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Robustness of large-span timber roof structures - structural aspects

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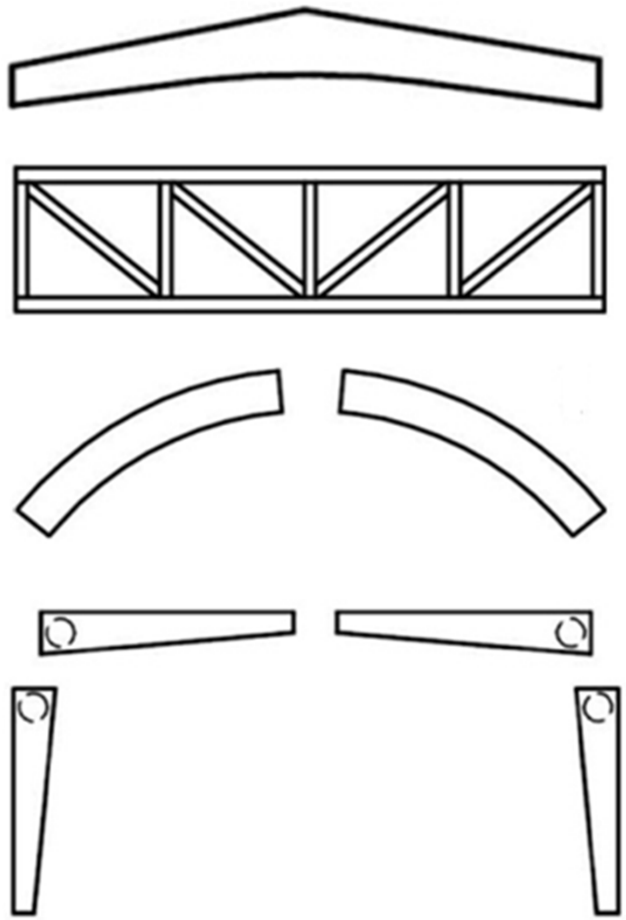
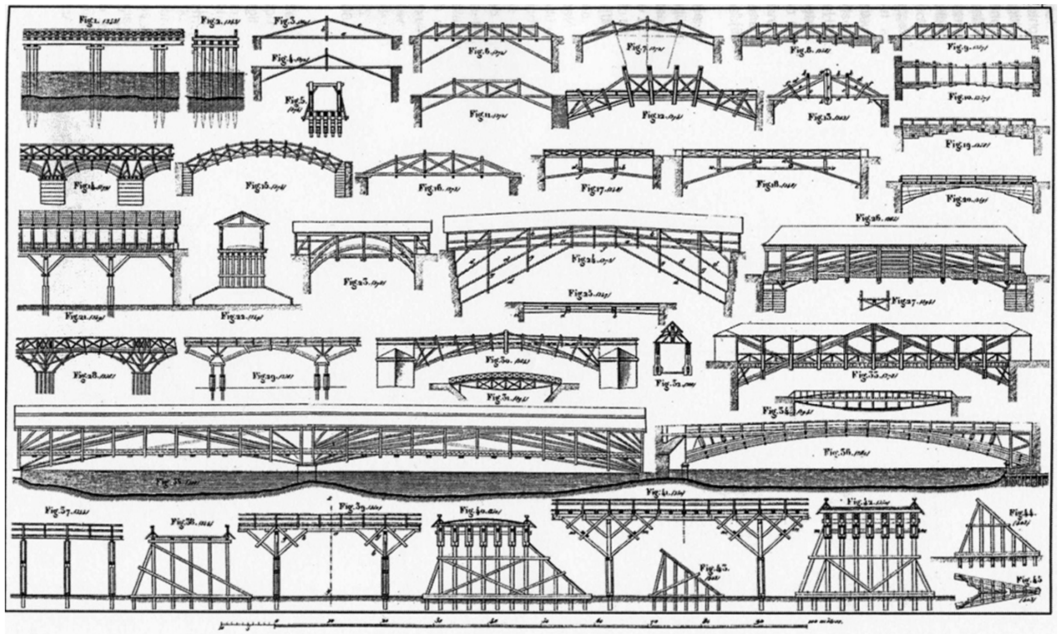
Structural elements for large-span timber structures

- Primary structure
  - Today: mainly determinate systems (pitched cambered beams, trusses)

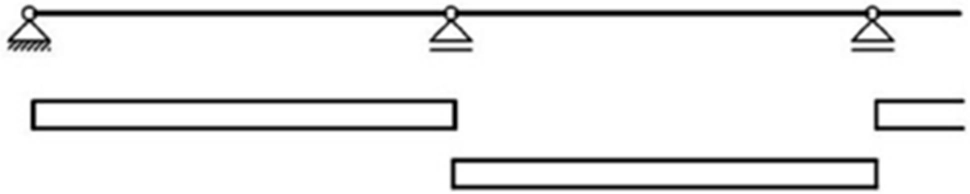




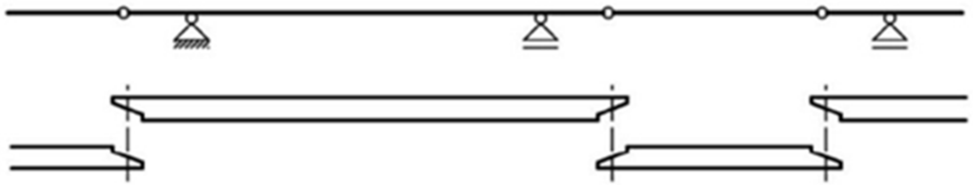
[Emy, A.R.; Traité de L'Art de la Charpenterie, Anselin, Paris, 1837]

Structural elements for large-span timber structures

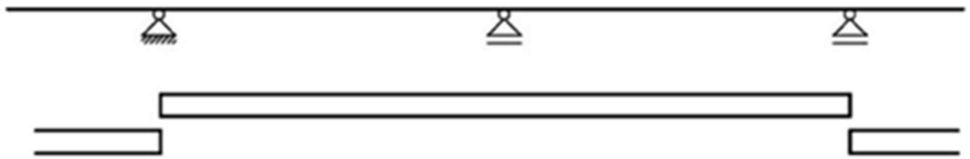
- Secondary structure - Purlins
  - simply supported beams



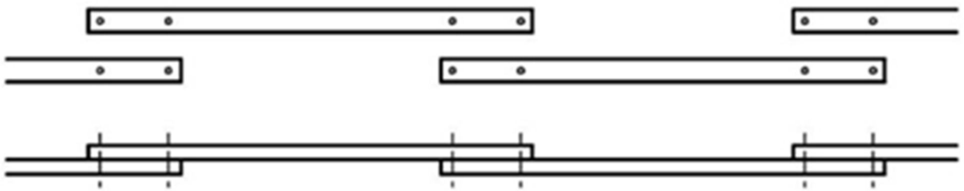
  - gerber beams



  - continuous beams



  - lap-jointed purlins

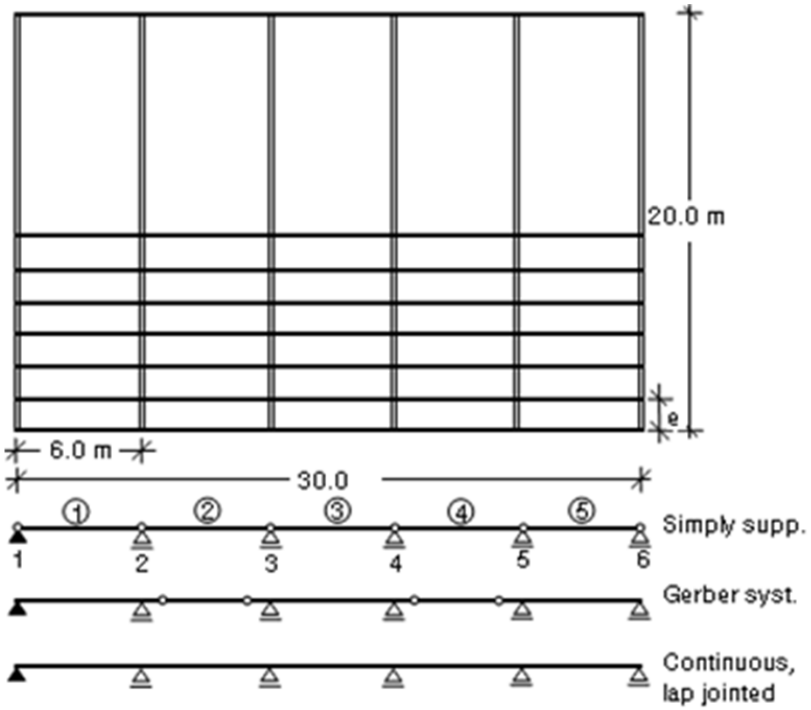


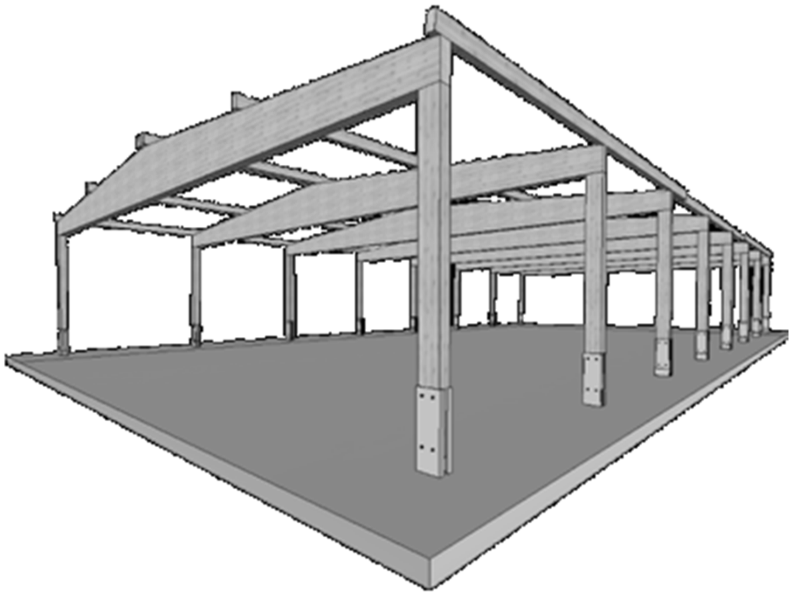
General robustness requirements

- Structure shall be insensitive to local failure
- Progressive collapse shall be prevented

→ Possibility of verification by load case “removal of a limited part of the structure”

→ Evaluated for a typical timber roof structure





Removal of a limited part of the structure – Results*

- Determinate secondary systems
    - Failure of one member will not result in substantial overloading of remaining members (depending on connection stiffness)
- Redundant secondary systems
    - Failure of one purlin will lead to maximum stress increase in remaining purlins of up to 50%
    - Failure of one main member will result in an additional load on remaining main members of up to 82% (depending on purlin strength and stiffness)

→ In the accidental load case this will not lead to utilization factors $\eta > 1.0$

→ Most probably not critical in the case of local damage

→ In the case of high correlation of errors/damages → critical load increase!

* For a more detailed description and account of the results please refer to: Dietsch, P., Winter, S.; Robustness of secondary structures in wide-span timber structures; WCTE 2010 Conference Proceedings; Riva del Garda; Italy; 2010

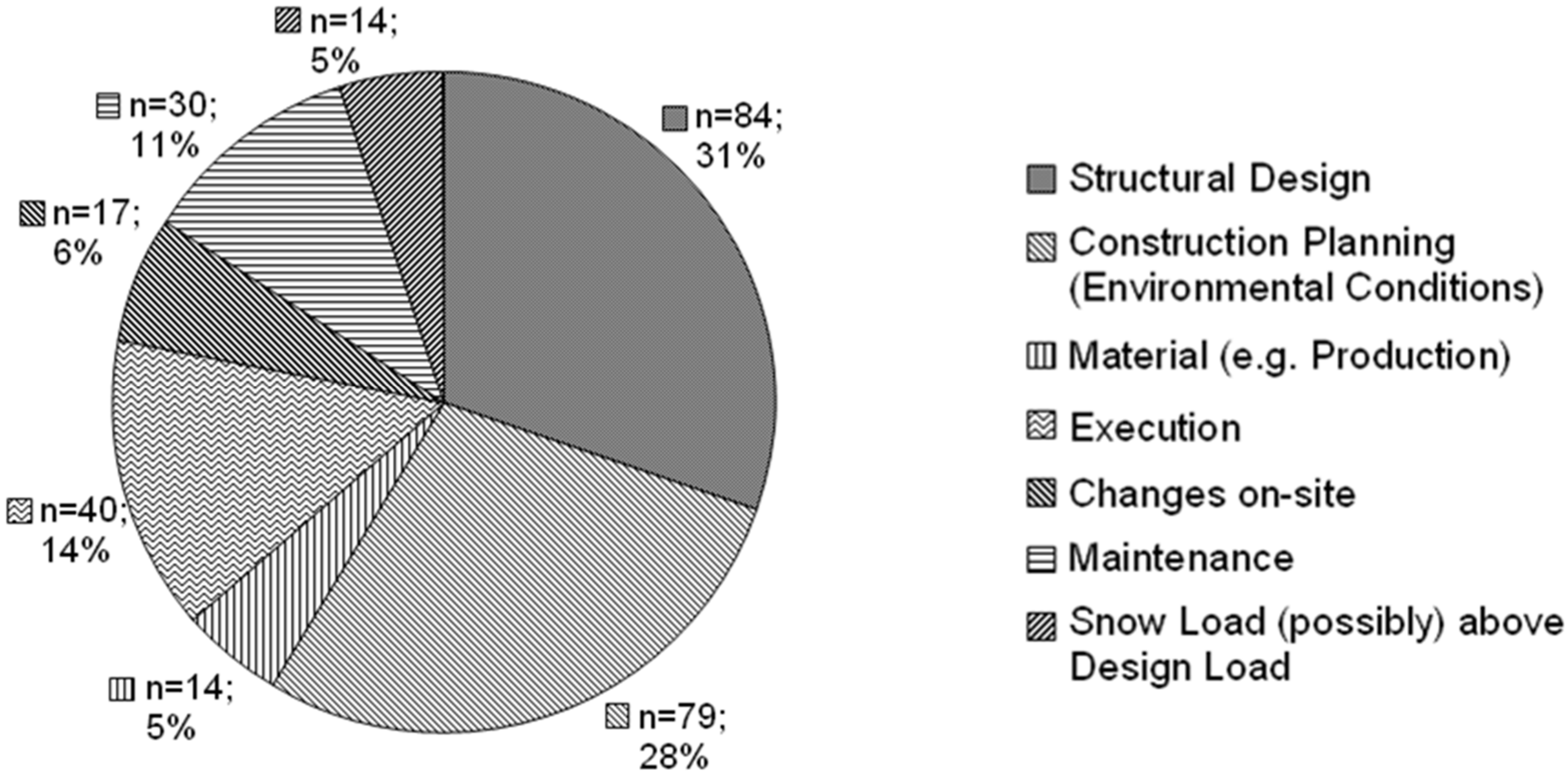
Causes for failure in timber structures

- numerous studies on failures in timber structures (Blaß, Frese; Frühwald et al.; Dietsch, Winter) have shown that the majority of failures were not due to local effects or statistically random occurrences, but due to systematic mistakes or global deterioration (large correlation of failures or developing weak spots)
- Reason is: timber structures are usually composed of repetitive elements, connected by analogical construction principles

→ mistakes during planning or construction phase, will most likely repeat itself in all identical elements

→ structures containing global defects (systematic mistakes or global deterioration) will not be able to withstand a large load increase due to load distribution from one failing member, meaning they are more fragile to collapse progressively

Evaluation of failed Timber Structures - Accountability for Failure



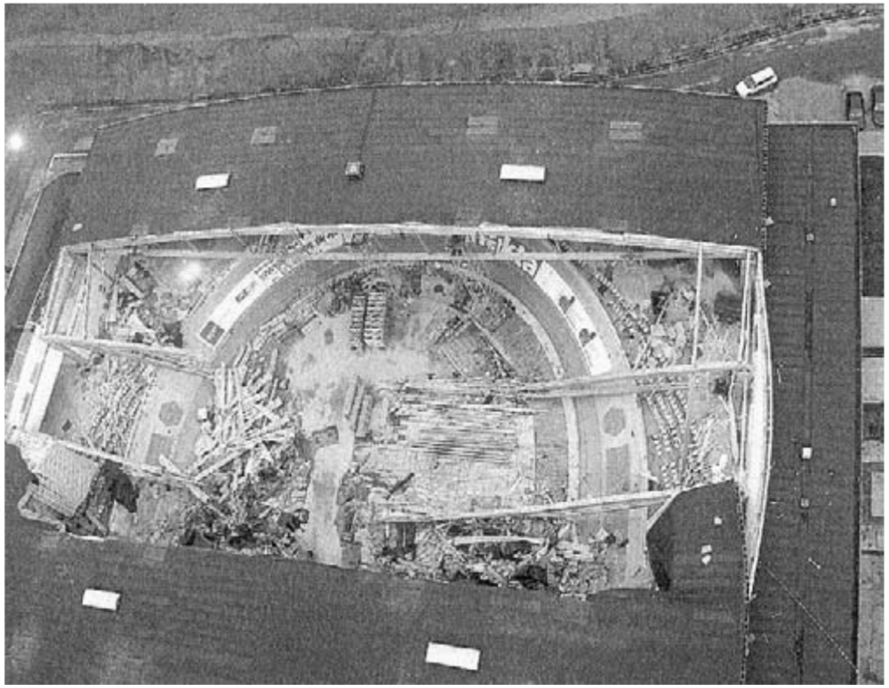
Examples – redundant secondary systems

Bad Reichenhall [Winter, Kreuzinger] [Photo: LKA Bayern]

Reithalle Grafling [MPA BAU/TUM]

Examples – determinate secondary systems

Messe Salzburg [MPA BAU/TUM]



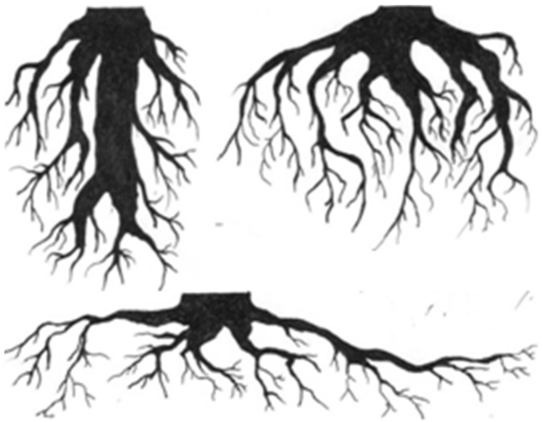
Siemens Arena [Hansson, Larsen]

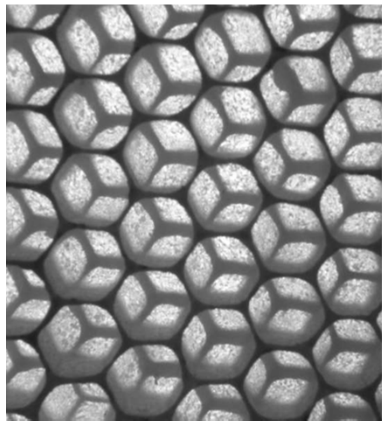
Synopsis: robustness requirements for timber structures

Local effects – local failures, e.g.	Global effects, e.g.
• Local deterioration of element from e.g. local water ingress • Local weakening of element from e.g. holes • Local overloading from e.g. local snow accumulation	• Global weakening of structural elements due to systematic mistakes • Global deterioration of elements from e.g. wrong assumption of ambient climate • Global overloading from e.g. addition of green roof without structural verification
Robustness approach: • Redistribution of loads to adjacent (undamaged) elements by e.g. redundant secondary system	**Robustness approach:** • Limiting failure to local level by e.g. determinate secondary systems with “weak/flexible” connections • Compartmentalization / Segmentation

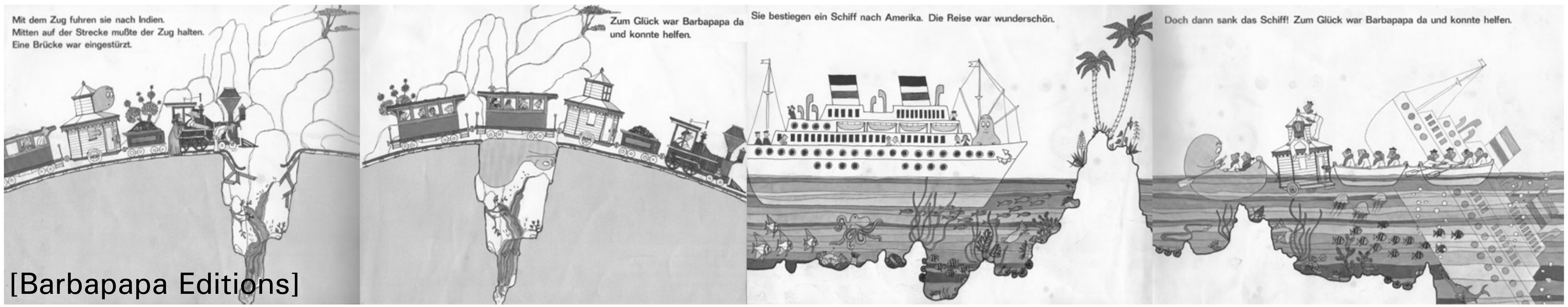
Concept applied by nature: Diversity

- “Survival of the fittest”
  - Not the physically fittest (or most optimized)
  - But the best equipped and adapted to live in changing environments






[Zuk, Clark, 1970, S. 19]



[Barbapapa Editions]

Diversity and redundancy in structural systems

→ higher demands in terms of design, planning, manufacture and execution

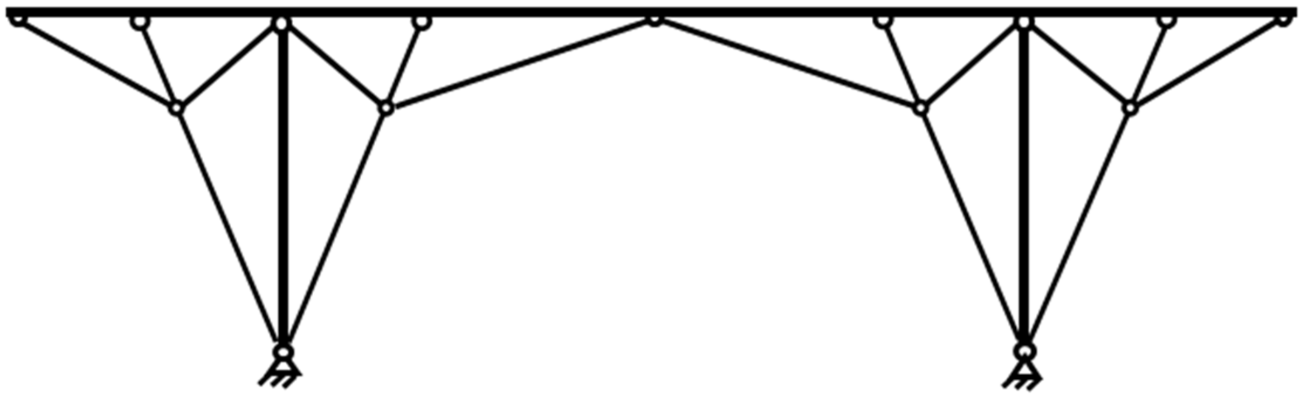
→ higher possibility of human error?

→ smaller consequence of human error (less correlation of errors)?

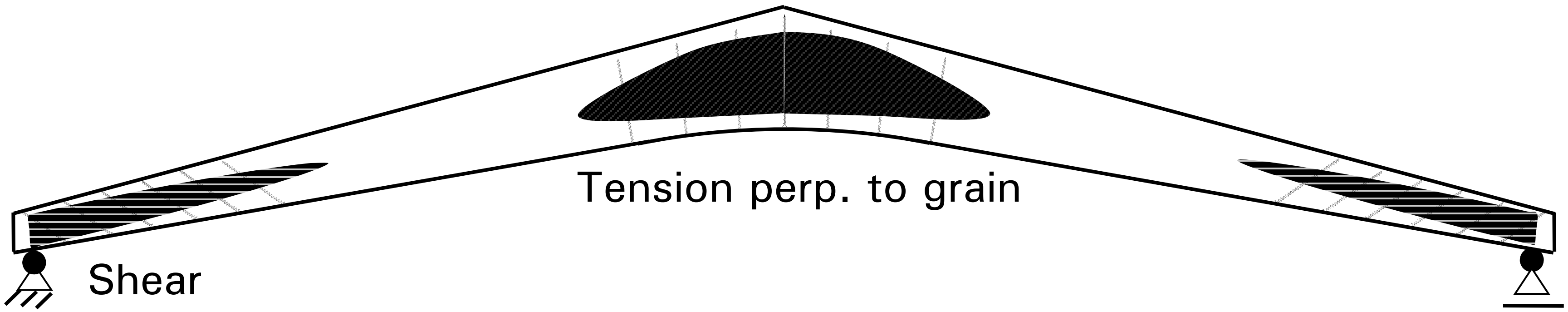
→ should the depth of quality control be more dependent upon the number of identical elements designed?

Proposals towards designing for robustness – primary structure

- Structural indeterminacy



- Internal indeterminacy through reinforcement: second barrier against brittle failure modes



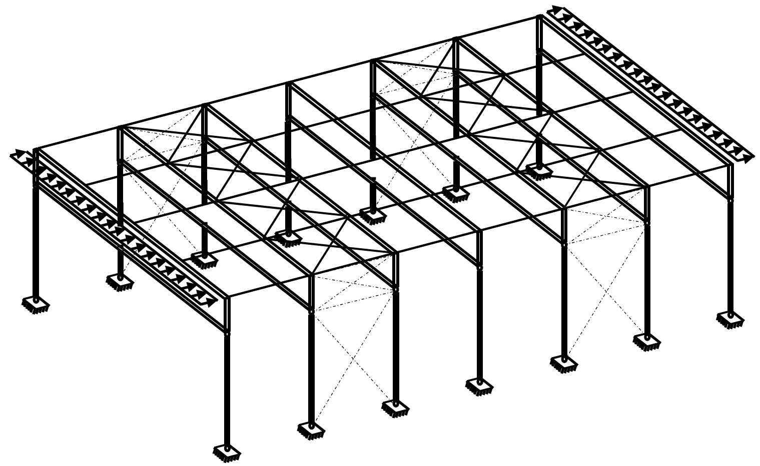
Proposals towards designing for robustness - secondary structure

- Determinate secondary systems to enable compartmentalization

→ additional challenge: dual requirement for typical purlin systems:

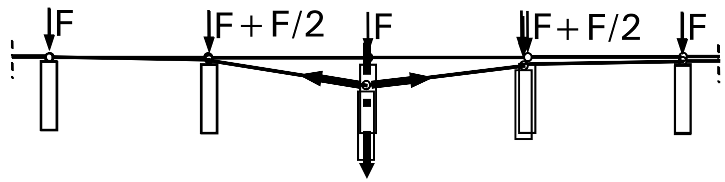
a) to carry and transfer vertical loads from the roof structure

b) to perform as part of the bracing system, transferring horizontal loads and laterally stabilizing main members



→ purlins have to transfer horizontal (axial) loads in tension and compression

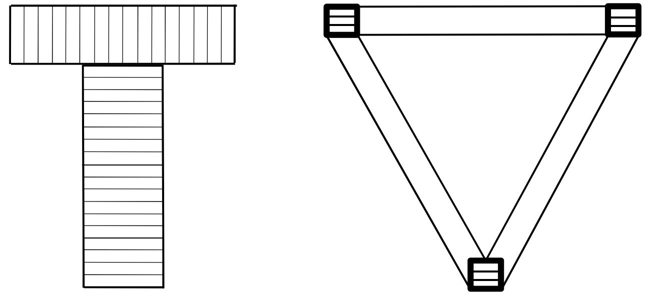
→ if one main member fails, the purlin systems will develop into a tie member, transferring the vertical loads from the failing member to the adjacent members



Determinate secondary systems – possible details

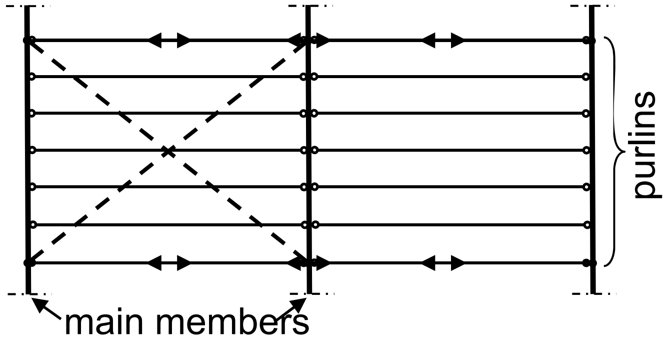
a) Primary elements with internal stability

- purlins to carry vertical loads



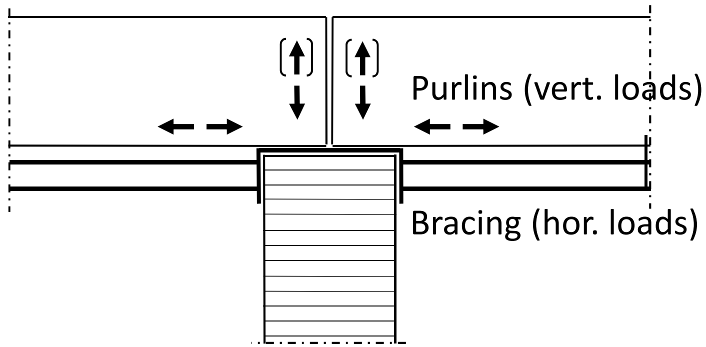
b) Differentiate between purlins according to function(s)

- only purlins which are part of the bracing system should be given axial load-carrying capacity



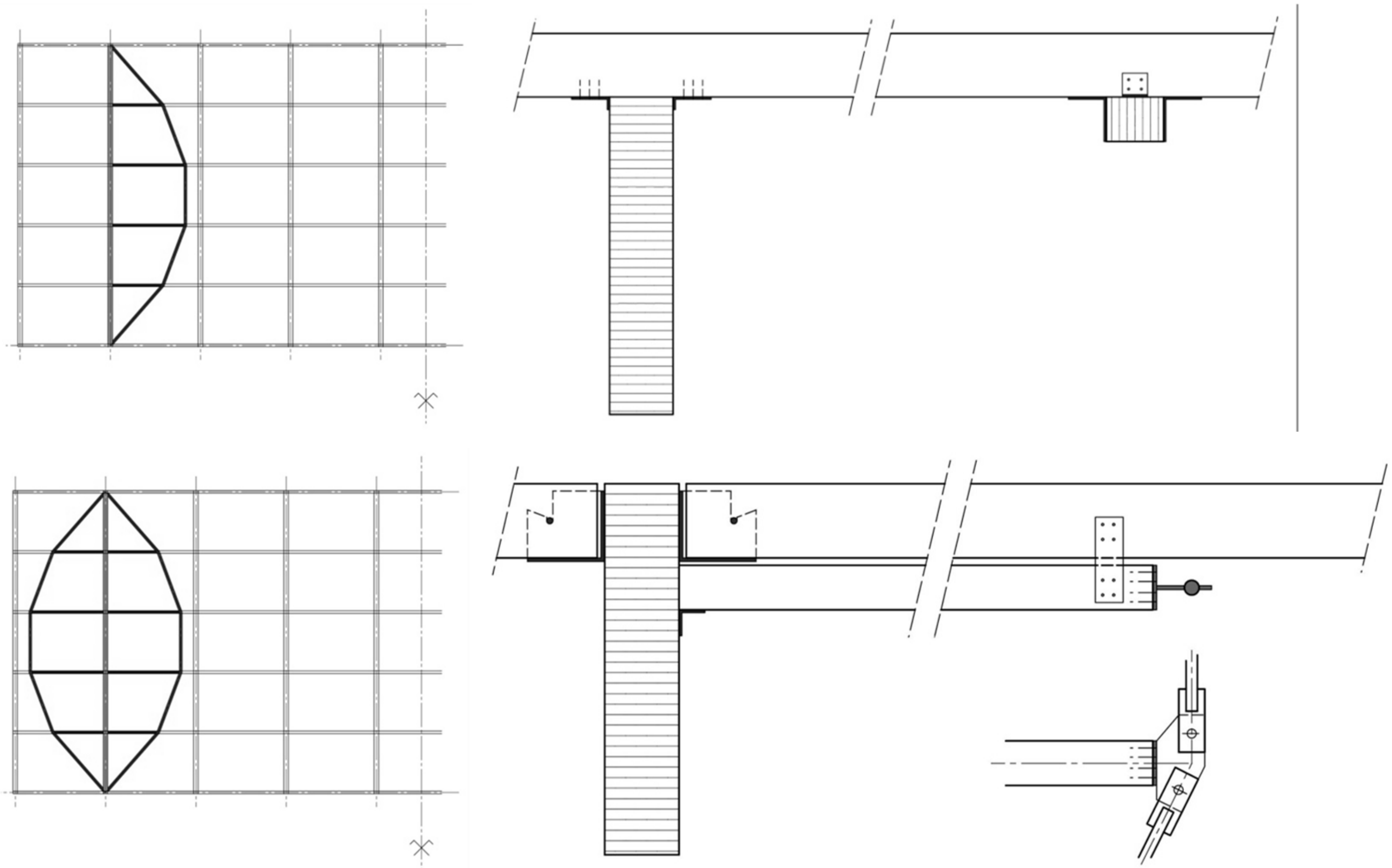
c) Separate both functions

- purlin system for vertical loads
- bracing system for horizontal loads



Determinate secondary systems – possible details

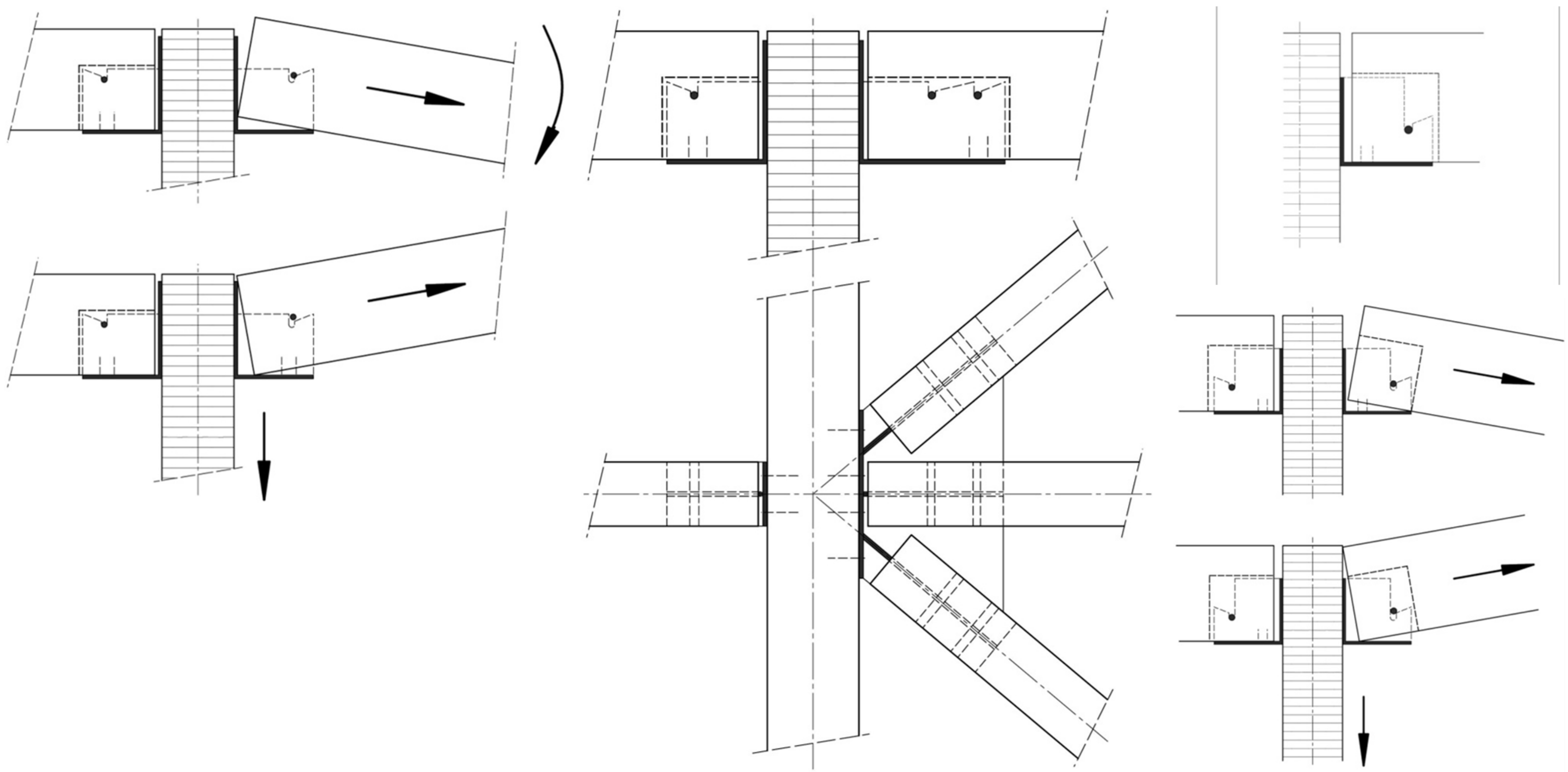
d) Bracing system which is only connected to one primary member
→ reduce necessary axial load-carrying capacity of connections



[Waidelich, M.; Master Thesis; Chair for Timber Structures and Building Construction; Technische Universität München; 2011]

Determinate secondary systems – possible details

d) Use rotation of purlin in case of failure to enable easy detachment between primary and secondary members (not applicable for seismic areas)



[Waidelich, M.; Master Thesis; Chair for Timber Structures and Building Construction; Technische Universität München; 2011]

Chair for Timber Structures and Building Construction

Outlook

- Research project in collaboration with Prof. Daniel Straub, Engineering Risk Analysis Group, TUM

  “Risk-based assessment of robustness and collapse behavior of secondary structures in large-span timber structures”

  Miraglia, S. et al.; “Comparative Risk Assessment of Secondary Structures in Wide-span Timber Structures”; ICASP 11,
  1 – 4 August 2011, ETH Zürich, Switzerland

Action E55

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