Improving Digital Twin Experience Reports

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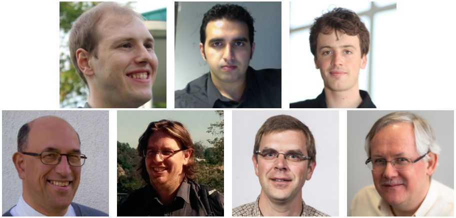
Who We Are

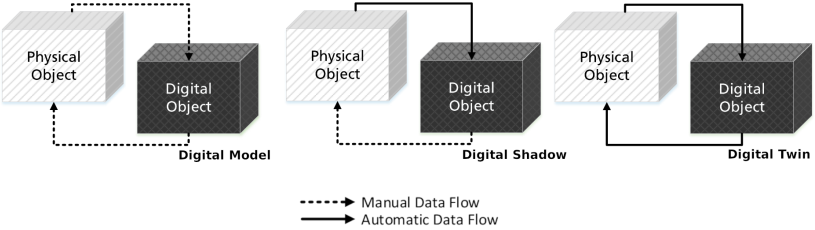


- Researchers at the University of Antwerp and Flanders Make.
- Active in modelling and simulation, model-based engineering, cyber-physical systems, testing/verification.
- Projects building, configuring, and testing Digital Twins (DT).

Definitions of DTs

Madni *et al.* - "a DT is a virtual instance of a physical system (twin) that is continually updated with the latter's [...] data [...]"

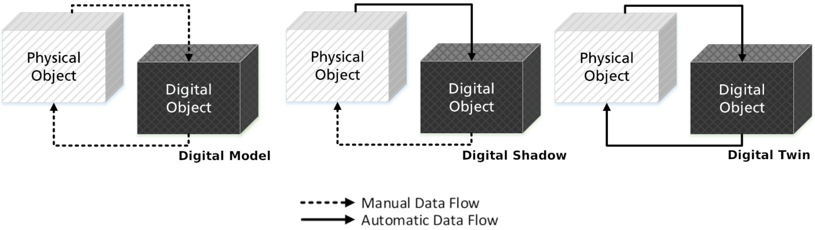
Further classification from Kritzinger *et al.*:



Emphasis on the *capabilities* of a DT and *automation*.

Original question: What DTs are in academic or industrial experience reports (classified by Kritzinger *et al.*)?

Unclear classification due to missing *automation information*.



Other characteristics often not reported:

- ↔ *Real-time* communication between objects?
- δ *Modifications* (sensors/actuators) required to support DT?
- ≈ *Fidelity* considerations in building the DT?

...

- **Context:** Collaborative industrial assembly process with human and robot sharing workstation.
- **Challenges:** Ensure that both work efficiently and will not collide.

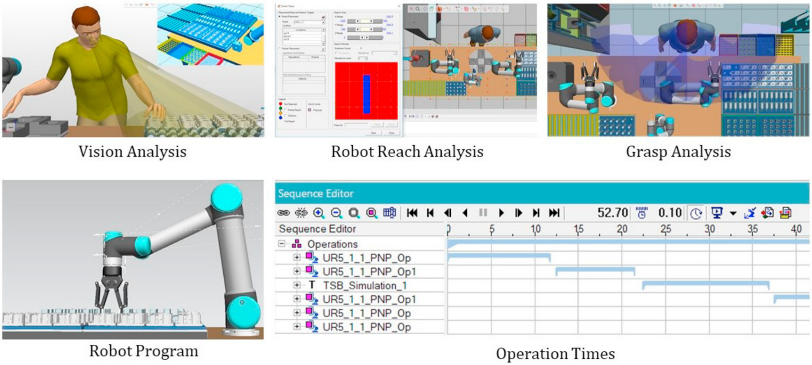
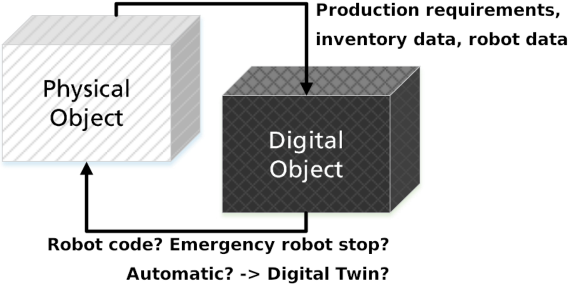


Figure from Malik and Bilberg (2018).

Well-done report, but *actions* and *time-scale* could use elaboration: "real-time performance metrics, optimization analytics and alerts for a robot"



Missing information hampers understanding and classification.

Contributions

Propose:

1. **General conceptual structure for reporting DTs**.
2. **Checklist of fourteen characteristics**.

Encourages practitioners to systemically assess whether DT capabilities are well-reported.

Structure/characteristics certainly not relevant or appropriate for all stakeholders/domains.

Modelling/simulation bias.
Instead of (for example) Internet of Things (IoT).

Starting point for academic/industrial discussion
$\rightarrow$ specialization for individual domains.

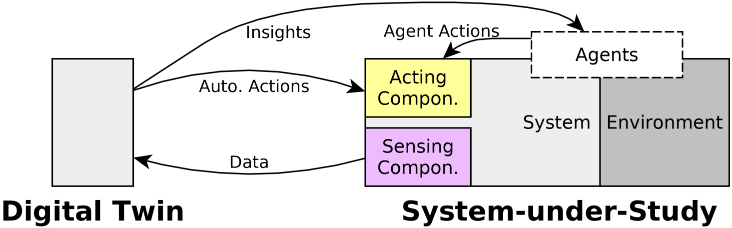
DT Characteristics

Next five slides touch on the fourteen proposed characteristics:

- System-under-study, Multiplicity
- Usages, Enablers, Models and Data, Slices
- Fidelity Considerations
- Data, Insights and Actions, Time-scale
- Acting and Sensing Comp., Life-cycle Stages, Evolution

Descriptions and examples found in the paper.

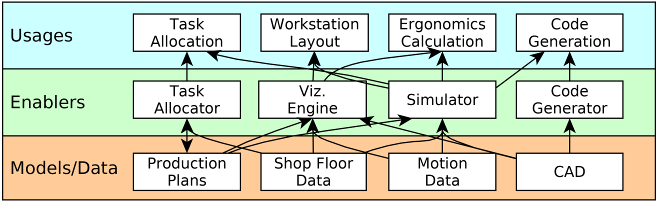
1) *System-under-study (SUS)* -
The scope of the SUS including the system, environment, and agents.



2) *Multiplicity* -
How many DTs and SUS entities are involved in the solution and their relationship.

DT CHARACTERISTICS 2/5

DTs are conceptually divided into three layers:



3) *Usages* - The activities the DT is used for.
4) *Enablers* - DT components which use models/data to support usages.
5) *Models and Data* - The input and output for enablers.

6) *Slice* - Relationships between usages, enablers, and models and data.

DT Characteristics 3/5

7) *Fidelity Considerations* -
Explanations of fidelity of DT to SUS with respect to each DT usage.

Examples:

- Approximation of dynamics for real-time analysis.
- Approximation for visualizations.

Emphasizes that a *high-fidelity model* is not (by itself) a DT.

Instead, fidelity relates to *properties-of-interest* and *usages* of a DT.

DT Characteristics 4/5

8) *Data Communicated* -
What is transferred from SUS to DT (manually and automatically).

9) *Insights and Actions* -
What is communicated from DT to SUS.

- (Manual) Insights: Factory layout insights, dashboards.
- (Automatic) Actions: Production facility commands.

10) *Time-Scale* -
Time-scale of the data, insights, actions, and simulations used.

- Slower-than-real-time: Insights provided to humans, visualizations, scheduled maintenance.
- Real-time: SUS optimization.
- Faster-than-real-time: Predictive simulations.

DT Characteristics 5/5

11) and 12) *Acting and Sensing Components* -
Additions/modifications of sensors/actuators to SUS to enable DTs.

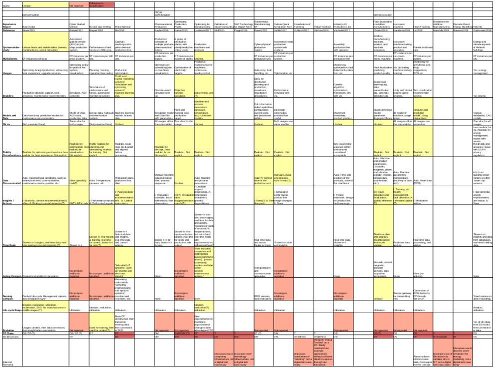
13) *Life-cycle Stages* -
What stage DT is utilized for, usages, and (if varying) SUS scope.

- Design: Optimization, visualization.
- Development: Assembly planning.
- Operation: Maintenance scheduling.

14) *Evolution* - How the DT evolves over the DT project timeline.

Paper presents five reports with further fifteen online, to support utility of conceptual structure.

Unclear or missing information on the selected DT characteristics is highlighted. (Yellow is unclear, red is missing)



Six cases where DT Model/Shadow/Twin classification differs from Kritzinger *et al.* and Fuller *et al.*

Conclusion

Paper motivates **conceptual structure for digital twins** and proposes **fourteen characteristics to present in experience reports**:

- System-under-study, Multiplicity
- Usages, Enablers, Models and Data, Slices
- Fidelity Considerations
- Data, Insights and Actions, Time-scale
- Acting and Sensing Comp., Life-cycle Stages, Evolution

List of characteristics **not complete**, and **not applicable to all stakeholders and domains**.

Twenty experience reports are expressed in proposed structure to indicate how unclear information hampers insights and classification.

Future work is iterative development to assist understanding usage and possibilities of DTs.

Questions or comments?

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