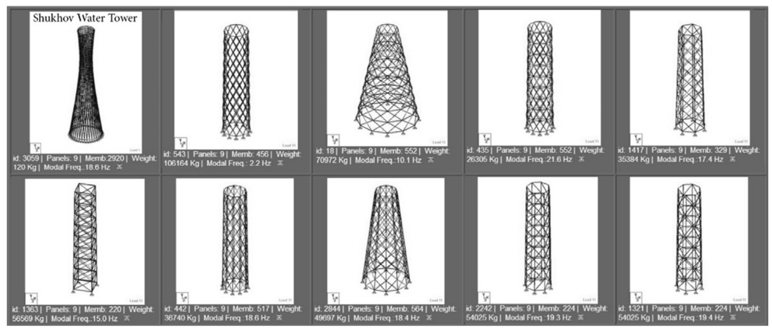


Optimal Topologies

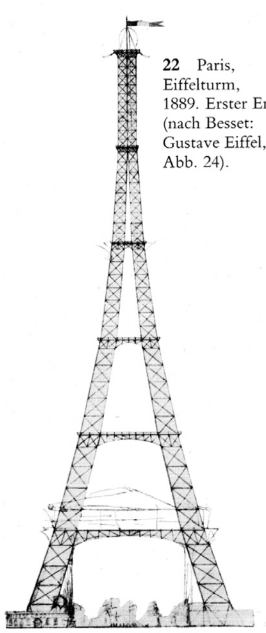
Form Exploration and GA-Based Optimization of Lattice Towers Comparing with Shukhov Water Tower

(A Khodadadi, 2014)

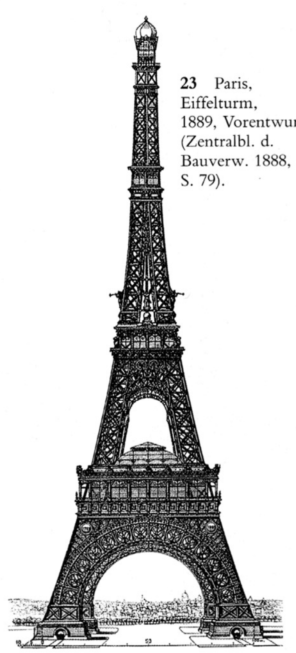




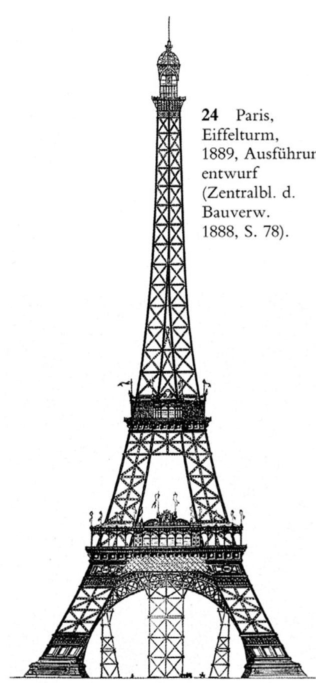
Gustave Eiffel tower



22 Paris, Eiffelturm, 1889. Erster Entwurf (nach Besset: Gustave Eiffel, 1957, Abb. 24).



23 Paris, Eiffelturm, 1889, Vorentwurf (Zentralbl. d. Bauverw. 1888, S. 79).

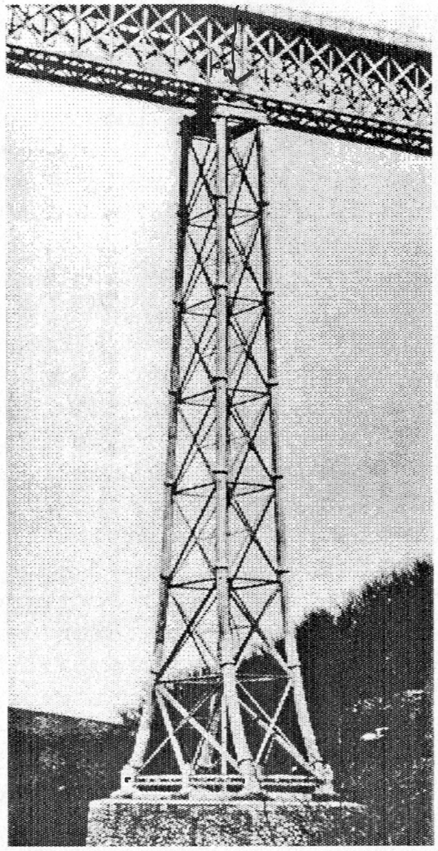


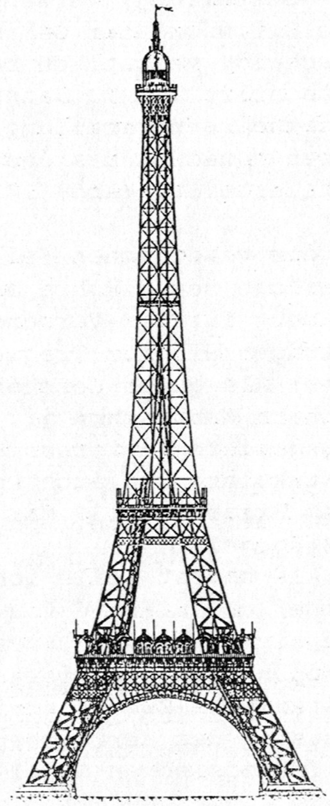
24 Paris, Eiffelturm, 1889, Ausführungsentwurf (Zentralbl. d. Bauverw. 1888, S. 78).

Eifel

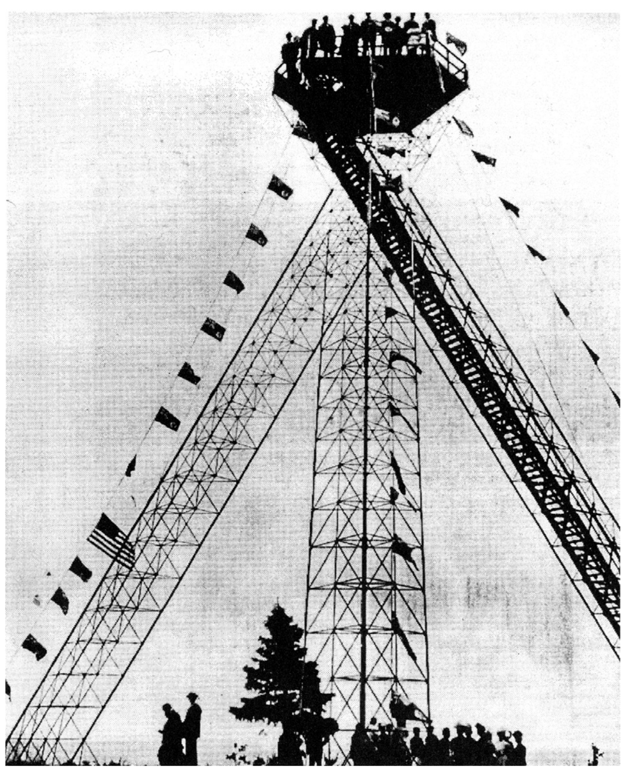
1868-71

1886-89

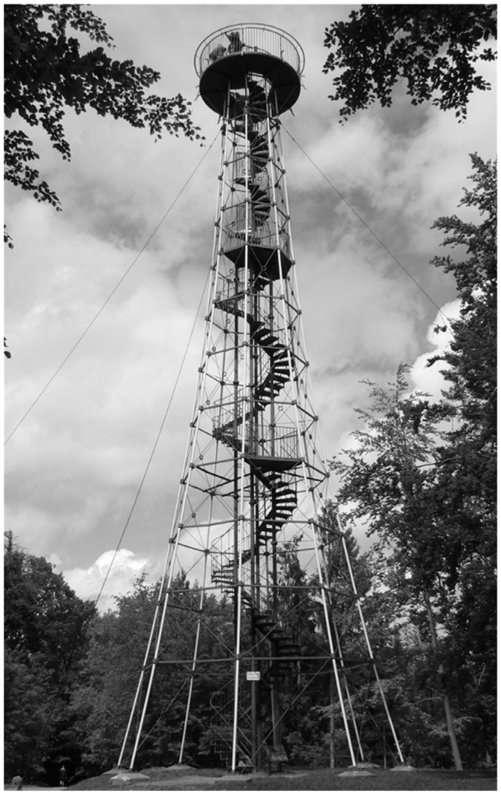




Alexander Graham Bell



Pforzheim towers



Büchenbronn 1883 25m

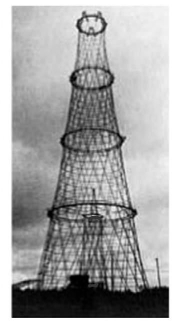
Hohe Warte 2002 40m

Vladimir Shukhov

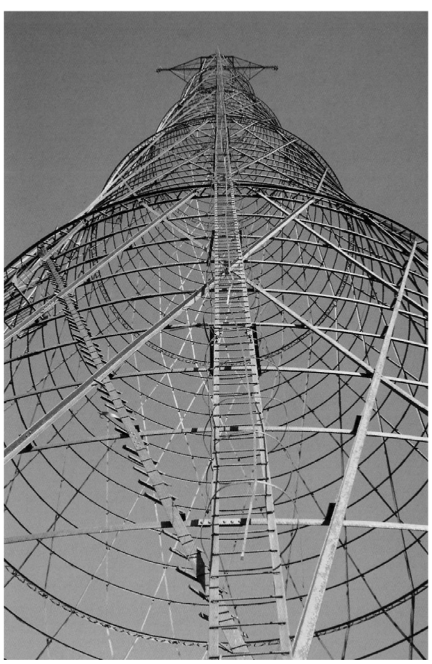
1853-1939

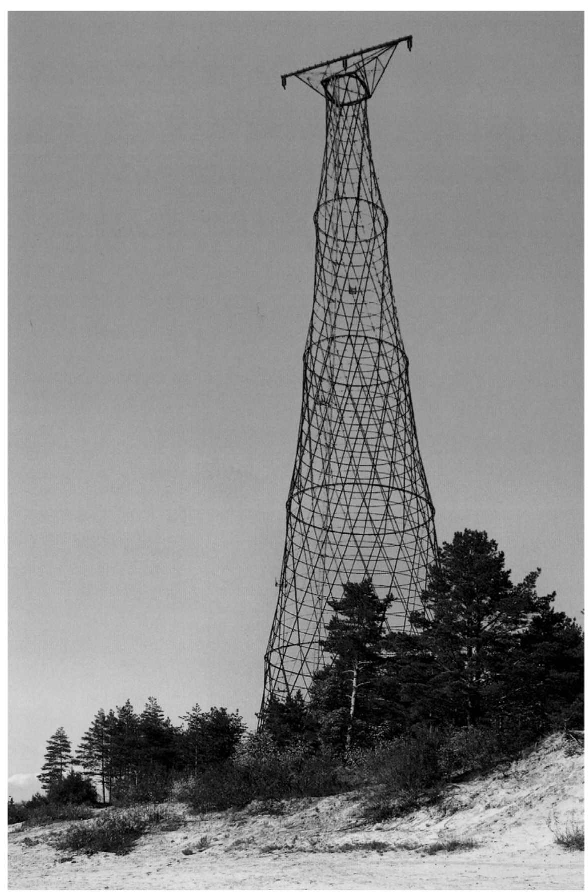
Vladimir Suchov

High tension power line towers
on the Oka, 1927-1930
114 m



Vladimir Suchov





High tension power line towers
on the Oka, 1927-1930
114 m

Jörg Schlaich

Killesbergturm, Stuttgart 2001