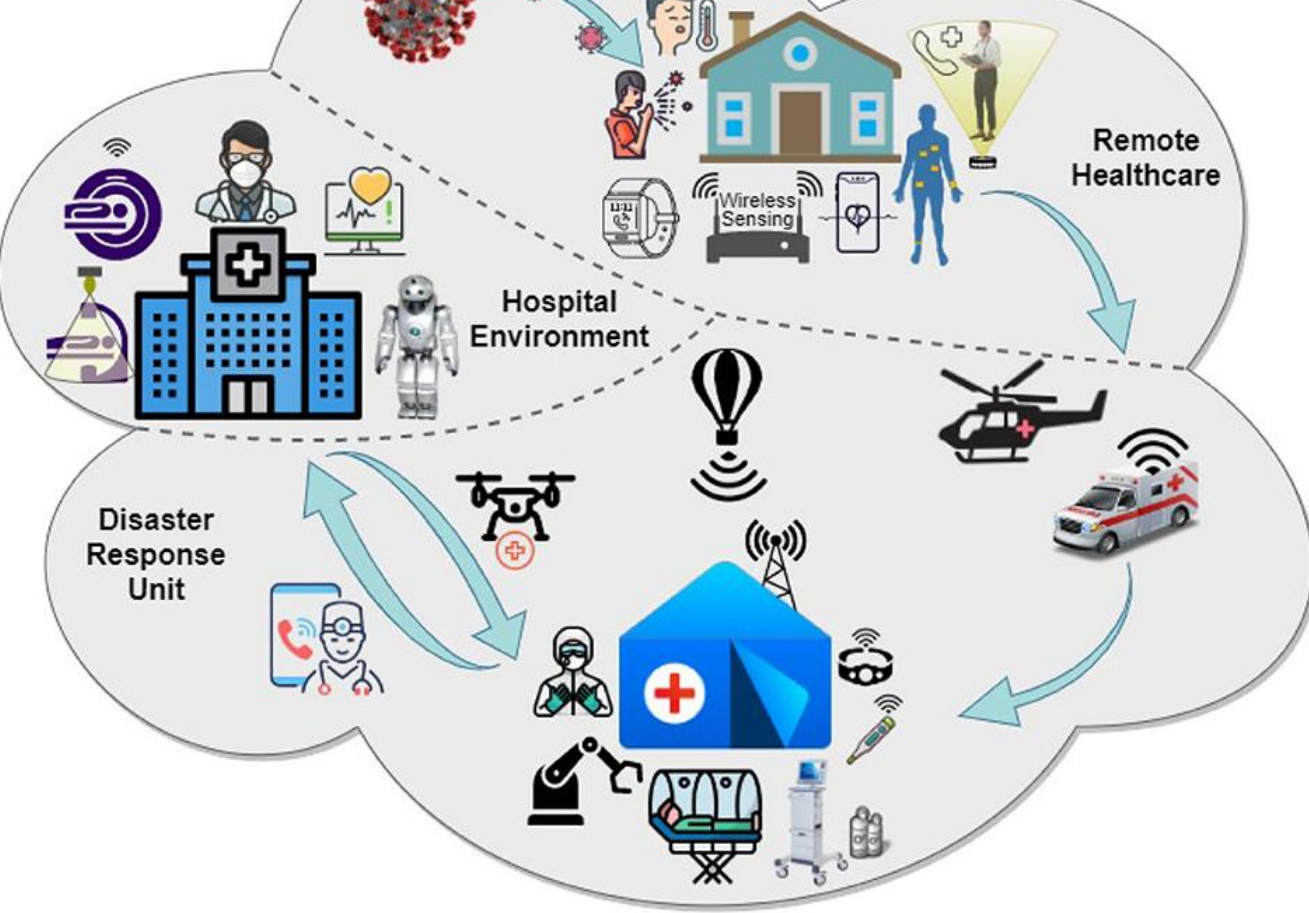




A Review of Design Methods for the Transition of Large-Scale Systems

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WE CAN build a better tomorrow, today
It's time for a Green New Deal



Example: German Energiewende



- Decisions mainly drawn from a techno-economic scenario analysis (Dieckhoff et al., 2016)

Conclusions:

- Limitations of used approaches have been pointed out (Dieckhoff et al., 2016; Schmid et al., 2016; Fischer et al. 2016)
- No multi-dimensional view taken into account → Stakeholder dependencies etc.
- Technology treated as „building blocks“ → No latencies for deployment taken into account

Dieckhoff, Christian; Leuschner, Anna, eds. (November 2016). *Die Energiewende und ihre Modelle: Was uns Energieszenarien sagen können – und was nicht* [The Energiewende and its models: What energy scenarios can tell us – and what not] (in German). Bielefeld, Germany: transcript Verlag.

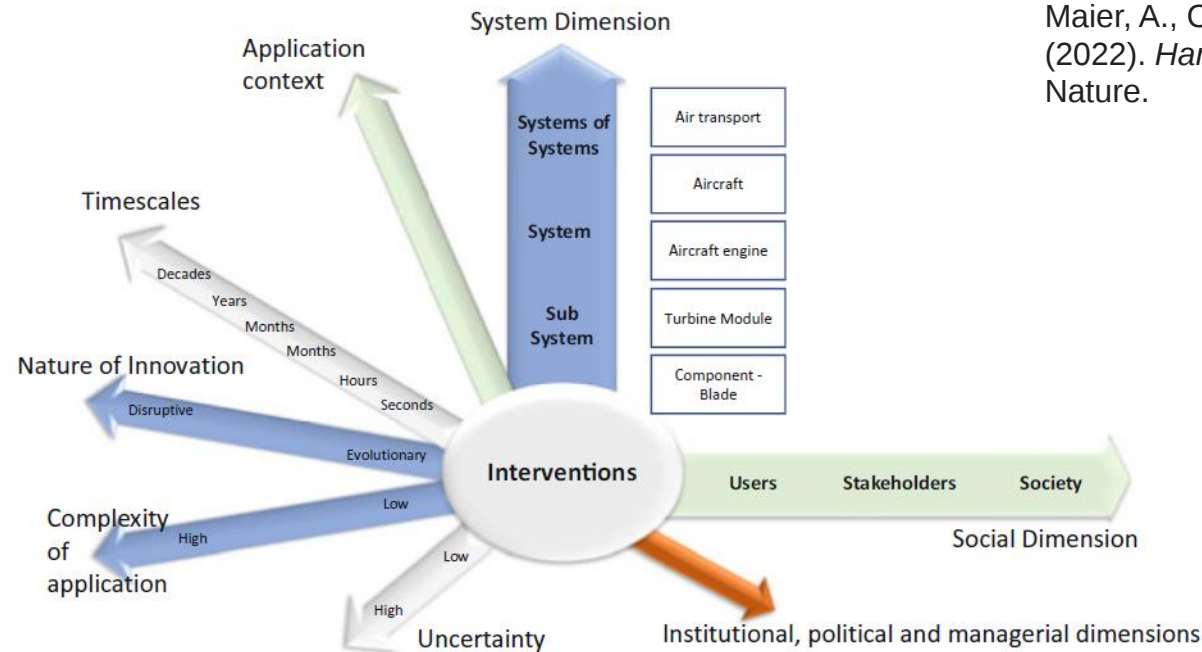
Schmid, E., Knopf, B., & Pechan, A. (2016). Putting an energy system transformation into practice: The case of the German Energiewende. *Energy Research & Social Science*, 11, 263-275.

Fischer, W., Hake, J. F., Kuckshinrichs, W., Schröder, T., & Venghaus, S. (2016). German energy policy and the way to sustainability: Five controversial issues in the debate on the “Energiewende”. *Energy*, 115, 1580-1591.

How can we design **transitions of large-scale systems** „better“?

Designing Transitions and Interventions

In large-scale systems, usually nothing is designed from „scratch“ → Rather changes to existing systems
→ Called „transitions“ or „interventions“ to indicate that we are transforming something existing.



Maier, A., Oehmen, J., & Vermaas, P. E. (Eds.).
(2022). *Handbook of Engineering Systems Design*. Springer
Nature.

Objective: Survey existing approaches for designing transitions and interventions

Emerging Approaches

- 1) **Technology transitions** focus on describing transitions as an interaction between multiple layers, namely, the technological niche, socio-technical regime, and landscape development
- 2) **Transition design** (co-creation of interventions with stakeholders; Focus on radical transitions for wicked problems; soft approach),
- 3) **DesignX** (design and implementation of interventions; Favors incrementalism and satisficing),
- 4) **Engineering systems design** (application of systems engineering and operations research approaches),
- 5) **Systems of systems engineering** (linking technical systems with collaborations between actors, governance).

Economics, STS

Service design,
design thinking

Systems
engineering,
Operations
research

Technology transitions

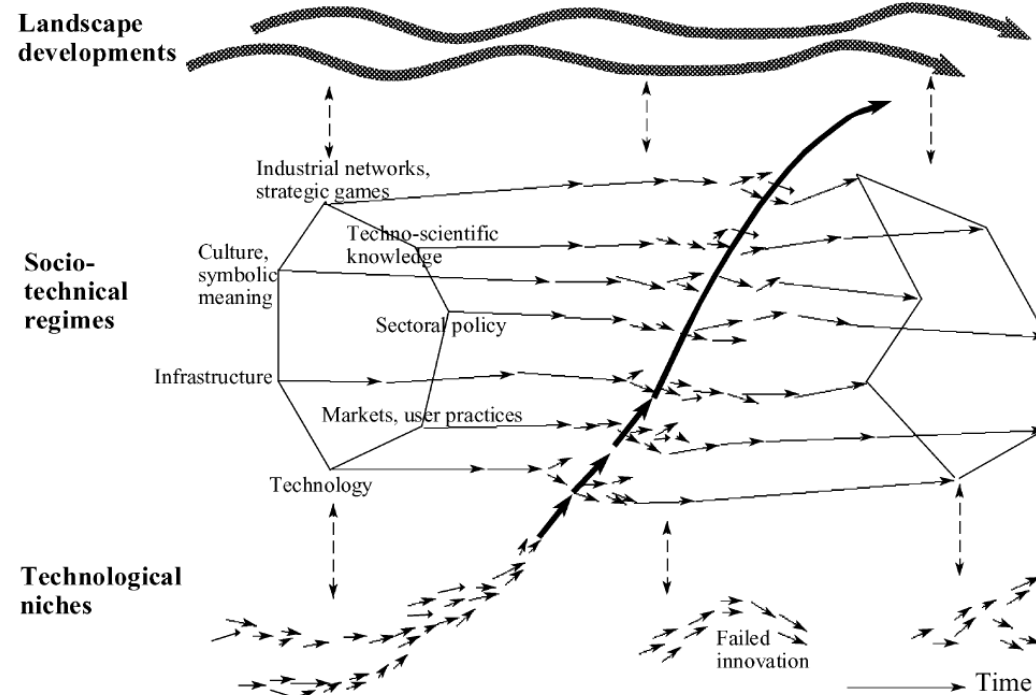


Fig. 5. A dynamic multi-level perspective on TT.

- Transdisciplinary foundations: Merges concepts from evolutionary economics, socio-technical studies, structuration theory, and neo-institutional theory
- More of a descriptive approach rather than for designing transitions as such

Operationalization for use as a design method would be needed

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy*, 31(8-9), 1257-1274.

Grin, J., Rotmans, J., & Schot, J. (2010). *Transitions to sustainable development: new directions in the study of long term transformative change*. Routledge.

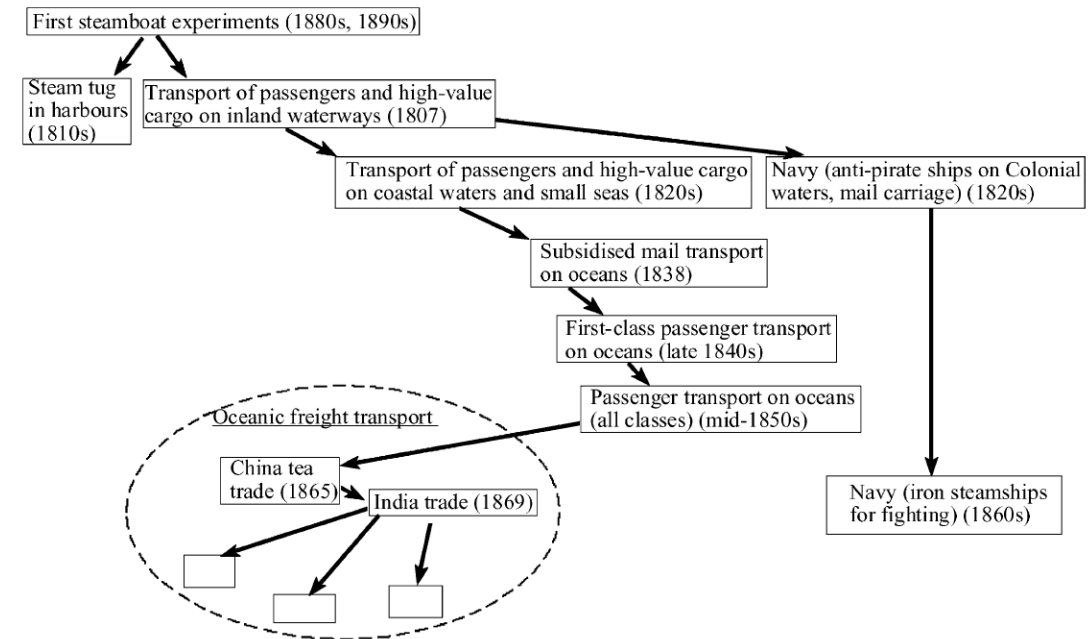
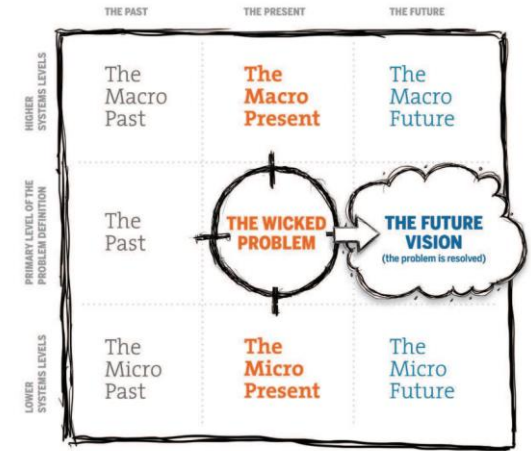
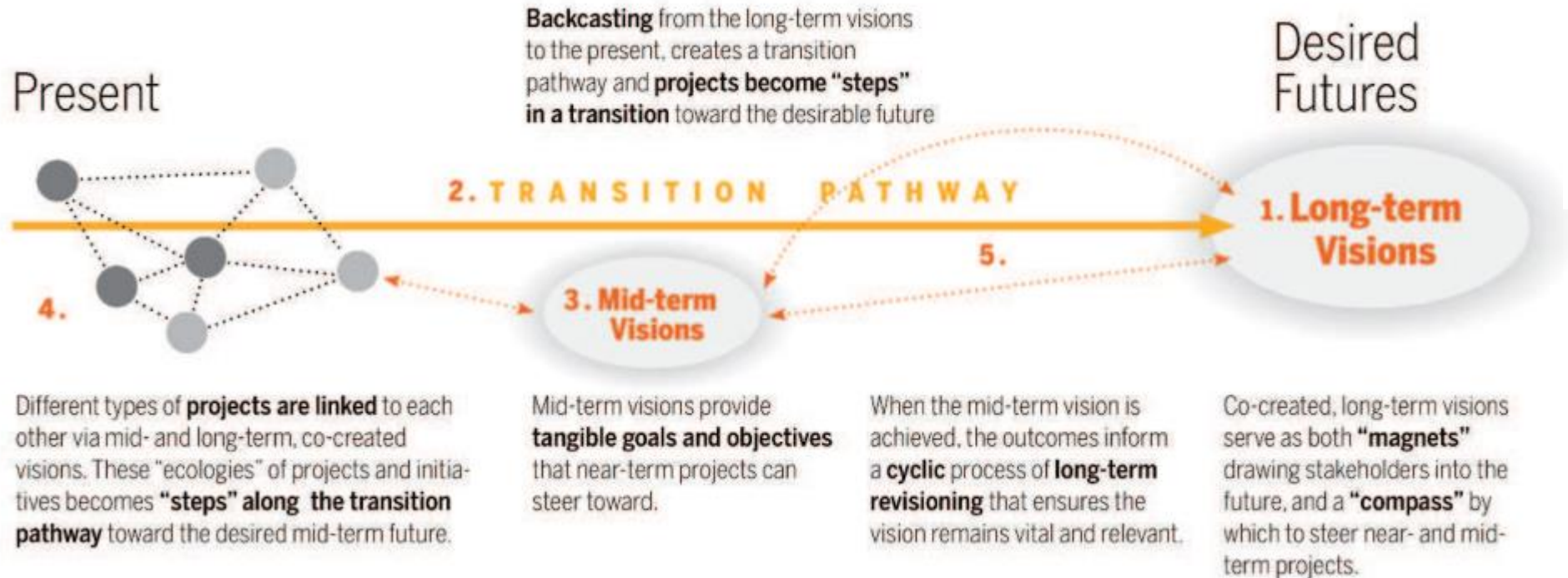


Fig. 10. Trajectory of niche-cumulation for the breakthrough of steamships.

Transition design



- Qualitative, co-creation of interventions with stakeholders;
- Focus on radical transitions for wicked problems;
- Soft approach

Flexible framework combining different methods with a relatively **narrow forus** (radical transitions of wicked problems)

Irwin, T. (2015). Transition design: A proposal for a new area of design practice, study, and research. *Design and Culture*, 7(2), 229-246.

Scupelli, P. (2015). Designed transitions and what kind of design is transition design?. *Design Philosophy Papers*, 13(1), 75-84.

Kossoff, G., Irwin, T., & Willis, A. M. (2015). Transition design. *Design Philosophy Papers*, 13(1), 1-2.

DesignX

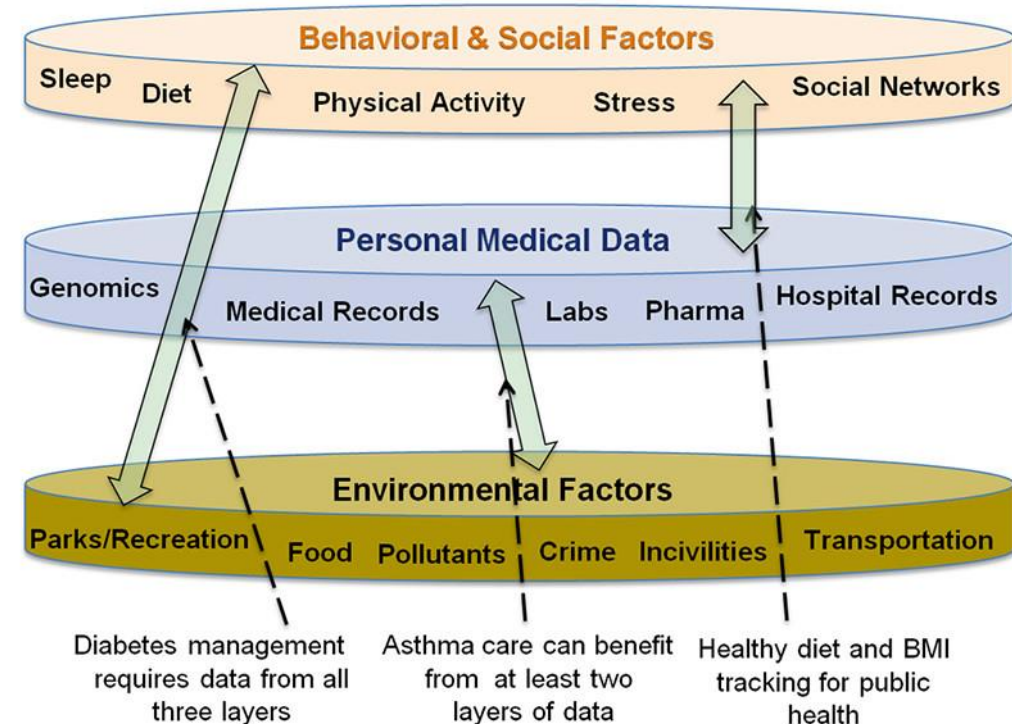
“DesignX is a new, **evidence-based approach** for addressing many of the complex and serious problems facing the world today.”

- Emphasis on validated methods, frameworks, patterns, heuristics (evidence-based design)
- Incrementalism and opportunistic acting (“muddling through”): large uncertainties, unknowns
- Satisficing (sufficiently good) rather than optimizing

Seems rather like a **manifesto / research program** rather than an operational method

Norman, D. A., & Stappers, P. J. (2015). DesignX: complex sociotechnical systems. *She Ji: The Journal of Design, Economics, and Innovation*, 1(2), 83-106.

Müller, L., Budde, M., Weibel, N., Spencer, E. A., Beigl, M., & Norman, D. (2017, September). Learning from failure: designing for complex sociotechnical systems. In *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers* (pp. 988-991).



Engineering systems design

Maier, A., Oehmen, J., & Vermaas, P. E. (Eds.). (2022). *Handbook of Engineering Systems Design*. Springer Nature.

Bartolomei, J. E., Hastings, D. E., De Neufville, R., & Rhodes, D. H. (2012). Engineering Systems Multiple-Domain Matrix: An organizing framework for modeling large-scale complex systems. *Systems Engineering*, 15(1), 41-61.

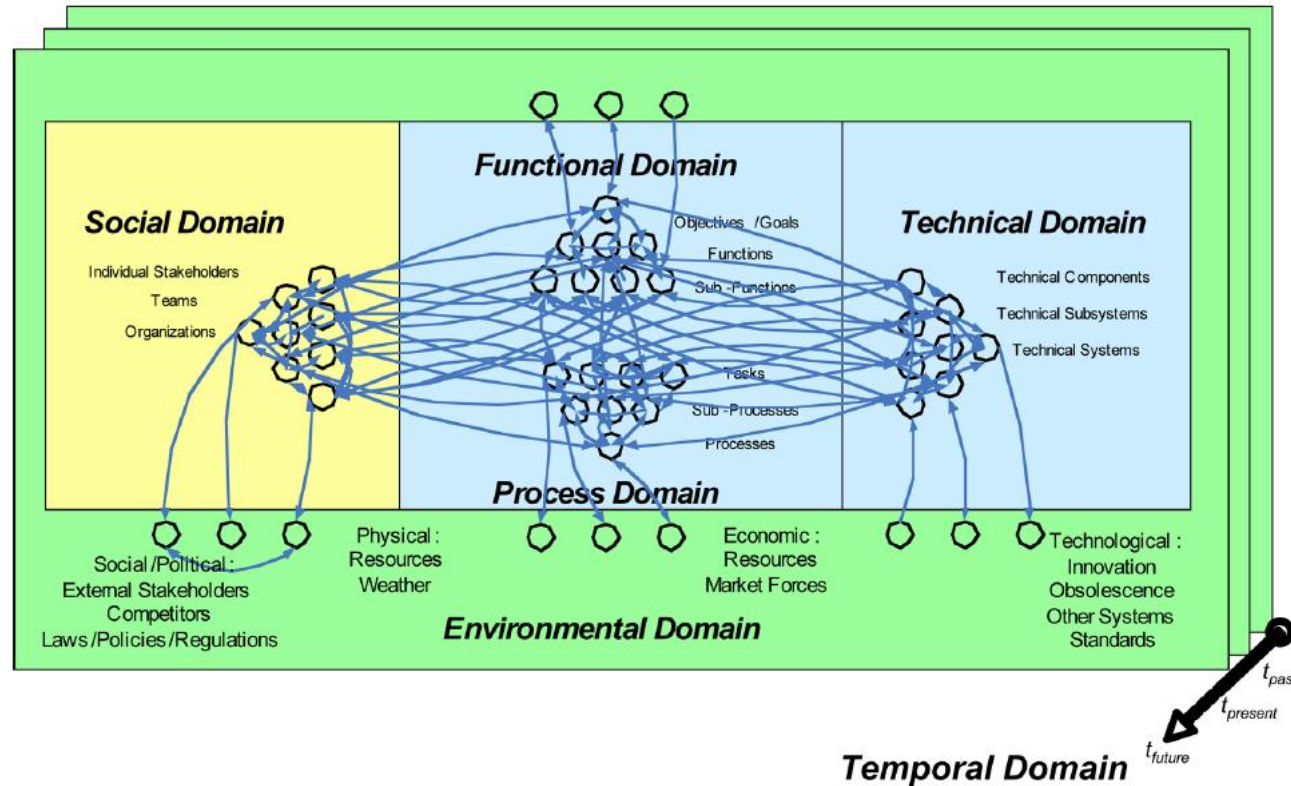


Figure 1. Engineering system conceptual model. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

- *Legacy*: systems engineering, systems architecting (flexibility), program management, socio-technical systems
- *Fragmented method landscape*: Only common point is engineering systems
- *Future research directions* (Maier et al., 2022): Managing system requirements at societal scale, designing, scale-covariant systems, and making connectability a core systems capability

Engineering design researchers looking at larger-scale problems

Systems of systems engineering

Hein, A. M., Chazal, Y., Boutin, S., & Jankovic, M. (2018, June). A methodology for architecting collaborative product service system of systems. In *2018 13th Annual Conference on System of Systems Engineering (SoSE)* (pp. 53-59). IEEE.

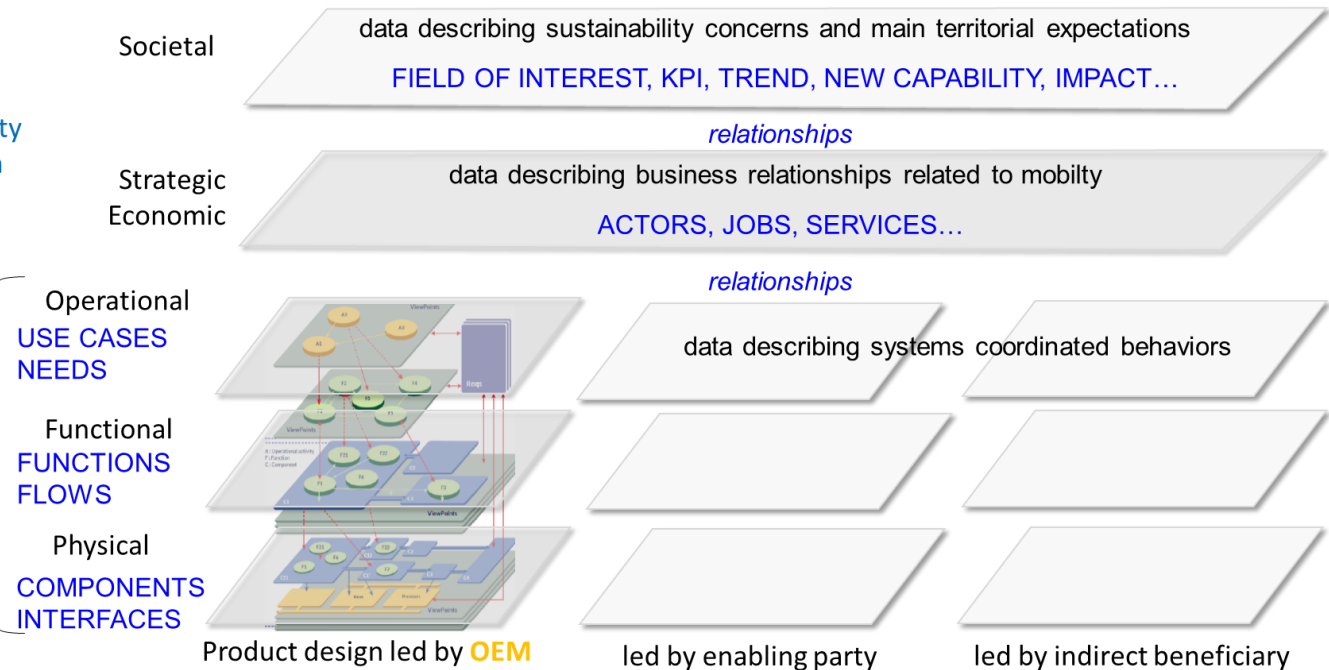
What is a system of systems (SoS)?

„collaboratively integrated systems“:

- **Operational independence of the components:** „the components fulfill customer-operator purposes on their own.“
- **Managerial independence of the components:** „The component systems are separately acquired and integrated but maintain a continuing operational existence independent of the system-of-systems.“

extension to
address mobility
services design

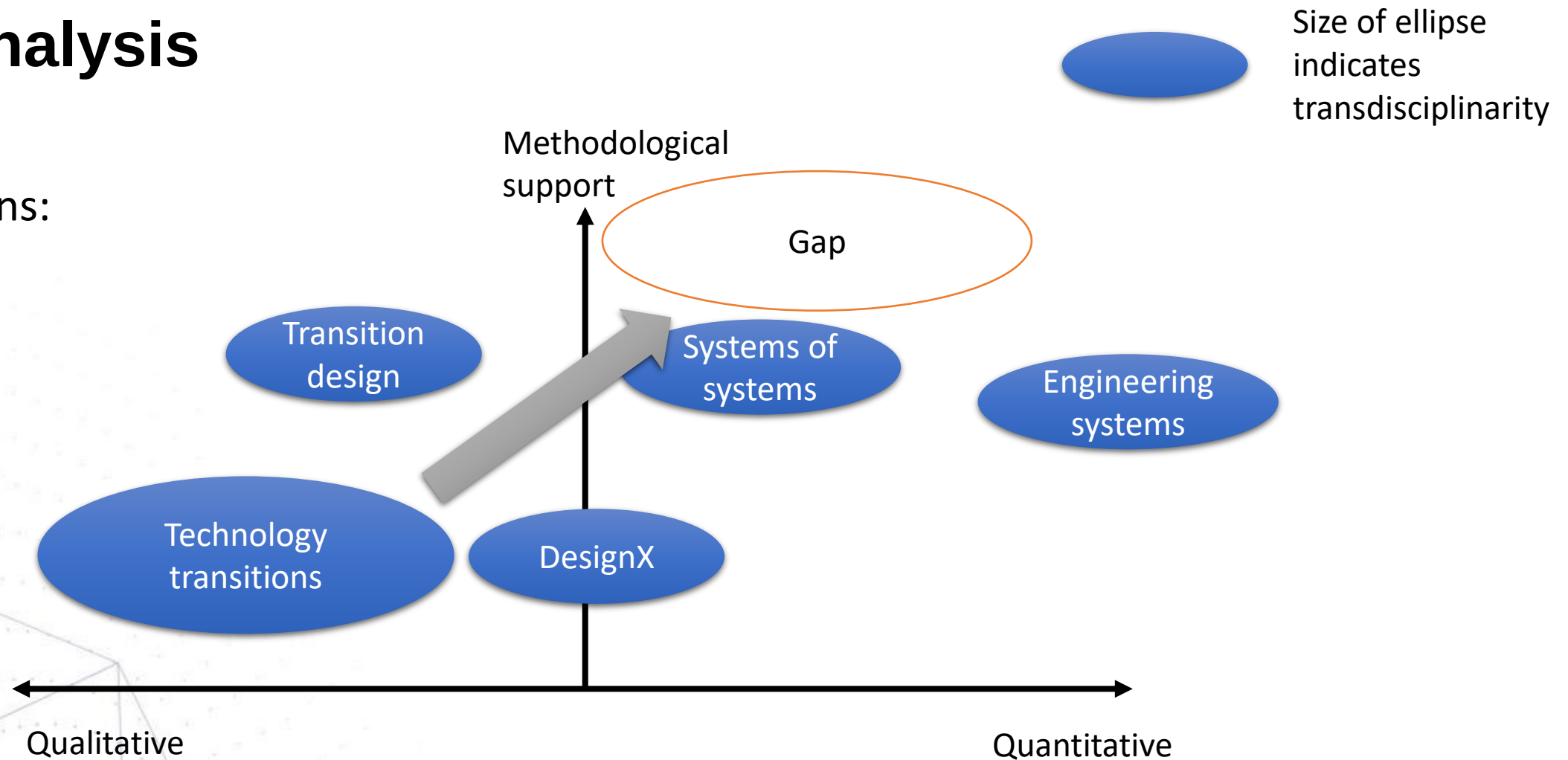
Systems
Engineering



Systems engineering / systems architecting moving to modeling collaborations.

Gap Analysis

Dimensions:



Existing quantitative approaches and those with methodological support lack the transdisciplinary conceptual foundation → **Potential to address gap**

Conclusions

- Several **emerging approaches** for large-scale systems design exist
- Most have a rather **restricted conceptual foundation** (technology transitions is an exception)
- Potential to develop an **open, integrative framework** for large-scale systems design

