Business Informatics Group

Towards Architectural Coordination for Digital Twins

Hend*erik* A. Proper

Business Informatics Group

Towards Architectural Coordination for Digital Twins of Socio-Technical Systems

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Part of ongoing work

Marianne Schnellmann, Marija Bjeković, Henderik A. Proper, and Jean-Sébastien Sottet. *Towards architectural coordination for digital twins*. In Luise Pufahl and Jana-Rebecca Rehse, editors, Proceedings of the 15th International Workshop on Enterprise Modeling and Information Systems Architectures, EMISA 2025, Heilbronn, Germany, May 14-16, 2025, volume P-362 of Lecture Notes in Informatics, page 10, Bonn, Germany, 2025. Gesellschaft für Informatik.

Interreg North-West Europe
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Twin4Resilience

LIST

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Agenda

Digital Twins

Architectural Coordination

Planning challenges for Digital Twins

Towards Architectural Coordination for DT development

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Digital Twins

Physical Entity

bi-directional
data flow

Virtual Representation

Source: https://www.ascr.at/wp-content/uploads/2022/03/2022-UC15-DE.pdf

Digital Twins

Carry the promise of supporting better **decision-making**, **decision-execution**, **monitoring**, and **learning** in relation to the twinned entity, by integrating novel technologies, including *digital models*, symbolic and sub-symbolic *AI*, as well as advanced *optimization*, *simulation*, and *visualization techniques*

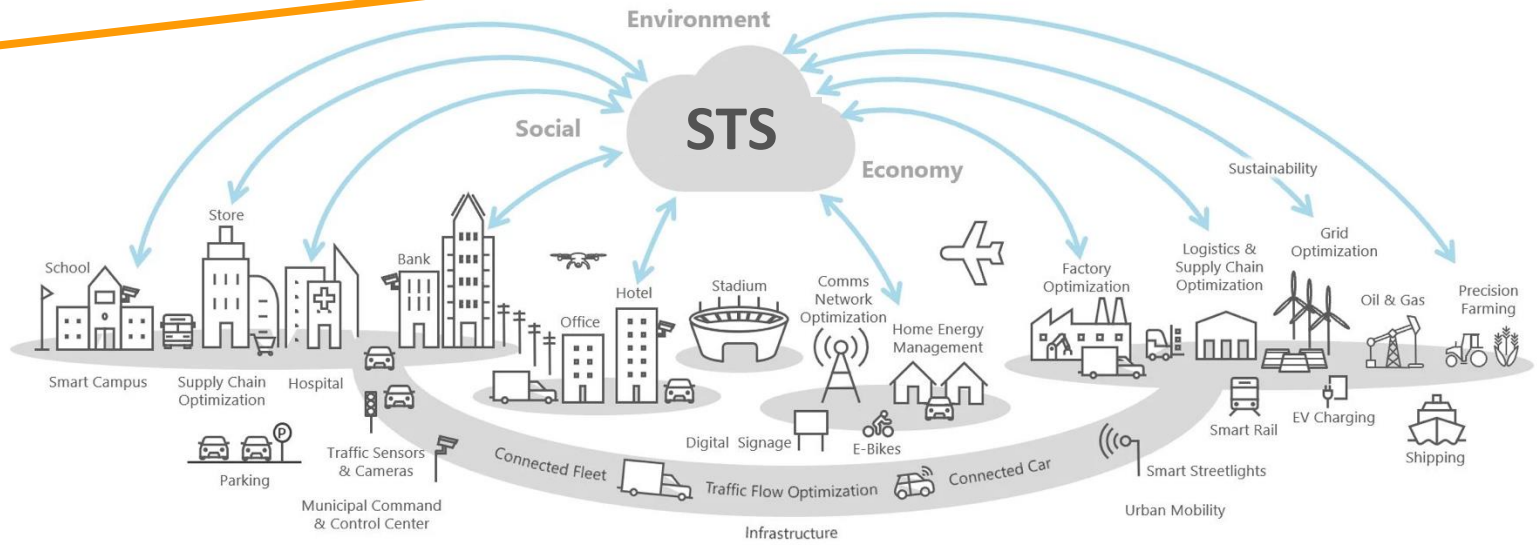
Source: https://www.ascr.at/wp-content/uploads/2022/03/2022-UC15-DE.pdf

Broadening of the possible subjects of twinning

Physical Entities

Socio-technical Systems (STS)

Source: https://www.ascr.at/wp-content/uploads/2022/03/2022-UC15-DE.pdf



Source: https://azure.microsoft.com/de-de/blog/connecting-urban-environments-with-iot-and-digital-twins/

Urban Planning

Nochta, T.; Wan, L.; Schooling, J. M.; Parlikad, A. K.: A Socio-Technical Perspective on Urban Analytics: The Case of City-Scale Digital Twins. Journal of Urban Technology28 (1–2), pp. 263–287, 2021.

Digital Twins – *A* classification

Digital Model

Digital Shadow

(Real) Digital Twin

Digital Twin Predictive

Fidelity of the digital model

Werner Kritzinger, Matthias Karner, Georg Traar, Jan Henjes, and Wilfried Sihn. *Digital twin in manufacturing: A categorical literature review and classification*. IFAC-PapersOnLine, 51(11):1016-1022, 2018. 16th IFAC Symposium on Information Control Problems in Manufacturing INCOM 2018. ISSN: 2405-8963

Digital Twins

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So, DTs are advanced, possibly active, information systems

Therefore, also part of a larger (inter-organizational) IS portfolio

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Also *data-hungry* and *computing intensive*

Do the benefits outweigh the costs?

Socio-economic sustainability of a Digital Twin?

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System Architecture

TOGAF & IEEE:

> "*a formal description of a system, encompassing its components, their interrelationships, and the principles and guidelines that govern their design and evolution*"

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System Architecture Management

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System Architecture Management

TOGAF & IEEE:

> "*a formal description of a system, encompassing its components, their interrelationships, and the principles and guidelines that govern their design and evolution*"

Martin Op 't Land, Henderik A. Proper, Maarten Waage, Jeroen Cloo, and Claudia Steghuis. Enterprise Architecture – Creating Value by Informed Governance. The Enterprise Engineering Series. Springer, Berlin, Germany, 2009

~~System~~ Architecture Management

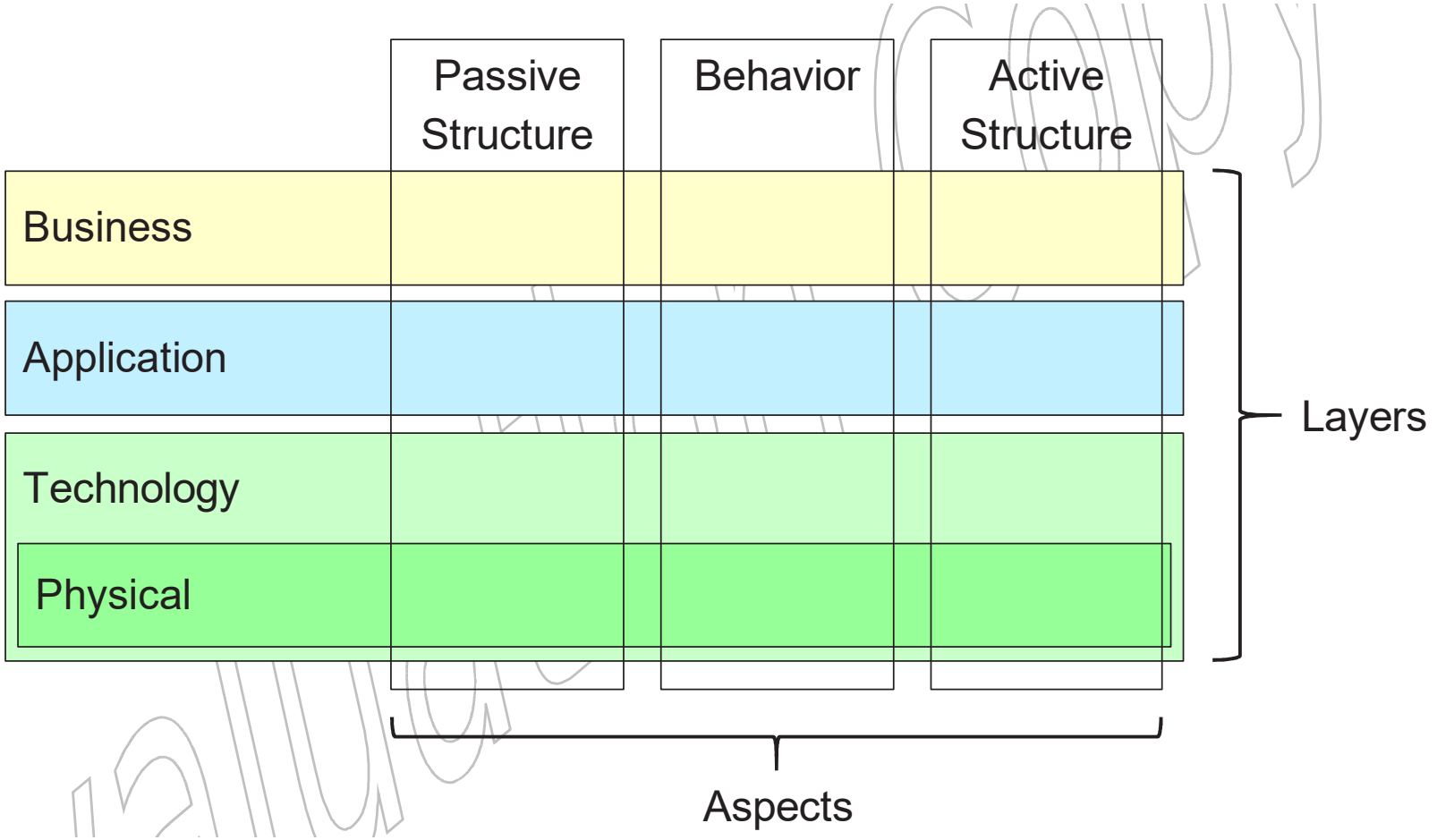
TOGAF & IEEE:

> "*a formal description of a system, encompassing its components, their interrelationships, and the principles and guidelines that govern their design and evolution*"

Danny Greefhorst and Henderik A. Proper. Architecture Principles - The Cornerstones of Enterprise Architecture, The Enterprise Engineering Series. Springer, Berlin, Germany, 2011

> "*Those properties of an artifact that are necessary and sufficient to meet its essential requirements*"

Enterprise Architecture



Source: The Open Group. ArchiMate 3.2 Specification.
Van Haren, Zaltbommel, The Netherlands, 2024

Architectural Coordination

Multiple change projects *and other change efforts*

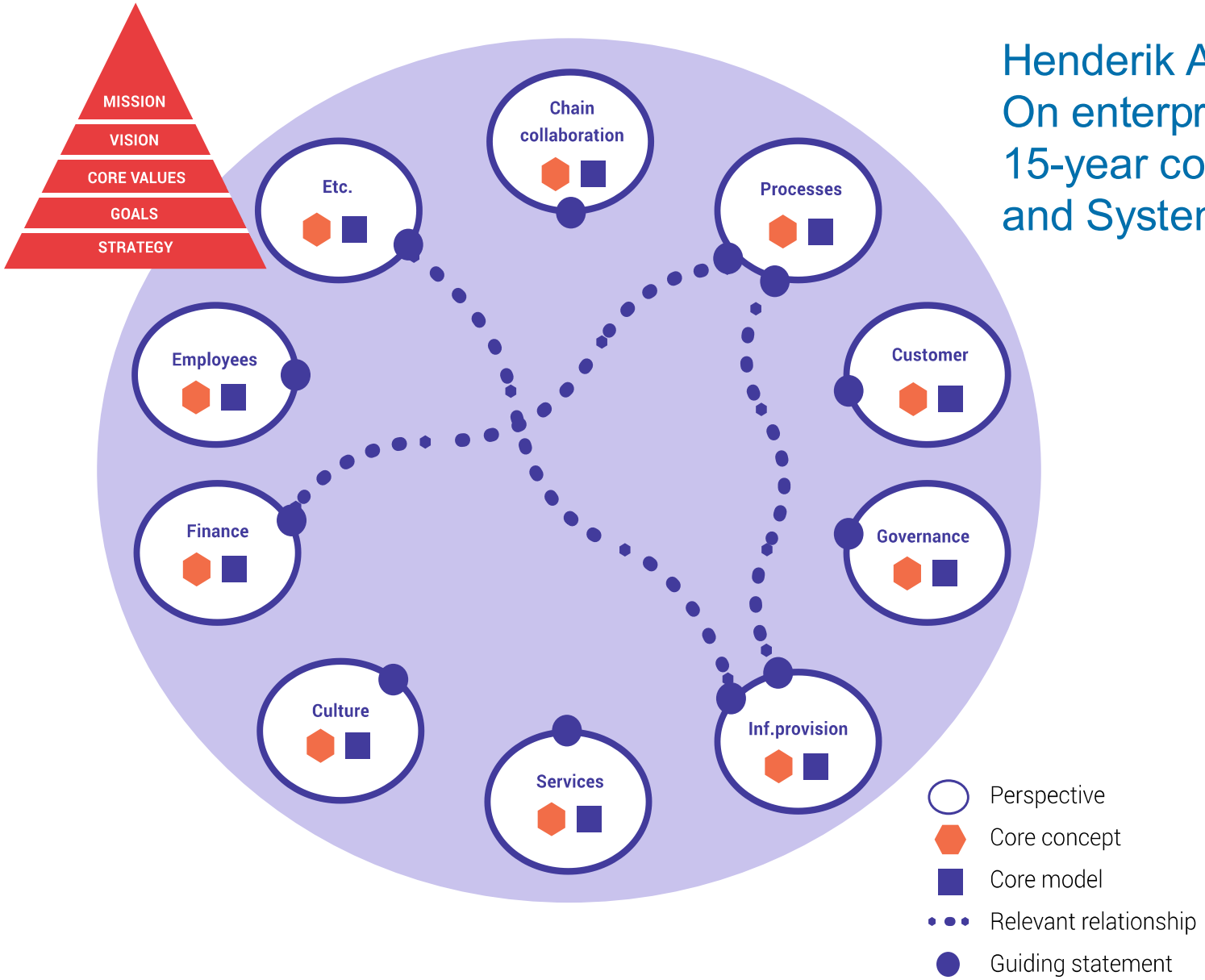
Within one organisation, but also across organisations

Requires coordination in the face of fragmenting forces:

- Short-term and long-term interests
- Central interests and diverse local interests
- …

Focus on the essential requirements …

Stakeholder engagement for coordination



Henderik A. Proper, Roel Wagter, and Joost Bekel. On enterprise coherence governance with GEA: A 15-year co-evolution of practice and theory. Software and Systems Modeling, 22(2):551-571, 2023.

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Architectural Coordination for Digital Twin development

Conclusion

Some planning challenges for Digital Twins

Ad-hoc & isolated development

Lack of user awareness & engagement

Fragmented & complex data ecosystems

Potential for synergies in the IT landscape

Some planning challenges for Digital Twins 4 STS

Ad-hoc & isolated development

Lack of user awareness & engagement

Fragmented & complex data ecosystems

Potential for synergies in the IT landscape

Needs Architectural Coordination

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Towards Architectural Coordination for DTs

The basic idea …

Think of a Digital Twin, not as a single dedicated system, but rather as a collection of functional components and their dependencies

Treat these as parts of the portfolio of (potential) functional components of the (inter-organizational) information systems landscape in general

What's needed …

Towards Architectural Coordination for DTs

A reference framework for digital twin functional components:

- across different levels of fidelity,
- catering for an inter-organizational STS context, and
- with generic growth/degrowth roadmaps

Situation specific roadmaps, aligned to stakeholder interests:

- Grow/degrow DT functionality based on cost/benefits
- Optimise for synergies
- No regret investments in infrastructure
- Create awareness for benefits of further growth steps

Example of an overview of DT functionalities

DS.AR AI Model Repository	**DS.AG** Data Aggregation	**IR.AS** API Srvices				**UX.GM** Gamification	**UX.DB** Dashboards
DS.SR Simulation Model Repository	**DS.AS** Asynchronous Integration	**IR.CL** Collaboration Platform Integration	**IC.CS** Composition	**IC.SM** Simulation	**IC.RP** Reporting	**UX.3R** 3D Rendering	**UX.XR** Extended Reality (XR)
DS.SA Data Storage and Archive Services	**DS.RT** Real-time Processing	**IR.DT** Digital Twin Integration	**IC.DL** Distributed Ledger and Smart Contracts	**IC.FL** Federated Learning	**IC.AL** Alerts and Notifications	**UX.GE** Gaming Engine Visualization	**UX.ER** Entity Relationship Visualization
DS.DS Domain Specific Data Management	**DS.BP** Batch Processing	**IR.IO** OT/IoT System Integration	**IC.BR** Business Rules	**IC.AI** Artificial Intelligence	**IC.OS** Orchestration	**UX.BP** Business Process Mgmt & Workflow	**UX.RM** Real-time Monitoring
DS.IR Digital Twin Instance Repository	**DS.CX** Data Contextualization	**IR.EG** Engineering Systems Integration	**IC.PS** Prescriptive Recommendations	**IC.PR** Prediction	**IC.IC** Command and Control	**UX.BI** Business Intelligence	**UX.AV** Advanced Visualization
DS.RP Digital Twin Model Repository	**DS.TR** Data Transformation and Wrangling	**IR.ET** Enterprise System Integration	**IC.MA** Mathematical Analytics	**IC.AA** Data Analysis and Analytics	**IC.SR** Search	**UX.CI** Continuous Intelligence	**UX.BV** Basic Visualization
DS.ON Ontology Management	**DS.ST** Data Streaming	**MG.DG** Data Governance	**MG.SM** System Monitoring	**TW.RP** Responsibility	**TW.RL** Reliability	**TW.PR** Privacy	**TW.DS** Device Security
DS.SG Synthetic Data Generation	**DS.AI** Data Acquisition and Ingestion	**MG.EL** Event Logging	**MG.DM** Device Management	**TW.RS** Resilience	**TW.SF** Safety	**TW.SC** Security	**TW.EX** Data Encryption

Data Services Integration Intelligence UX Management Trustworthiness

Source: https://www.digitaltwinconsortium.org/initiatives/capabilities-periodic-table/

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Data Services Integration Intelligence UX Management Trustworthiness

Research challenges

Quantify, or at least better qualify, the "*better* ***decision-making***, ***decision-execution***, ***monitoring***, *and* ***learning*** *in relation to the twinned entity*"

Development of a suitable reference framework, and associated method to develop situation specific roadmaps

Possibly extend/refine existing EA frameworks (content & process) to better cater for (business-case driven) DT in an (inter-organizational) STS context

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