Multi-approach based digital twin development methodology

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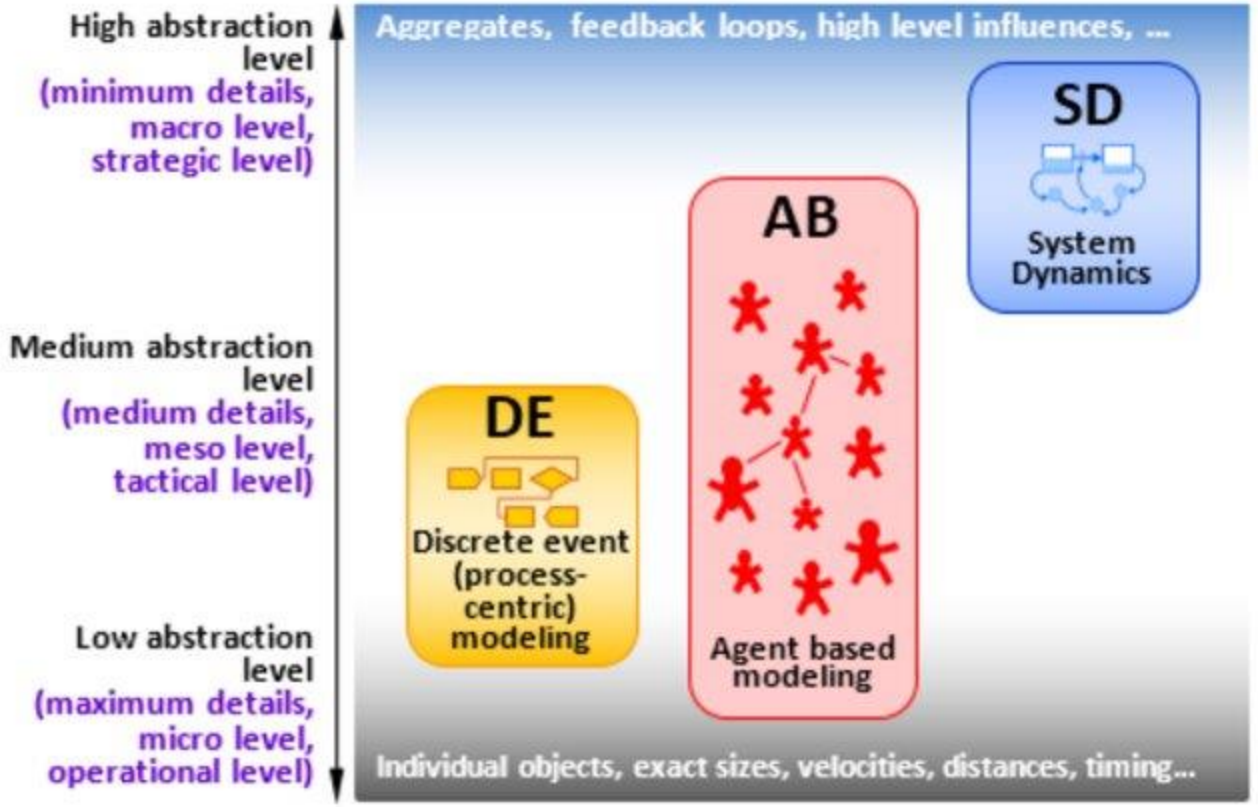
Multi-approach model

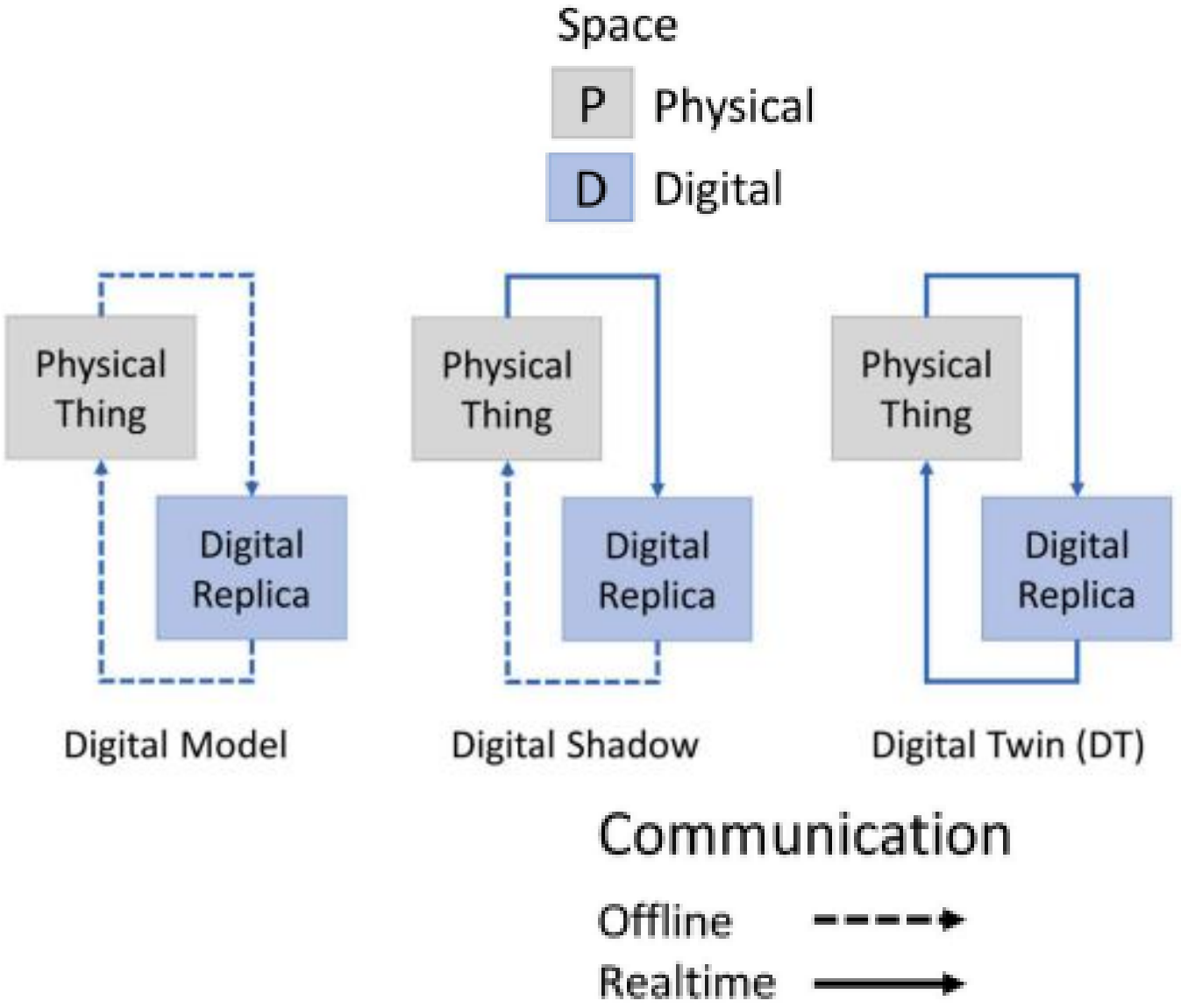
- Simulation modelling is the process of **creating** and analyzing a **digital prototype of a physical model** to predict its performance in the real world.



Grigoryev, I. (2015). AnyLogic 7 in three days. A Quick Course in Simulation Modeling, 2.

Digital twin

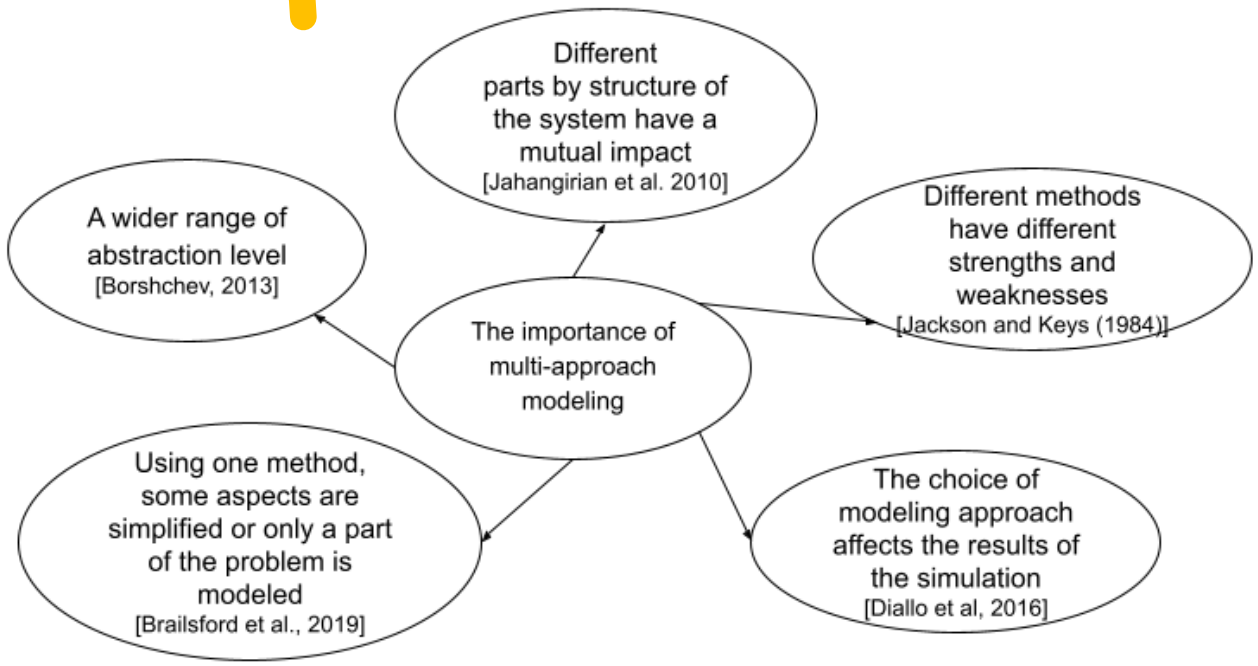
- A digital twin is a digital model of a physical object that can evolve in real time by receiving data from the physical object to maintain its consistency with the physical object throughout its lifecycle. (M. Liu et al., 2021)



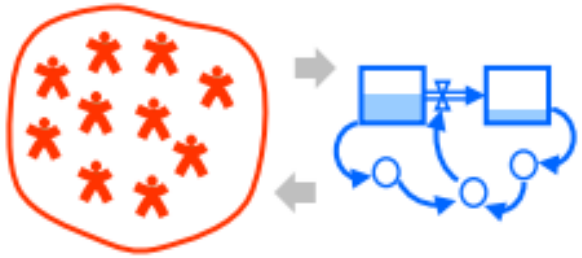
W. Kritzinger et al., "Digital Twin in manufacturing: A categoricalliterature review and classification," in IFAC-PapersOnLine, 2018, vol.51, no. 11, pp. 1016–1022

The problem

- Complex cyber-socio-technical systems **require accurate representation** to support decision-making.
- Existing digital twin development approaches are **fragmented**, lacking integration of multiple modelling methods in a single transparent methodology.
- Modelling process implementation is **time-consuming and requires specialized simulation programming skills**, limiting accessibility for domain experts.



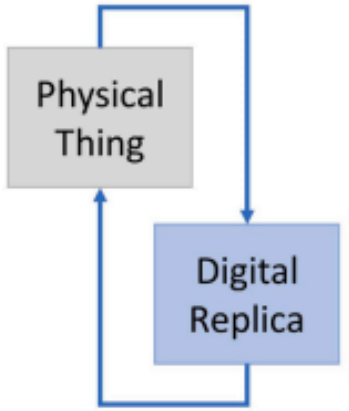
The goal, the object and the subject of the doctoral thesis



- **The goal** of the thesis is to develop a methodology for the development of a multi-approach-based digital twin for cyber-socio-technical systems.

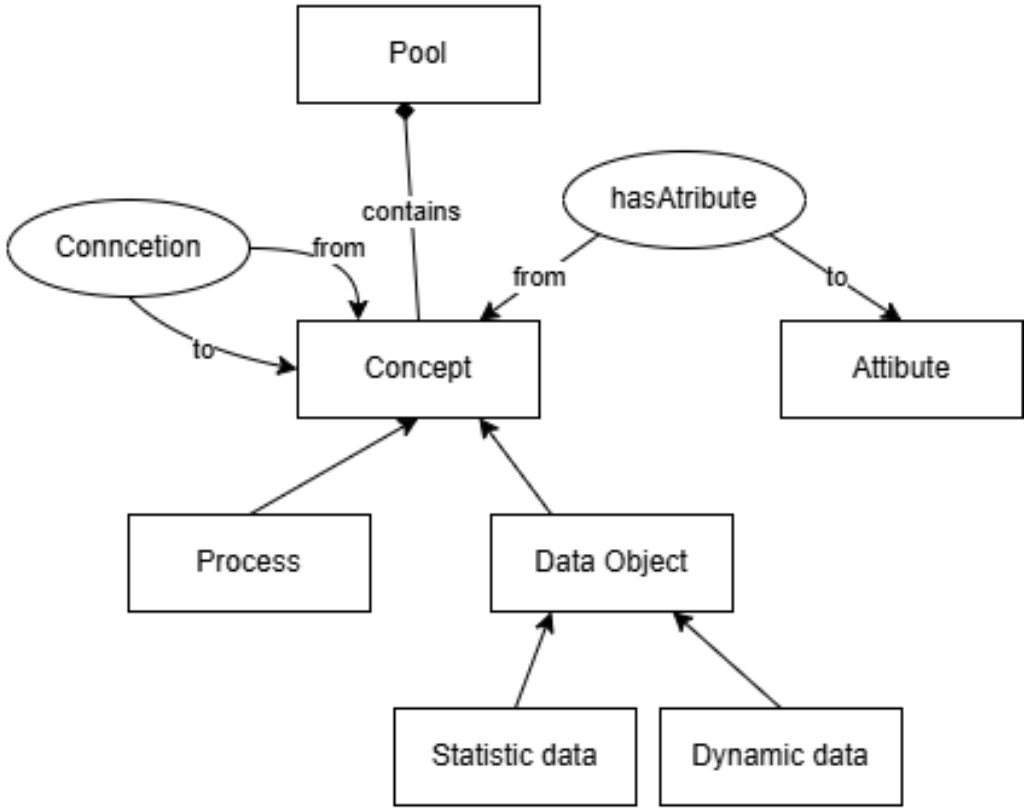
- **Object of the thesis -** Multi-approach based digital twin development methodologies for cyber-socio-technical systems.

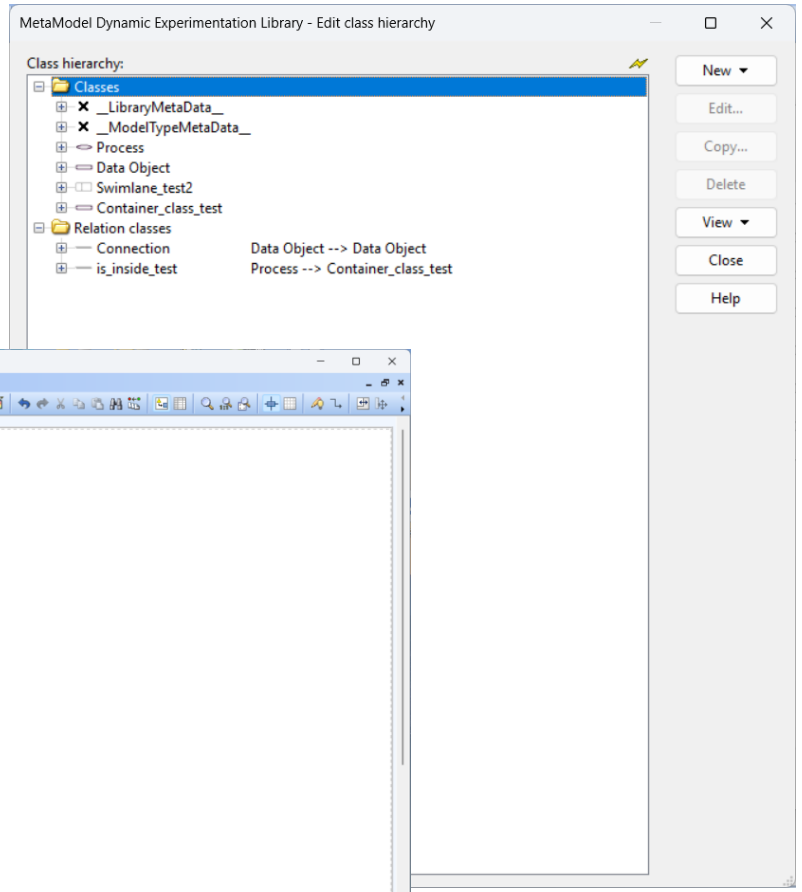
- **Subject of the thesis** - Development of a domain-specific modelling methodology and tool that enables the creation of baseline multi-approach digital twin models directly from graphical representations in ADOxx.

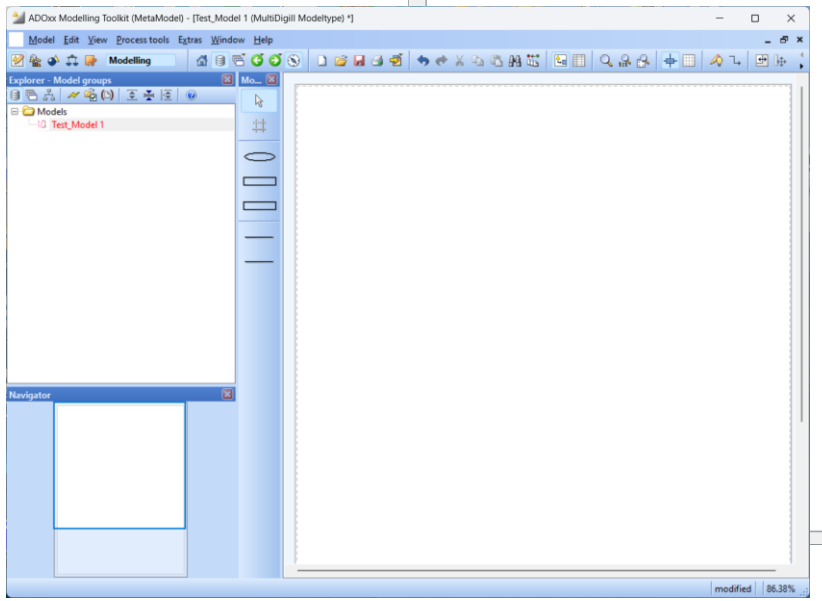


MetaModel in Adoxx environment

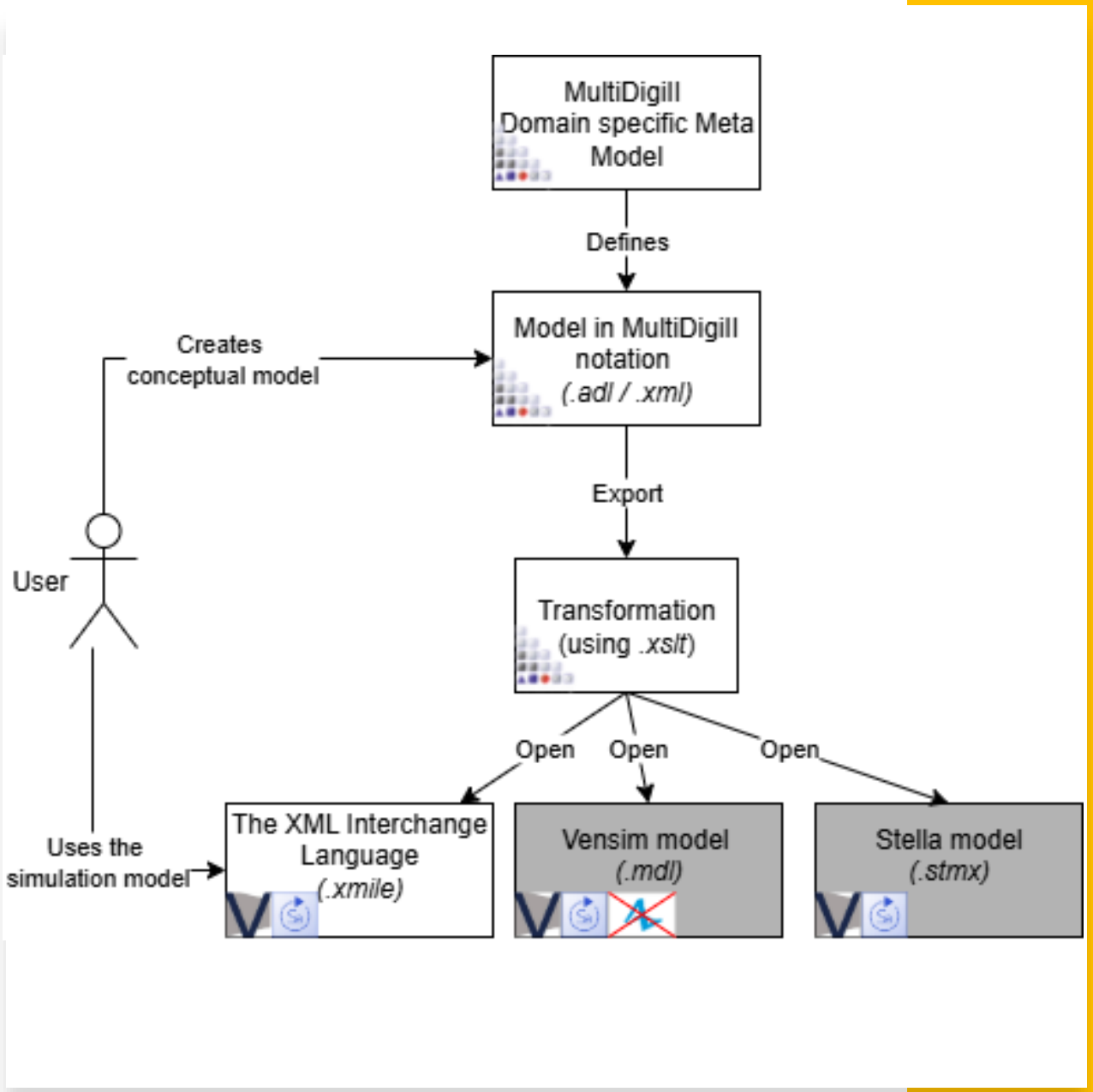
(Developed by the author)







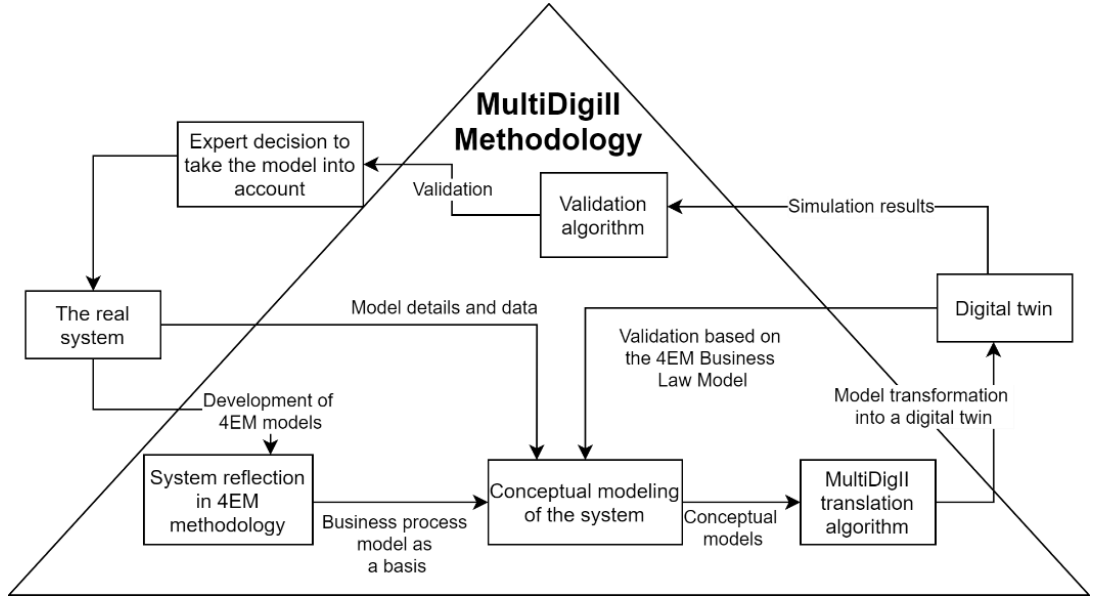
Transformation



(Developed by the author)

Scientific novelty

- **Development of a methodology** for building multi-approach-based digital twins.
- Creation of a domain-specific modelling language (DSML) that:
  - Supports user-friendly **graphical model creation**,
  - Enables **automatic generation of baseline simulation models** from conceptual diagrams.
- Bridges **conceptual modelling and simulation implementation**.



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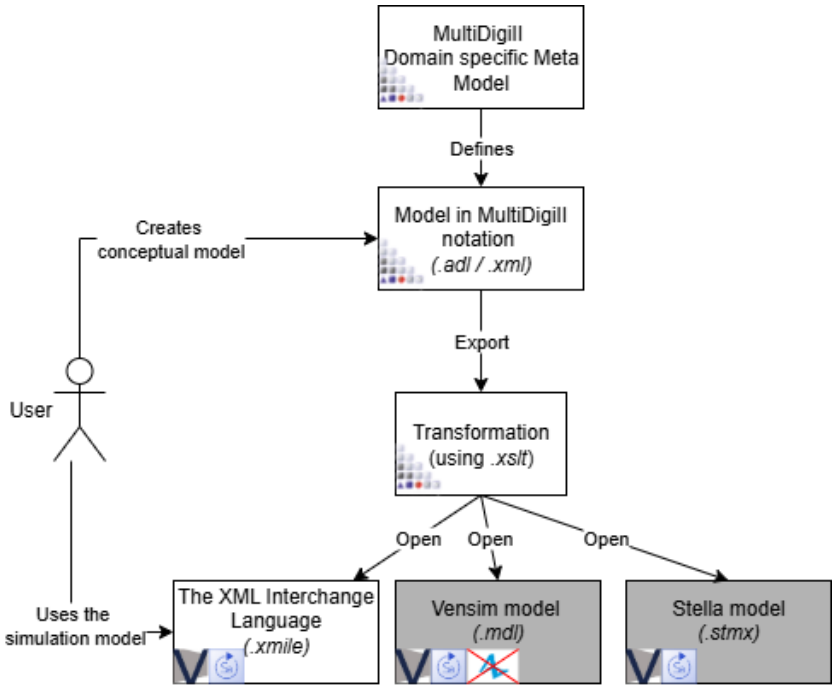
Practical significance



(Developed by the author)

Empowers domain experts to **graphically design their system models** without deep simulation programming expertise.

Generates **baseline simulation models automatically**.

Reduces **development time and complexity**, enabling faster deployment of digital twins for decision support, monitoring, and optimization.

Materials and Methods

- Development platform: **ADOxx meta-modelling environment** to create the MultiDigiII domain-specific modelling language (DSML).
- Model creation: User builds a model in **MultiDigiII notation** within ADOxx (.adl / .xml format).
- Model transformation: Uses **XSLT transformations** to convert MultiDigiII XML to simulation-compatible format.
- Output format: Generates models in **XML Interchange Language (.xmile).**
- Model import: The resulting .xmile file can be opened and further developed in simulation tools such as **Stella Architect and Vensim**.
- Validation: Applied to **case studies** to evaluate practical applicability and transformation accuracy.

Discussion

- **Bridges the gap between conceptual domain modelling and simulation implementation** by automating baseline model generation.
- Compared to existing methodologies, this **reduces required technical expertise** and enables domain experts to participate directly in model creation.
- The integration of **multi-approach modelling paradigms enhances** model fidelity and adaptability, which is essential for complex cyber-socio-technical systems.
- **Challenge identified** - Extending baseline models to fully executable validated simulations.

Conclusions

1. Developed a **domain-specific modelling methodology and tool (MultiDigiII)** for multi-approach digital twin development.
2. Multi-approach modeling offers **flexibility** in selecting the most suitable modeling approach for each system component, thereby overcoming the limitations of a single method and improving simulation accuracy.
3. Provides both **scientific contribution** (method engineering for multi-approach digital twins) and **practical impact** (user-friendly baseline model generation for rapid prototyping).
4. The structured development of multi-approach models fosters the creation of **integrated and adaptable modeling solutions** for various simulation needs.

Published scientific publications

1. Zake, M., & Majore, G. (2022, October). Application of Multi-perspective Modelling Approach for Building Digital Twin in Smart Agriculture. In 2022 63rd International Scientific Conference on Information Technology and Management Science of Riga Technical University (ITMS) (pp. 1-7). IEEE.
2. M. Zake, G. Majore, G. Krūmiņš and Z. Zakis, "Methodology for Construction of Multi-approach Based Digital Twin in Strategic Communication," 2020 IEEE 8th Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE), 2021, pp. 1-6, doi: 10.1109/ AIEEE51419.2021.9435626
3. Lescevica, M., Zamuele, A., Zake, M., & Jirgensons, J. (2019). Minimizing migration: Modeling of Latvian diaspora's involvement in cooperation with education and science, and governmental institutions, businesses and society. Procedia Computer Science, 149, 483–490.
4. Majore, G., Fjodorovs, A., Zake, M., Majors, I., Kepka, M., Integration of Web Map Application and Simulation Modeling Tools for Sustainability Analysis in Regional Development, Procedia Computer Science, ICTE 2016, Latvia, 2017, Volume 104, pp. 213-221.
5. Majore G., Zakis V., Zake M., Ginters E., Zakis K., Fjodorovs A. Holistic Benchmarking of the Bioeconomy in Protected Landscape Areas. Procedia Computer Science . ICTE in Regional Development, December 2014, pp. 118-126. [indeksēts Scopus]
6. Mairita Zake, Egils Ginters. Migration among simulation paradigms and tools. //In: Proceedings of 26th Europen Modelling & Simulation Symposium (EMSS 2014), ISBN 978-88- 97999-38- 6 / EMSS 2014 (paperback) ISBN 978-88- 97999-32- 4, 10-12 September, 2014, Bordeaux, France, pp.364-371

Research work in scientific projects

02.04.2024. – PAŠLAIK Klimata neitralitātes lēmumu modeļi Darbībā (VPP_KEM) Nr.0B000-3.2.2.1-e/3

01.06.2021. – 31.12.2023 Sabiedrības kiberdrošības spēju paaugstināšana (Advancing human performance in cybersecurity - ADVANCES), Projekta Nr. S-BMT-21-6

03.12.2019. – 30.09.2023. Horizon 2020 program project - reSilienT fARminG by Adaptive microclimaTe managEment (STARGATE)

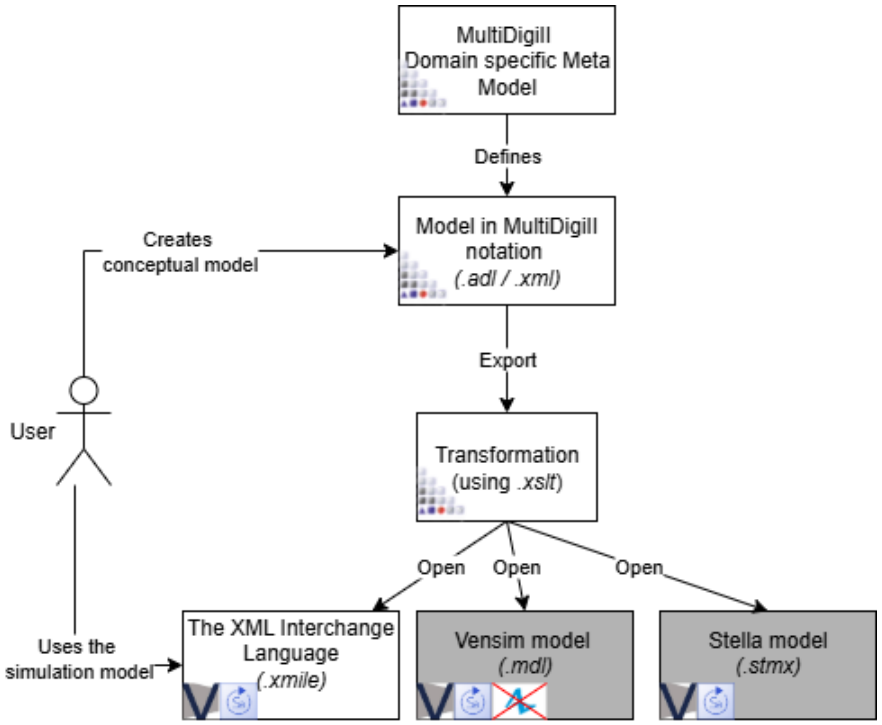
05.05.2020. – 04.05.2021. Vidzemes Augstskolas akadēmiskā personāla pilnveide un cilvēkresursu attīstība, projekta Nr.8.2.2.0/18/A/012 (SAM822)

17.09.2020. – 23.12.2020. Dzīve ar COVID-19: Novērtējums par koronavīrusa izraisītās krīzes pārvarēšanu Latvijā un priekšlikumi sabiedrības noturībai nākotnē (COLife) (Nr. VPP-COVID-2020/1-0013) WP5

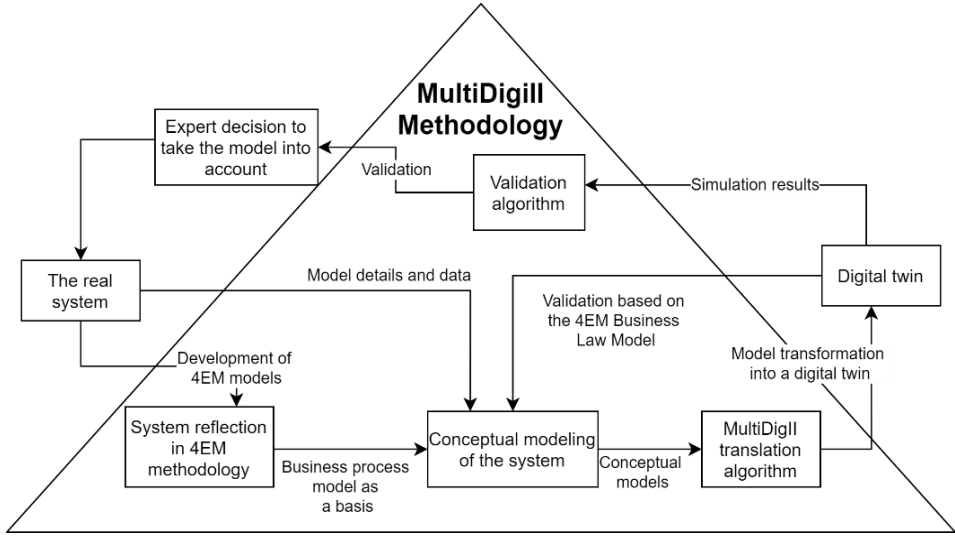
02.10.2017. – 30.11.2017. Valsts pētījumu programmas EKOSOC-LV projektā Nr.5.2.2. "Inovācijas un uzņēmējdarbības attīstība Latvijā atbilstoši viedās specializācijas stratēģijai"

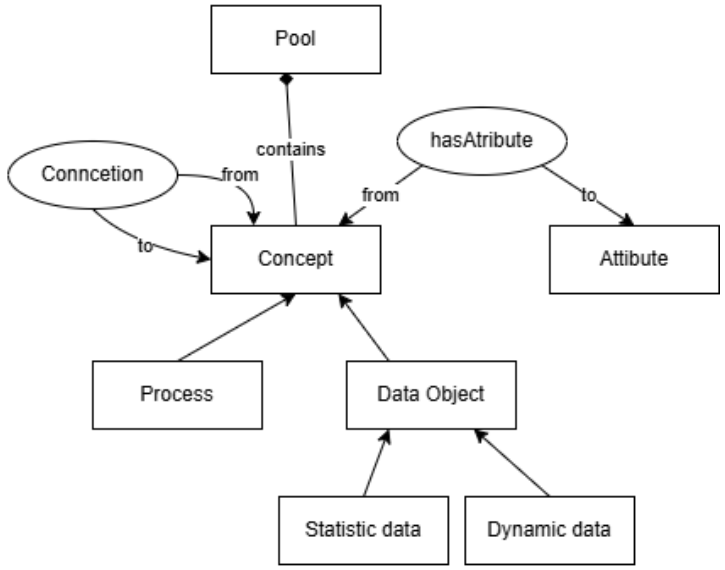
01.11.2016. – 15.12.2016. Valmieras pilsētas pašvaldības finansēto zinātnisko grantu projektā "Imitācijas modeļa un platformu savienojamas programmatūras prototipa izstrāde pašvaldību objektu energoresursu patēriņa ilgtermiņa analīzei un monitoringam"

01.04.2014. – 30.11.2014. Valmieras pilsētas pašvaldības finansēto zinātnisko grantu projektā "Imitāciju modeļa un programmatūras prototipa izstrāde dabas resursu izmantošanas un ilgtspējas novērtēšanai mājsaimniecībās aizsargājamo ainavu apvidū"


MultiDigiI
Domain specific Meta Model
Defines
Model in MultiDigiI notation
(.adl / .xml)
Creates conceptual model
Export
User
Transformation
(using .xslt)
Open
Open
Open
Uses the simulation model
The XML Interchange Language
(.xmile)
Vensim model
(.mdl)
Stella model
(.stmx)

Questions?


MultiDigiI Methodology
Expert decision to take the model into account
Validation
Validation algorithm
Simulation results
The real system
Model details and data
Digital twin
Validation based on the 4EM Business Law Model
Development of 4EM models
Model transformation into a digital twin
System reflection in 4EM methodology
Business process model as a basis
Conceptual modeling of the system
Conceptual models
MultiDigiI translation algorithm


Pool
contains
hasAtribute
Conncetion
from
from
to
to
Concept
Attibute
Process
Data Object
Statistic data
Dynamic data