

# Eco-construction for sustainable development – Konzepte für Materialbanken

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16. Oktober 2020 | 24. Dresdner Baustatik-Seminar



# Überblick

Nachhaltiges Bauen - Materialbanken

Projekt Econ4SD

Teilaspekt – Reversible Architektur

Teilaspekt – Alterung von Betonbauteilen



# Hinterlegte Werte durch Bautätigkeit

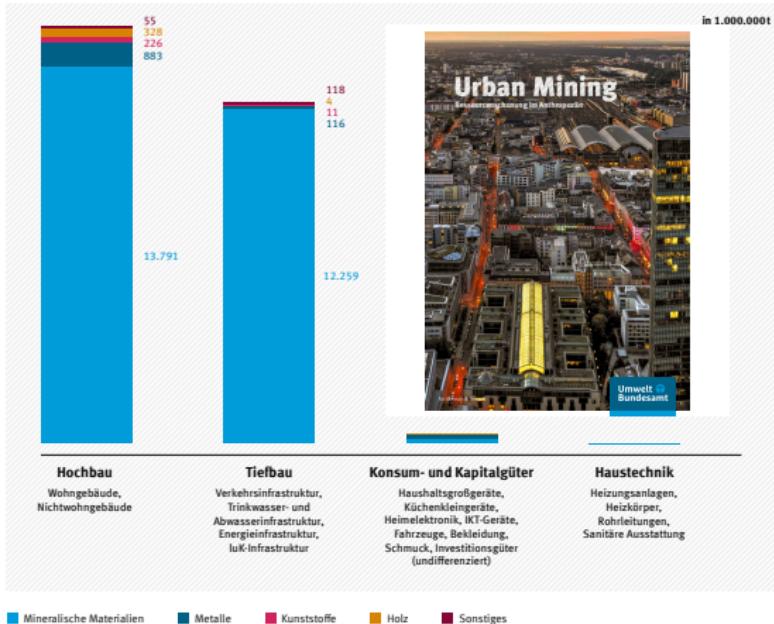


## Deutschland

- ▶ 1,3 Billionen Euro Materialwert
- ▶ +500 Mio Tonnen Material pro Jahr
- ▶ Recycling < 20%

*Anthropogenes Materiallager Deutschland 2010, aus [1].*

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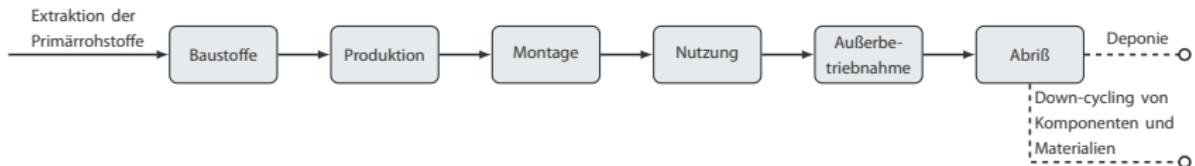


## Luxemburg

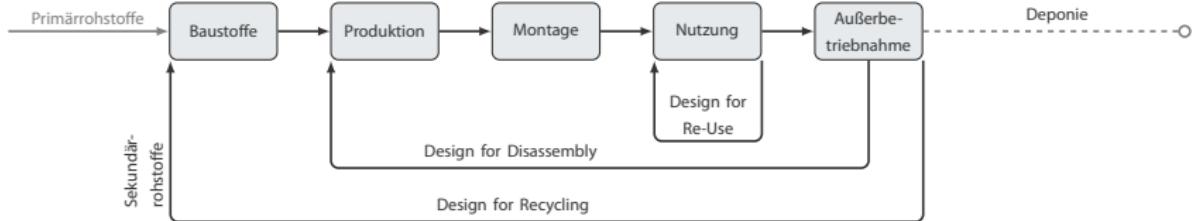
- ▶ Bau: 6% BIP
- ▶ Verdichtung

# Materialeinsatz durch das Bauwesen

## Sequentiell



## Zirkulär



*Konventioneller und kreislauforientierter Produkteinsatz.*



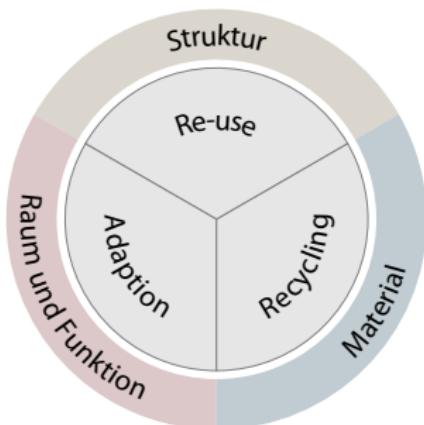
# Reversibles Bauen

## Design for Recycling

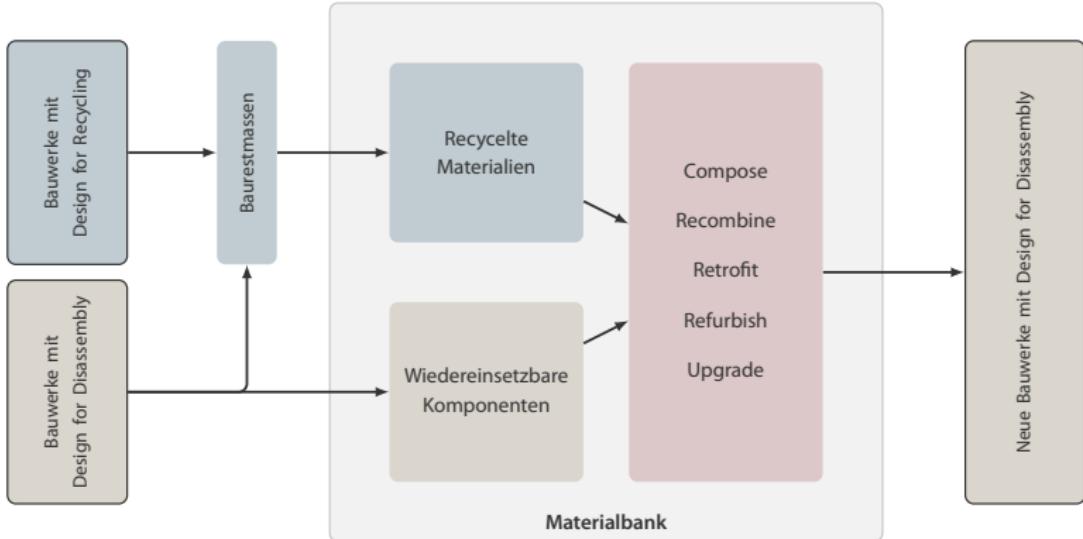
- ▶ Einsatz recyclebarer Materialien prinzipiell vorsehen,
- ▶ Rezyklierbarkeit bewerten und wichtigen,
- ▶ räumlichen Zugang sichern (Planung für Umbau, Rückbau und Abriss),
- ▶ detaillierte Dokumentation der eingesetzten Materialien/Produkte.

## Design for Disassembly

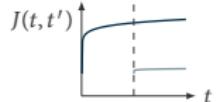
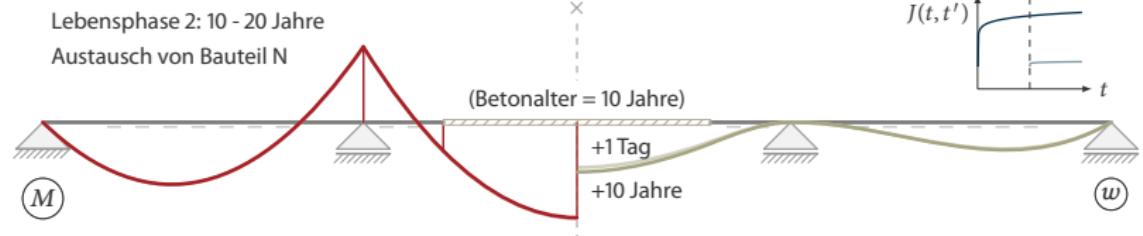
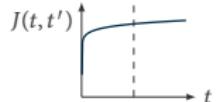
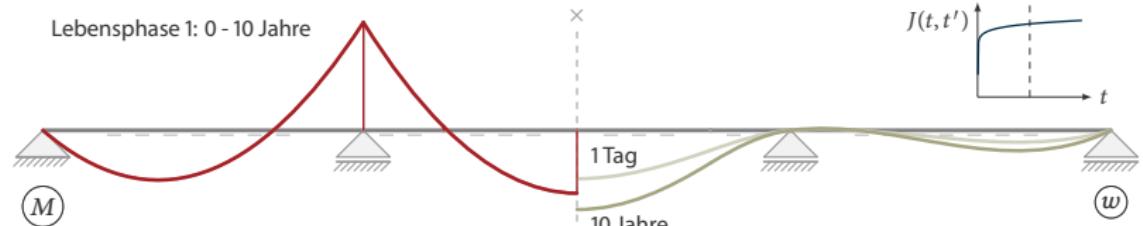
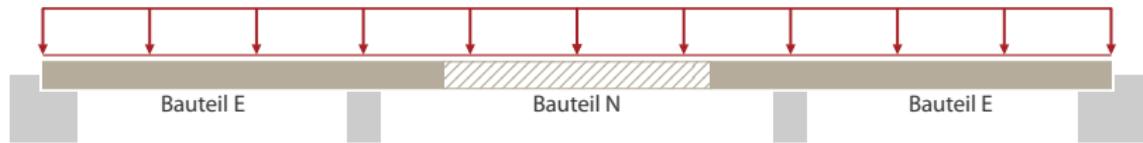
- ▶ räumliche und funktionale Transformation,
- ▶ Rekonfiguration und Erneuerung von Tragwerkskomponenten zulassen,
- ▶ modular-hierarchische Bauweisen mit entsprechenden konstruktiven Lösungen,
- ▶ Dokumentation des Bauwerkzustandes.



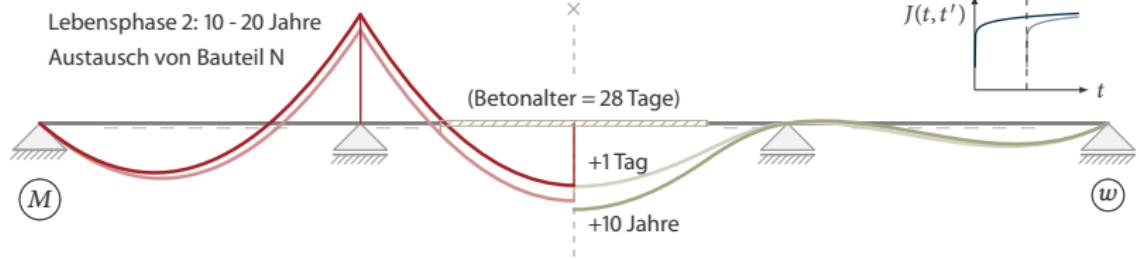
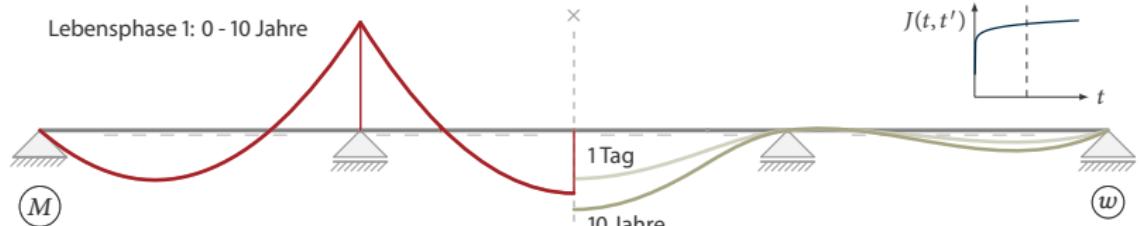
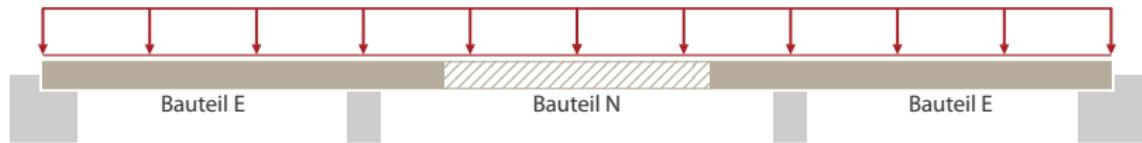
# Konzept der Materialbank



# Herausforderungen: Re-use



# Herausforderungen: Re-use



# Hierarchisches *digital twinning*



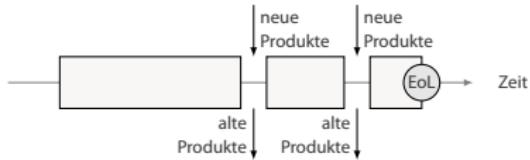
o



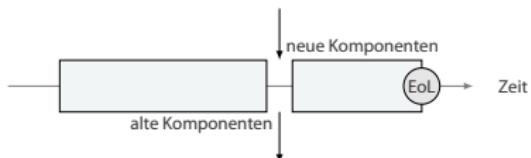
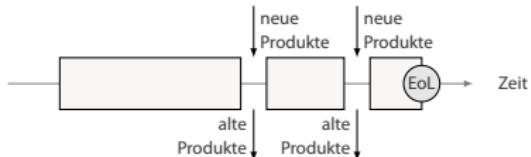
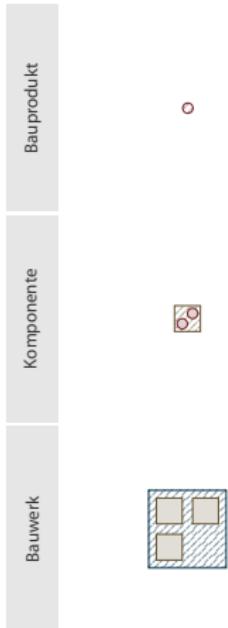
# Hierarchisches *digital twinning*



o



# Hierarchisches *digital twinning*



# Hierarchisches *digital twinning*



Bauprodukt



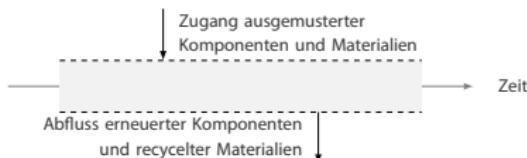
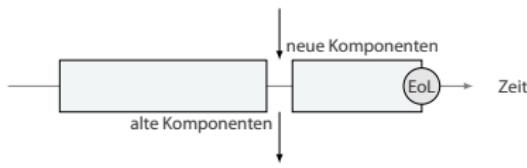
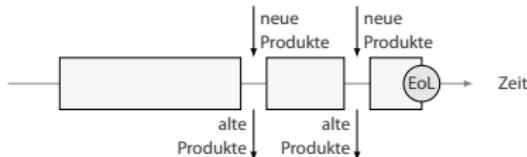
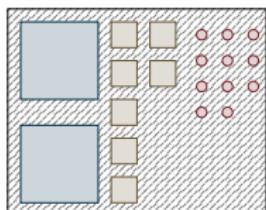
Komponente



Bauwerk

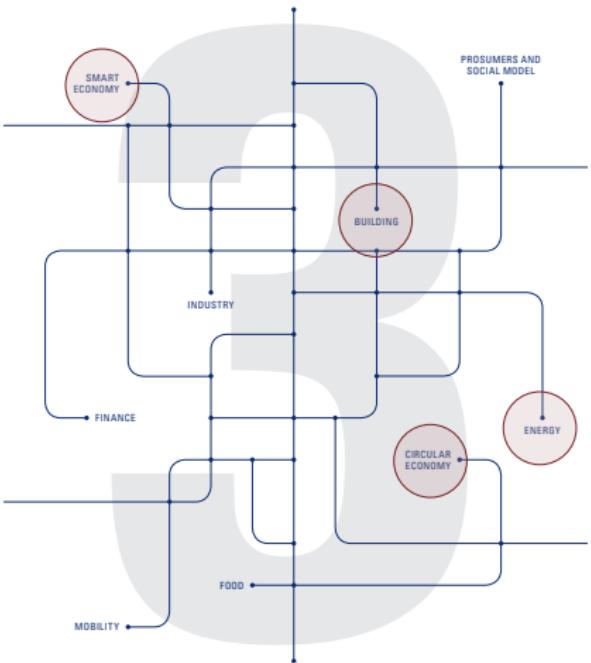


Materialbank



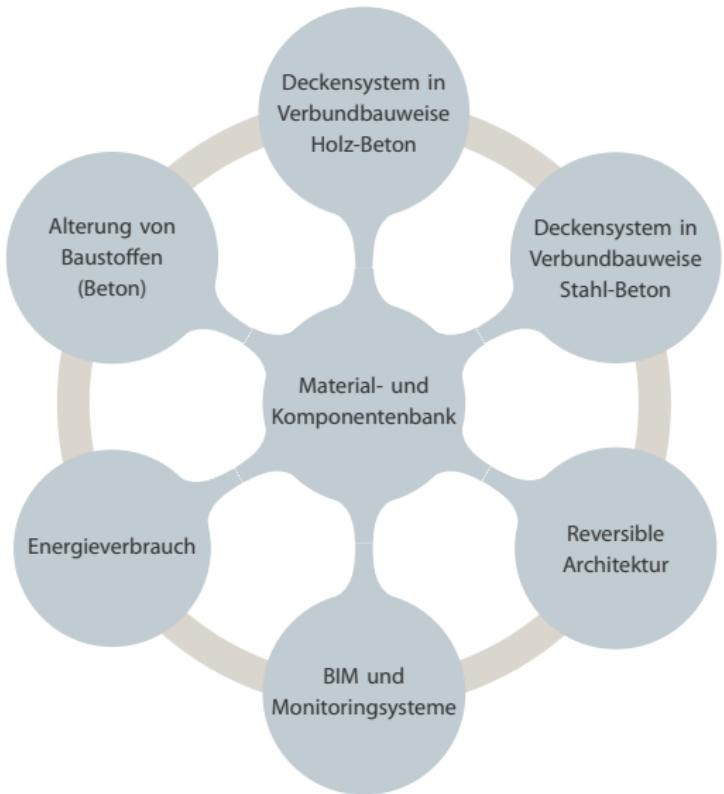


## THE 3<sup>RD</sup> INDUSTRIAL REVOLUTION STRATEGY STUDY

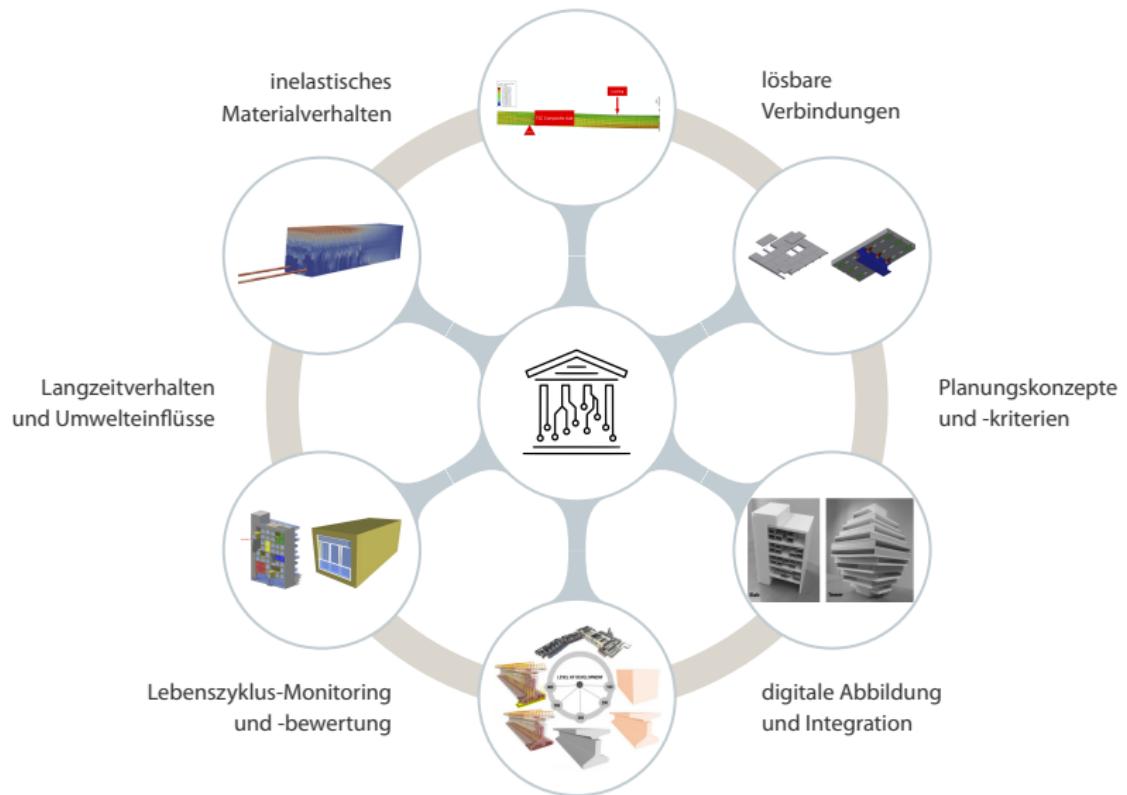


FOR THE GRAND DUCHY OF LUXEMBOURG

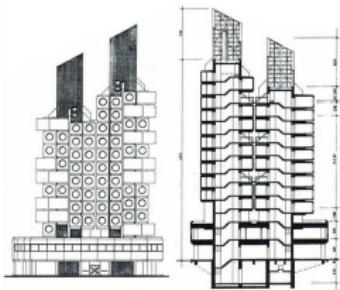
# Econ4SD – Themen



# Econ4SD – Themen



# Recyclebare Architektur (?)



Kisho Kurokawa, Nakagin Capsule Tower, 1970-72, [2].

Heide & Von Beckerath, Cohousing, 2010–2013, [4].



Werner Sobek, Einfamilienhaus R128, 1998-2000, [3].



Gramazio Kohler Architects, NEST, 2010-2016, [5].

# Reversible Architektur

## Tendenzen

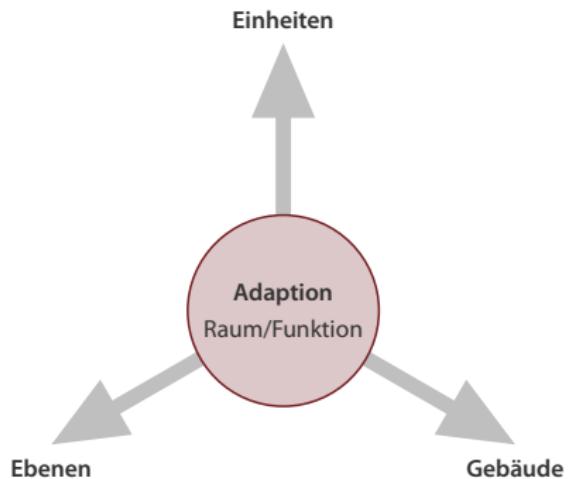
- ▶ Innovation oft zunächst auf Bürogebäude ausgerichtet
- ▶ Hemmnisse nachträglicher Modifikation minimieren

## Ziele – Raum und Funktion

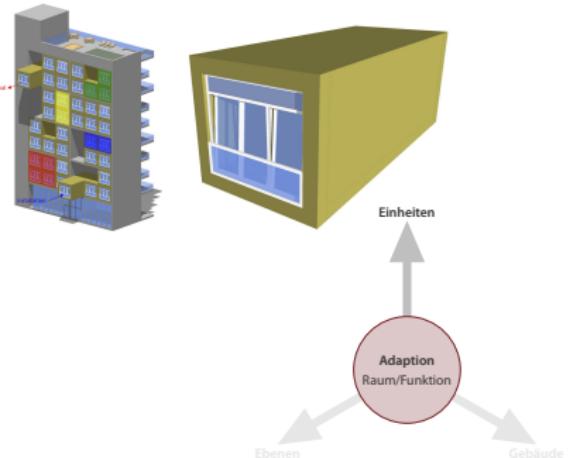
- ▶ Flexibilität
- ▶ Zugänglichkeit
- ▶ Ausführbarkeit

## Ziele – Struktur und Material

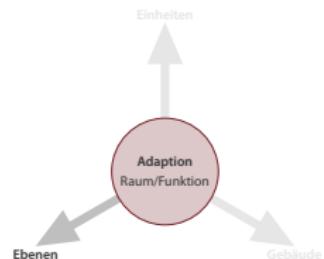
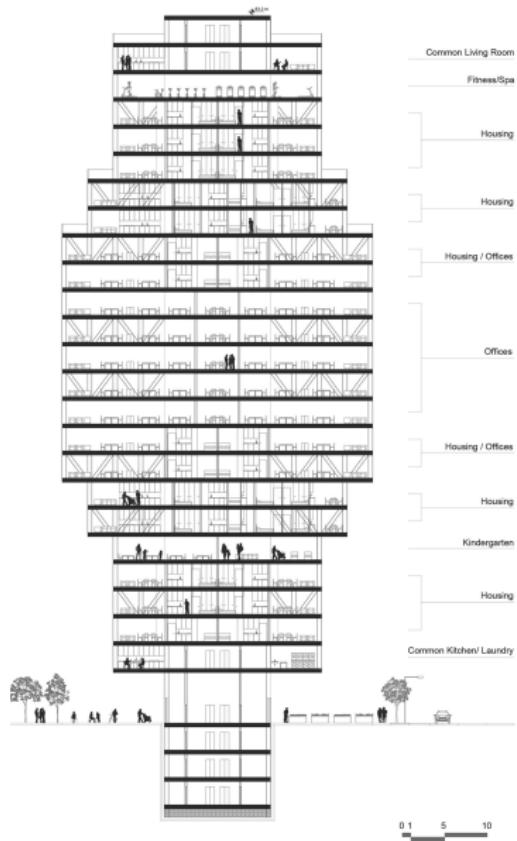
- ▶ Recycling
- ▶ Dekonstruierbarkeit



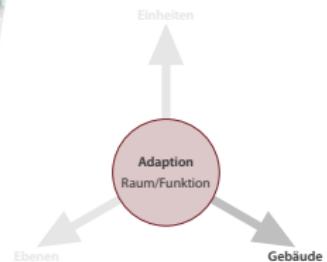
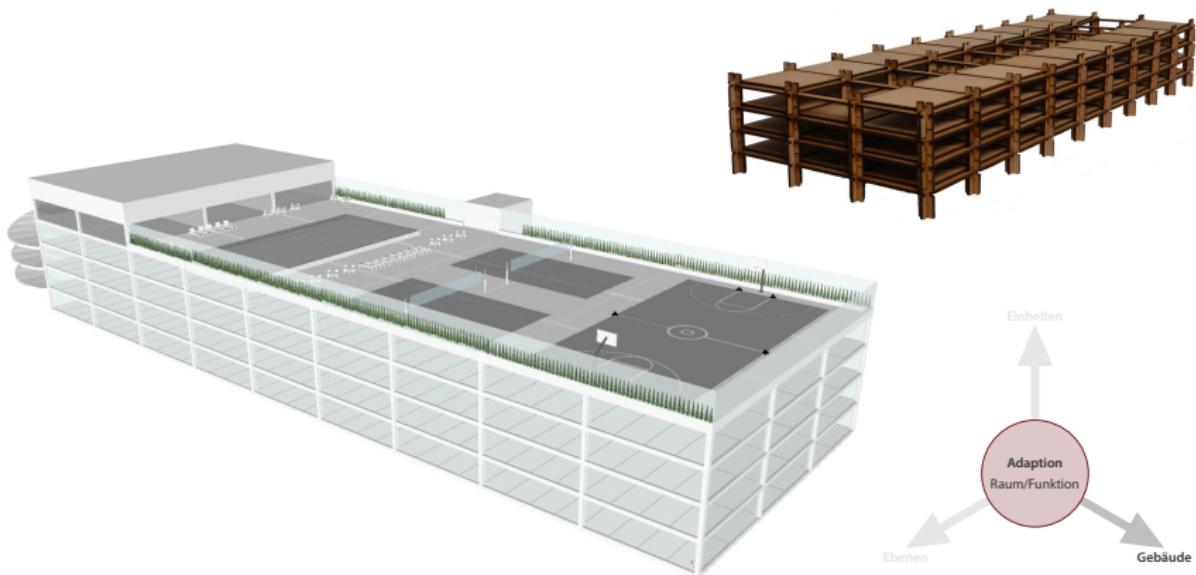
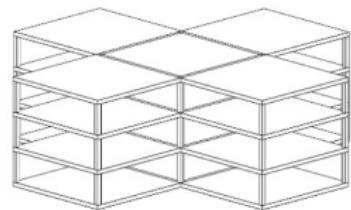
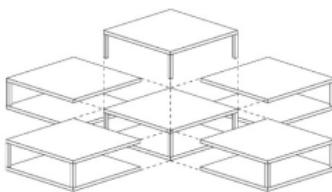
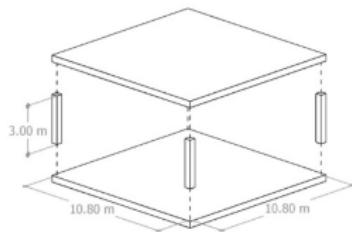
# Reversible Architektur – Entwurf Slab



# Reversible Architektur – Entwurf Tower



# Reversible Architektur – Entwurf *Demountable*



# Betonalterung - Phänomenologie



## Deformationsprozess

- elastisch
- inelastisch:  
visko-elastisch, elasto-plastisch
- Schwinddehnungen
- Temperaturdehnungen
- Schädigung

## Diffusions-Reaktions-Prozesse

- Feuchte
- Temperatur
- Kohlendioxid
- Chlorid, ...

# Betonalterung - Phänomenologie



## Deformationsprozess

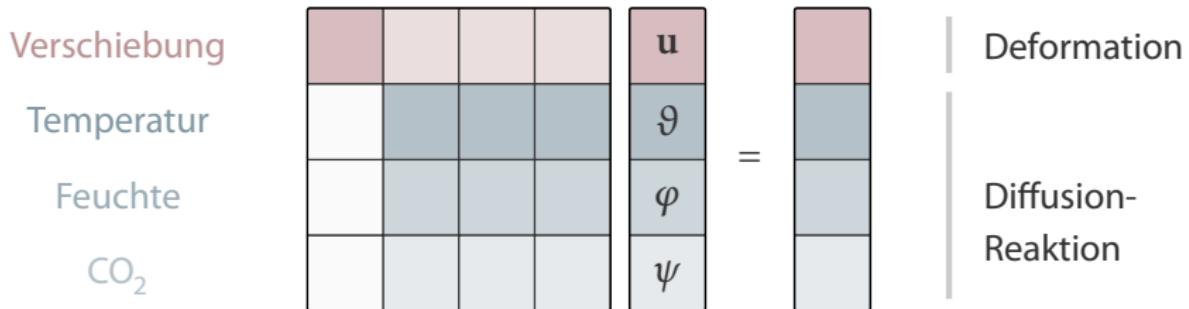
- **elastisch**
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visko-elastisch, elasto-plastisch
- **Schwinddehnungen**
- **Temperaturdehnungen**
- **Schädigung**

## Diffusions-Reaktions-Prozesse

- **Feuchte**
- **Temperatur**
- **Kohlendioxid**
- **Chlorid, ...**

# Betonalterung - Mehrfeldproblem

- ▶ alterungsabhängiges Kriechen nach Bažant [6]
- ▶ isotrope Schädigung und exponentielle Entfestigung
- ▶ Wärme- und Feuchtetransport nach Künzel [7]
- ▶ CO<sub>2</sub>-Transport nach Wittmann [8]



- !! nichtlinear, zeitabhängig, gekoppelt (schwach)
- !! unterschiedliche Zeitskalen der Teilprozesse
- !! Lösungsaufwand vom Deformationsproblem dominiert

# Betonalterung - Deformation

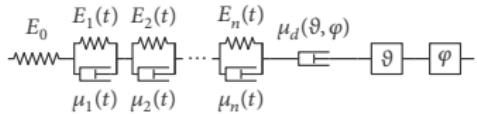
$$\boldsymbol{\sigma} = \mathbb{C}_{\text{eff}} : [\boldsymbol{\varepsilon}(\mathbf{u}) - \boldsymbol{\varepsilon}_K(t, \boldsymbol{\sigma}(t), \vartheta, \varphi) - \boldsymbol{\varepsilon}_T(\vartheta) - \boldsymbol{\varepsilon}_S(t, \varphi)]$$

## Linear Ageing Viscoelasticity

- ▶ Integraltyp-Konstitutivbeziehung

$$\boldsymbol{\varepsilon}_K = \int_{t'}^t J(t, t'; \vartheta, \varphi) d\boldsymbol{\sigma}(t)$$

- ▶ Ratentyp-Konstitutivbeziehung (Approximation), MPS



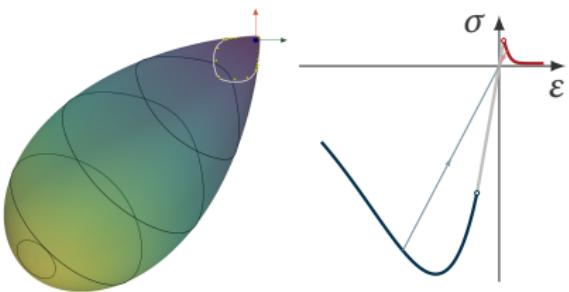
- ▶ *continuous retardation spectrum*, Bažant [9], Jirásek/Havlásek [10]
- ▶ *exponential algorithm*, Bažant [11]

## Schädigung

- ▶ Versagen mit Einflächenmodell

- ▶ exponentielle Entfestigung

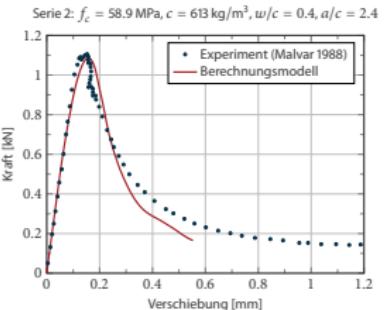
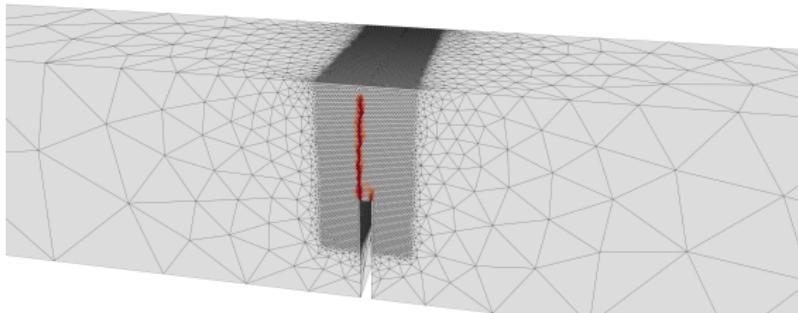
$$\mathbb{C}_{\text{eff}} = (1 - d) \mathbb{C}$$



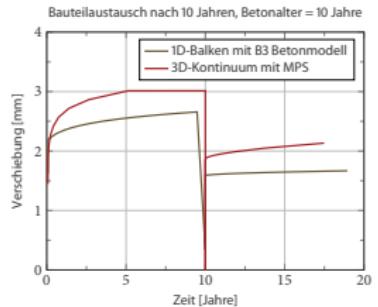
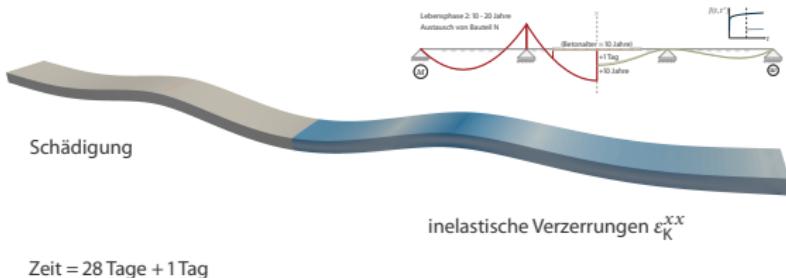
- ▶ *automatische Differentiation und Quellcode-Erzeugung (FEniCS)*

# Betonalterung - Beispiele

## 3-Punkt-Biegeversuch: gekerbt, Schädigung, kein Kriechen

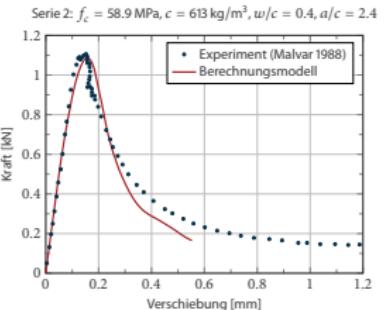
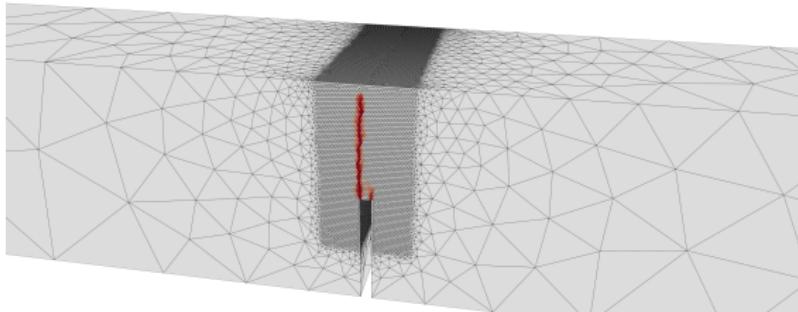


## Durchlaufträger: Bauteilaustausch, mit Schädigung und Kriechen

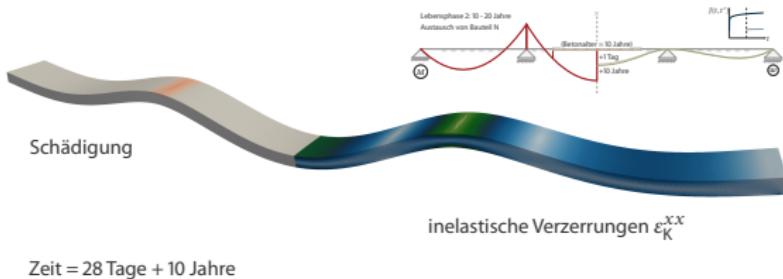


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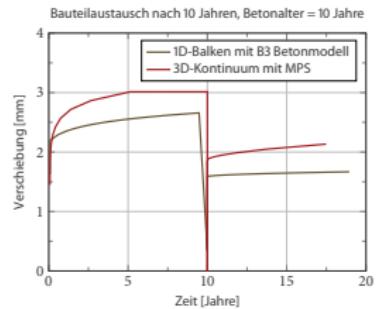
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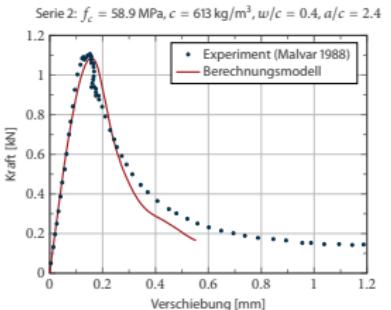
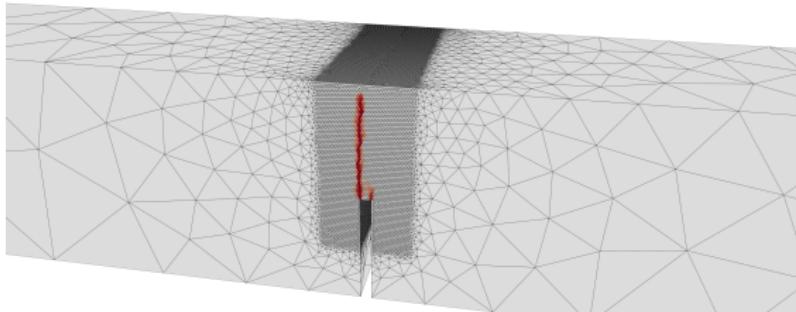


Zeit = 28 Tage + 10 Jahre

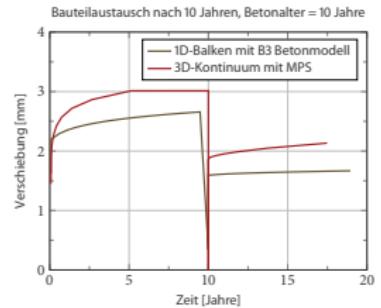
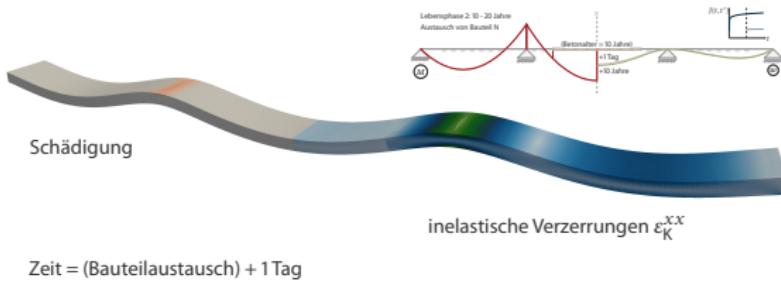


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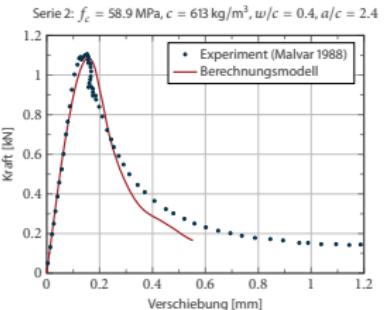
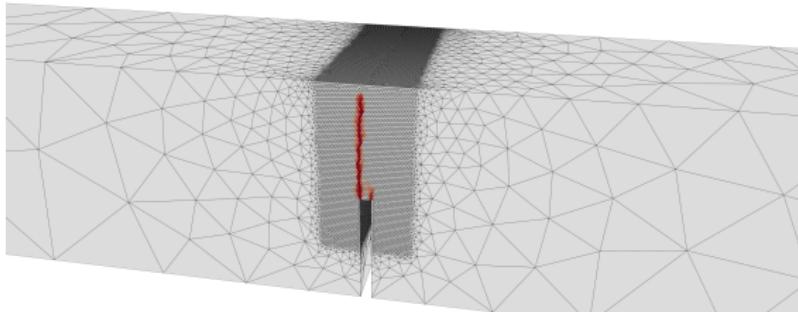


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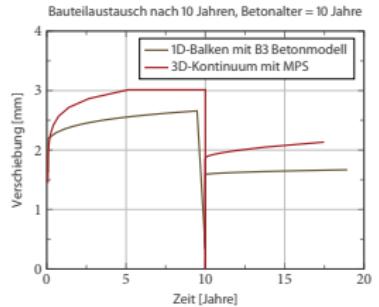
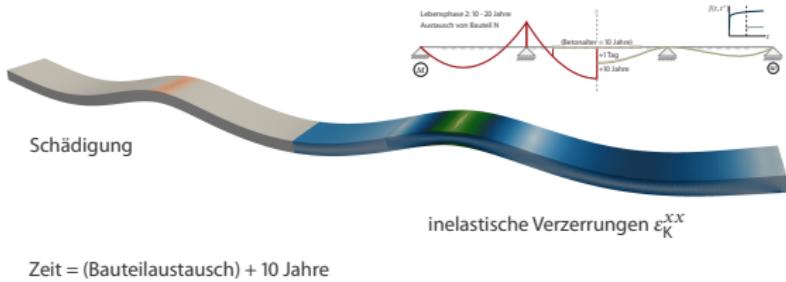


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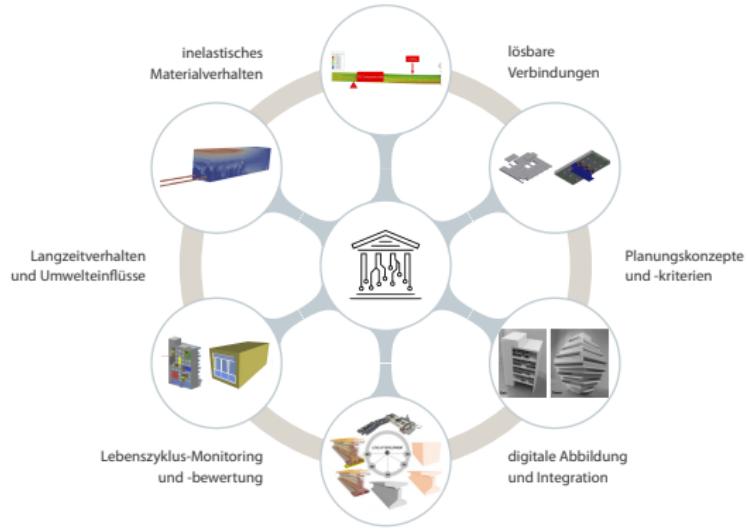
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## Durchlaufträger: Bauteilaustausch, mit Schädigung und Kriechen



# Zusammenfassung und Danksagung



- ▶ *Design for Deconstruction*
- ▶ Material- und Komponentenbank
- ▶ hierarchische digitale Zwillinge
- ▶ unterstützende Lösungsansätze

Das Projekt *Eco-construction for Sustainable Development* (Econ4SD) wird durch das Programm *Investissement pour la croissance et l'emploi* des Europäischen Fonds für regionale Entwicklung (2014-2020) unterstützt (Fördervereinbarung 2017-02-015-15).

# Literatur

- [1] Felix Müller. *Urban Mining – Ressourcenschonung im Anthropozän*. 2017. URL: [https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/uba\\_broschuere\\_urbanmining\\_rz\\_screen\\_0.pdf](https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/uba_broschuere_urbanmining_rz_screen_0.pdf).
- [2] URL: <https://archeyes.com>.
- [3] URL: <https://www.wernersobek.de/en/projects/focus-en/design-en/r128/>.
- [4] URL: <https://heidevonbeckerath.com/single/r50-cohousing>.
- [5] URL: <http://www.gramaziokohler.com/web/e/bauten/196.html>.
- [6] Z. P. Bažant et al. "Microprestress-Solidification Theory for Concrete Creep. I: Aging and Drying Effects". In: *Journal of Engineering Mechanics* 123.11 (1997), pp. 1188–1194.
- [7] H. M. Künzel. *Simultaneous heat and moisture transport in building components*. Tech. rep. Fraunhofer Institute of Building Physics, 1995.
- [8] L. M. Brieger and F. H. Wittmann. "Numerical simulation of carbonation of concrete". In: *Int. Colloquium Werkstoffwissenschaften und Bausanierung*. 1986.
- [9] Z. P. Bažant and Y. Xi. "Continuous Retardation Spectrum for Solidification Theory of Concrete Creep". In: *Journal of Engineering Mechanics* 121.2 (Feb. 1995), pp. 281–288. DOI: [10.1061/\(asce\)0733-9399\(1995\)121:2\(281\)](https://doi.org/10.1061/(asce)0733-9399(1995)121:2(281)). URL: [https://doi.org/10.1061/\(asce\)0733-9399\(1995\)121:2\(281\)](https://doi.org/10.1061/(asce)0733-9399(1995)121:2(281)).
- [10] M. Jirásek and P. Havlásek. "Accurate approximations of concrete creep compliance functions based on continuous retardation spectra". In: *Computers & Structures* 135 (2014), pp. 155–168.
- [11] Z. P. Bažant. "Numerically Stable Algorithm with Increasing Time Steps for Integral-Type Aging Creep". In: *SMiRT*. 1971.