Unlocking Potential: Rocking the Sustainable Future with Digital Twins

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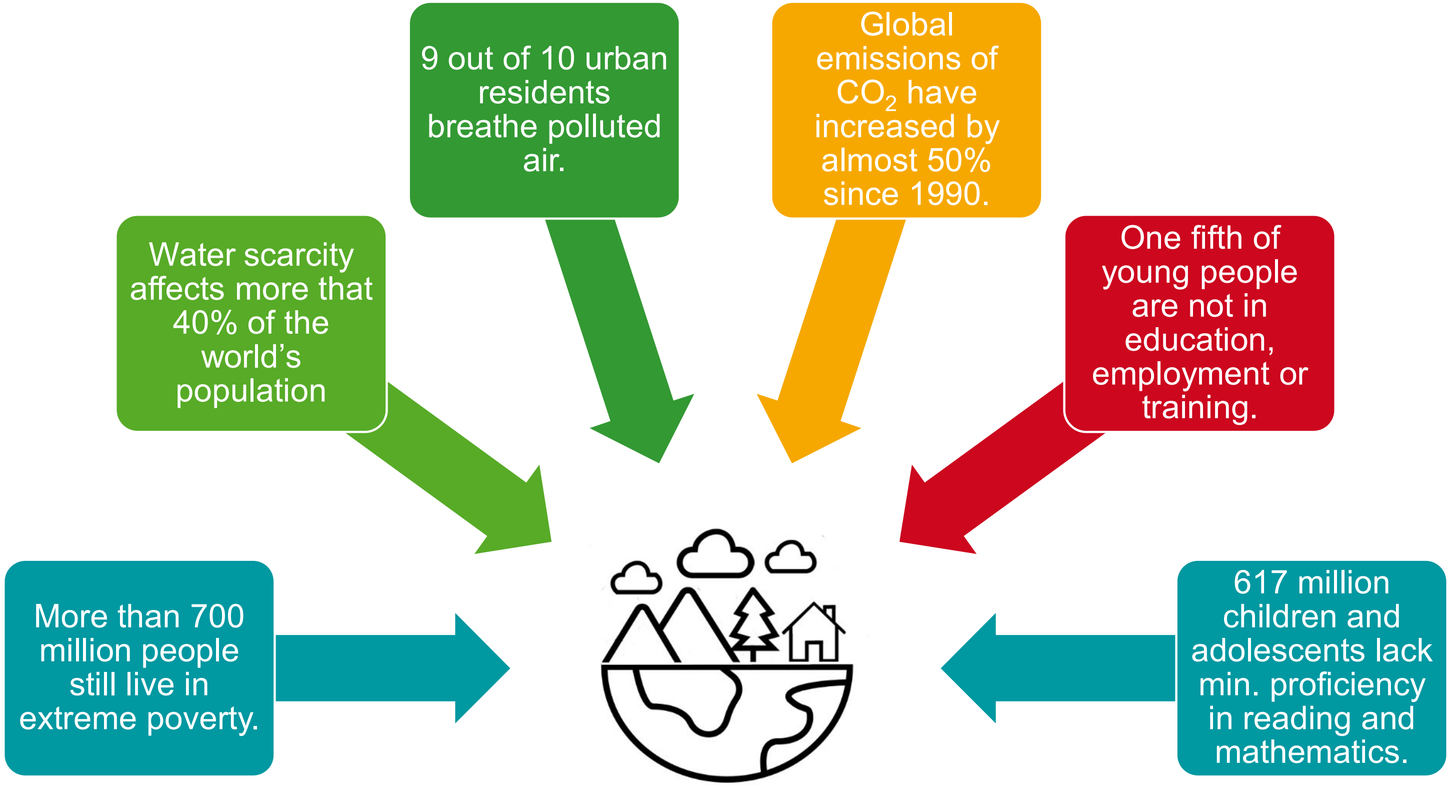
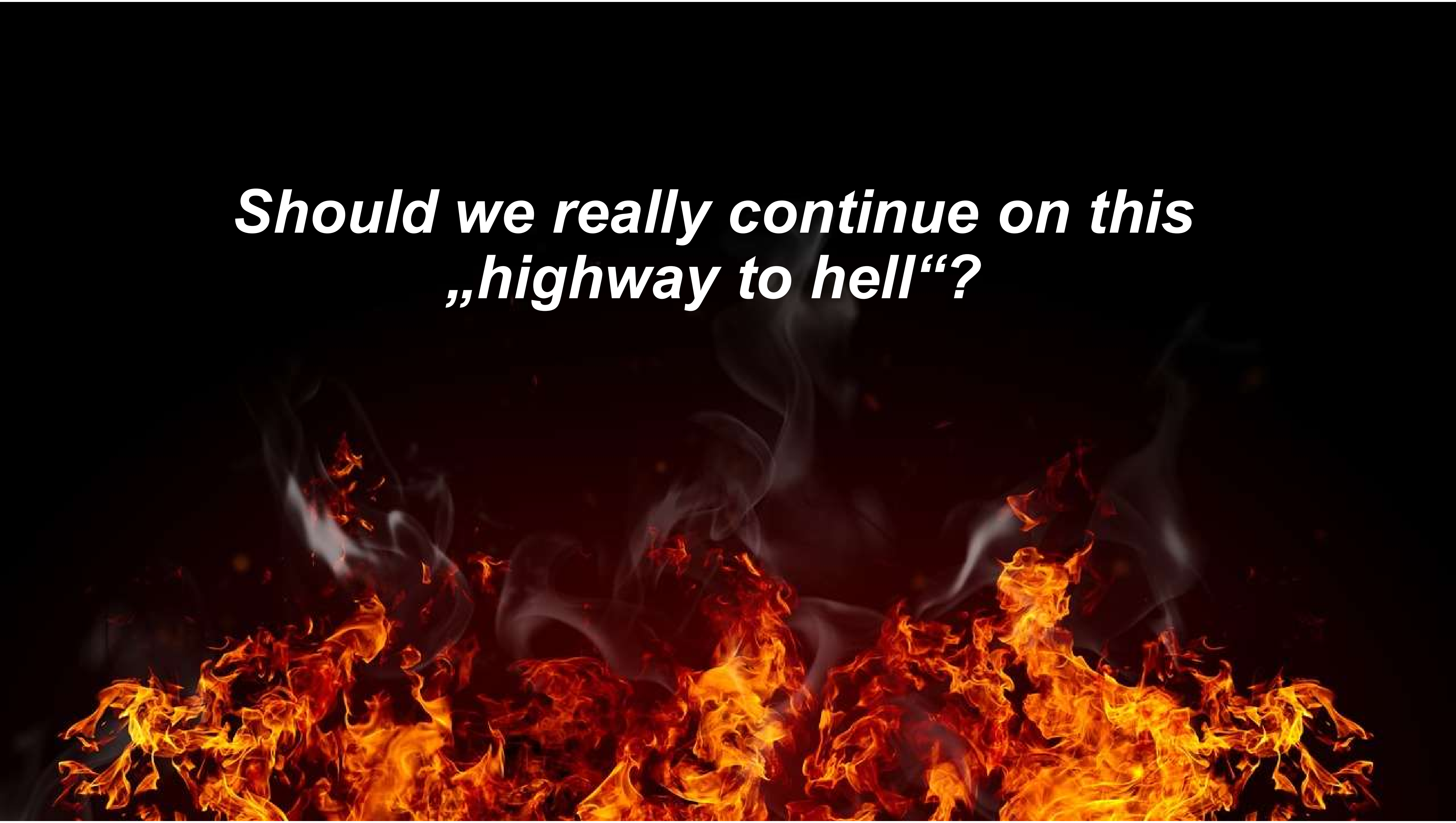
SE Software Engineering | RWTH AACHEN UNIVERSITY

Real world challenges (some…)



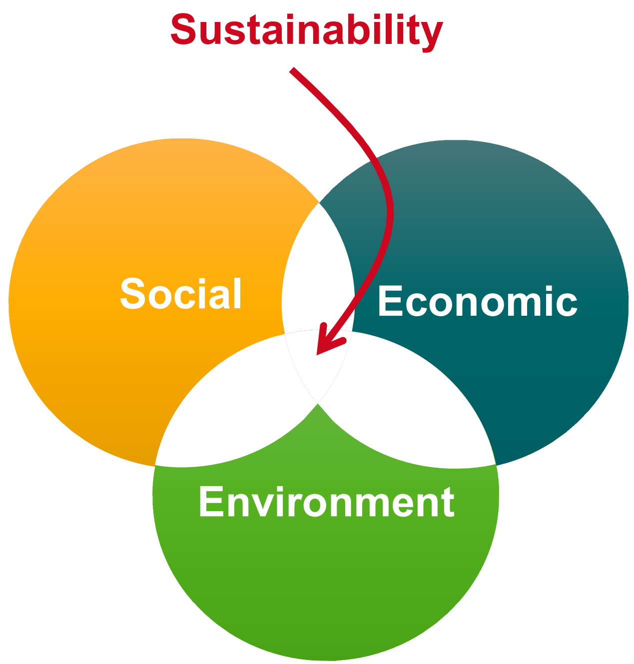
Source: https://www.un.org/sustainabledevelopment/sustainable-development-goals/


Should we really continue on this
„highway to hell“?

How can we from ModDiT contribute to a better world?

Sustainability

- Ecological Sustainability
  - preserve and protect the *natural environment* over time
  - *meet present needs* without compromising the *availability of resources* in the future
- Social Sustainability
  - focus on the *well-being of people* and communities
  - promoting equity, human rights, access to education and health care, and decent work
- Economic Sustainability
  - conduct *economic activities* in a way that *long-term economic well-being* is possible
  - balance between economic growth, resource efficiency, social equity, financial stability



B. Purvis, Y. Mao, and D. Robinson, “Three pillars of sustainability: In search of conceptual origins,” Sust. Science, vol. 14, no. 3, 2019.

UN Sustainable Development Goals

- 17 goals
  - 169 targets
  - measured by 231 indicators

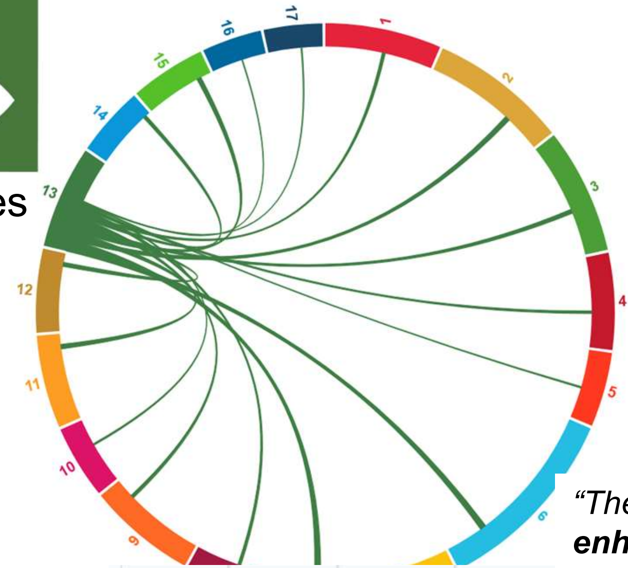
Example

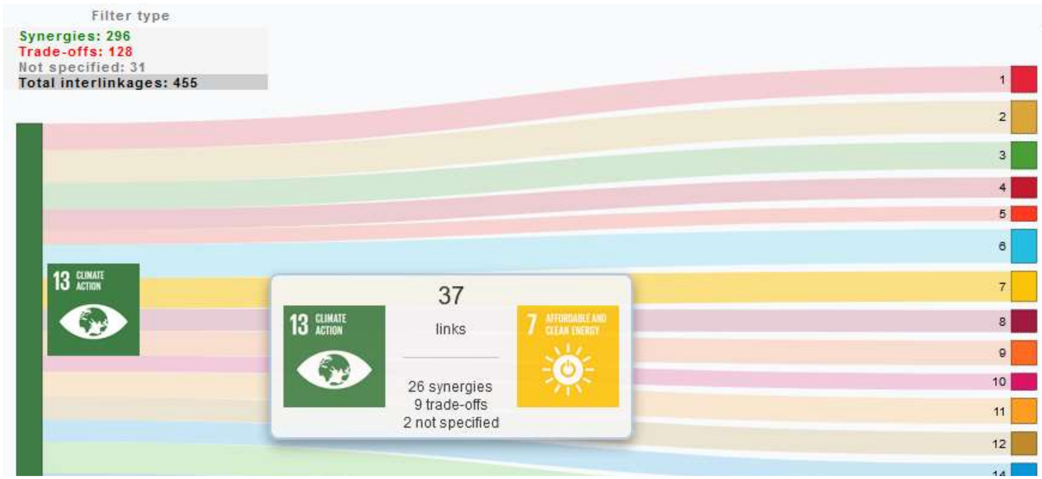
- SDG 7
  Affordable and clean energy
- 5 targets, e.g.,
  - *7.3 “By 2030, double the global rate of improvement in energy efficiency.”*
- 6 indicators, e.g.,
  - *7.3.1 “Energy intensity measured in terms of primary energy and GDP.”*

https://sdgs.un.org/goals

SDG Interlinkages | Synergies and Trade-Offs

Synergies





*"The increase in diversity of (clean) energy sources and related infrastructure investments would **enhance access** to modern energy services (here we defined all low-carbon energy sources as modern), **but energy affordability may be affected**."*

13	7	trade-off	yes

energy services (here we defined all low-carbon energy sources as modern), but energy affordability may be

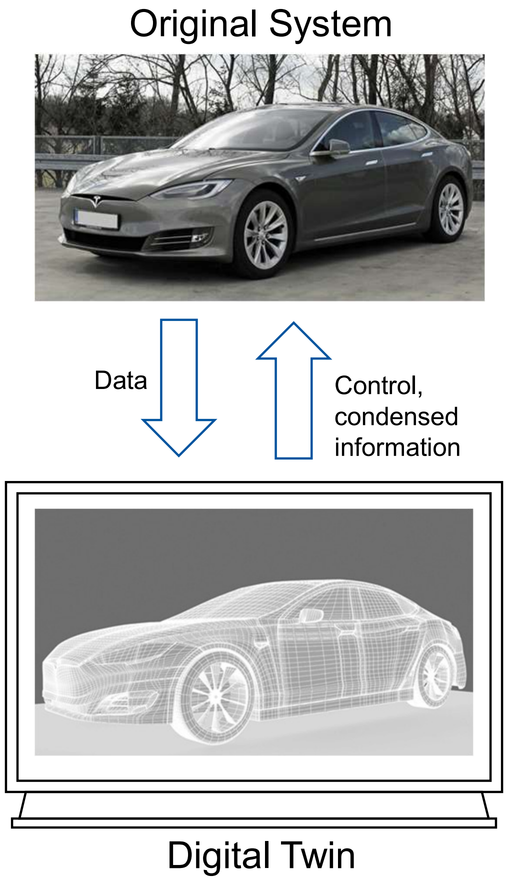
Publication ID	Method type	Geographic scale	Geographic context	Year	Title	Authors	Link
Iacobuta_2021	Mixed (Literature review; Expert judgement)			2021	Transitioning to low-carbon economies under the 2030 agenda: Minimizing trade-offs and enhancing co-benefits of climate-change action for the sdgs	Iacobuţă G.I., Höhne N., van Soest H.L., Leemans R.	

Source: https://knowsdgs.jrc.ec.europa.eu/interlinkages-goals

Digital Twins *of Cyber-Physical Systems*

Digital Twins *of Systems*

Digital Twins as *complex, long-lasting, software-intensive systems*



contextual data and their aggregation and abstraction

A Digital Twin of a system consists of
- a set of models of the system and
- a set of digital shadows,
  - both of which are purposefully updated on a regular basis, and
- provides a set of services to use both purposefully with respect to the original system.

- The digital twin interacts with the original system by
  - providing useful information about the system's context and
  - sending it control commands.


Digital Twins enable us
to connect reality with
the digital world
and back

How can our research contribute to the sustainable engineering of digital twins?

Software Engineering and Sustainability

Sustainable Business Practices

How Green Is Your Software?

by Sanjay Podder, Adam Burden, Shalabh Kumar Singh, and Regina Maruca

September 18, 2020

Illustration by Ricardo Tomás

Harvard Business Review: https://hbr.org/2020/09/how-green-is-your-software

Green Software Foundation | About | Working Groups | Projects | Resources | Articles

10 RECOMMENDATIONS FOR GREEN SOFTWARE DEVELOPMENT

Green Software Foundation: https://greensoftware.foundation/articles/10-recommendations-for-green-software-development

Forbes

FORBES > INNOVATION

The Power Of Sustainable Software

Alexander Belokrylov Forbes Councils Member
Forbes Technology Council COUNCIL POST | Membership (Fee-Based)

Forbes: https://www.forbes.com/sites/forbestechcouncil/2022/08/18/the-power-of-sustainable-software/

GREEN
Energy, Hardware, Software,
Software Engineering Processes, …

GREEN (washing?)

Energy, Hardware, Software,
Software Engineering Processes, …

Green IT

- ecological sustainability
- aims to reduce the environmental impacts associated with conventional IT, e.g.,
  - energy efficient hardware, data centers, server virtualization, monitoring systems

13 CLIMATE ACTION

The biggest impact of ICT as an industry is the amount of *greenhouse gas emissions*.

Source: https://www.innoq.com/en/articles/2023/02/what-is-sustainable-software/

1.5% to 4% of global GHG emissions

Bieser, J. C. T., Hintemann, R., Hilty, L. M., & Beucker, S. (2023). A review of assessments of the greenhouse gas footprint and abatement potential of information and communication technology. Environmental Impact Assessment Review, 99.

Green software development

Green Software Foundation

- Focus on & control features with *higher power consumption* and *common usage scenarios*
- Reduce *data usage*
- Limit *computational accuracy*
- *Monitor* real-time energy consumption of the application
- Developing and using *less-power-consuming ML models*
- Monitor *real-time power consumption* during development

Source: https://greensoftware.foundation/articles/10-recommendations-for-green-software-development

Sustainable Software Engineering

Six principles for
Sustainable Software Engineers

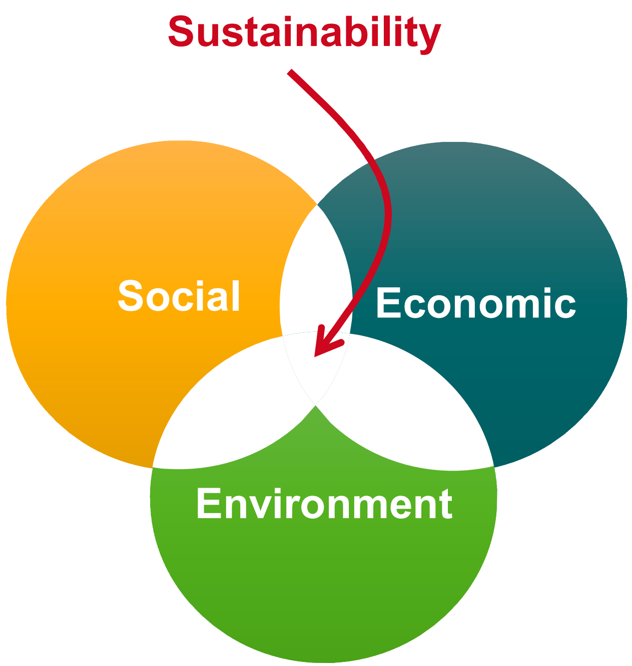
- *Carbon, Electricity, and Hardware Efficiency* when building applications
- *Carbon Awareness*: Consume electricity with the lowest carbon intensity
- *Measurement* to improve sustainability
- *Climate Commitments*: Defining the exact mechanism of carbon reduction

Source: https://learn.microsoft.com/en-us/training/modules/sustainable-software-engineering-overview/

Human Sustainability in SE

- Impact sourcing
- Ethical outsourcing
- Fair trade software

Ramautar, V., Overbeek, S., España, S. (2021). Human Sustainability in Software Development. In: Calero, C., Moraga, M.Á., Piattini, M. (eds) Software Sustainability. Springer

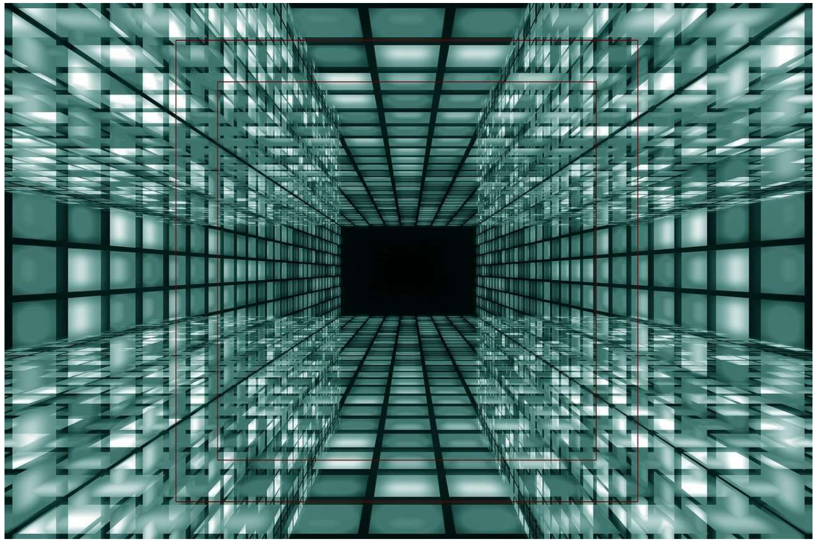


Sustainable Software Engineering

Sustainability is *“preserving the function of a system over a defined time span”*

- 3 variables: system, function, and time

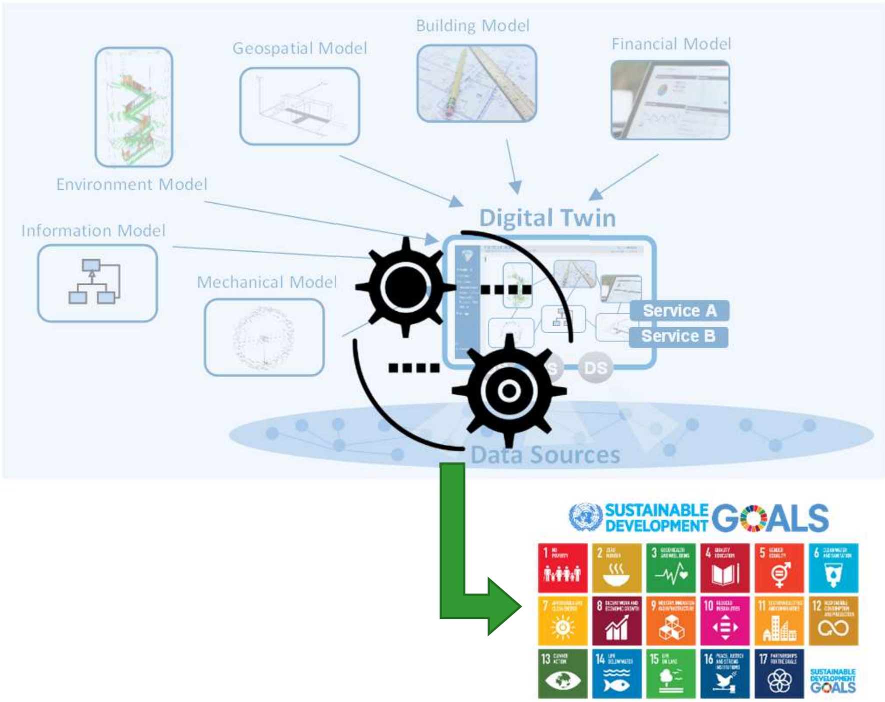
B. Penzenstadler, “Towards a definition of sustainability in and for software engineering,” In ACM Symp. on Applied Comp. (SAC), 2013.



Perspectives

- *Development processes*
  - SE processes with responsible use of ecological, human, financial resources
- *Software maintenance*
  - maintain and evolve software with min. environmental impact, well-managed knowledge, sufficient economic balance
- *System production*
  - software is a concrete product including its hardware and the resources needed for production
- *System usage*
  - entire period of use of the software and its operational environment

Sustainable Digital Twin Engineering



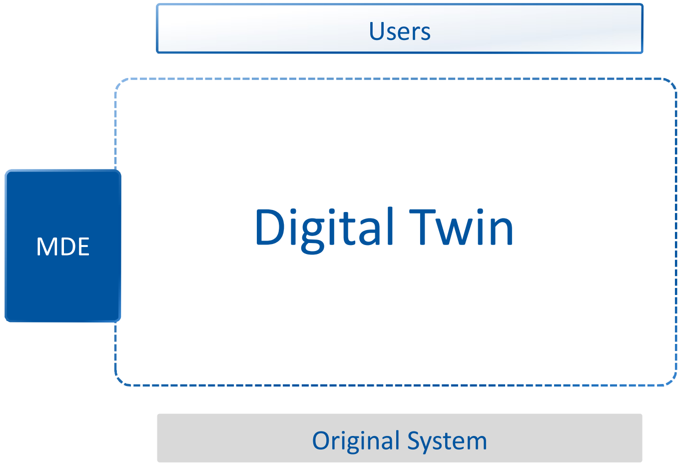
*Digital twins are **active software systems***

- Digital twins can be sustainably developed
  - Apply practices used for other software systems

Investigate

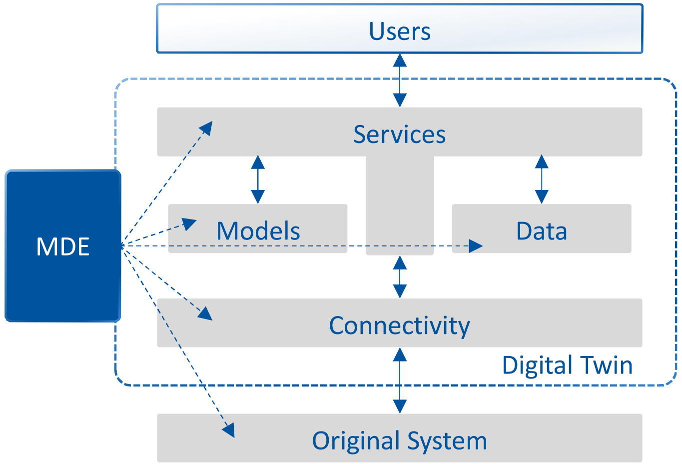
- What are *specifics* for digital twins?
- How can *MDE* support us in sustainable DT engineering?
- What are *challenges* using MDE for sustainable DT engineering?

Model-Driven Engineering of Digital Twins | Benefits



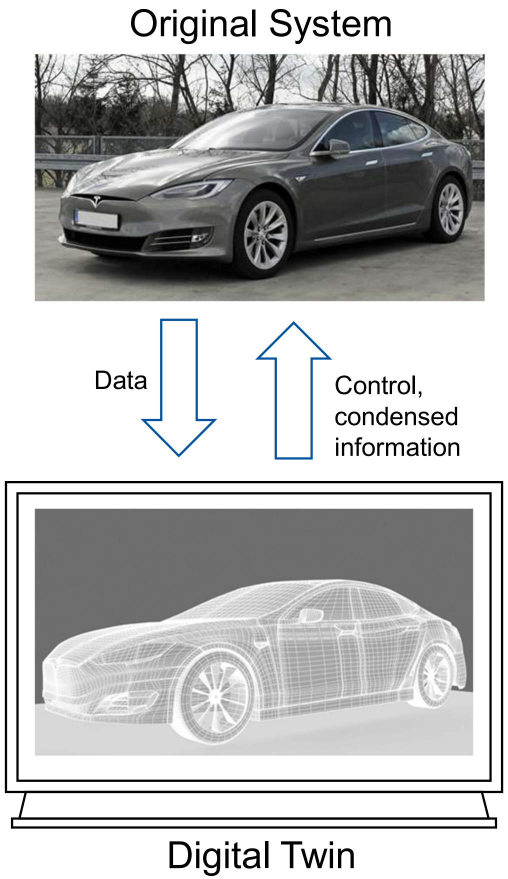
- Increased development speed and reduced development time
- Better software quality, e.g., less bugs,
  - well-defined domain-specific modeling languages, automated model checking, transformation, test and test case generation,…
- Improved maintainability
  - Cross-cutting implementation aspects can be changed in one place which again reduces development time
- Empowered domain experts by providing low-code platforms for the development of digital twins
- …

MDE of Digital Twins | Where and how to consider sustainability?



- Models
  - In addition to models for DT engineering:
    model sustainability, e.g., sustainability requirements and goals for DT engineering process and runtime of the DT
- Data
  - Measure sustainability targets & KPIs
  - Reduce data usage
- Services
  - *Monitor* relevant indicators
  - *Simulate, forecast* sustainability indicators
  - Relate *low-level* sustainability goal with *higher-level* SDGs
  - *Analyze the DT* and the “twinned” system and suggest more sustainable processes, connectivity, hardware, less power consuming services,…
  - *Visualize* metrics, analysis results

MDE of Digital Twins | Costs & Research topics



- *Understand the costs of automation*
  - balance high quality in engineering processes vs. not wasting resources
  - analyze processes e.g., nightly built, run tests, deploy daily
    - reduce energy consumption by, e.g., iterative builds
- *Power consuming services & models* within DTs
  - analyze services and, e.g., use less-power-consuming ML models, re-use pre-trained ML models to avoid costly retraining of networks
- *Analyze the „twinning“ functionality*
  - Which degree of synchronization is needed?
  - What accuracy of models is needed?
- *Composition/ Federation* of DTs
  - How to compose DTs to improve maintainability?
  - What are the costs of federation vs. integration?

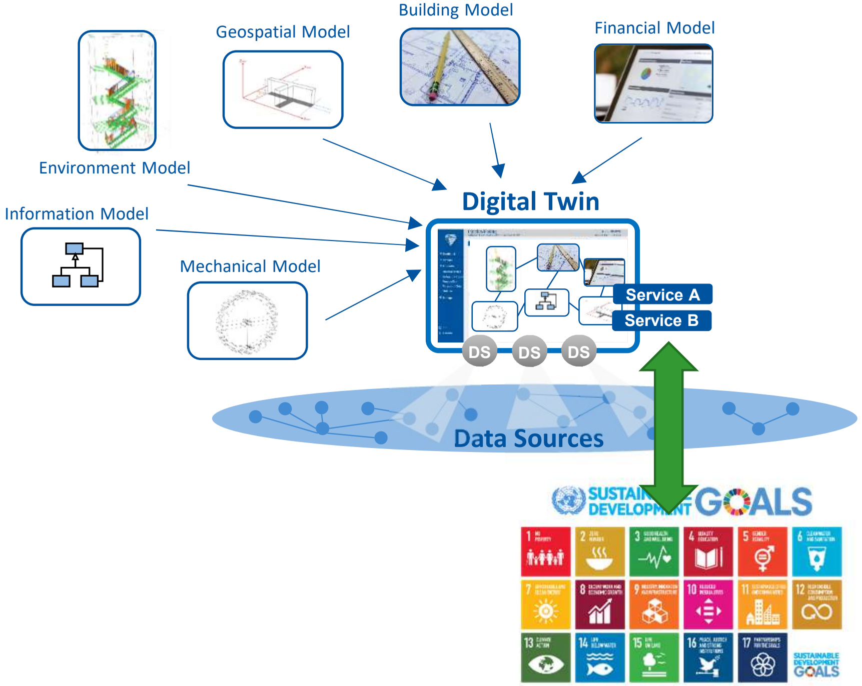
Finding balances is not easy!

HOW CAN WE USE DTS TO ASSESS THE SUSTAINABILITY OF COMPLEX, SOFTWARE-INTENSIVE SYSTEMS?

Digital Twins for Sustainability

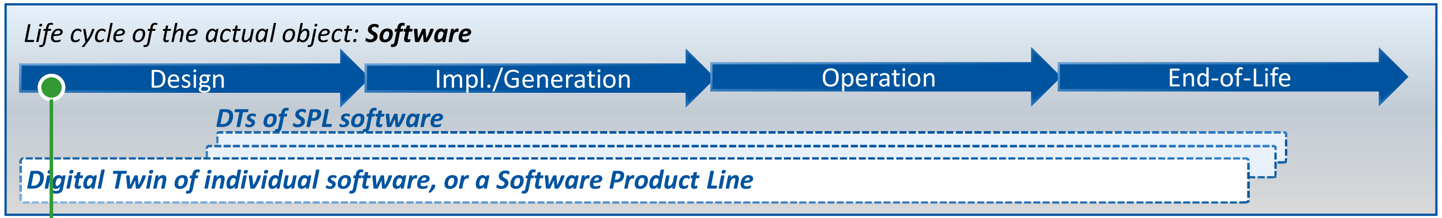
- Creating DTs for sustainability assessment
  - assessment of sustainability targets
    - monitor, calculate and visualize key sustainability indicators
  - simulation and forecasting of sustainability indicators
    - use historic information together with forecasting algorithms

- Digital Twin services to
  - enable simulation of different variants of digital twins before building the physical one to improve resource efficiency
  - facilitate optimizing production processes towards waste reduction and energy saving allowing a responsible production
  - provide self-adaptability to improve resource efficiency
  - assist with responsible consumption and use in relation to created products



17 UN development goals (SDGs) with 169 associated targets

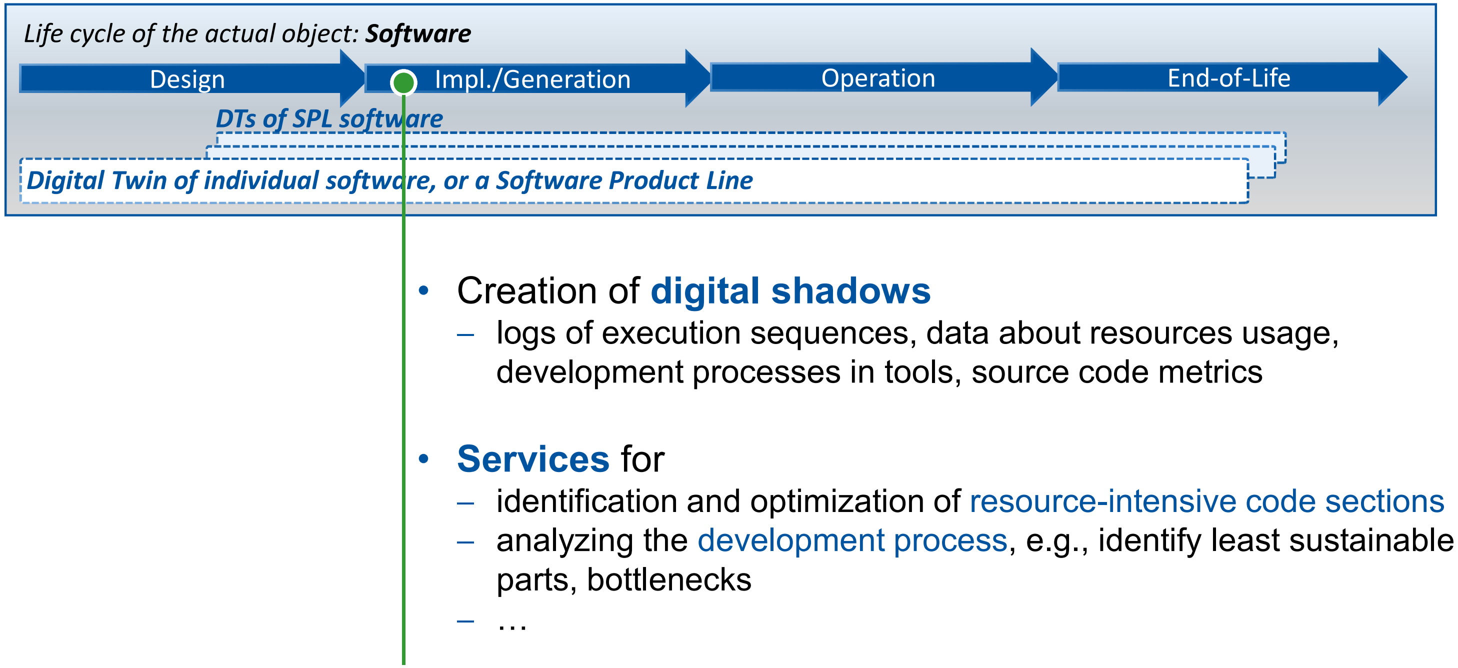
DT during *design* of a software system



- Services for **analysis of sustainability**
  - architecture model analysis, e.g., optimize consumed resources
  - scenario-based analysis, e.g., resource usage, identify resource-intensive parts
  - …

[HHMR23] M. Heithoff, A. Hellwig, J. Michael, B. Rumpe: Digital Twins for Sustainable Software Systems. GREENS'23 Workshop at ICSE'23

DT during *implementation/ generation* of a software system



- Creation of **digital shadows**
  - logs of execution sequences, data about resources usage, development processes in tools, source code metrics
- **Services** for
  - identification and optimization of resource-intensive code sections
  - analyzing the development process, e.g., identify least sustainable parts, bottlenecks
  - …

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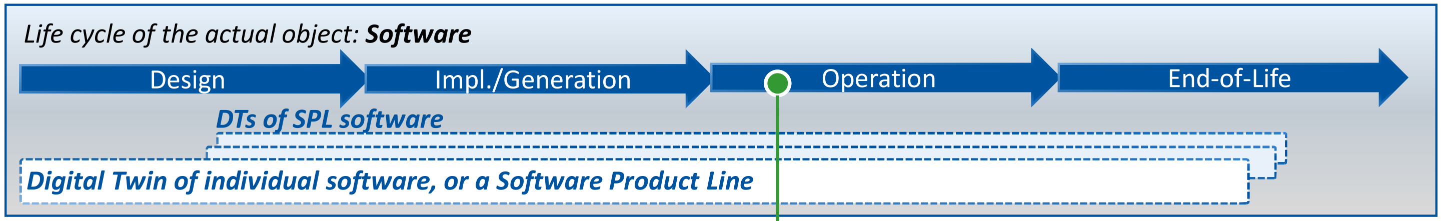
DT during *operation* of a software system



- Creation of **digital shadows**
  - runtime data of the software system
- **Monitor & report**
- **Analyze** sustainable operation & energy peaks
- **Optimize** & **intervene** in the software system
  - allocating resource adjusted to the current needs, reconfiguring system parameters, cleanups to guarantee durability
- …

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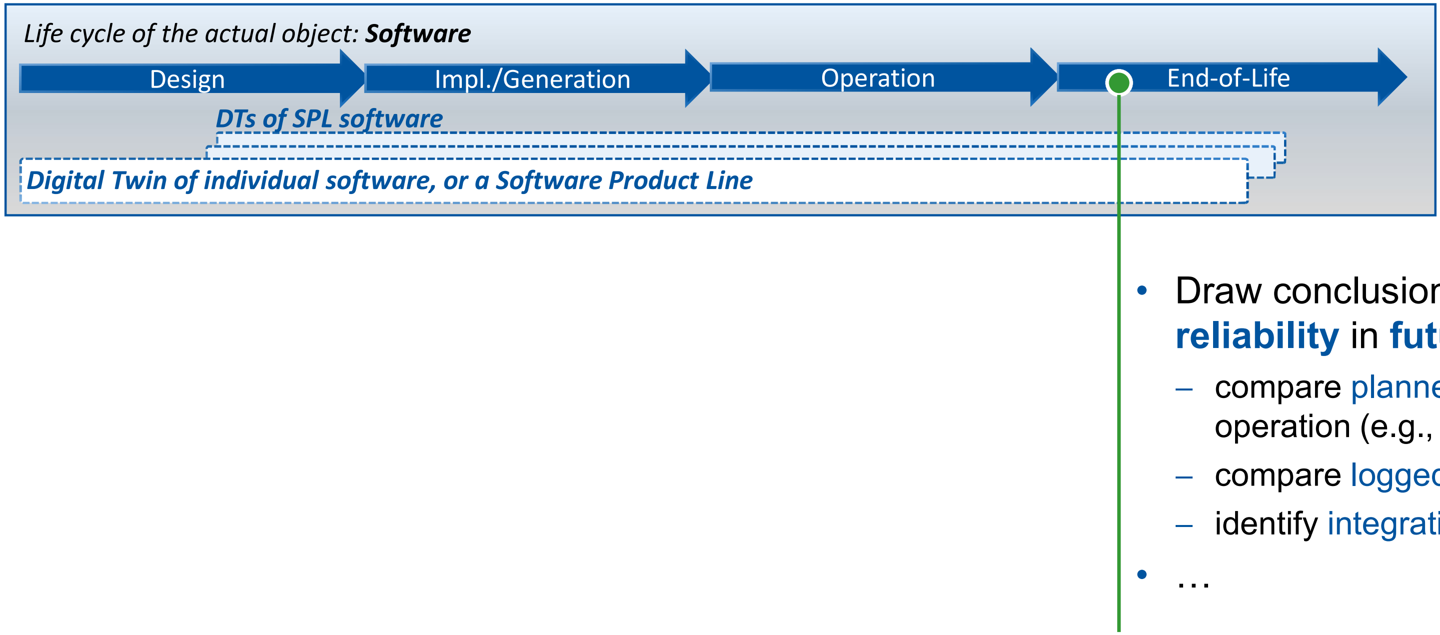
DT during *end-of-life* of a software system



- Draw conclusions about a **component's relevance and reliability** in **future software systems**
  - compare planned behavior in design with actual behavior in operation (e.g., process conformance, analyses on error logs)
  - compare logged energy consumption with energy goals
  - identify integration problems by analyzing test reports
- …

[HHMR23] M. Heithoff, A. Hellwig, J. Michael, B. Rumpe: Digital Twins for Sustainable Software Systems. GREENS'23 Workshop at ICSE'23

Paper: Digital Twins for Sustainable Software Systems

Digital Twins for Sustainable Software Systems

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Judith Michael, Software Engineering, RWTH Aachen University, Aachen, Germany, michael@se-rwth.de
Bernhard Rumpe, Software Engineering, RWTH Aachen University, Aachen, Germany, rumpe@se-rwth.de

Abstract—**Sustainable software systems aim to create resource-efficient software products and reduce the carbon impact of applications. Current approaches for sustainability assessment of software are either only focused on their operation or rely on methods in their engineering. More holistic approaches for sustainable software system spanning are missing. Thus, we are interested in the engineering of sustainable software systems together with the monitoring of their sustainability goals over their whole lifetime. Within this paper, we suggest using digital twins to accompany software systems in all life cycle phases with a specific focus on using model-driven engineering methods for the creation of applications. We can generate accompanying digital twins which share relevant models and data with the actual system and provide services for the assessment of sustainability indicators. In the long run, this provides us with better assessment options for software systems.**

Index Terms—**Model-Driven Engineering, Digital Twins, Sustainable Software Systems**

I. INTRODUCTION

When technical developments are considered in terms of their social, economic, and environmental aspects of sustainability [1], they should have a positive impact on our world. To assess this impact, the United Nations have developed 17 sustainable development goals (SDGs) with 169 associated targets [2] we should achieve. Assessing software systems [3] based on these targets requires manual effort as one has to evaluate various aspects and take data from heterogeneous data sources into account. Up to now, sustainability assessment of software systems is often a manual task. One has to manually assess different sustainability criteria [4], e.g., with scenario-based techniques [5], and continuously update the assessment in case of changes in the software.

Our aim is to investigate how to create sustainable software systems with Model-Driven Engineering (MDE) methods and monitor the sustainability goals of these synthesized systems.

We suggest using Digital Twins (DTs) to accompany software systems in all life cycle phases to reach this goal. Up to now, digital twins are mainly used to accompany Cyber-Physical Systems (CPSs), e.g., airplanes [6], cars [7], wind turbines [8], machine elements [9], injection molding machines [10], or buildings [11]. The experiences made at DT engineering for CPSs [12] can be transferred to DTs for software systems created using MDE methods. We discuss the life cycle of software systems, relevant aspects for sustainability assessment, and how MDE methods support the engineering of their DTs.

The paper is structured the following: Section II provides foundations and related work. Section III presents our vision on how to use digital twins for sustainability assessment and discusses it, and the last section concludes.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC 2023 Internet of Production - 390621612. Website: https://www.iop.rwth-aachen.de

II. FOUNDATIONS AND RELATED WORK

Whereas the General Assembly of the United Nations provides us with concrete 17 SDGs with 169 associated targets [2], translating these goals to software systems is still a challenge. Penzenstadler [13] defines sustainability "as preserving the function of a system over a defined time span" requiring to define the three variables system, function, and time. These can be defined in software engineering from four perspectives:

- Development processes: This includes software engineering processes with responsible use of ecological, human, and financial resources.
- Software maintenance: This includes the maintenance and evolvement of a software system with minimized environmental impact, well-managed knowledge, and sufficient economic balance.
- System production: In this perspective, the software is considered a concrete product including its hardware and the resources needed for production.
- System usage: Here, we take the entire period of use of the software and its operational environment into account.

There exists a large variety of metrics to assess green software [14]. Venters et al. [3] suggest considering software sustainability as a non-functional requirement. Measuring the extensibility, interoperability, maintainability, portability, reusability, scalability, and usability of a system enables us to make statements about its sustainability. This allows analyzing, evaluating, and reasoning about sustainability at an architectural level [15]. Kern et al. [4] describe causal chains from software products to their impacts on natural resources, e.g., energy. Design choices in software engineering, e.g., which programming language to use, compiler optimization, and implementation choices, have an influence on the energy efficiency of programs [16].

Digital Twins. We suggest using DTs to accompany software systems in all life cycle phases to support their sustainability

Digital Twins of software systems to support the sustainability assessment of applications

- …more in the paper

- Questions to discuss
  - Is the engineering of an additional software system (the DT) sustainable?
  - What are pros and cons for including sustainability services directly in software systems?

GREENS 2023

Preprint
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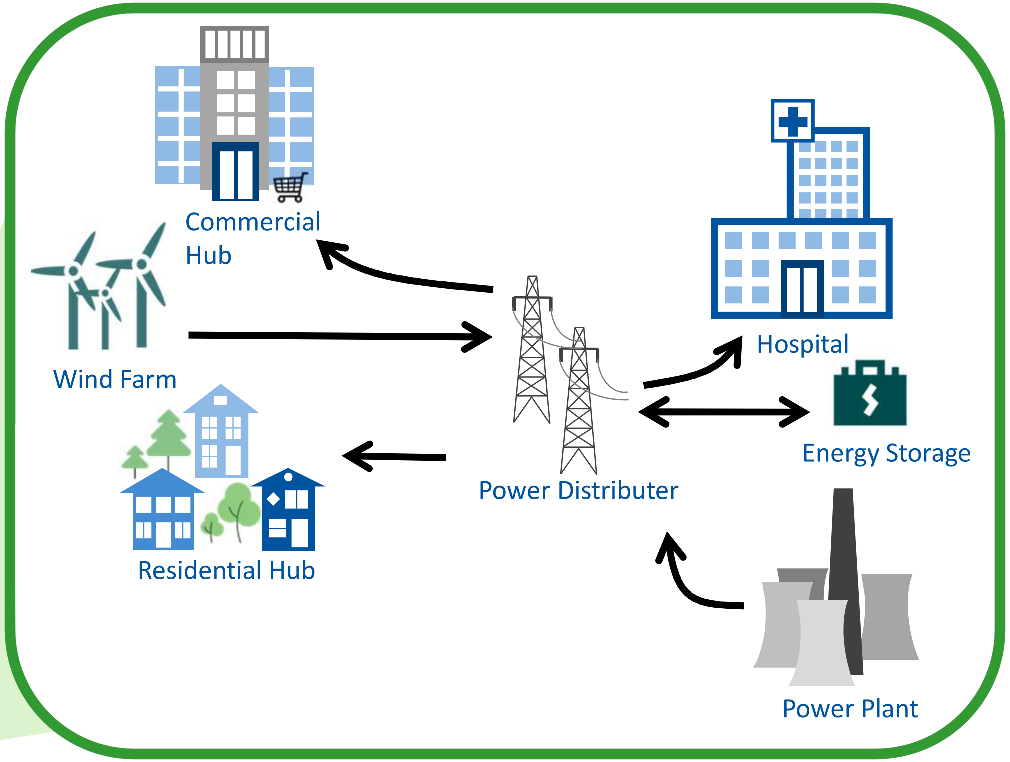
Digital Twins for Sustainable (Cyber-Physical) Systems?

Sustainable Evolvement of Systems

Planning *Citizen Energy Communities* example

- Citizens and small commercial entities
- Local energy generation & storage
- Local energy trading
- Citizens interact directly with electrical distribution system



Research Question:

How to enable system developers to iteratively evolve a system throughout its life cycle in a sustainable way?

[GKM+23] G. Gramelsberger, H. Kausch, J. Michael, F. Piller, F. Ponci, A. Praktiknjo, B. Rumpe, R. Sota, S. Venghaus: Enabling Informed Sustainability Decisions: Sustainability Assessment in Iterative System Modeling. In: ME Workshop @MODELS, 2023.

Sustainable Evolvement of Systems

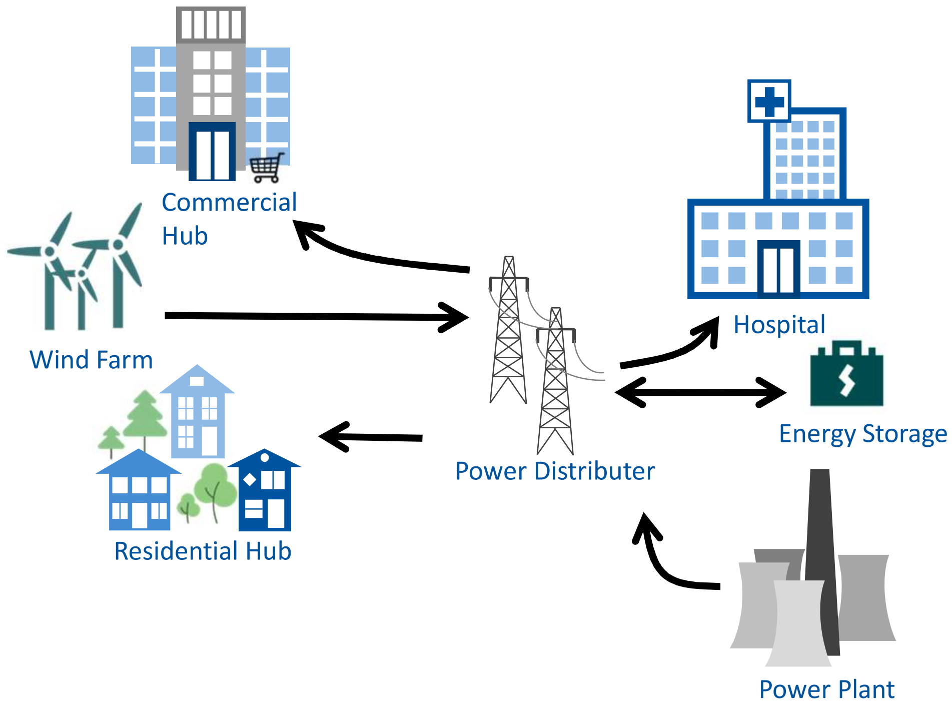
- Describe system with an architecture description language
  - MontiArc (MontiCore language workbench)

```
component CitizenEnergyCommunity{                      MA
  … port …

  component Hospital hospital;
  component CommercialHub comHub;
  component ResidentialHub resHub;
  component WindFarm windfarm;
  component PowerDistributor distrib;
  component EnergyStorage storage;
  component CoalPowerplant powerplant;




}
```



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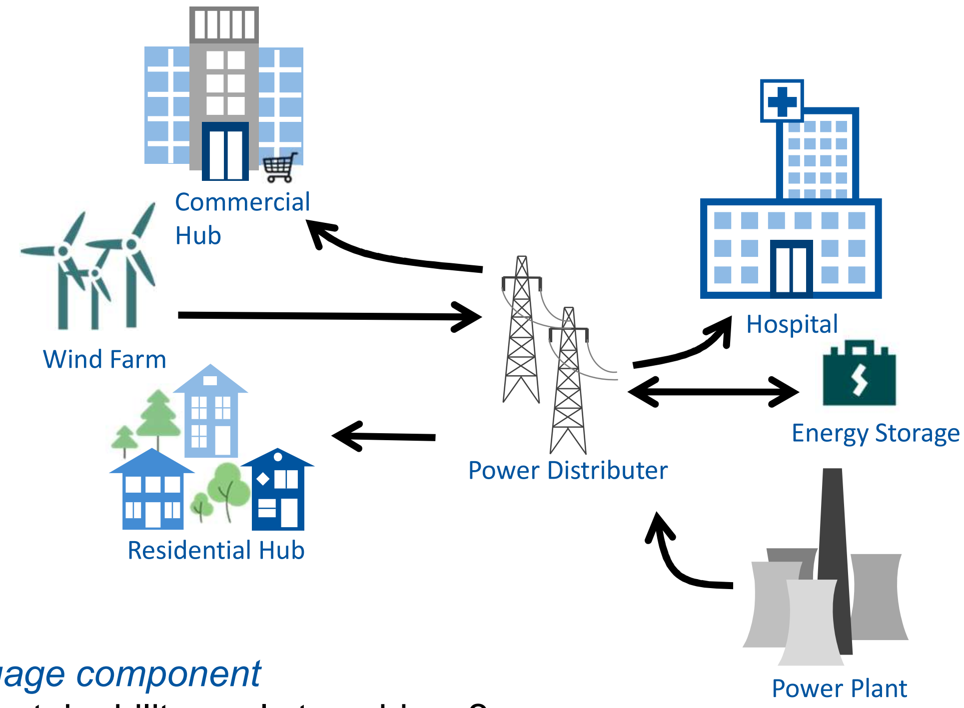
  … port …

  component Hospital hospital;
  component CommercialHub comHub;
  component ResidentialHub resHub;
  component WindFarm windfarm;
  component PowerDistributor distrib;
  component EnergyStorage storage;
  component CoalPowerplant powerplant;

  satisfy sustainability{
    sdg: [7,11,13]…
  }
}
```

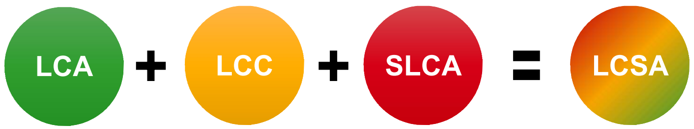


- *SDG language component*
  - Which sustainability goals to achieve?
  - DSL library: domain-specific indicators for energy planning

[GKM+23] G. Gramelsberger, H. Kausch, J. Michael, F. Piller, F. Ponci, A. Praktiknjo, B. Rumpe, R. Sota, S. Venghaus: Enabling Informed Sustainability Decisions: Sustainability Assessment in Iterative System Modeling. In: ME Workshop @MODELS, 2023.

Sustainability Assessment

- *Lifecycle Sustainability Assessment* (LCSA)
  - LCA = Environmental Life Cycle Assessment
  - LCC = LCA-type Life Cycle Costing
  - SLCA = Social Life Cycle Assessment

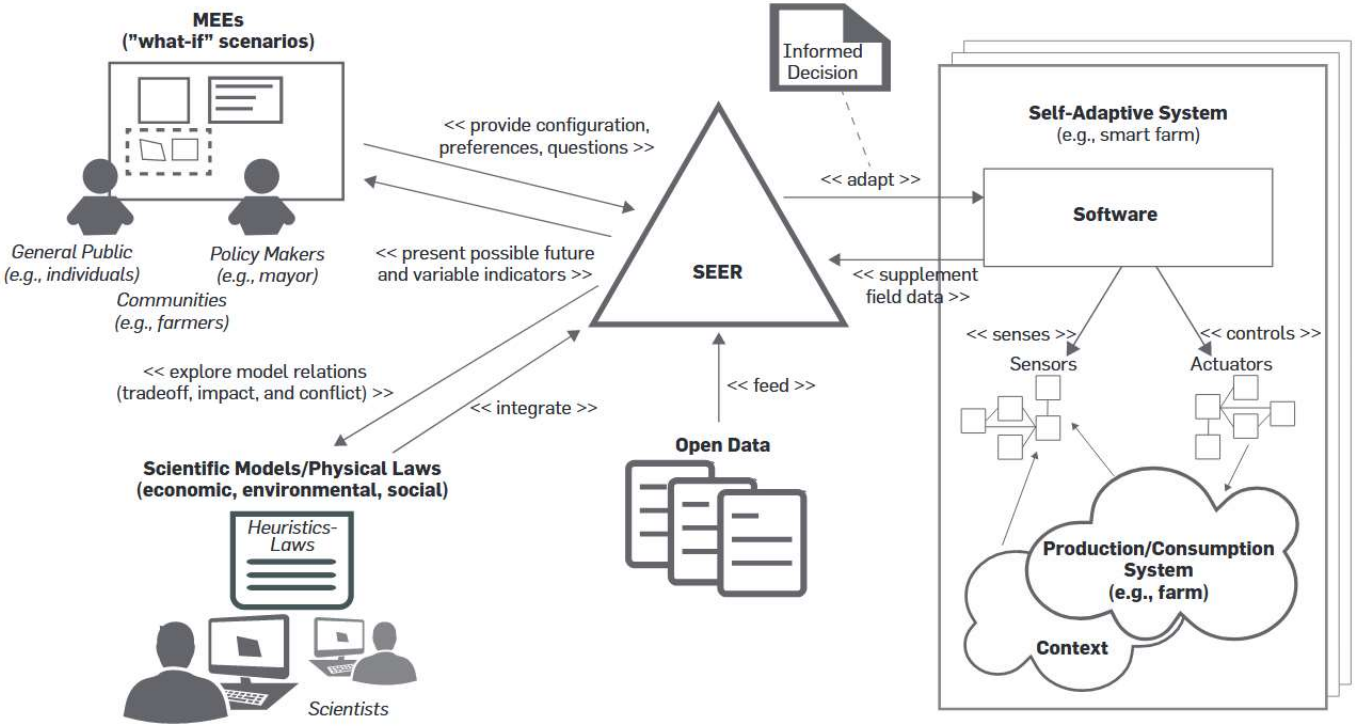


- Lack a *connection* between *LCSA indicators* and *SDG goals* and more concrete target
  - As of 2022, 14 SDG goals have not yet been assigned LCSA indicators

- *(Some) Challenges*
  - Tool supported but also *manual effort*
  - Data *availability*
  - Some approaches in practice consider *only two* of the *three main sustainability aspects*
  - Lack *interconnectedness* among the three areas
  - Do not follow *cause-effect chains*
  - System *boundaries* unclear/ inconsistent
  - Non-transparent *weighting of results*
  - *Lack of agreement* in the international community on *social targets* to achieve for many social indicators
  - …

Sources:
- *M. Finkbeiner, E.M. Schau, A. Lehmann, M. Traverso: Towards Life Cycle Sustainability Assessment. Sustainability, 2010.*
- *S. Valdivia, J. G. Backes, M. Traverso, G. Sonnemann, S. Cucurachi, J. B. Guinée, T. Schaubroeck, M. Finkbeiner, N. Leroy-Parmentier, C. Ugaya, C. Peña, A. Zamagni, A. Inaba, M. Amaral, M. Berger, J. Dvarioniene, T. Vakhitova, C. Benoit-Norris, M. Prox, R. Foolmaun, M. Goedkoop: Principles for the application of life cycle sustainability assessment," The International Journal of Life Cycle Assessment, vol. 26, no. 9, 2021.*
- *J. Martínez-Blanco, A. Lehmann, P. Muñoz, A. Antón, M. Traverso, J. Rieradevall, M. Finkbeiner: Application challenges for the social Life Cycle Assessment of fertilizers within life cycle sustainability assessment. Journal of Cleaner Production, vol 69, 2014.*

Conceptual model-based framework
"*Sustainability Evaluation Experience R*" (SEER)



Source: J. Kienzle, G. Mussbacher, B. Combemale, L. Bastin, N. Bencomo, J.-M. Bruel, C. Becker, S. Betz, R. Chitchyan, B.H.C. Cheng, S. Klingert, R.F. Paige, B. Penzenstadler, N. Seyff, E. Syriani, C.C. Venters: Toward model-driven sustainability evaluation. Commun. ACM 63, 3, 2020.

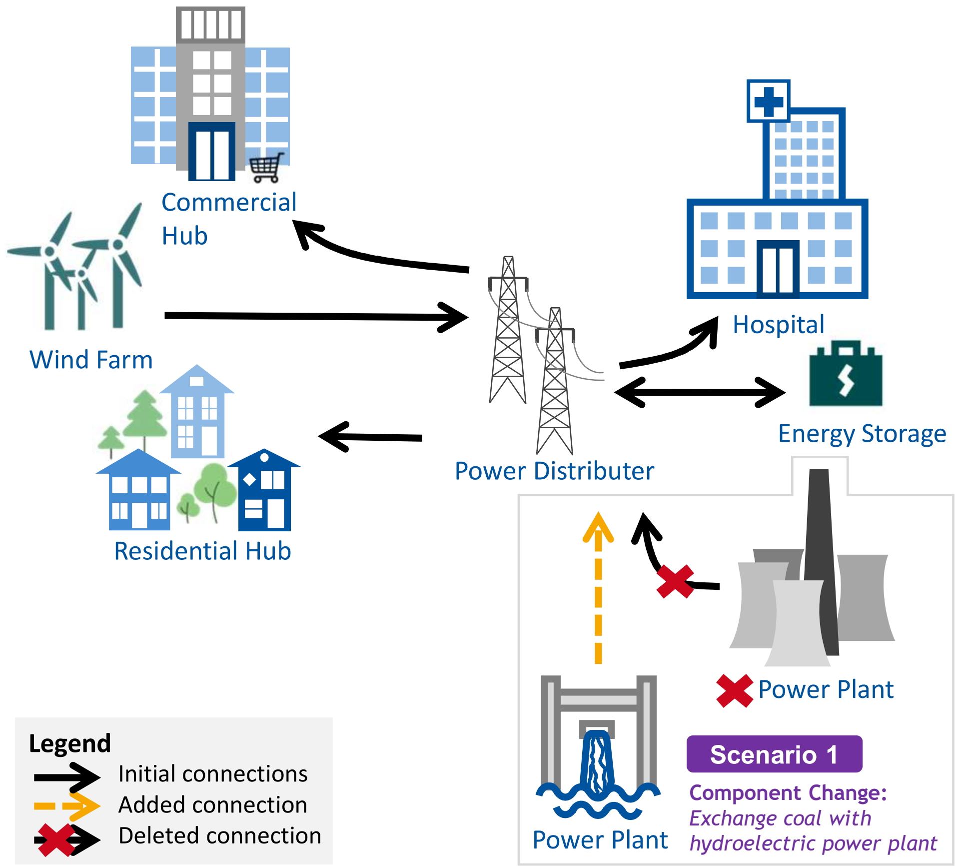
Sustainable Evolvement of Systems

- Indicators in components
  - Iterative Development | Component Change

MA

```
component HydroPowerplant{
  port
    out ElectricalEnergy ee;

  sustainability{
    type: energy, structure, process;
    indicators{
      consumption: renewable, hydro;
      co2Emission: 24 gCO2/kWh;
      landscapeUsage: 2km^2;
      ...
    }
  }
}
```



[GKM+23] G. Gramelsberger, H. Kausch, J. Michael, F. Piller, F. Ponci, A. Praktiknjo, B. Rumpe, R. Sota, S. Venghaus: Enabling Informed Sustainability Decisions: Sustainability Assessment in Iterative System Modeling. In: ME Workshop @MODELS, 2023.

Sustainable Evolvement of Systems

Enabling Informed Sustainability Decisions: Sustainability Assessment in Iterative System Modeling

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***Abstract*—When planning, creating, and evolving systems throughout their lifecycle, it is essential to assess their impact on our world. Despite this pressing need, existing structured methods for systematically assessing social, economic, and environmental impacts are not related to targets of the United Nations' sustainable development goals. Moreover, existing Architecture Description Languages (ADLs) lack concepts and tooling for sustainability assessment. Our aim is to allow modeling systems, their sustainability properties, and sustainability questions in a structured manner for a wide domain. This paper proposes the engineering and design of a domain-specific language for sustainability assessment embedded into ADLs and showcases its use for evaluating a citizen energy community system as a case study. We discuss possibilities on how to use such models in their further processing and explore challenges in technical realization. This initial step towards standardizing the sustainability assessments of modeled systems throughout the development is both comprehensive and formal so that developers can make informed, sustainable decisions based on consequence assessments upfront.**

***Index Terms*—Systems Engineering, Domain-Specific Languages, Model-Driven Engineering, Sustainable Development Goals, Life-Cycle Sustainability Assessment, Architecture Description Language, Energy Planning**

I. INTRODUCTION

Motivation. When developing and evolving systems, technologies, and processes over a longer period of time sustainability plays a significant role in each decision point of developers. Such systems include the production domain, Internet of Things (IoT), Cyber-Physical System (CPS), or pure software systems. Development decisions may lead to negative influences on different sustainability goals [1] in the areas of social, economic, and environmental sustainability [2].

Research Question. We tackle the main research question of how to enable system developers to iteratively evolve a system throughout its life cycle in a sustainable way.

Contribution. To make these informed decisions, we suggest a model-based approach that incorporates sustainability descriptions in Architecture Description Language (ADL) models. This paper explores and introduces an approach to combine sustainability assessment defined in a Domain-Specific Language (DSL) with ADL models throughout an iterative development process. The approach supports decision-making through a system's evolution and leads to the implementation of sustainable systems. As a running example, we show two development scenarios in an energy planning case study for a citizen energy community.

Structure. We provide foundations, use a running example to introduce the methodology for sustainable system development, and conclude with a roadmap for implementing DSLs and assessing sustainability.

II. PRELIMENARIES

Architecture Description Languages. For modeling systems, ADLs [3] offer great possibilities for iterative development. Most ADLs follow the component-connector approach, where a system architecture is defined by its components/parts and their connectors/ports. Often, additional (behavior) description possibilities are offered for atomic components through language compositions, e.g., state charts [4]. Components define their communication interface through input and output ports.

*Corresponding author.

Facilitate the *sustainability decision-making*
throughout the *lifecycle of systems*
by embedding *sustainability descriptions* in *ADL models*

…more on Tuesday!

International Workshop on
Models and Evolution
Special theme: Sustainability
3 October 2023, Västerås, Sweden
Co-located with MODELS 2023

Tue 3 Oct 2023 10:30 - 12:00 at 104 (40) - ME: Session 2

★ ME: Session 2

- **10:30 - 11:00** *"Towards a Taxonomy of Digital Twin Evolution for Technical Sustainability"*
  by Istvan David and Dominik Bork
- **11:00 - 11:30** *"Enabling Informed Sustainability Decisions: Sustainability Assessment in Iterative System Modeling"*
  by Gabriele Gramelsberger, Hendrik Kausch, Judith Michael, Frank Piller, Ferdinanda Ponci, Aaron Praktiknjo, Bernhard Rumpe, Rega Sota, and Sandra Venghaus

Scientific commercial break

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Intent to submit	Oct 9th, 2023
Submission deadline	Nov 1st, 2023
Notification	end of Feb 2023

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DIGITAL TWIN EVOLUTION

SPECIAL THEME

Digital twins are increasingly being leveraged within research and industrial sectors to oversee and regulate cyber-physical systems (CPSs) across a multitude of domains—spanning from autonomous driving and biology to medicine and smart manufacturing. These computational counterparts of CPSs offer substantial capabilities, mitigating development expenses and timelines, refining operational pro- cesses, and providing profound insights into the underlying systems they mirror. The applications of digital twins are as multifaceted and varied as their purposes, including but not limited to system analysis, control, and predictive behavior. Their utilization is not confined to a specific time span relative to the physical system; they can be employed pre-implementation to explore potential design avenues or during system operation in sync with the physical system to optimize its performance. In essence, digital twins serve as flexible, versatile, and dynamic tools for system exploration, optimization, and management, offering boundless potential for efficient system development and enhanced understanding across their complete lifespan.

Considering the lifespan of a physical system, e.g., app. 20 years for an injection molding machine, 50 years for a bridge, and 100 years for a dam. Clearly, these systems and their surrounding context will change. This requires their digital twin to evolve in accordance with this system and context evolution. Evolution is relevant in different life cycle phases of a system:

1. the experimental nature of the original system, e.g., when simulating properties and changing configurations and design models, is constantly affecting the digital twin as-designed and requiring changes to it;
2. from as-designed to as-operated, i.e., for twins (often idealized) representing a specific kind of system to a digital twin representing a very specific instance of that type;
3. from as-operated to as-maintained, i.e., by adjusting the digital twin to match the changing properties of its physical twin (e.g., due to wear and tear), continuously throughout its lifespan.

Aims and Topics

This Special Issue of the Journal of Object Technology aims to provide a platform for Digital Twin researchers and practitioners to report novel results, evidence of successful application, and to present roadmaps for the evolution of Digital Twins. Therefore, the Journal of Object Technology invites original, high-quality submissions for its Special Issue on Digital Twin Evolution. Articles describing any aspect of evolution for and with Digital Twins are in scope. We particularly encourage submissions addressing:

- Correctness of Evolution
- Digital Twin Conformance
- Evolution and Variability
- Lifespan and Lifecycle of Digital Twins
- Migration of Digital Twins
- Model, Data and Data-Structure Evolution
- Requirements Evolution
- Verification and Validation of Evolving Digital Twin Artefacts
- Reference Architectures and Architectural Patterns to Facilitate Evolution

Submission

- Manifest your intent to submit via email to jot2023dtevolution@easychair.org (latest Oct 9th, 2023)
- Prepare your submission with the JOT LaTeX template
- Submit using the QR code available on this page

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Intent to submit	01 Dec 2023
Paper submission	01 Mar 2024
Notification	01 May 2024

Software and Systems Modeling

Theme Section:

Modeling and Sustainability

The perception of the value and propriety of modern engineered systems is changing. In addition to their functional and extra-functional properties, nowadays' systems are also evaluated by their sustainability properties. The next generation of systems will be characterized by an overall elevated sustainability—including their post-life, driven by efficient value retention mechanisms. Current systems engineering practices fall short to support these ambitions due to the highly multi-systemic and stratified nature of sustainability, and need to be revised appropriately.
Modeling offers numerous benefits in understanding and assessing the sustainability properties of engineered systems. Modeling languages and tools support subject matter experts in expressing their views, process models allow for reasoning about trade-offs across the end-to-end systems engineering process, and runtime models allow for controlling engineering endeavors for sustainability. These are just a few of the many ways to support sustainability ambitions by modeling. It is, however, equally important to develop sustainable model-driven engineering techniques to avoid defeating the purpose.

To this end, the *Journal of Software and Systems Modeling* (SoSyM) prepares a theme section on "Modeling and Sustainability" and invites high-quality submissions covering topics including but not limited to

- modeling for sustainability and sustainability of modeling,
  - technical sustainability: system/model (co-)evolution, techniques promoting prolonged system lifecycle
  - environmental sustainability: energy consumption of modeling, modeling and simulation of energy consumption
  - social sustainability: ethical concerns and modeling4good
  - economic sustainability: quality and cost trade-offs, cost assessment methods
- modeling languages and formalisms for sustainability
- frameworks and tools
  - reference frameworks, taxonomies, ontologies
  - open-source modeling and simulation tools
- digitalization for sustainability: Digital Twins, Digital Thread
- Industry 5.0 as a sustainability-focused movement
- sustainable and circular systems engineering
- empirical inquiries, surveys, case studies, tool evaluations
- training and education, especially on the topic of developing the next generation of systems engineering professionals

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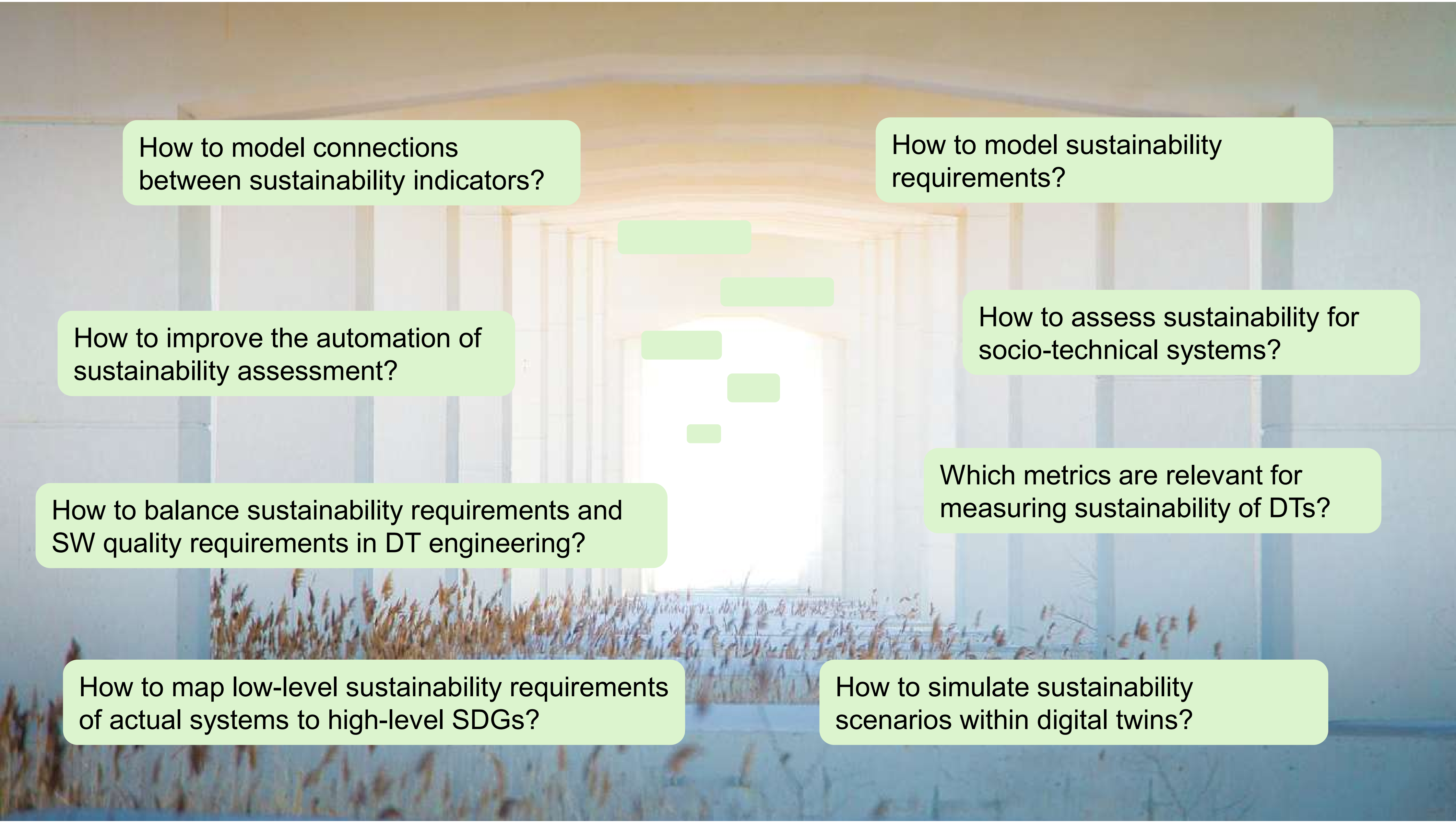
How to model connections between sustainability indicators?
How to model sustainability requirements?
How to improve the automation of sustainability assessment?
How to assess sustainability for socio-technical systems?
Which metrics are relevant for measuring sustainability of DTs?
How to balance sustainability requirements and SW quality requirements in DT engineering?
How to map low-level sustainability requirements of actual systems to high-level SDGs?
How to simulate sustainability scenarios within digital twins?

Let us go crazy…

go crazy on digital twin research with an impact

- Develop *sustainable engineering methods* to create DTs
- Develop *sustainable methods* to run DTs
- Use DTs to *assess* the sustainability of systems
- *Model* sustainability

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