Digital Twins : usages, technologies et apports pour la supervision et la conduite de systèmes physiques

Adaptation du Processus de Conception Centrée Utilisateur pour les Interfaces Opérationnelles des Digital Twins :

Application au DT de la Grille Electrique du Luxembourg

Camille Fayollas[1] & Philippe Palanque[2]

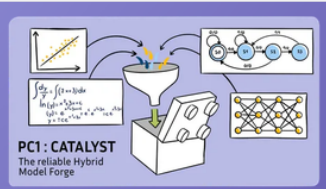
[1] Université Toulouse Capitole & [2] Université de Toulouse
IRIT, Toulouse, France

Contexte du travail

1. Projet Engineering Digital Twins (17M€, 5 WP, 40 thèses) - https://www.edtlab.fr/en/

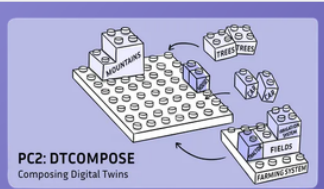
Focused Projects

EDT is structured around five targeted projects (PC1 to PC5), each dedicated to a key aspect of digital twin technology. Closely interconnected, these projects share common use cases and build on each other's progress to collectively form an integrated and comprehensive platform for digital-twin engineering.



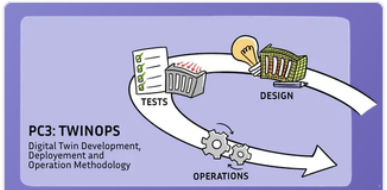
Developing systematic approaches for combining physical models and data-based models through standardized interfaces and hybridization operators in digital twins

Explore →



Developing modular Digital Twin architectures that enable flexible composition, federation, and interoperability through systematic approaches and semantic web technologies

Explore →



Developing specialized methodologies, development life cycles, and domain-specific languages for engineering digital twins with AI integration and collaborative approaches

Explore →



Addressing bidirectional data flows between physical and digital twins with focus on reliability, security, and real-time synchronization for effective digital coupling

Explore →



Developing interactive systems for human-digital twin interaction through VR, AR, collaborative environments, and immersive visualization technologies

Explore →

Operated by

RÉPUBLIQUE FRANÇAISE

Inria

Supported by

FRANCE 2030

anr agence nationale de la recherche

This work benefited from government funding managed by the French National Research Agency under the France 2030 programme, with the reference "ANR-25-APJN-0001".

Contexte du travail

1. Projet Engineering Digital Twins (17M€, 5 WP, 40 thèses) - https://www.edtlab.fr/en/
2. 2 thèse en co-supervision dans l'équipe ICS (début: 1/11/2026) - IRISA (Rennes) et LIG (Grenoble)

   Ingénierie des systèmes interactifs de commande et contrôle de DT par des DT

   Approche systématique d'identification et de suivi de tâches prévues et non prévues dans les DTs
3. Première publication



Designing Usable User Interfaces of Digital Twins: Benefits and Limitations of Applying the User Centered Design Process

Tasks Discovery | Operator Tasks | Digital Twins | User Centered Design Process | Usability | PC5

Pierre Treton, Hafiyyan Sayyid Fadhlillah, Camille Fayollas, Philippe Palanque, Arnaud Blouin, Benoit Combemale, François Fouquet • 2026

Conference Paper • HCSE 2026 - 11th International Working Conference on Human-Centered Software Engineering

Overview

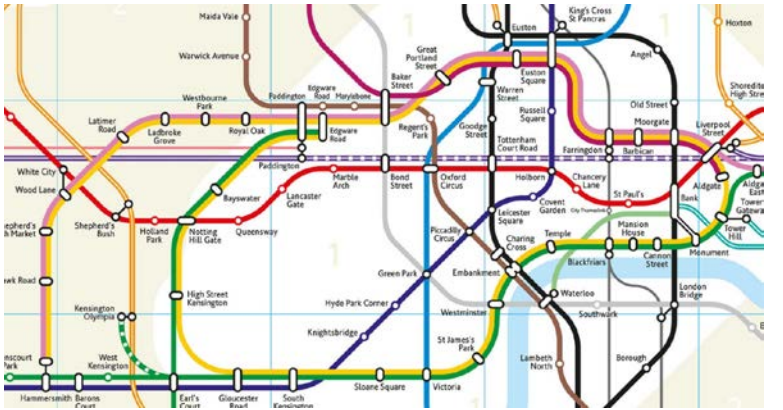
- The context
- The focus: Interactive Systems for Digital Twins
- Digital Twins and their specificities
- User Centered Design
- User Centered Design is not enough
- The use case of Luxemburg Electric Grid (Kopr)

Same system, two UIs - different tasks

Geographic view



Stylized view



Same system, two UIs - different tasks

Geographic view



Stylized view



> "How close in km are these stations?"

Same system, two UIs - different tasks

Geographic view



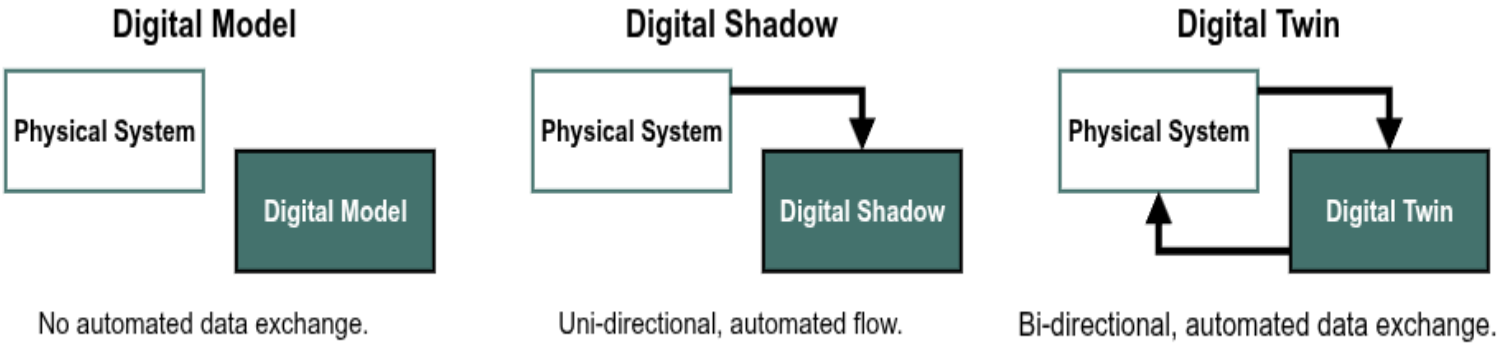
Stylized view



> How many stations are there between two stations?
>
> How many line changes between two stations?

Digital Twins

Three levels of integration[1]:



Important to consider also control beyond data

More recent definition[2]:

> "a set of models and data associated with the Physical System (Actual System) that enables the creation of a set of services"

[1] Kritzinger, W., Karner, M., Traar, G., Henjes, J., Sihn, W.: Digital Twin in manufacturing: A categorical literature review and classification. IFAC-PapersOnLine 51(11), 1016–1022. https://doi.org/10.1016/j.ifacol.2018.08.474

[2] Eramo, R., Bordeleau, F., Combemale, B., Brand, M. van den, Wimmer, M., & Wortmann, A. (2022). Conceptualizing Digital Twins. IEEE Software, 39(2), 39. https://doi.org/10.1109/MS.2021.3130755

Specificities of Digital Twins

1.Continuous telemetry (**monitoring tasks**) - real-time visualization, situation awareness, abnormal-condition detection, without information overload

2.Actuation consequences (**commands tasks**)- feedback, traceability, confirmation, error prevention; a bad action propagates to the physical system

3.Inherent uncertainty (**probabilistic information**) - imperfect sensing, incomplete models, prediction errors; the UI must communicate confidence and alternatives, not just states

4.Non-static systems[4] (**dynamic systems**) - the PT evolves, contexts change, new data/models/services arrive; tasks themselves evolve from monitoring → prediction → diagnosis → decision support

[4] Alskaif, T., Babur, Ö., Bordeleau, F., Cleophas, L., Combemale, B., Denil, J., Haugen, Ø., Michael, J., Nguyen, P. H., Seceleanu, T., van den Brand, M., & Vangheluwe, H. (2025). Evolution at the Core of Digital Twin Engineering. Proceedings of the 2nd International Conference on Engineering Digital Twins, 1–6. https://inria.hal.science/hal-05221886

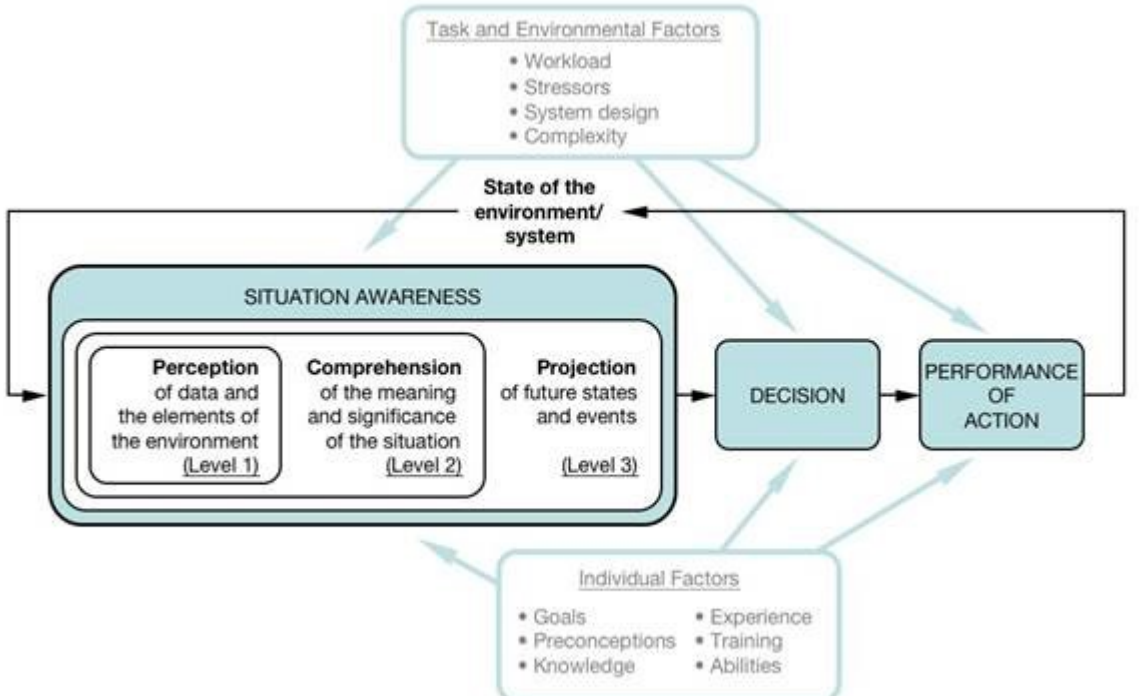
Specificities of Digital Twins

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2. Actuation co d action propagates to the physical sys

3. Inherent unc I must communicate confidence and

4. Non-static sy ive; **tasks themselves ev**



Endsley, M.R. (1995). Toward a theory of situation awareness in dynamic systems. Human Factors. 37 (1): 32–64. doi:10.1518/001872095779049543.

Specificities of Digital Twins

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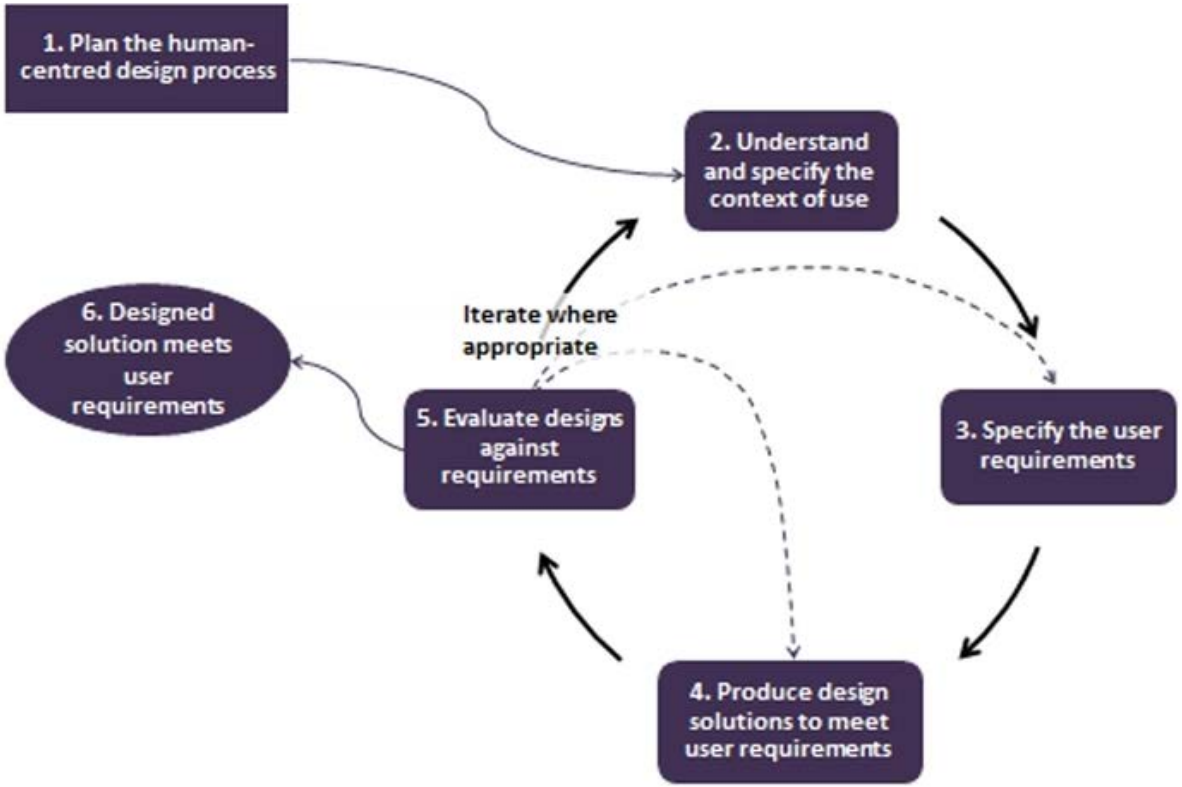
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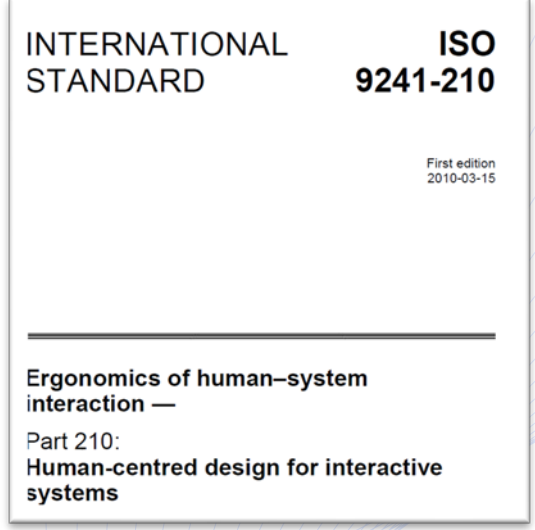
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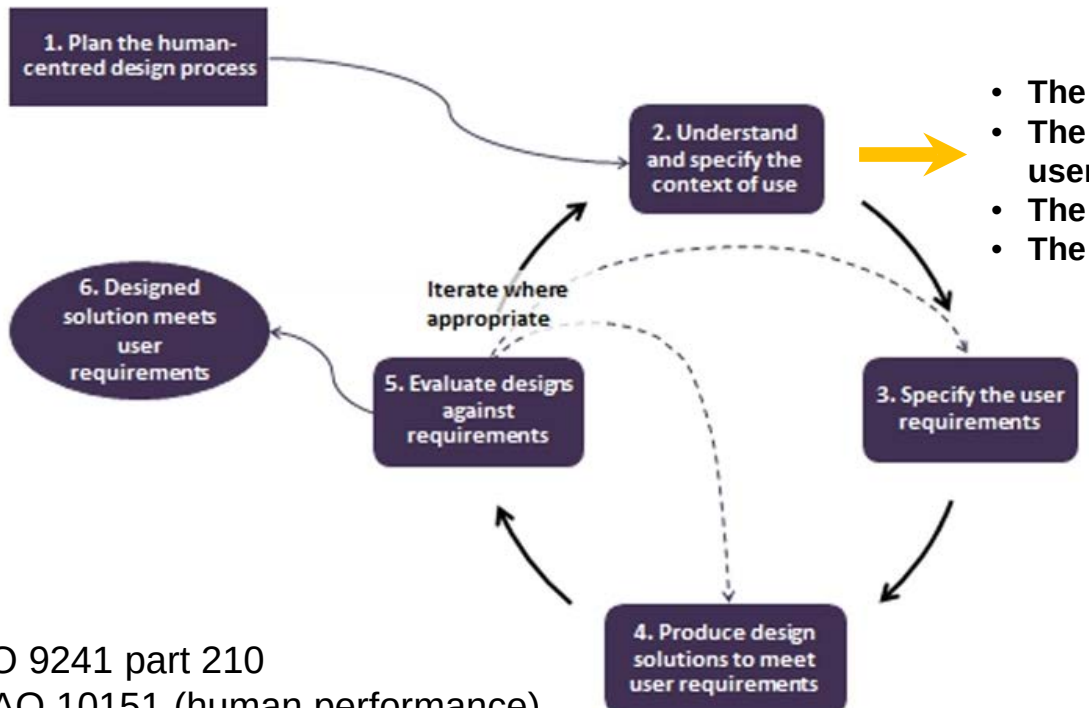
A quick overview of ISO 9241 HCD/UCD







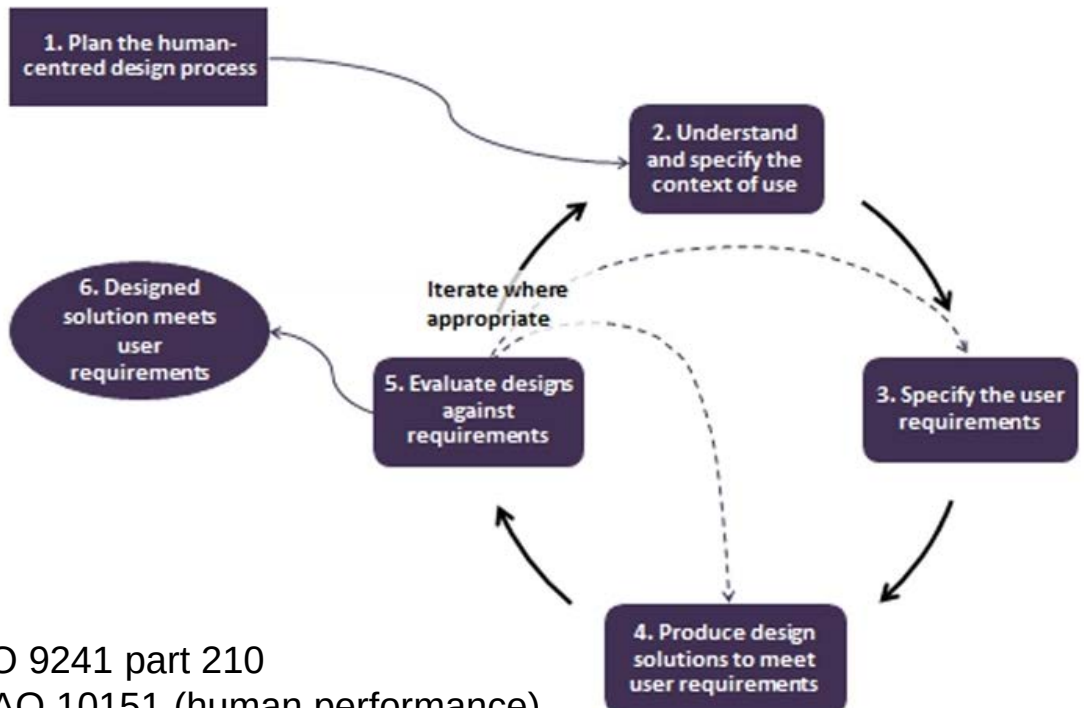
User Centred Design (standard ISO 9241)



- **The users and other stakeholder groups**
- **The characteristics of the users or groups of users**
- **The goals and tasks of the users**
- **The environment(s) of the system**

ISO 9241 part 210
ICAO 10151 (human performance)

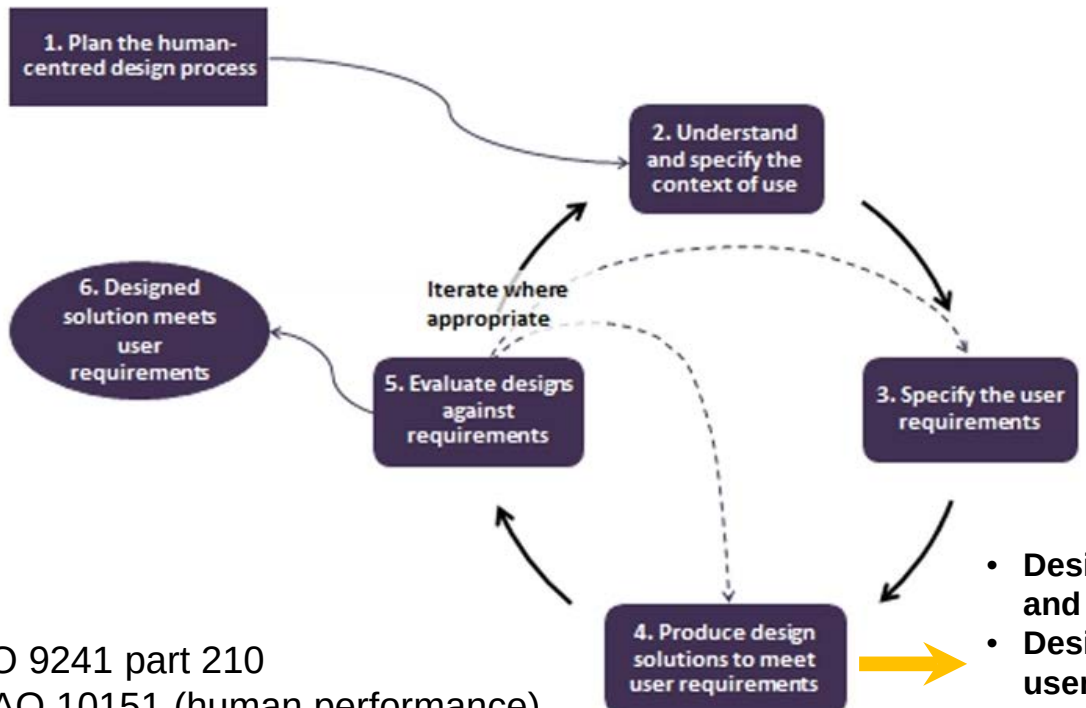
User Centred Design (standard ISO 9241)



- **Identifying user and other stakeholder needs**
- **Deriving user requirements**
- **Resolving trade-offs between user requirements**
- **Ensuring the quality of user requirements specifications**:

ISO 9241 part 210
ICAO 10151 (human performance)

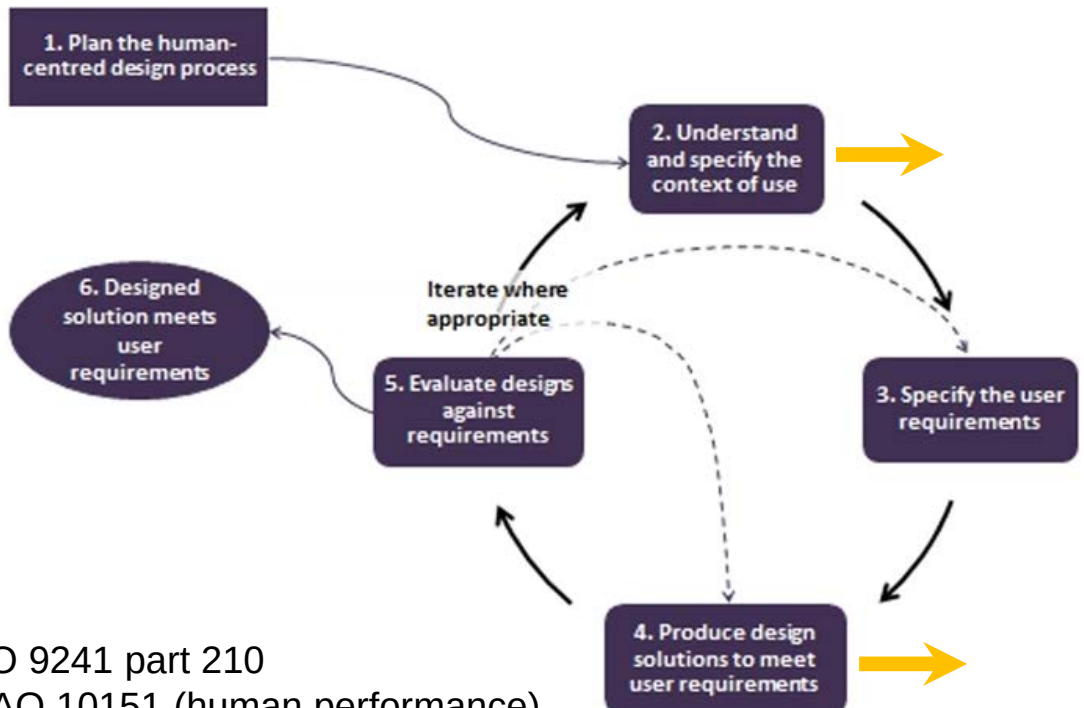
User Centred Design (standard ISO 9241)



ISO 9241 part 210
ICAO 10151 (human performance)

- **Designing user tasks, user–system interaction and user interface to meet user requirements …**
- **Designing the tasks and interaction between user and system**
- **…**

User Centred Design (standard ISO 9241)



ISO 9241 part 210
ICAO 10151 (human performance)

Analysis, understanding, modelling and exploitation of user tasks

as corner stone

of the design, development and evaluation of sociotechnical systems

Methods and tools for UCD/HCD

For each phase in the process, methods have been proposed

2. Understand and specify the context of use

- User interviews, Field studies, Observations, Focus Groups, Personas …

3. Specify the user requirements

- Requirements Languages, Requirements Engineering, MoSCoW method (**M**ust have, **S**hould have, **C**ould have, and **W**on't have), …

4. Produce design solutions to meet user requirements

- Card Sorting, Low-fidelity protoyping, High-precision prototyping, Design workshops, Wizzard of Oz…

5. Evaluate designs against requirements

- Summative or formative usability testing, Think-aloud protocols, A/B testing, Heuristic evaluation, SUS, …

Fundamental aspect of User Centered Design

Designs are always bad, but there are solutions

- User at the centre
- User needs not user requirements
- Iterations in desgns with evaluations



Fundamental aspect of User Centered Design

Designs are always bad, but there are solutions

- User at the centre
- User needs not user requirements
- Iterations in design with evaluations



Why UCD needs to be extended

First UCD activity specifies users, tasks and environment.

- Users → users → … Some users are known at design time, DT data and associated fuctions attracts new users it was not built for.
- Tasks → Users assemble them from the Generic UIs. They cannot be fully specified at design time.
- Environment → DT evolves, the tasks grow and evolve with it.

> UCD for DTs needs a continuous, usage-based method to support the specification of the context of use.

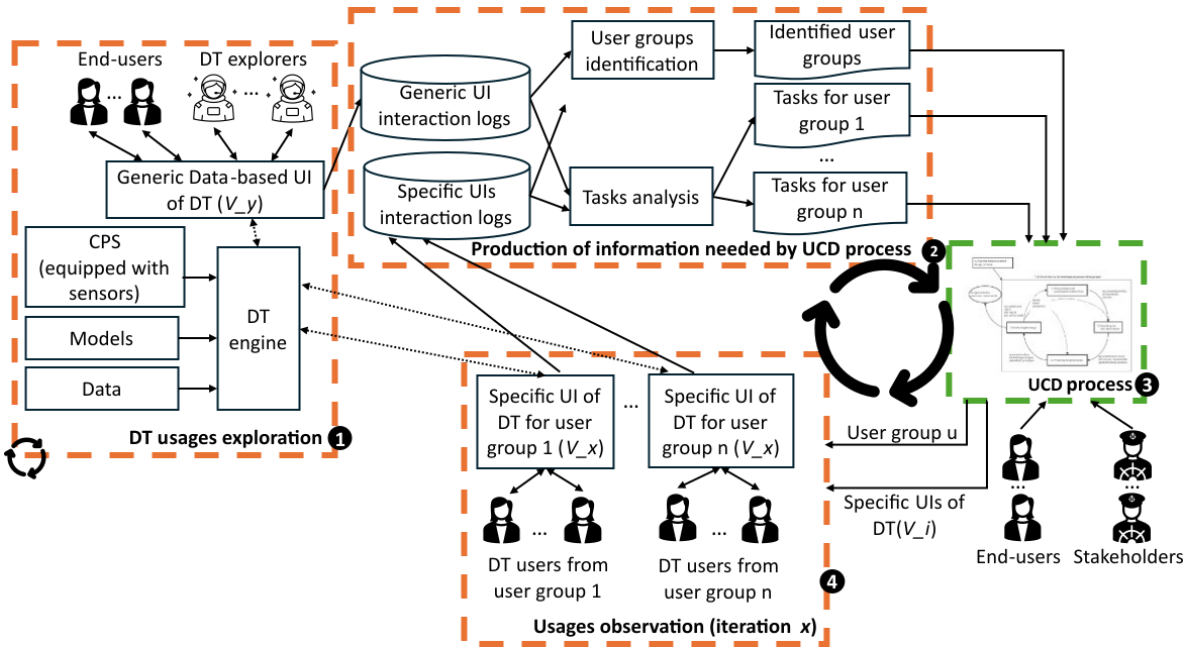
Our contribution: a tuned-for-DT UCD process

3 phases that produce the context of use from usage.

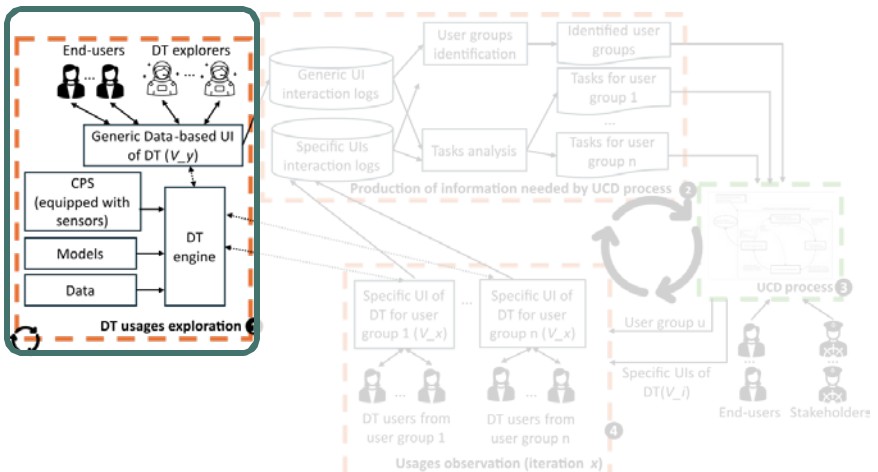
Explore → Generic UI lets users compose their own tasks.

Analyse → Candidate user groups and their tasks.

Observe → Specific UIs stay instrumented; the loop allows refinment.



The tuned process, step by step



Step 1: DT Usage exploration

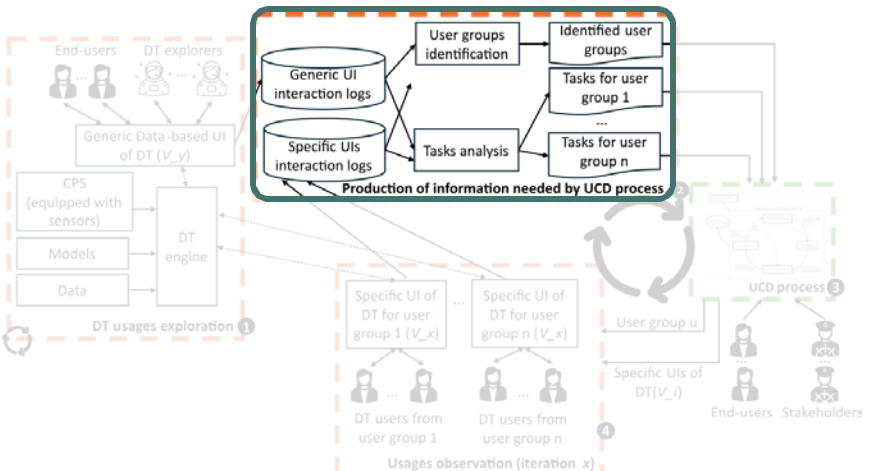
Exploration of the generic UI:

- Generic data-based tasks, e.g., dataviz, data querying
- DT model interaction, e.g., 3D model, map visualization

> Input: Generic data-centric/model-centric UI

> Output: Interaction logs

The tuned process, step by step



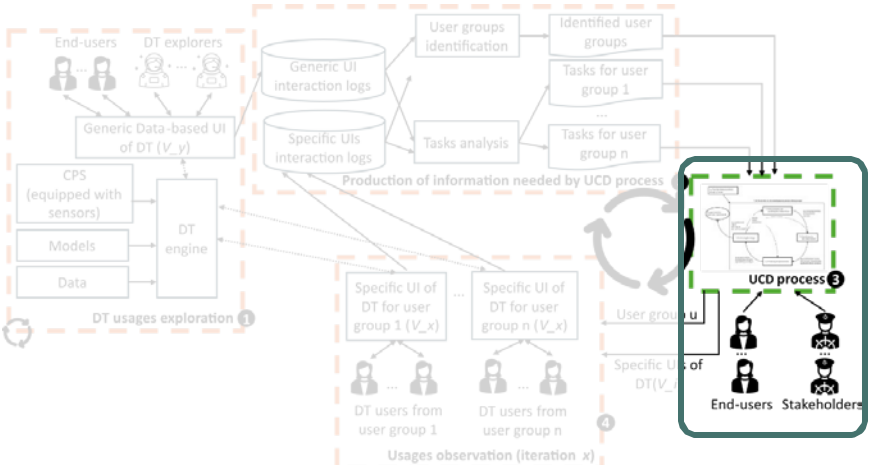
Step 2: Producing user groups and tasks

- Analyzing usage → potential user groups + their tasks
- Logs give *sequences*, not *intent* → complement with interviews

> Input: Usage data (interaction logs)
>
> - for generic UIs
> - for specific UIs

> Output: Potential user groups and associated tasks

The tuned process, step by step



Step 3: UCD process per user group

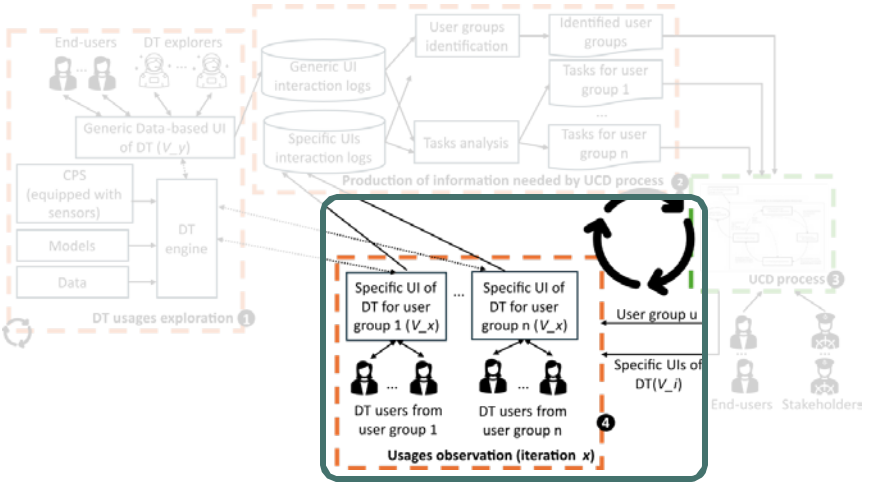
Apply the standard UCD process:

- With eager users
- Identified user group members
- Prototype evaluated with users from the group
- Ends when the prototypes fit user needs

> Input: Identified user groups and their tasks

> Output: Dedicated UIs P for user groups U for performing associated tasks T

The tuned process, step by step



Step 4: Usages observation over user groups

Exploration of the specific UIs:

- By real operators, performing real specific tasks
- Interactions logged → back to step 2

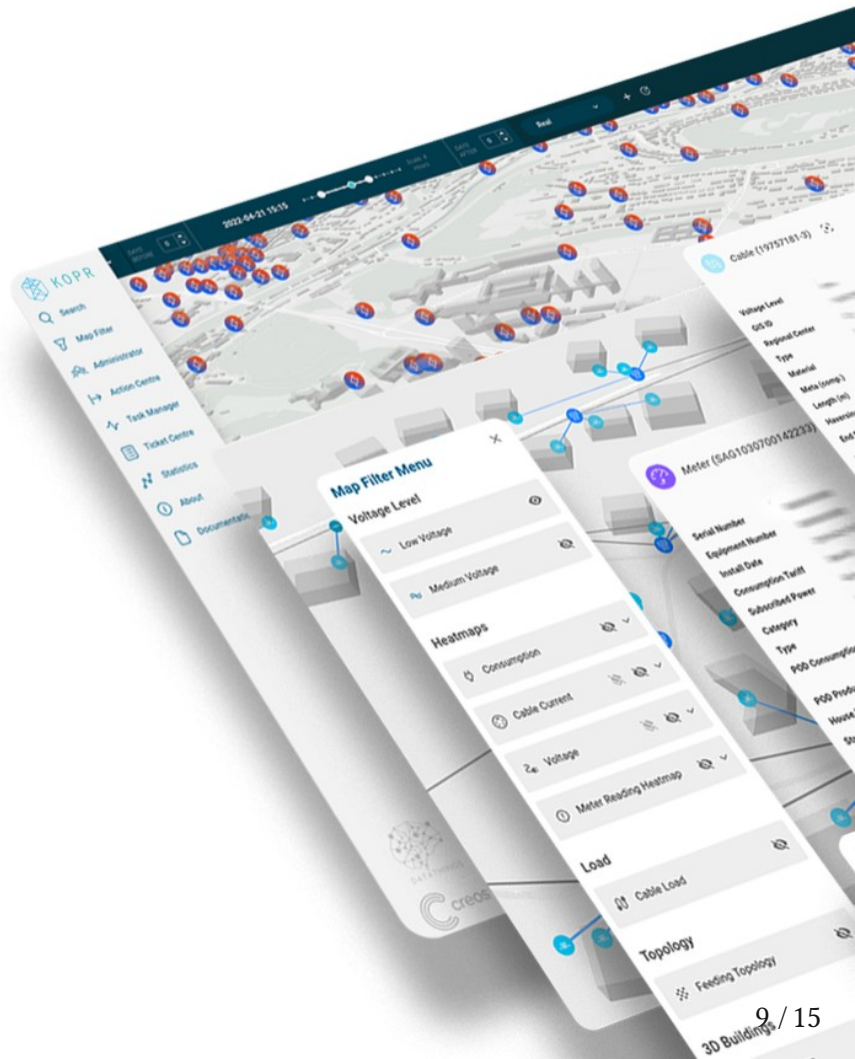
> Input:
> - Specific workflow UIs P
> - Associated user groups U

> Output: Interaction logs

Kopr case-study

- DT for supervision and operational analysis
- Aggregates GIS, metering infrastructure, real-time sensors
- > 50 billion temporal data points / year

> Context: renewable transition + rapid infrastructure growth → the DT's purpose keeps expanding.



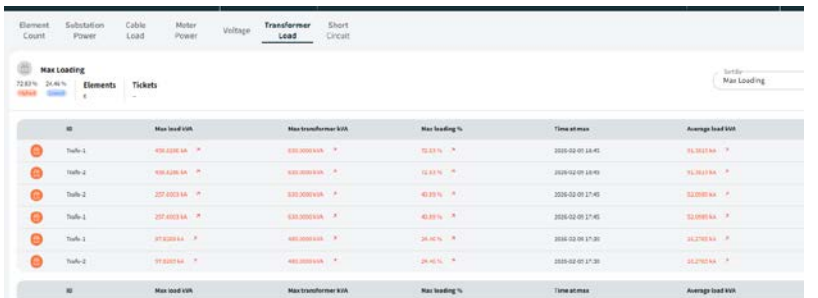
https://kopr-twin.com/

Generic UIs support multiple users' tasks

Map view



Tabular view



Grid planners → Evaluate risk areas on the low-voltage network

Long-term planners → Anticipate future demand in electricity

Maintenance managers → deploy corrective actions

> Very generic → not Efficient nor Effective for specialized user tasks.

Specialized workflows

Before the DT

- Manual, multi-tool: GIS → PowerFlow → load Profiles → computations
- Weeks, error-prone

After the DT

- Single popup, automated simulation
- Minutes, one-click validation

> Same task. From weeks of manual tool-hopping to a one-click validated decision.

> Better Efficiency and less Error → improved usability

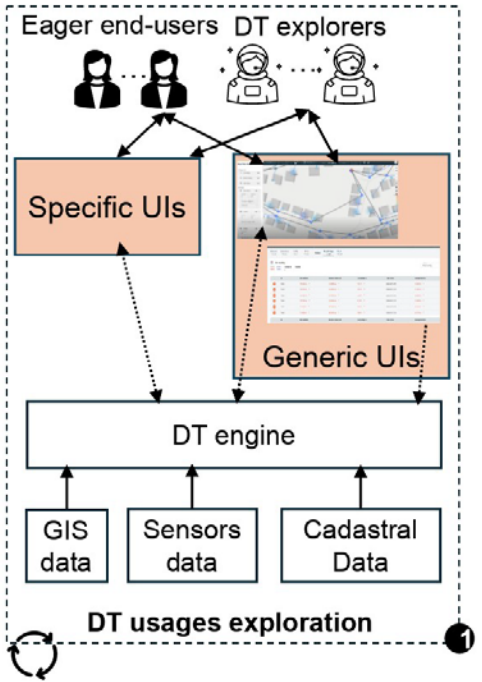
What standard UCD missed here

Within the same workflow, users split into two informational needs

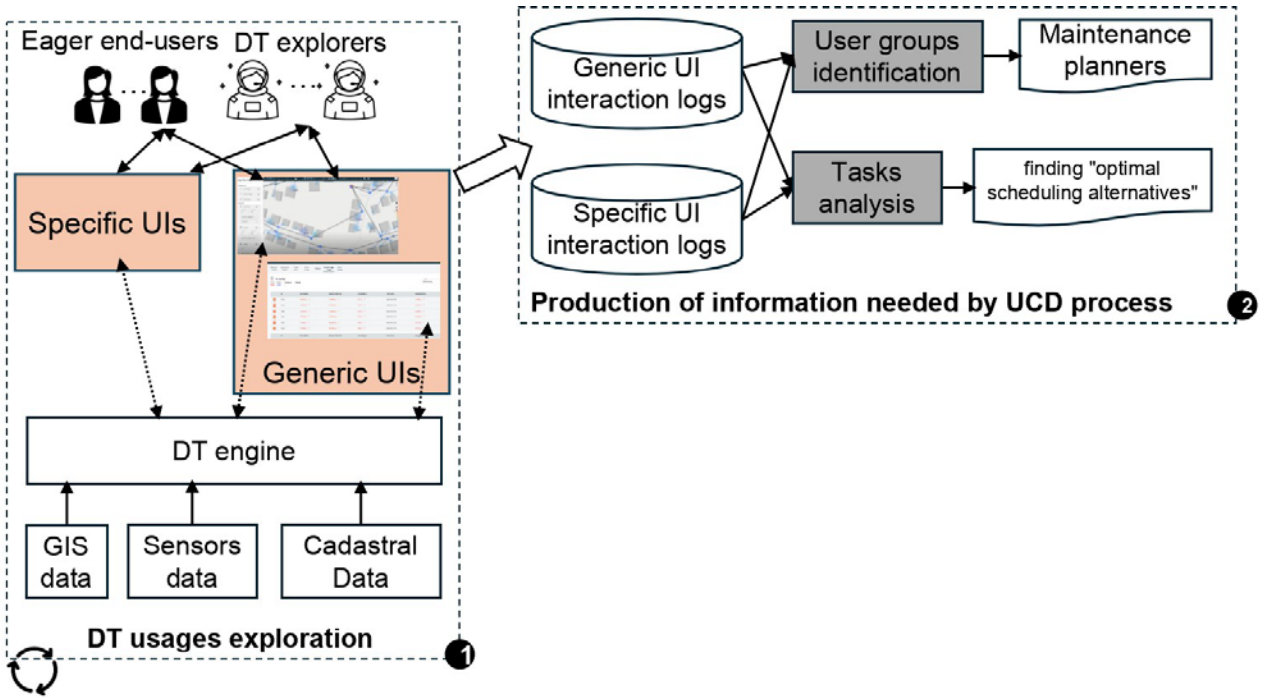
- Some users seek detailed inspection: cable type, safety margins, exact currents, time at max
- Others prioritize higher level inspection

> Why? UCD treats roles as fixed entities, not evolving groups, did not identify diverging needs.

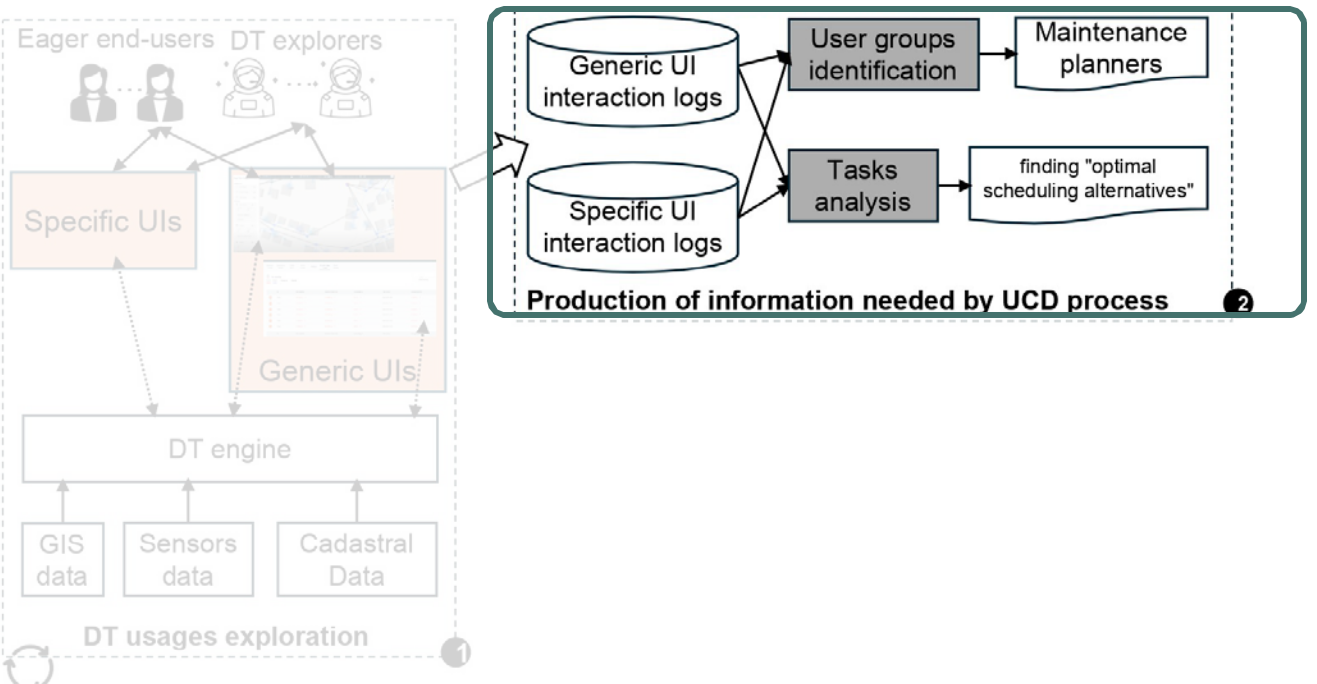
The tuned process applied: Maintenance Planning



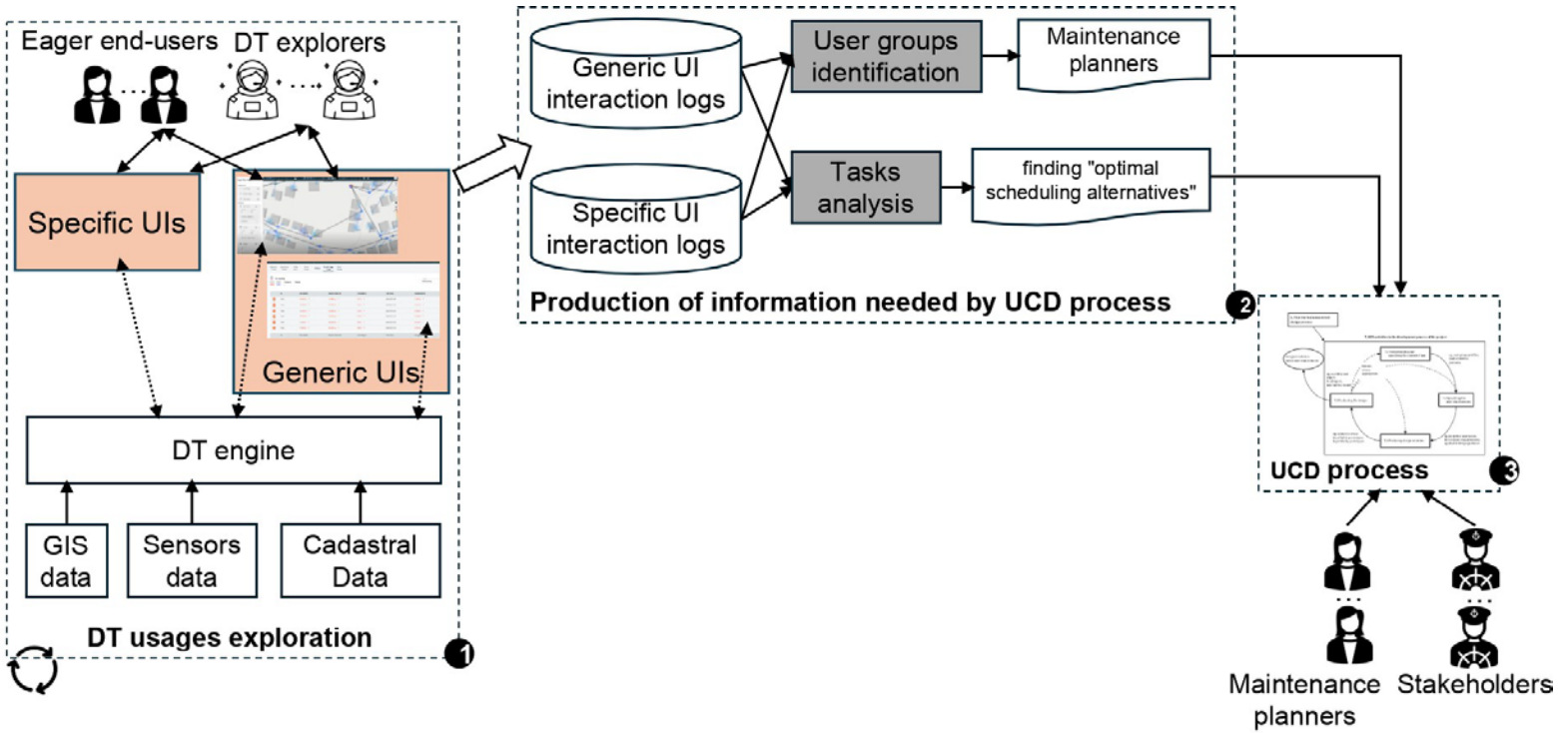
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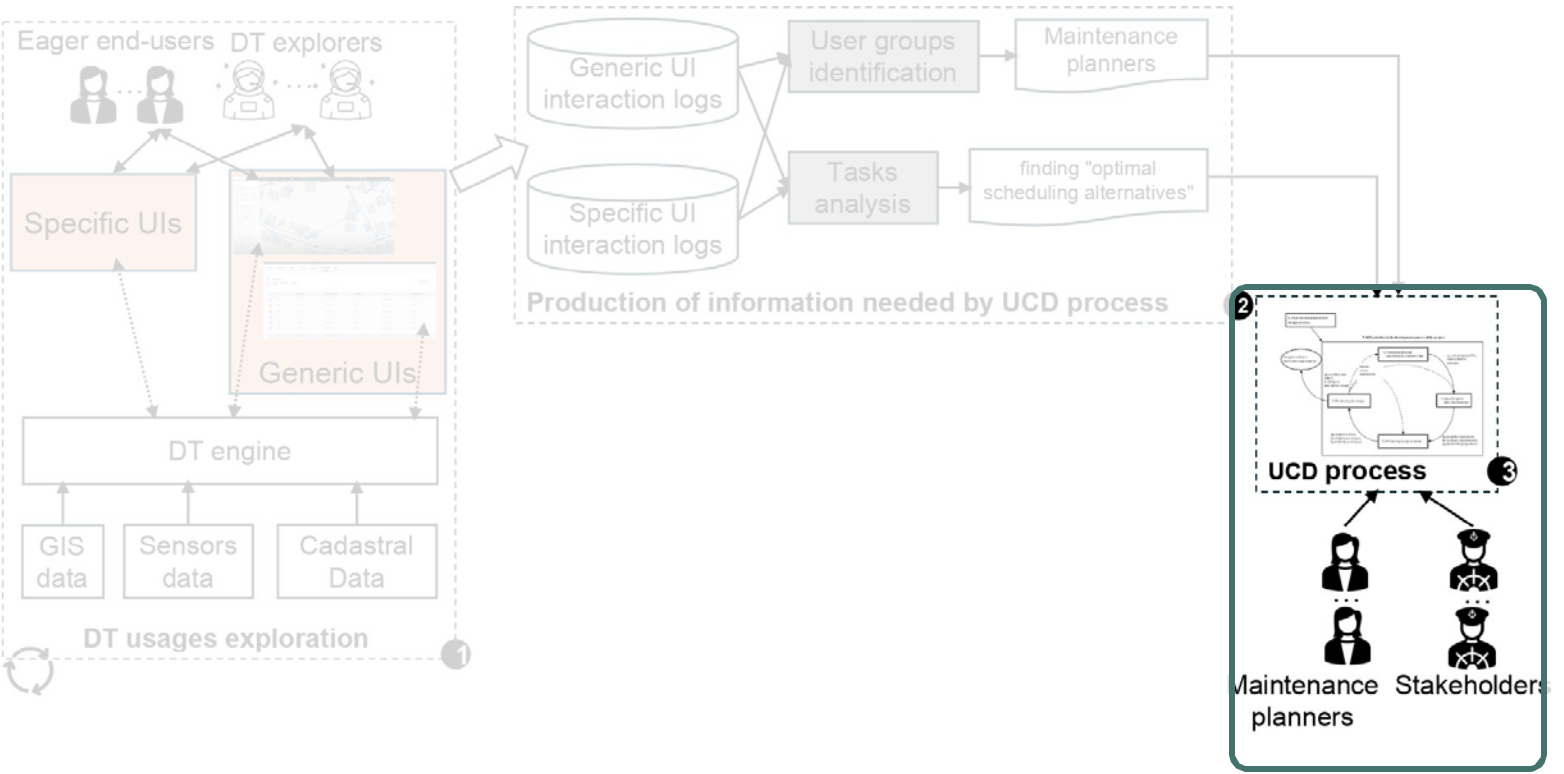
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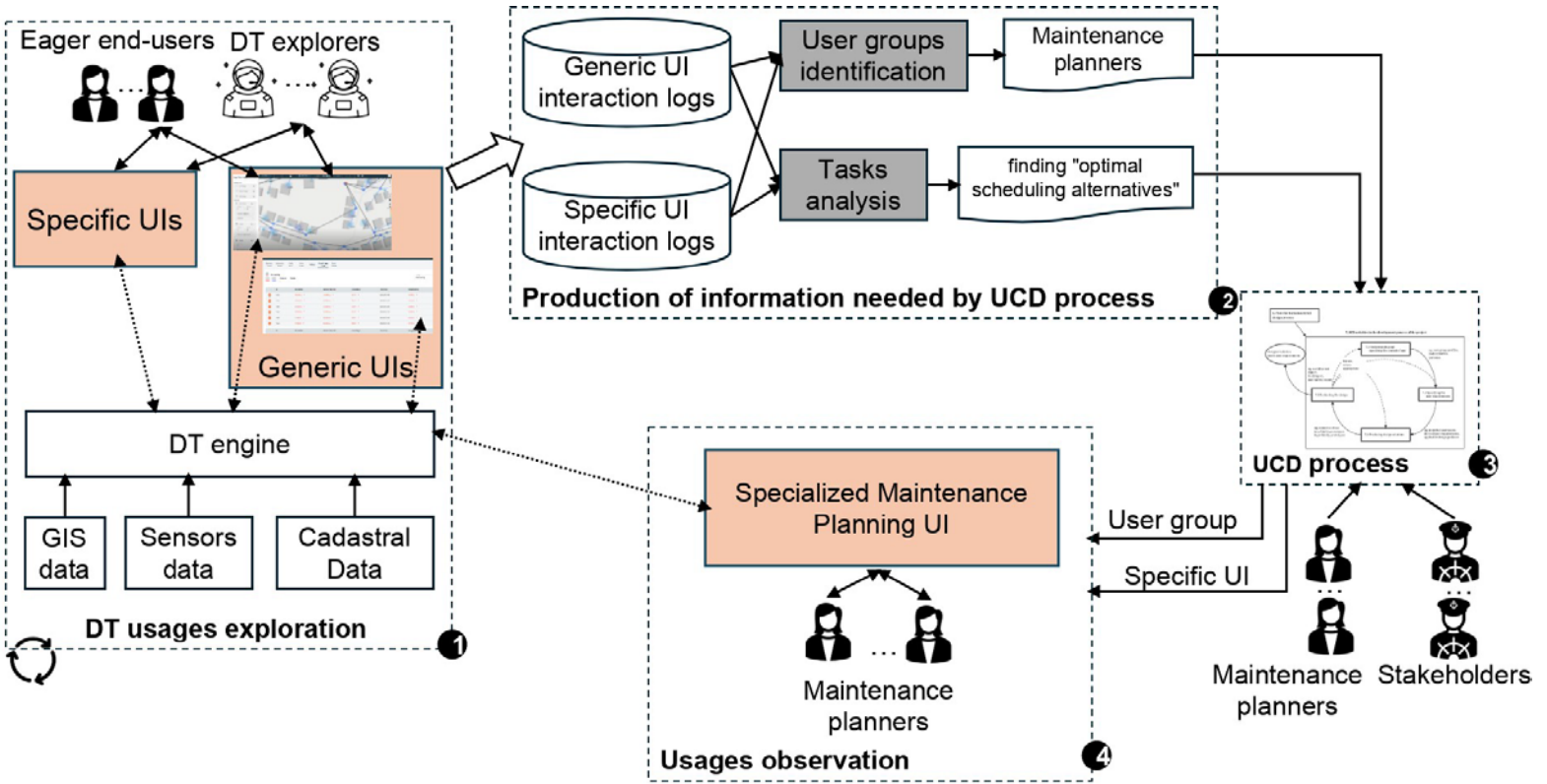
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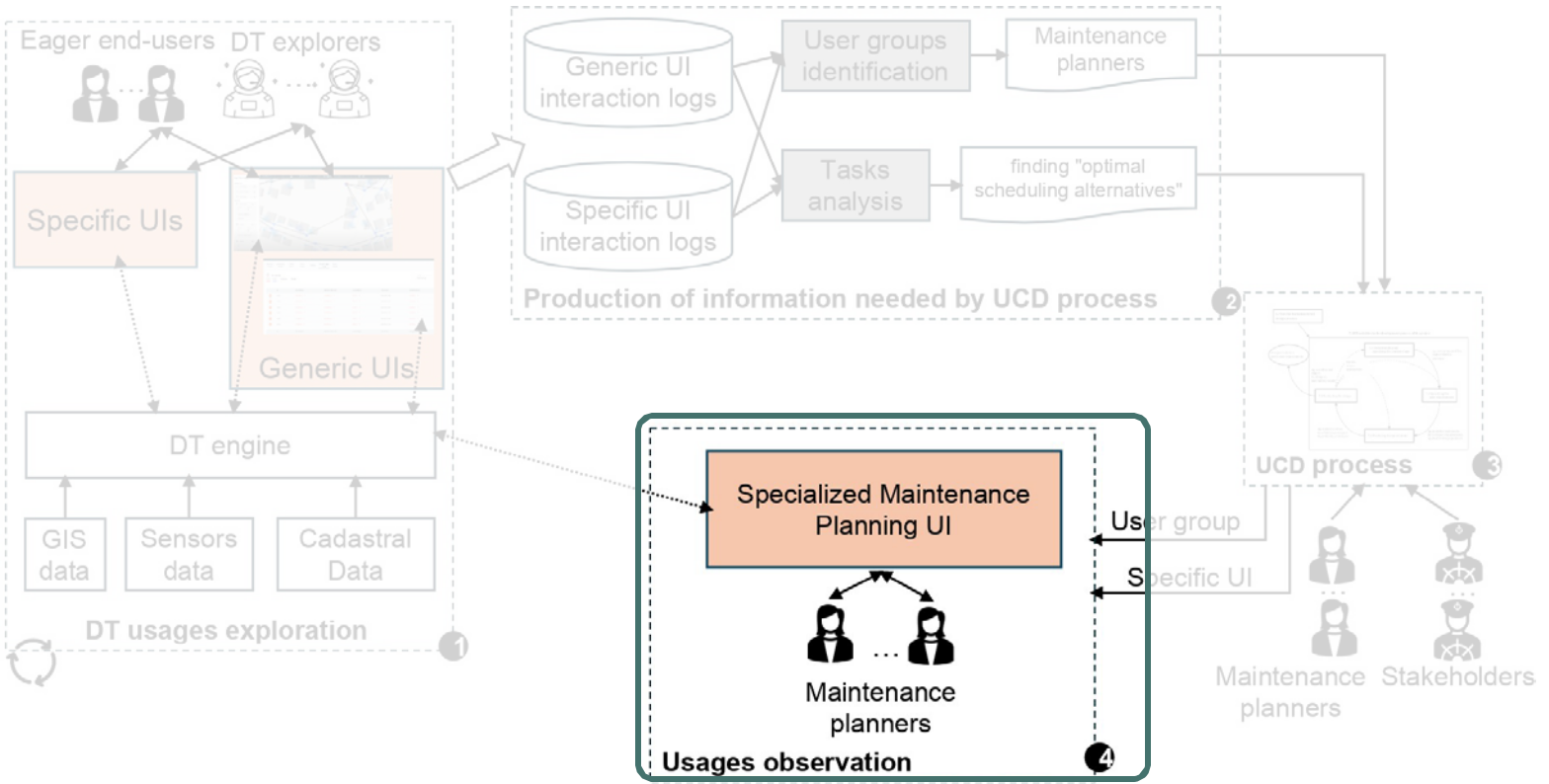
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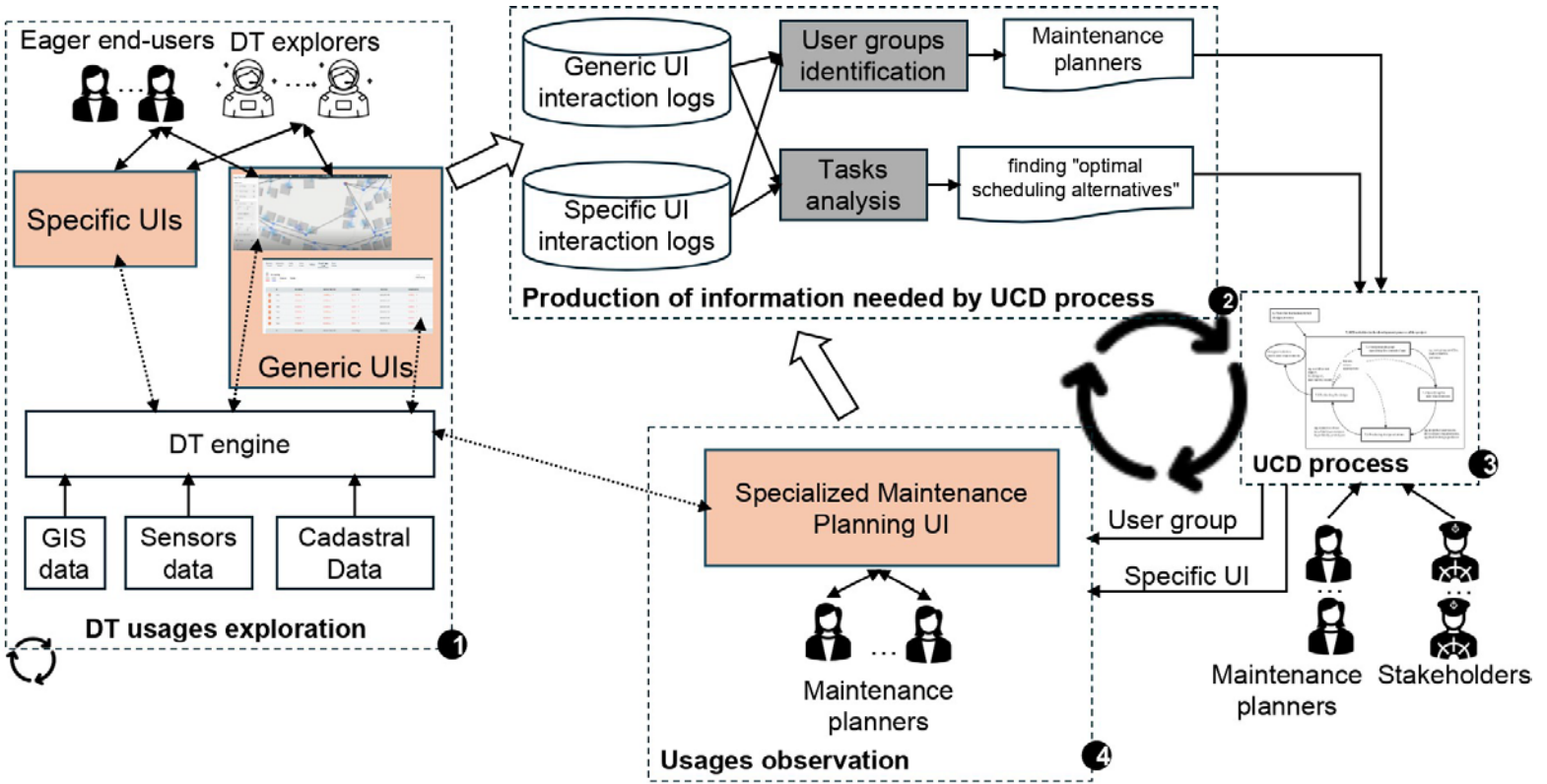
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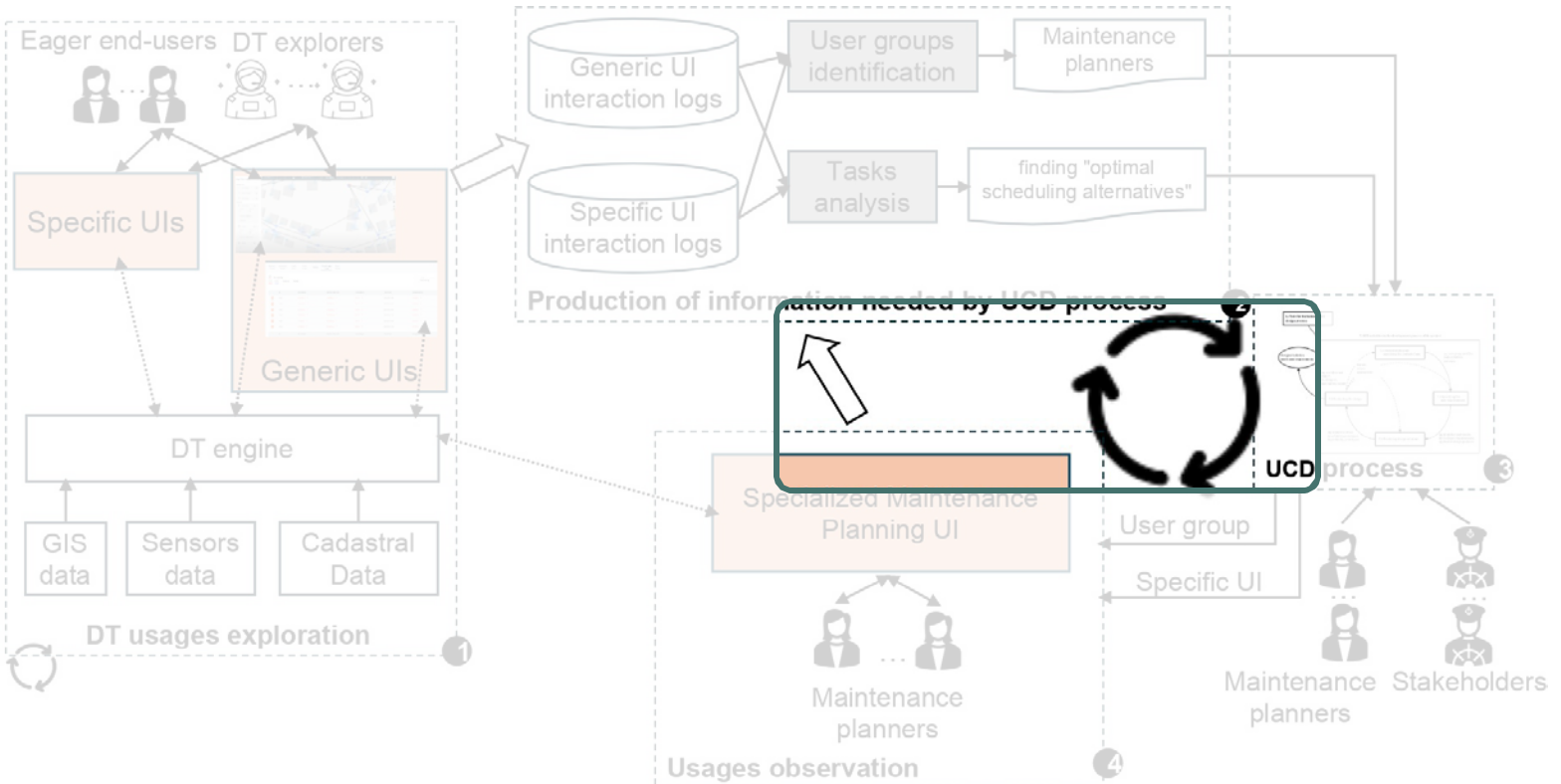
The tuned process applied: Maintenance Planning



The tuned process applied: Maintenance Planning



The tuned process applied: Maintenance Planning



Conclusion and future work

Problems

- DTs' UIs require dedicated methods to deal with the evolution of user needs and tasks.
- UCD methods are not good at identifying NEW user groups .
- UCD methods are not good for identifying tasks that are not known by users

Contribution A tuned-for-DT UCD process

- Explore → generic UI, instrumented
- Analyse → patterns become user groups and tasks
- Observe → specific UIs stay instrumented

Future work

- Develop new methods to support the identification of potential user groups and complex tasks
- Apply this tuned-for-DT approach to more use-cases
- Develop specific User Interfaces for each user group exploiting **similarity** and supporting **learnability** and **automaticity**

Conclusion and future work

F. Xavier Gaya-Morey, Cristina Manresa-Yee, Philippe Palanque, Célia Martinie, Camille Fayollas. Agentic AI: Understanding its Impact on Automation and Automaticity Workshop on Engineering Interactive Systems Embedding AI Technologies (EISEAIT), ACM Engineering Interactive Computin Systems conference.

Campos, J. C., Palanque, P., Rodriguez Hernando, D., Martinie, C., & Steere, S. (2026). Beyond" Do-They-Look-the-Same?" to" Do-They-Behave-The-Same?": Similarity Analysis and Assessment Across Interactive Critical Systems Behaviours. *Proceedings of the ACM on Human-Computer Interaction*, *10*(4), 1-35.

Future work

Saubanère, T., Martinie, C., Barboni, E., Palanque, P., Poupart, E., & Steere, S. (2026). Beyond monkey using: how to identify and model training needs of interactive critical systems operators using an ontology connected with task models. Proceedings of the ACM on Human-Computer Interaction, 10(4), 1-24.

and

Merci pour votre attention

Questions?

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Kopr: https://kopr-twin.com/

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Paper: *hal-05701147*

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