Welche Komponenten benötigt eine erfolgreiche digitale Technologie zur Leckage-Erkennung?

E. Steins, S. Persigehl, D. Steffelbauer,
E. Campbell, J. Koslowski, N. Langer,
and A. Cominola

June 2024

Project Partners:

Funded by:

Richard Webb / Burst water main / https://commons.wikimedia.org/wiki/File:Burst_water_main_(geograph_2646387).jpg

Problem: Leckagen

Europa:

. ca. ~25% Verlust des Wassers durch Leckagen

Weltweit:

. Spitzenwerte von >50%

. 126 Mrd. m^3 Wasser gehen pro Jahr verloren, Kosten von ca. 39 Milliarden USD

Praktische Anwendung

Akustische Technologie vor Ort

⟺

Wissenschaftliche Anwendung

Digitale Technologien

Online & Echtzeitanwendung

Viele fallspezifische Studien ohne Open-Access-Daten

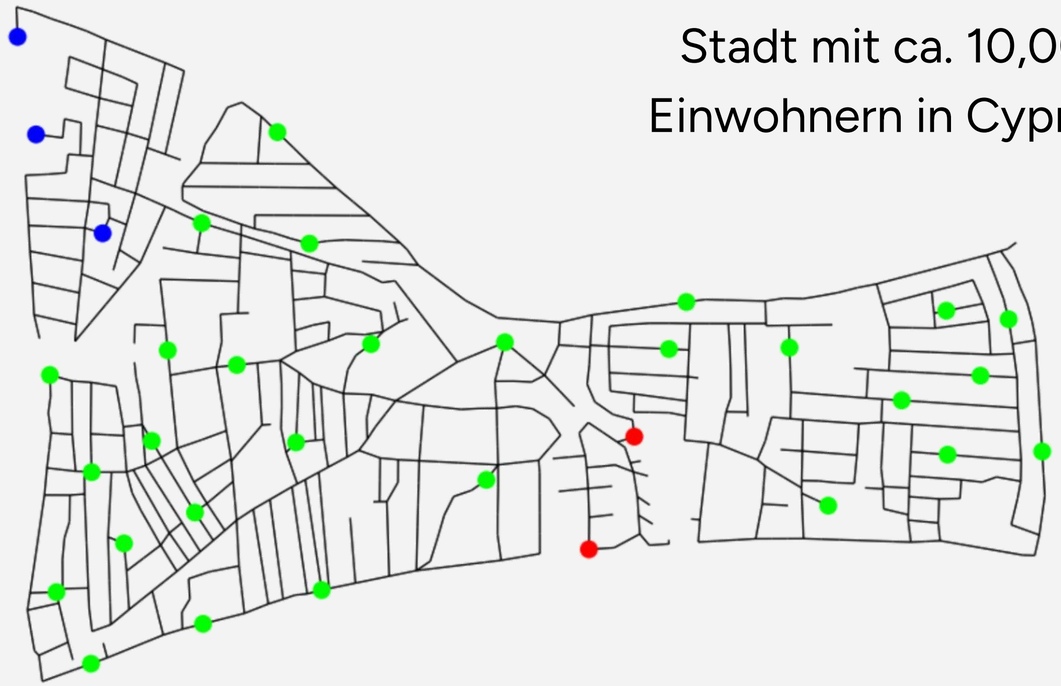
[1] Puust, R., Kapelan, Z., Savic, D. A., & Koppel, T. (2010). A review of methods for leakage management in pipe networks. *Urban Water Journal*, *7*(1), Article 1. https://doi.org/10.1080/15730621003610878

[2] Liemberger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. *Water Supply*, *19*(3), Article 3. https://doi.org/10.2166/ws.2018.129

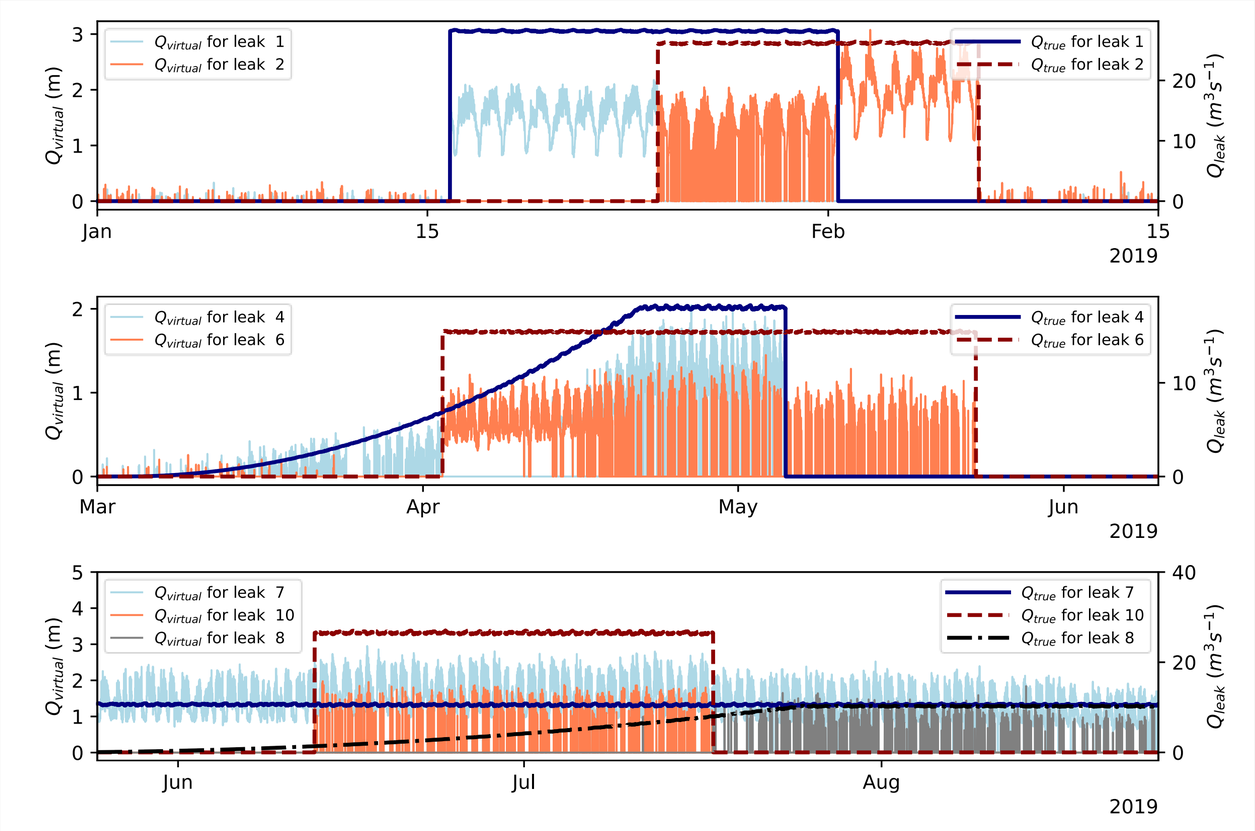
[3] Vrachimis, S. G., Eliades, D. G., Taormina, R., Kapelan, Z., Ostfeld, A., Liu, S., Kyriakou, M., Pavlou, P., Qiu, M., & Polycarpou, M. M. (2022). Battle of the Leakage Detection and Isolation Methods. *Journal of Water Resources Planning and Management*, *148*(12), 04022068. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001601

BattLeDIM 2020

Battle of the Leakage Detection and Isolation Methods



Stadt mit ca. 10,000 Einwohnern in Cyprus



- ✓2 Wasserreservoire
- ✓3 DMAs
- ✓33 Drucksensoren
- ✓82 AMR Sensoren
- ✓19 Leckagen (2019)

Digitale Leckage-Erkennungstechnologie

“das beste aus beiden welten”

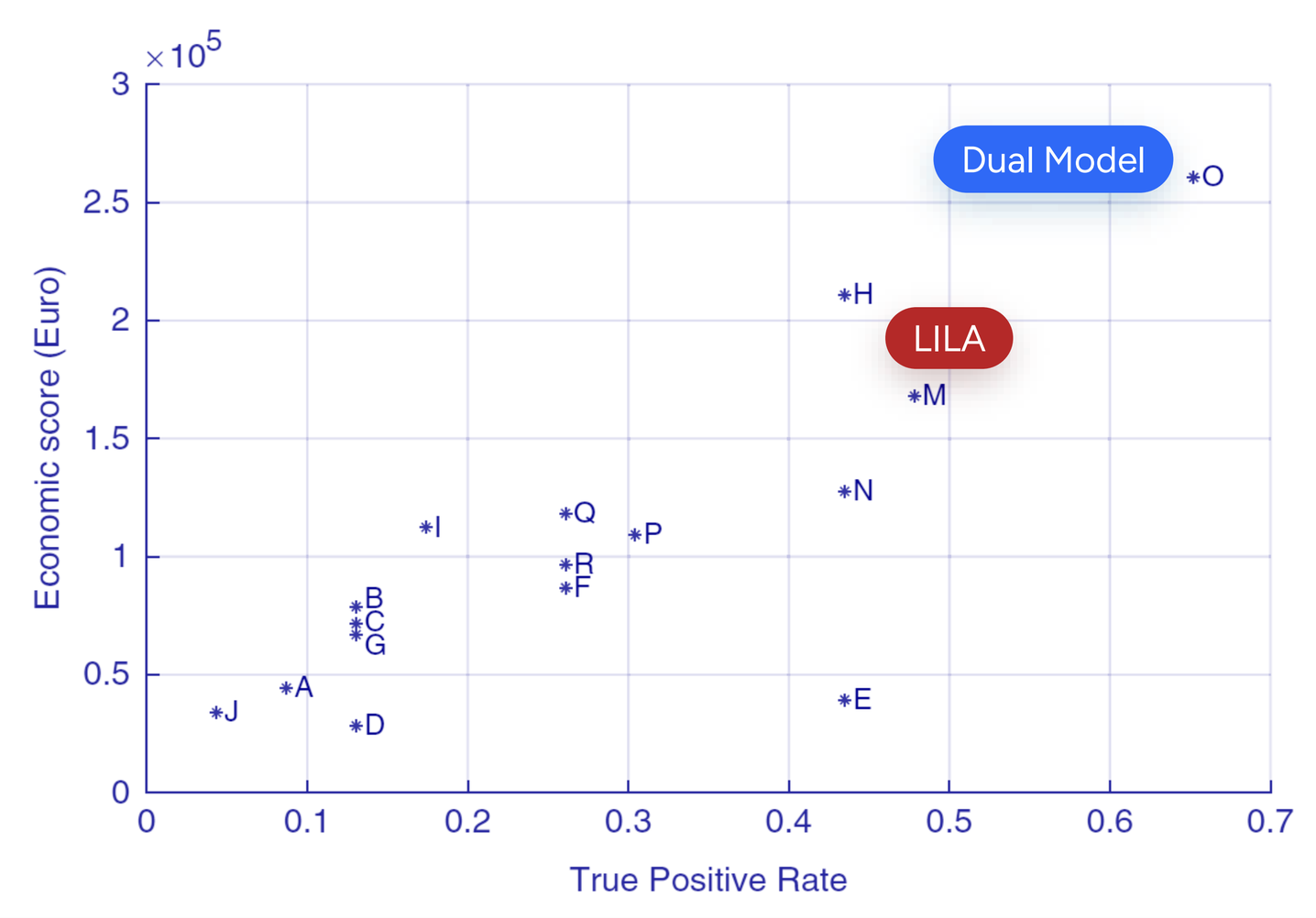


Figure Credits: D. Steffelbauer (KWB)

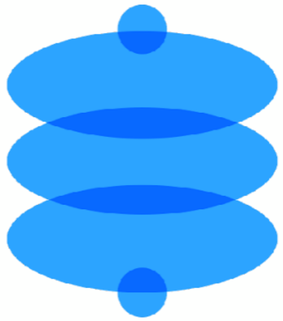
Steffelbauer, D. B., J. Deuerlein, D. Gilbert, E. Abraham, and O. Piller. 2022.
“Pressure-Leak Duality for Leak Detection and Localization in Water Distribution Systems.”
J. Water Resour. Plann. Manage., 148 (3): 04021106.
https://doi.org/10.1061/(ASCE)WR.1943-5452.0001515.

Daniel, I., J. Pesantez, S. Letzgus, M. A. Khaksar Fasaee, F. Alghamdi, E. Berglund, G. Mahinthakumar, and A. Cominola. 2022.
“A Sequential Pressure-Based Algorithm for Data-Driven Leakage Identification and Model-Based Localization in Water Distribution Networks.” *J. Water Resour. Plann. Manage.*, 148 (6): 04022025.
https://doi.org/10.1061/(ASCE)WR.1943-5452.0001535.

Welche Komponenten benötigt eine erfolgreiche digitale Technologie zur Leckage-Erkennung?

iOLE

intelligente Online
LEckage detection

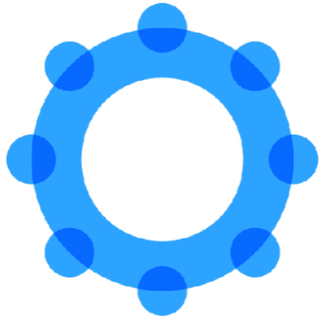


INTEGRIERT

iOLE kombiniert modellbasierte und datengesteuerte Leckage-Algorithmen

ROBUST

Robuste Leckageerkennung durch globale Sensitivitätsanalyse



HUMAN-CENTERED

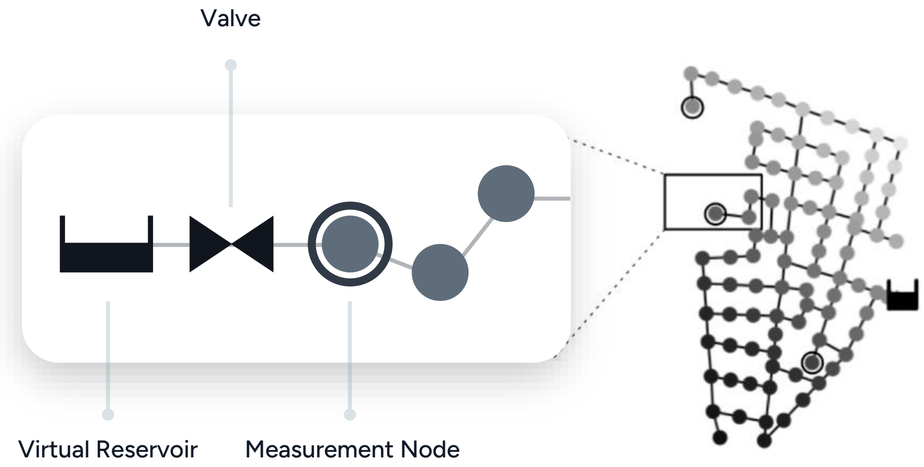
Software-Entwicklung mit human-centered Design-Ansatzes unter Einbeziehung des Konzepts der Benutzererfahrung

Technologie der Leckage-Erkennung

Digitale Leckage-Erkennungstechnologie

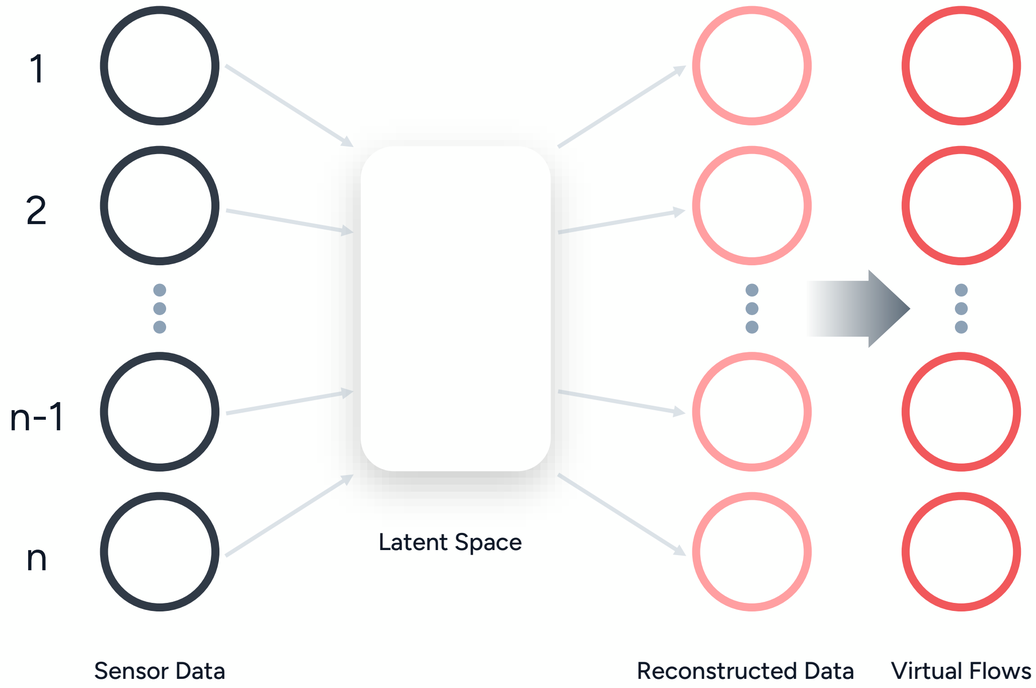
modellbasiert + datengesteuert

Dual Model



Steffelbauer, D. B., J. Deuerlein, D. Gilbert, E. Abraham, and O. Piller. 2022.
“Pressure-Leak Duality for Leak Detection and Localization in Water Distribution Systems.”
J. Water Resour. Plann. Manage., 148 (3): 04021106.
https://doi.org/10.1061/(ASCE)WR.1943-5452.0001515.

LILA



Daniel, I., J. Pesantez, S. Letzgus, M. A. Khaksar Fasaee, F. Alghamdi, E. Berglund, G. Mahinthakumar, and A. Cominola. 2022.
“A Sequential Pressure-Based Algorithm for Data-Driven Leakage Identification and Model-Based Localization in Water Distribution Networks.” *J. Water Resour. Plann. Manage.*, 148 (6): 04022025.
https://doi.org/10.1061/(ASCE)WR.1943-5452.0001535.

Digitale Leckage-Erkennungstechnologie

modellbasiert + datengesteuert

Dual Model

KWB Kompetenzzentrum Wasser Berlin

Schätzung von Wasserbedarf & Rauhigkeit

Hydraulisches Modell

“Primal” und “Dual Model”

Leckage: “Virtual flows”
(zusätzlicher Outflow des Dual Models)

➔ Identifikation und Lokalisierung der Leckage

Steffelbauer, D. B., J. Deuerlein, D. Gilbert, E. Abraham, and O. Piller. 2022.
“Pressure-Leak Duality for Leak Detection and Localization in Water Distribution Systems.”
J. Water Resour. Plann. Manage., 148 (3): 04021106.
https://doi.org/10.1061/(ASCE)WR.1943-5452.0001515.

LILA

Technische Universität Berlin

Lineare Regression zur Schätzung des Drucks
basierend auf Bernoulli
(kein hydraulisches Modell)

Reconstruction Error Analysis
(mit Druckdaten)

Change Point Detection

➔ Identifikation der Leckage

➔ Ungefähre Lokalisation der Leckage im zweiten Schritt möglich

Daniel, I., J. Pesantez, S. Letzgus, M. A. Khaksar Fasaee, F. Alghamdi, E. Berglund, G. Mahinthakumar, and A. Cominola. 2022.
“A Sequential Pressure-Based Algorithm for Data-Driven Leakage Identification and Model-Based Localization in Water Distribution Networks.” *J. Water Resour. Plann. Manage.*, 148 (6): 04022025.
https://doi.org/10.1061/(ASCE)WR.1943-5452.0001535.

Digitale Leckage-Erkennungstechnologie

modellbasiert + datengesteuert

Dual Model

KWB Kompetenzzentrum Wasser Berlin

Schätzung von Wasserbedarf & Rauhigkeit −

Hydraulisches Modell

“Primal” und “Dual Model”

Leckage: “Virtual flows”
(zusätzlicher Outflow des Dual Models)

➔ Identifikation und Lokalisierung der Leckage +

Steffelbauer, D. B., J. Deuerlein, D. Gilbert, E. Abraham, and O. Piller. 2022.
“Pressure-Leak Duality for Leak Detection and Localization in Water Distribution Systems.”
J. Water Resour. Plann. Manage., 148 (3): 04021106.
https://doi.org/10.1061/(ASCE)WR.1943-5452.0001515.

LILA

Technische Universität Berlin

Lineare Regression zur Schätzung des Drucks
basierend auf Bernoulli
(kein hydraulisches Modell) +

Reconstruction Error Analysis
(mit Druckdaten)

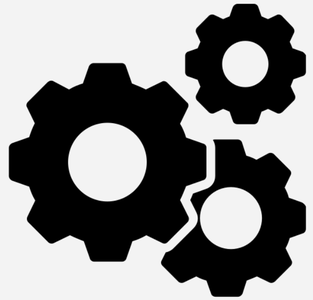
Change Point Detection

➔ Identifikation der Leckage

➔ Ungefähre Lokalisation der Leckage im zweiten Schritt möglich −

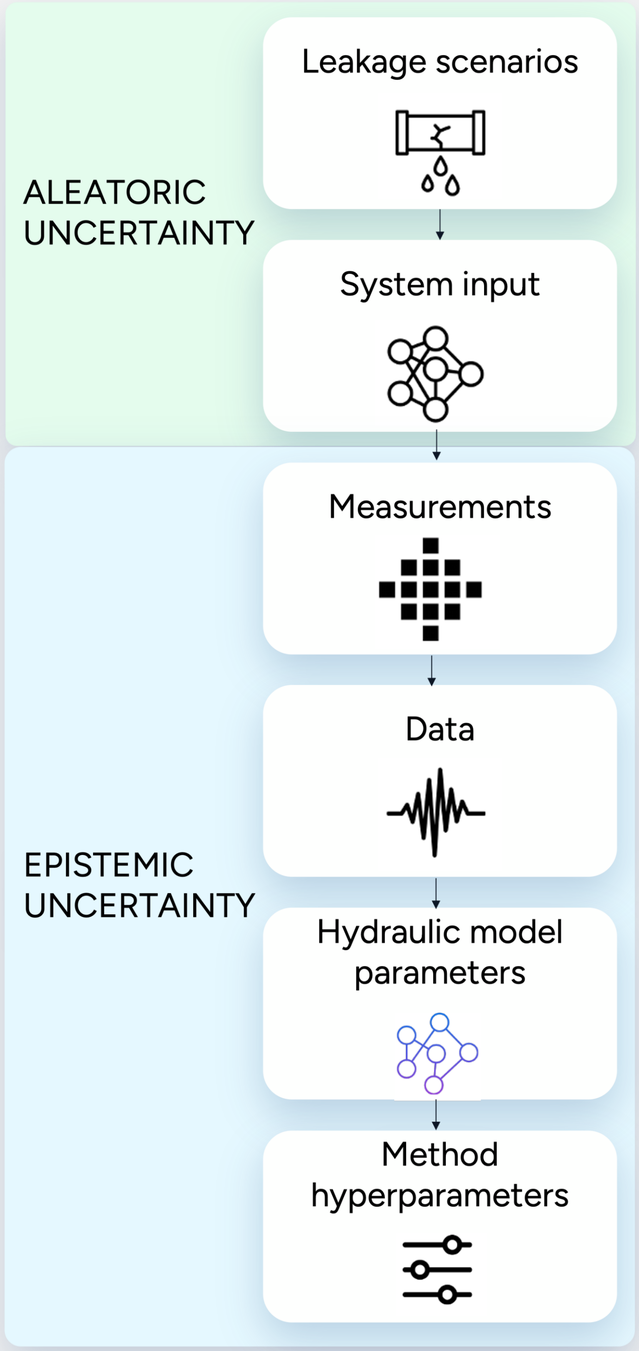
Daniel, I., J. Pesantez, S. Letzgus, M. A. Khaksar Fasaee, F. Alghamdi, E. Berglund, G. Mahinthakumar, and A. Cominola. 2022.
“A Sequential Pressure-Based Algorithm for Data-Driven Leakage Identification and Model-Based Localization in Water Distribution Networks.” *J. Water Resour. Plann. Manage.*, 148 (6): 04022025.
https://doi.org/10.1061/(ASCE)WR.1943-5452.0001535.

iOLE



Robustheit

Globale Sensitivitätsanalyse



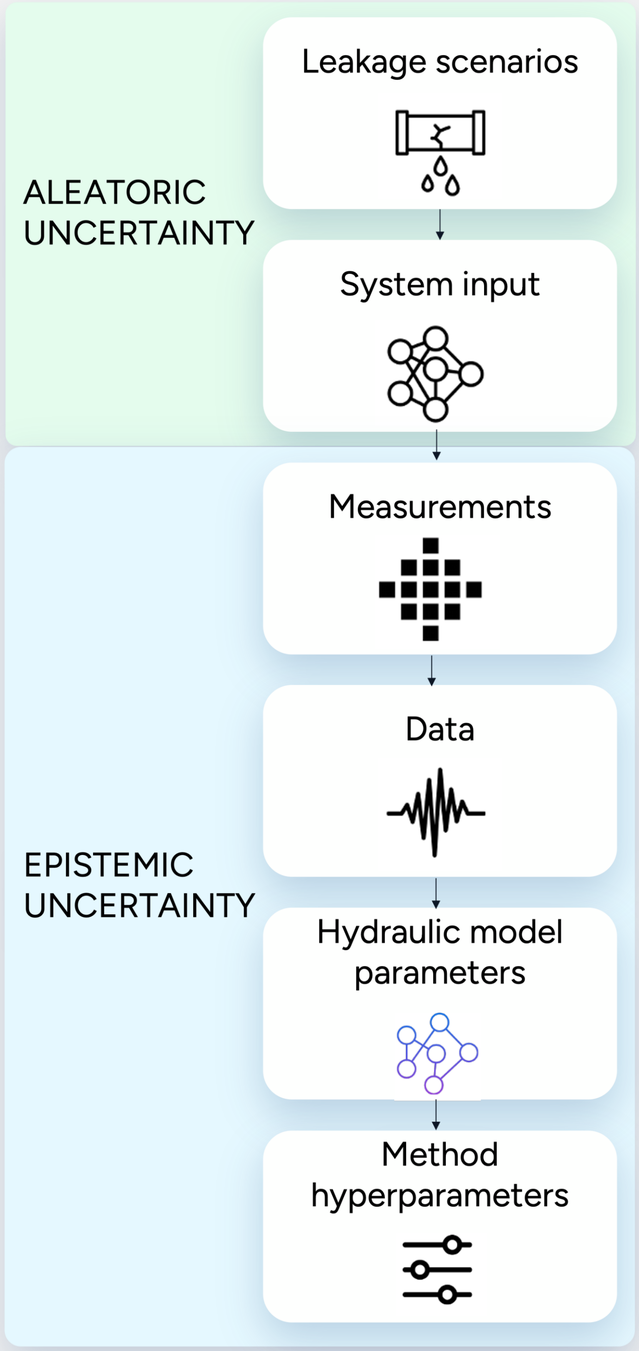
Ziele

. Mehr Vertrauen und Zuverlässigkeit: Algorithmen zur Erkennung von Leckagen in einer Vielzahl von Fällen getestet

. Kontinuierliche Weiterentwicklung: Entscheidungsgrundlage für die Weiterentwicklung der einzelnen Algorithmen

. How to - Praxis: Empfehlungen für die optimale Kombination von LILA und dem Dual Model

Globale Sensitivitätsanalyse



Hierarchischer Ansatz für mehrere Szenarien

Fai, H. and Ye, M. *Variance-based global sensitivity analysis for multiple scenarios and models with implementation using sparse grid collocation.* Journal of Hydrology, **2015**.

Sensitivitätsindex erster Ordnung und Gesamtindex der Sobol-Methode

$$\mathrm{S}_i = \frac{\mathbb{V}_i}{\mathbb{V}(y)} = \frac{\mathbb{V}_{\theta_i}(\mathbb{E}_{\theta\sim i}(y|\theta_i)}{\mathbb{V}(y)}$$

Nur Parameter θ_i wird variiert, gemittelt über Variationen der anderen Parameter

$$\mathrm{S}_{T_i} = \frac{\mathbb{V}_i + \mathbb{V}_{i,j} + \ldots + \mathbb{V}_{i,j,\ldots,d}}{\mathbb{V}(y)} = \frac{\mathbb{V}(y) - \mathbb{V}_{\theta\sim i}(\mathbb{E}_{\theta_i}(y|\theta_{\sim i}))}{\mathbb{V}(y)}$$

Berücksichtigung aller Variationen aufgrund von Parameterinteraktionen

Human-centered Design

Human-centered Design

Analyse & Feedback-Loops

2023 | 2024 | 2025

Stakeholderanalyse

Methoden

Strukturierte Analyse von Wasserversorgungsunternehmen und Startups, zur Identifikation:

- des Stands der Technik
- geografische Verteilung

Erkenntnisse

45 relevante Startups

. Aus 11 Ländern (USA, NL, UK, DE,...)

. 9 Hardware Startups + 24 Software Startups + 12 Hybride Lösungen

. 11 direkte Wettbewerber

22 relevante Wasserversorger

. Bestehende Kontakte zu 14 davon

→ Aktuell: Verständnis für Monitoring-Systeme stärken durch Austausch und Bedarfsabfrage

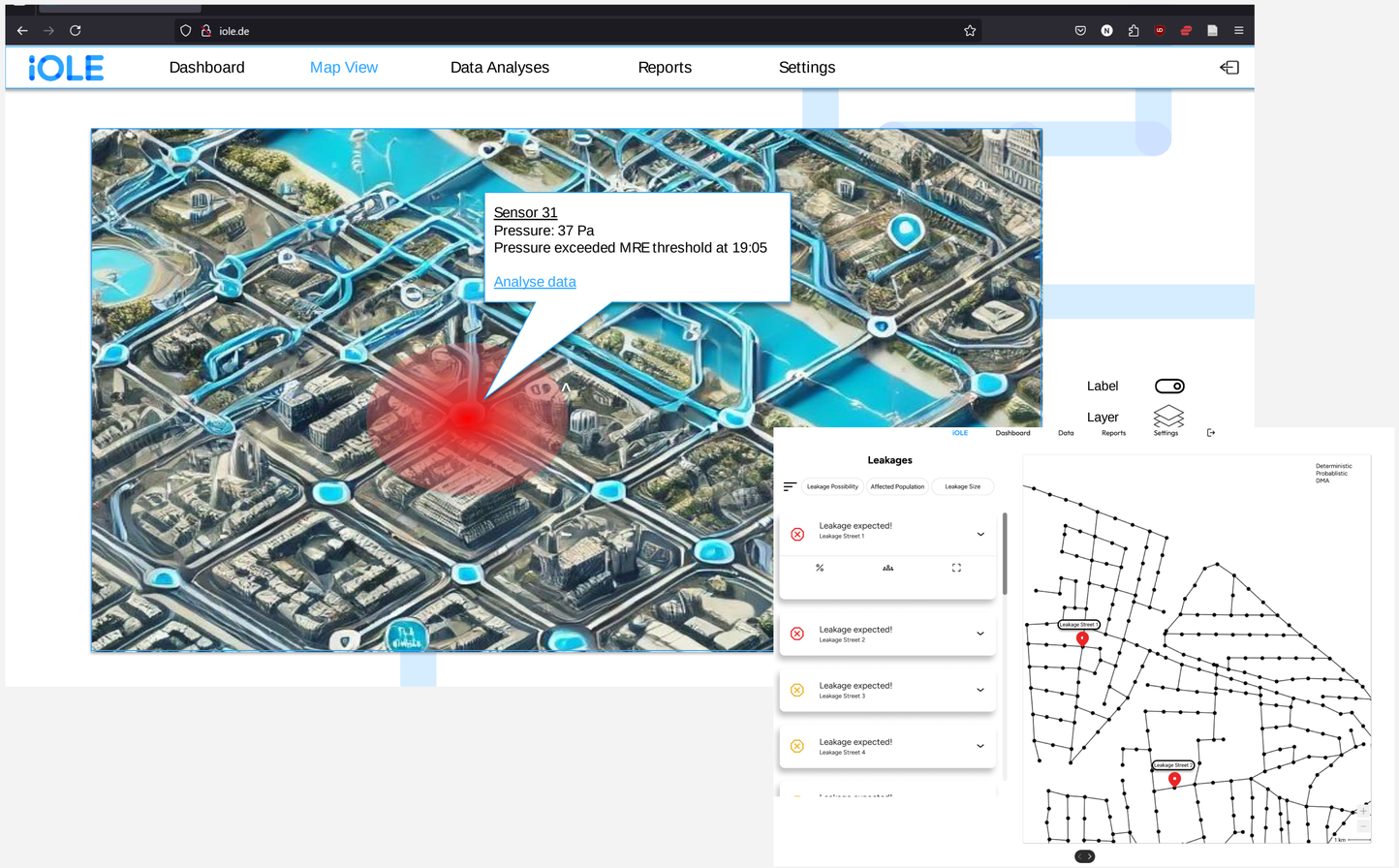
Competitor	Location	Description
SIWA (Siemens Water)	Global	SIWA applications are specifically developed for the water and wastewater industry so operators can optimize energy efficiency, avoid water loss, reduce contamination of water bodies and improve predictive maintenance measures.
Bunt Planet *Acquired by SIWA*	ES	The BuntBrain smart water management solution includes ten stand-alone modules which permit a water utility to manage its water network/assets remotely. Modules range from BuntBrain LeakFinder, a powerful tool for leak detection, to BuntBrain DigitalTwin, which can simulate events within the network.
HULO.ai	NL	Real-time leak localization in water distribution networks. HULO's algorithms provide water utilities with know-how about their water network. Together, we detect, localize and quantify leaks in the very early stages.
VODA.ai	US	Manage your pipes effortlessly. VODA.ai® helps utilities create project plans for mains and service lines with daVinci™ - the industry's most powerful AI engine that ranks pipes by Business Risk Exposure within 12 months and up to 20 years.
Preventio	DE	The Preventio platform is an AI-based SaaS solution. The platform provides customers with comprehensive and easily accessible information and insights, on predicting and preventing tap water damage.
FIDO Tech	UK	FIDO AI is over 92% accurate at detecting leaks on any pipe material at any pressure and in any environment. It is the first technology able to size leaks from acoustic and kinetic data.
Aqua Suite (Royal HaskoningDHV)	NL	Aqua Suite software operates as an AI-powered analyst and autopilot for water utilities and industries. It rapidly learns the relationship between processes, makes accurate predictions, and anticipates demand and changing conditions, while preserving valuable knowledge.
GoAigua Water/ Xylem Vue	US	GoAigua Water centralizes drinking water utilities' operational management to reduce costs, maximize efficiency and improve service.
Leakmited	FR	AI-Powered water leak detection for water utilities companies. After more than 3 years of research and development, Leakmited has developed a unique artificial intelligence algorithm that can drastically reduce the size of the areas to investigate to find leaks.
Olea Edge Analytics	US	Our sustainable, patented technology enables utilities to get a handle on water loss while providing safe, clean and affordable drinking water. Olea digitalizes the water distribution network, bringing insights to water using AI-based edge computing using IoT sensors.
Bentley Systems	US	Future-Proof Water Infrastructure. Confidently plan, design, build, operate, and maintain

Human-centered Design

Analyse & Feedback-Loops

2023 | 2024 | 2025

Workshops



Workshop 1:

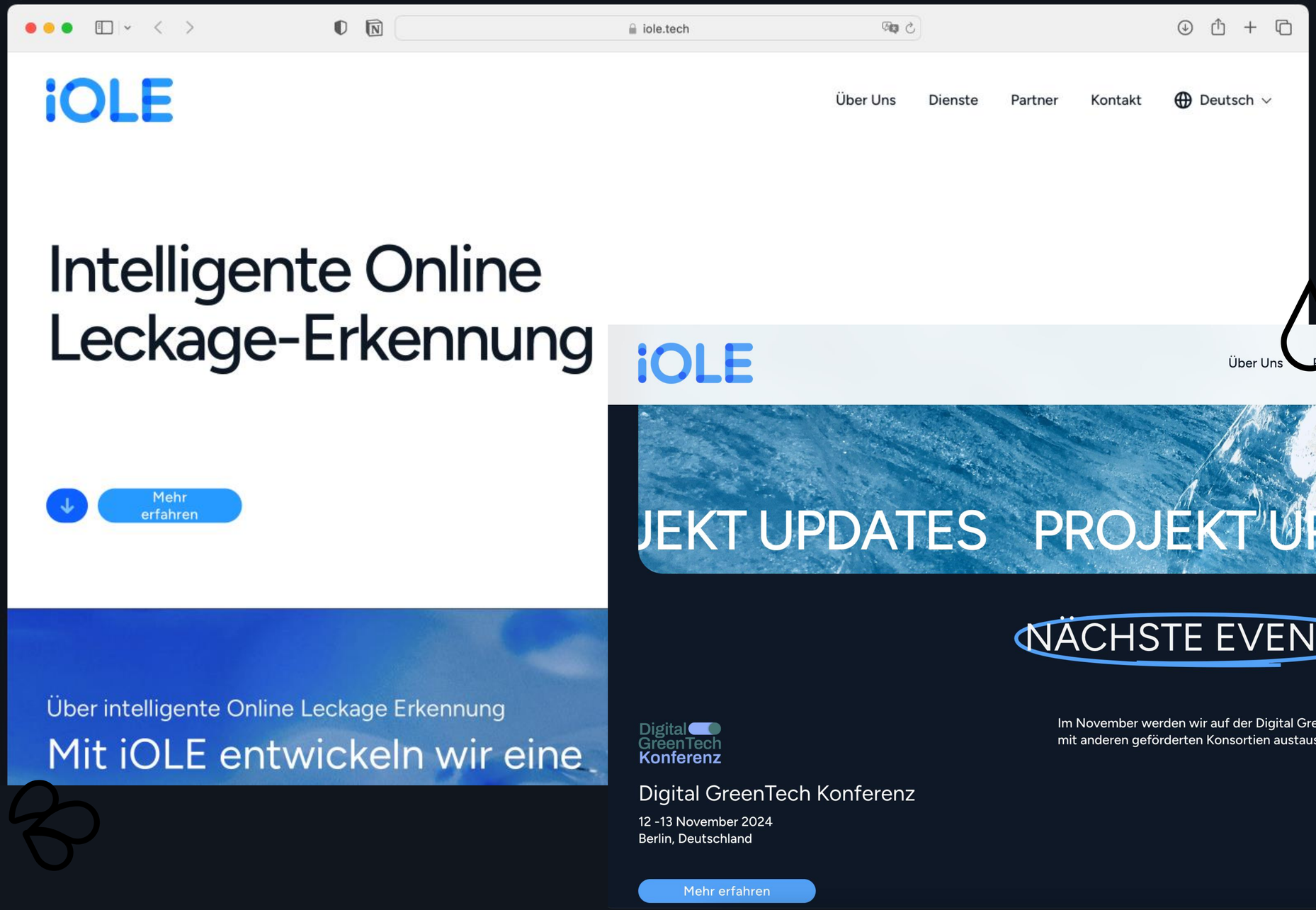
Bedarfe & Status Quo

- Austausch mit Wasserversorgern
- Verständnis aktueller Monitoring-Systeme
- Bedarfe & Wünsche, Hemnisse abbauen

Workshop 2:

Feeback-Loop

- Nutzung des Tools
- Feedback und Roundtable Runden
- Re-defining der Software (UI/UX)



Findet uns Online
www.iole.tech

Vielen Dank!

Ella Steins

Einstein Center Digital Future
Technische Universität Berlin

steins@tu-berlin.de

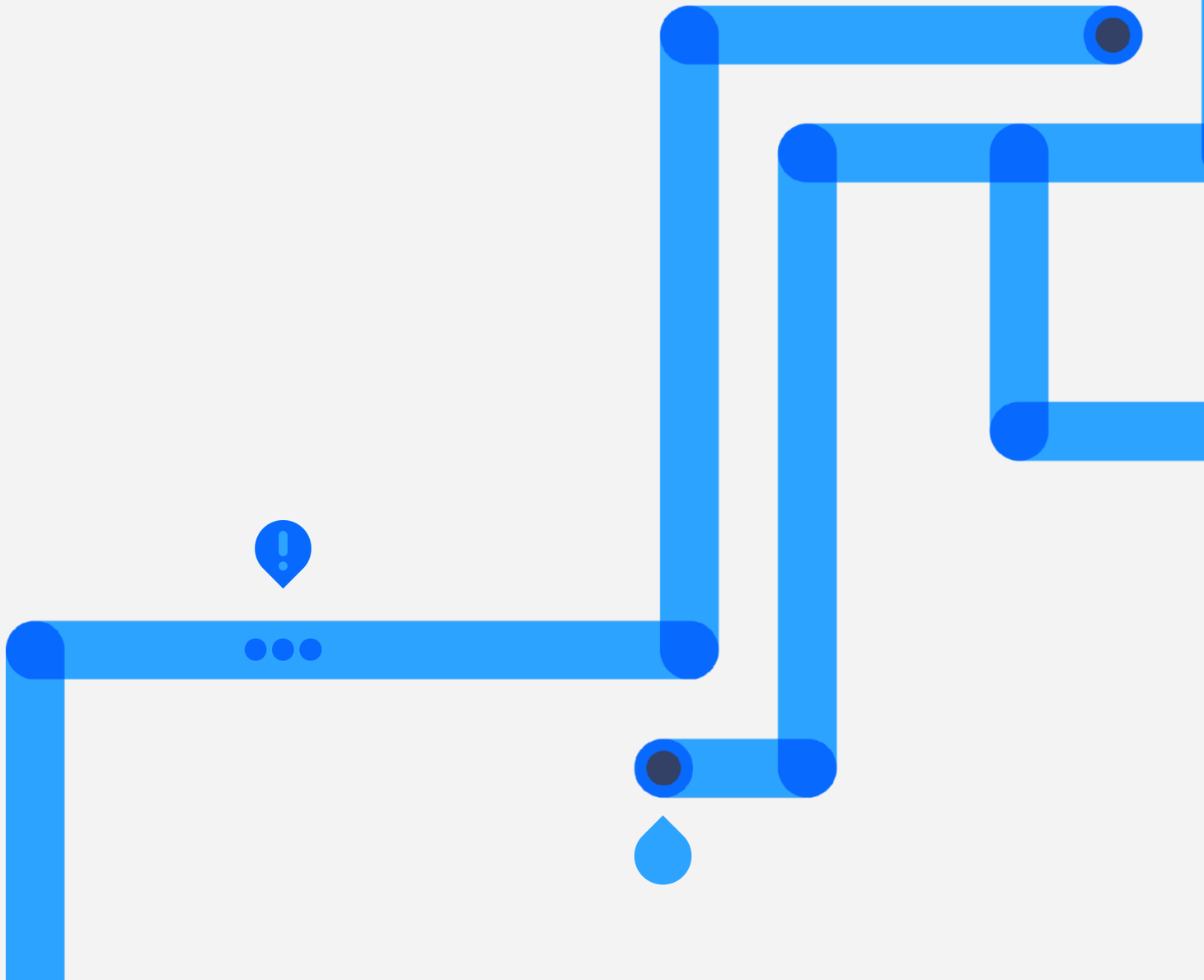
www.tu.berlin/swn

Sophie Persigehl

Urban Impact

sophie@urbanimpact.agency

www.urbanimpact.agency



October 2024