Digital Transformation in Water Distribution Networks: from Digital Twins to Digital Service Concept

Orazio Giustolisi

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DEA Research Transfer

Digital Water

Outlines

✓ **Challenges and needs in technical world**

✓ **Digital Twin paradigm in WDNs**

✓ **From WDN Digital Twin to Digital Water Services**

✓ **Example Digital Service approach for system analysus and
planning Leakage Management for Water Companies (e.g.,
Acquedotto Pugliese, Acqua ENNA, GAIA, Gruppo CAP, etc.)**

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Challenges and needs in technical world

- **Changes of regulation for WDN asset management**
  - **Efficiency** of investments
  - Ex-post evaluation of WDN **performances**
  - **Reward-penalty mechanisms**

- Needs of water company/consultants
  - Get **explicit support to solve past and new technical problems**
  - Exploit the opportunities from digital transition in WDN
  - Keep the **consistency with WDN hydraulics and service requirements**
  - Increase **rationality, replicability, scalability, efficiency, effectiveness, and flexibility**

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Few History details and trends (1/3)

- During the last century were born concepts, tools and wording of today digital transformation

- **Digital Twin concept** was born with the computers thirty years ago by *David Gelernter* and *Michael Grieves* firstly applied **Digital Twin concept** to prototype in industry to achieve efficiency ... later NASA

- **Complex Network Theory** was born centuries ago by *Euler* (**Graph Theory**) was established at the end of the last millennium with the studies of network models

Few History details and trends (2/3)

- **Machine Learning** was established by *Alan Turing* (eighty years ago) and during that ages the first concept of artificial neural networks by *McCulloch & Pitts*

- *Rumelhart, Hinton and Williams* developed the Error Back-Propagation (1986) to train **Artificial Neural Networks** and their use in water systems started in nineties

- *Ingo Rechenberg*, fifty years, theorized **Evolutionary Strategies for Optimization** while *John Holland*, fifteen years later (1976), established the theory for **Genetic Algorithms** and *David Goldberg* (1989) wrote a milestone book which established their use in nineties in water systems

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Few History details and trends (3/3)

- In 1992, *Koza* developed **Genetic Programming**

- The use of **Machine Learning as Symbolic Regression** started in nineties

- Fifteen years ago, *Giustolisi & Savic* proposed a symbolic regression (named **Evolutionary Polynomial Regression**), which is today used all over in the world in different fields

- In the last decade, many enhancements at the previous history have been proposed as for example **Deep Learning** strategies for pattern classification within **Artificial Neural Networks**

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The Lesson of the History

- Many concepts, tools and even wording have been developed by "classic world" and we already are on their shoulders. *Do not try to escape ... could be dangerous*

- What is changing today causing the digital transformation?

- We have the computer power, and the quantum computer will further change the history.

- We already have fast internet, and 5G will further change the history ... waiting for 6G

- We already have fixed network (LoRa, Sigfox) and NB-IoT to transfer metering data

- We already have capacity to store and analyze big amount of data and the quantum theory will further change the history

- We already have interoperability and augmented reality, and BIM concepts will further change the history

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Water distribution systems and Digital Twin

Need to be as much as possible twin of the physical system as topological and hydraulic behavior and system components description

- **Service for users while modelling packages to build the proper digital twin**
- **Advanced Hydraulic Modelling**
- **Topological Analysis**
- **Components of the Digital Transformation**
- **GIS, WEBGIS, BIM and Augmented reality**

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# From *WDN Digital Twin* to *Digital Water Services*

Digital Twin (topology, costumers and advanced hydraulic modelling)
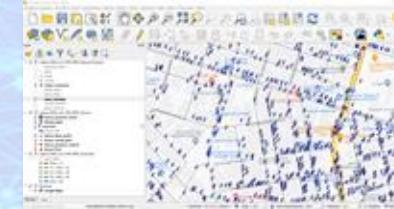
Monitoring Data

Complex network theory for WDN

Artificial intelligence/Machine learning

Multi-objective optimization strategy

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From *WDN Digital Twin* to *Digital Water Services*

Pre-requisites:

- *Digital Water Services* should expose quickly explicit results to support technical tasks (e.g., reports, design layouts, etc.)


WDNetXL

- *Digital Water Services* should run on widely used platforms for data management and visualization (e.g., GIS, WEBGIS, BIM)

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Example

DigitalWaterMassCalibration
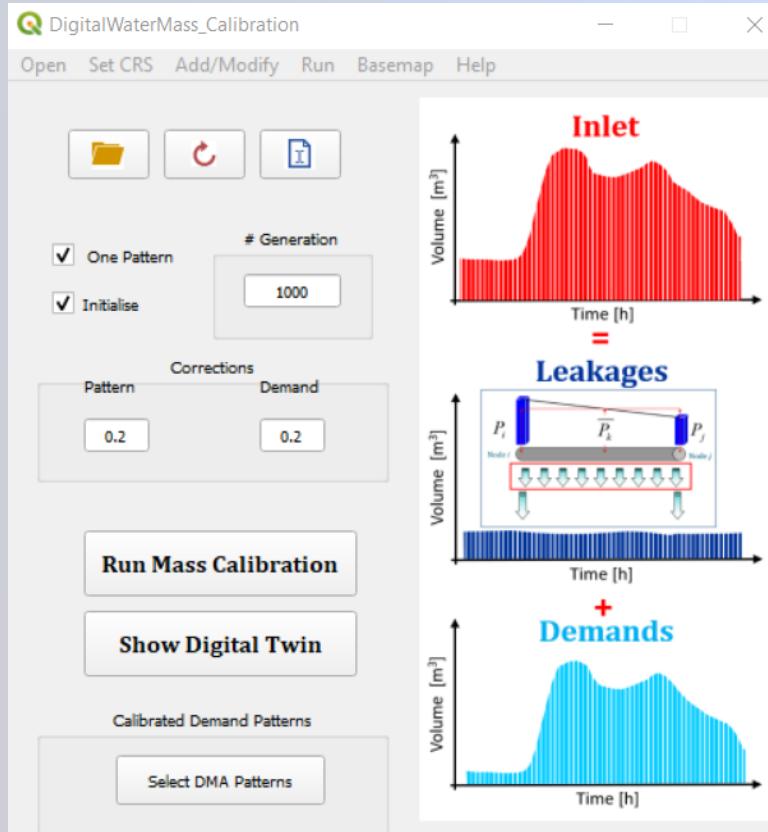
- **Digital Twin**
  - **Advanced Hydraulic Modelling**
  - **Topological behavior**
  - **GIS**

- **Complex Network Theory**
  - **Component Analysis**

- **Evolutionary Optimization**
  - **Genetic Algorithms**
  - **Multi-Objective**
  - **Decision Support**

- **Machine Learning (EPR)**
  - **Propensity to leakages from burst events data-modelling**

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How many *Digital Water Services?*

Potentially infinite!

No magic tools solving every problem!

Continuous dialog with water companies and consultants
Novel ideas comes from real-world

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Digital Water Experience to plan Leakage Management in AQP and GAIA systems

WDNetXL

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Main Digital Twins Used

WDNetXL

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To Analyse the WDN using the Correct Customer Demand Conditions
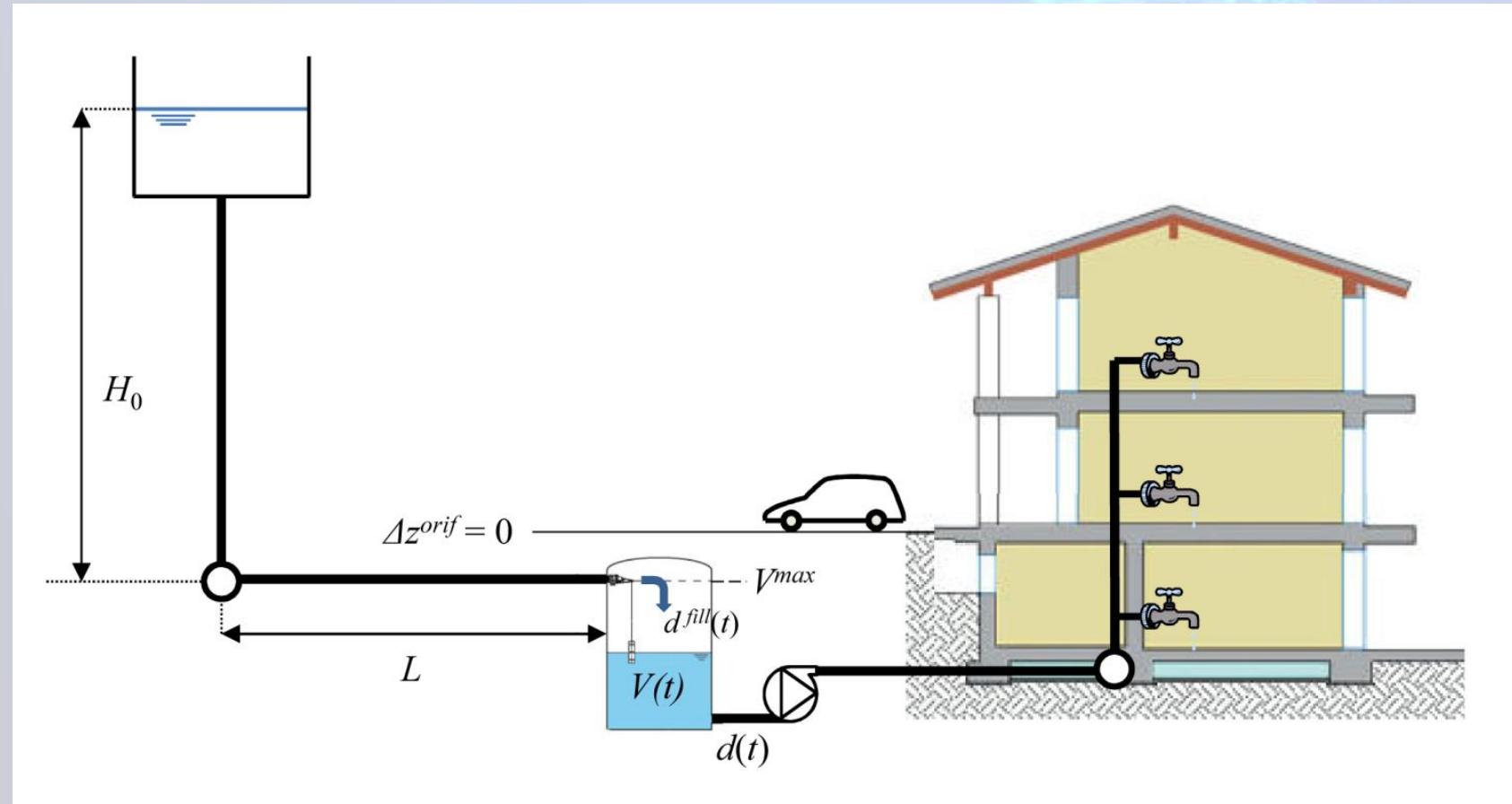
WDN of Apulian Town
Advanced Hydraulic Modelling

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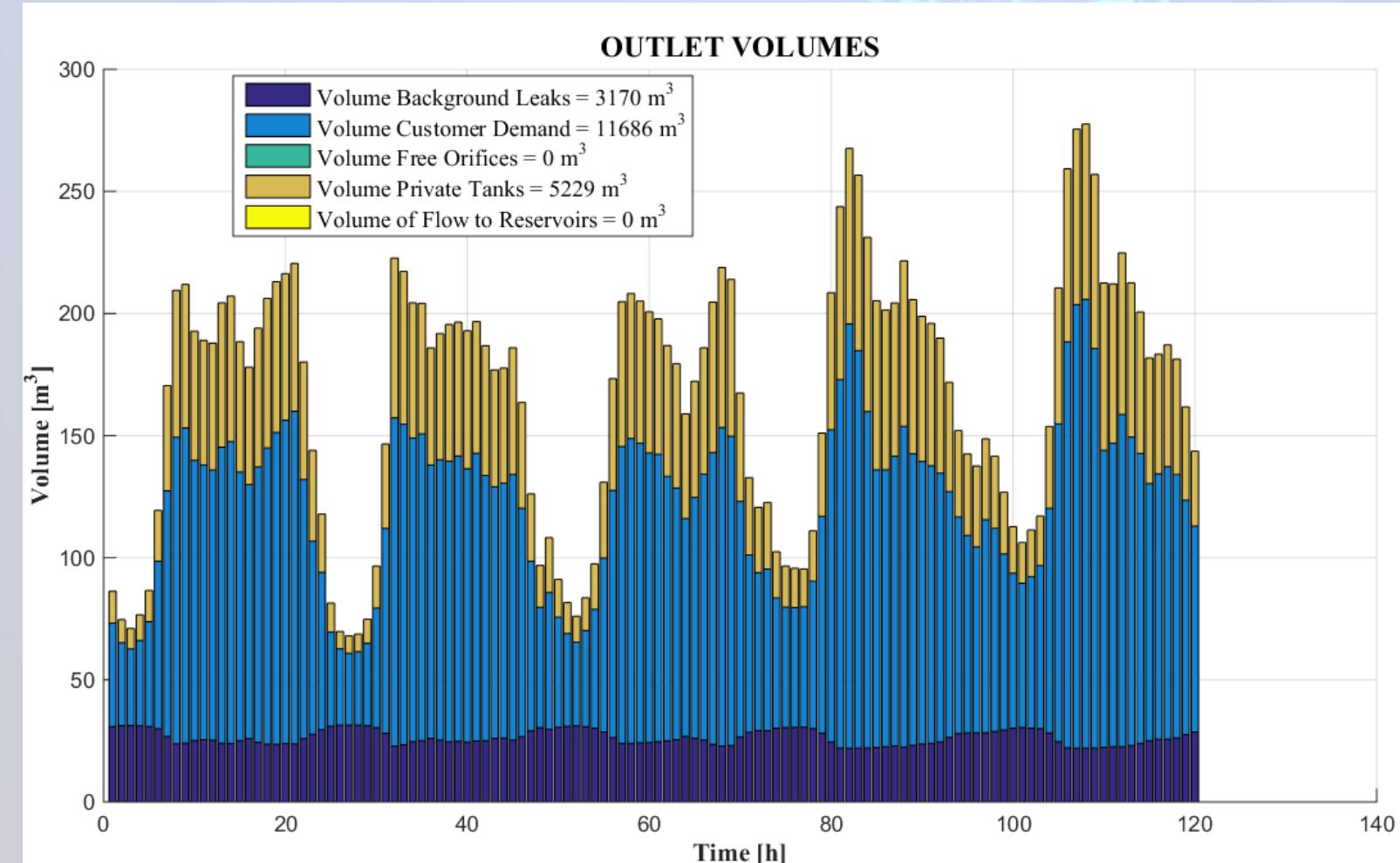
Digital Water Services: some examples

DigitalWaterDomainAnalysis
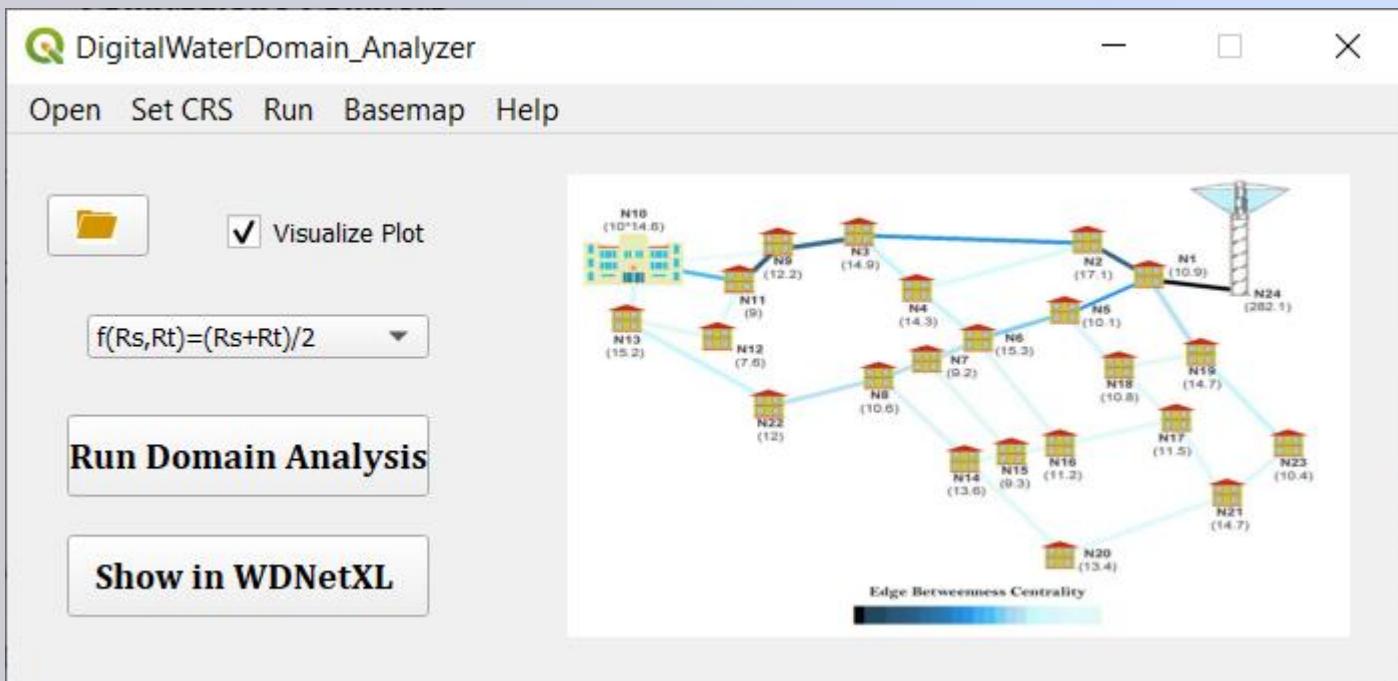
- **Digital Twin**
  - **Topological behavior**
  - **GIS**
- **Complex Network Theory**
  - **WDN-Tailored Betweenness for Domain Analysis**

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Digital Water Services: some examples

DigitalWaterVirtualDMA

- **Digital Twin**
  - **Advanced Hydraulic Modelling**
  - **Topological behavior**
  - **GIS**
- **Complex Network Theory**
  - **WDN-Tailored Modularity Index**
  - **Component Analysis**
- **Evolutionary Optimization**
  - **Genetic Algorithms**
  - **Multi-Objective**
  - **Decision Support**

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Digital Water Services: some examples

DigitalWaterIVSVulnerability
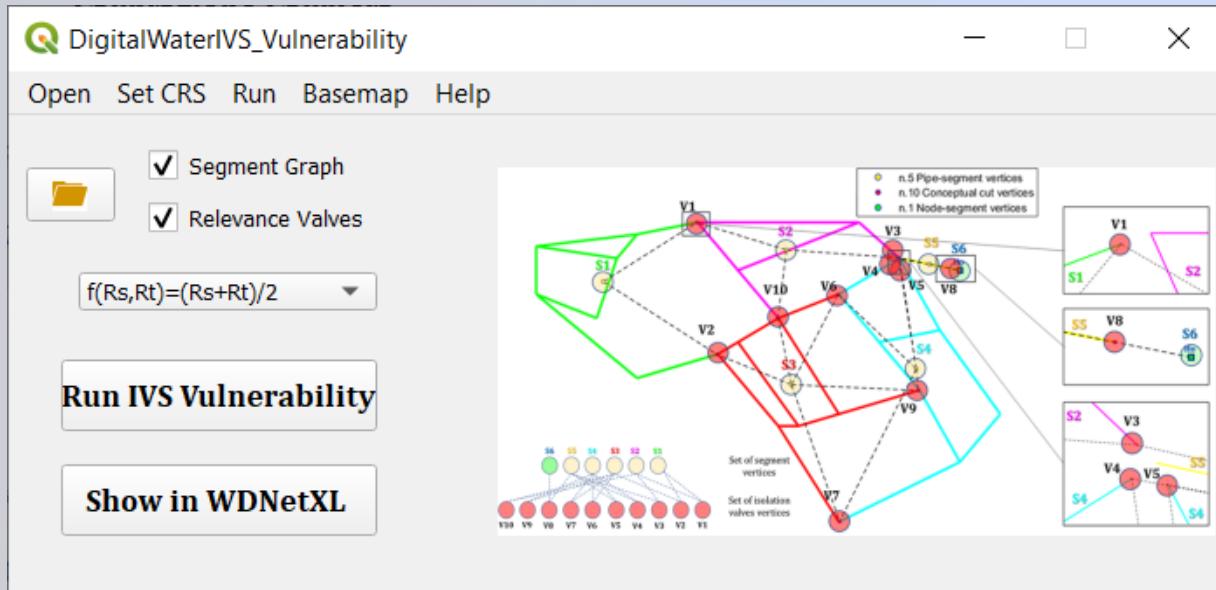
- **Digital Twin**
  - **Topological behavior**
  - **GIS**

- **Complex Network Theory**
  - **WDN-Tailored Betweenness for Isolation Valve Analysis**
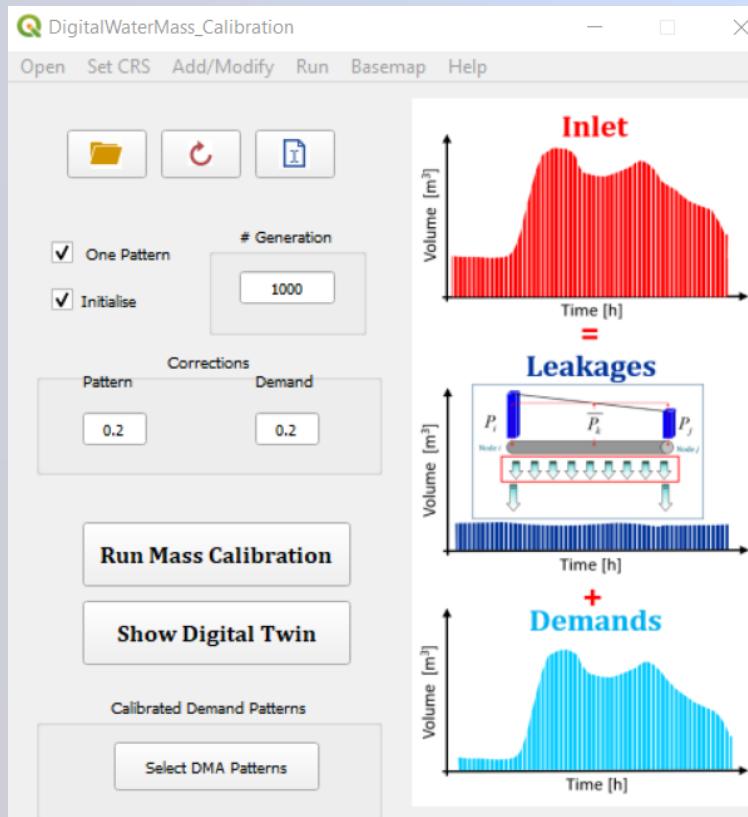
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Digital Water Services: some examples


DigitalWaterMassCalibration

- **Digital Twin**
  - **Advanced Hydraulic Modelling**
  - **Topological behavior**
  - **GIS**

- **Complex Network Theory**
  - **Component Analysis**

- **Evolutionary Optimization**
  - **Genetic Algorithms**
  - **Multi-Objective**
  - **Decision Support**

- **Machine Learning (EPR)**
  - **Propensity to leakages from burst events data-modelling**

Digital Water Services: some examples

DigitalWaterDMADesign
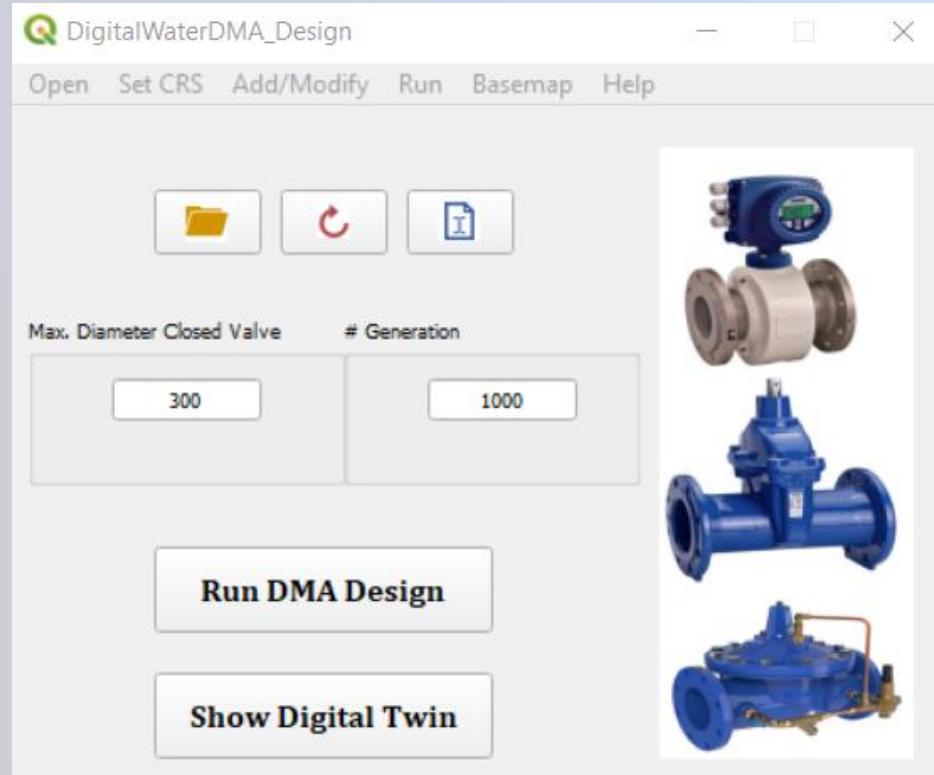
- **Digital Twin**
  - **Advanced Hydraulic Modelling**
  - **Topological behavior**
  - **GIS**
  - **Advanced hydraulic model**
- **Complex Network Theory**
  - **Component Analysis**
- **Evolutionary Optimization**
  - **Genetic Algorithms**
  - **Multi-Objective**
  - **Decision Support**

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Digital Water Services: some examples

DigitalWaterRehabilitation
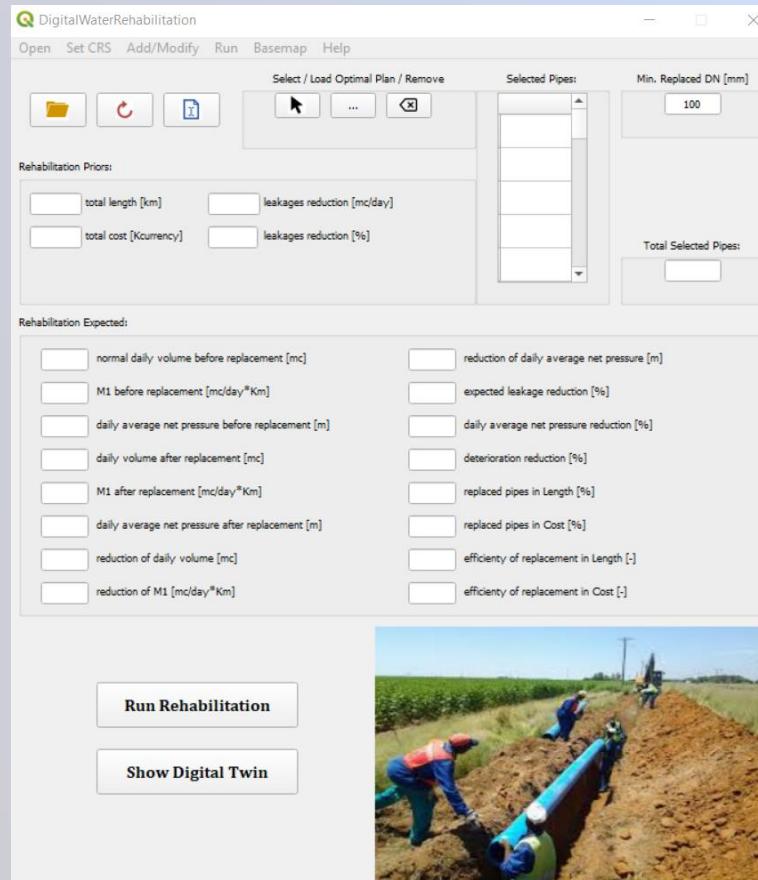
- **Digital Twin**
  - **Advanced Hydraulic modelling**
  - **Topological behavior**
  - **GIS**
- **Complex Network Theory**
  - **Component Analysis**
- **Machine Learning (Evolutionary Polynomial Regression)**
  - **Propensity to leakages from burst events data-modelling**

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Digital Water Services: some examples

BURSTS ANALYSIS
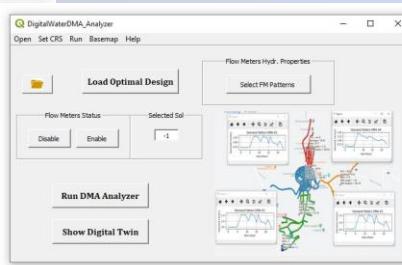
DMA ANALYZER
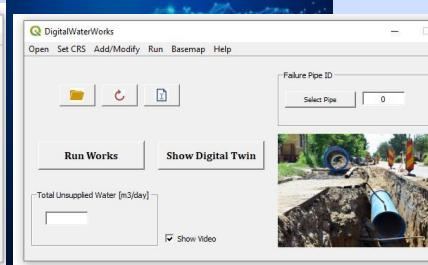
WORKS ANALYSIS

VIRTUAL DMA DESIGN
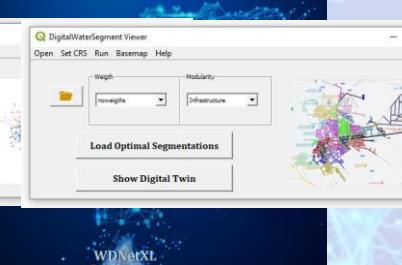
SEGMENT VIEWER

DMA DESIGN
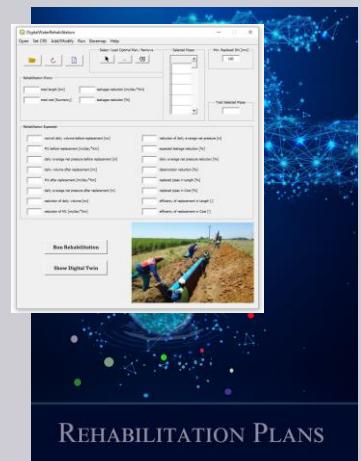
REHABILITATION PLANS
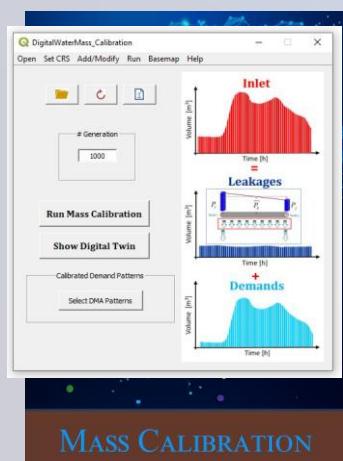
MASS CALIBRATION
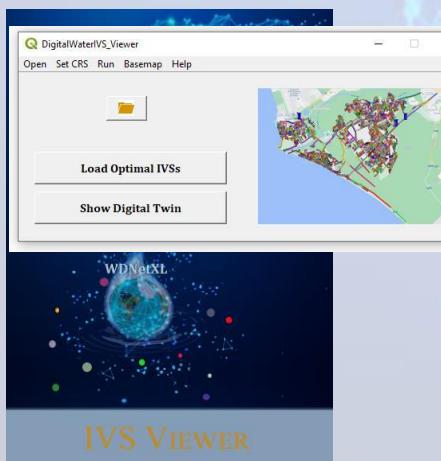
IVS VIEWER

IVS DESIGN
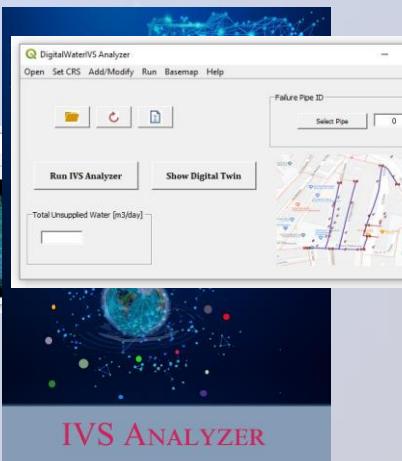
IVS ANALYZER

DMA BALANCE

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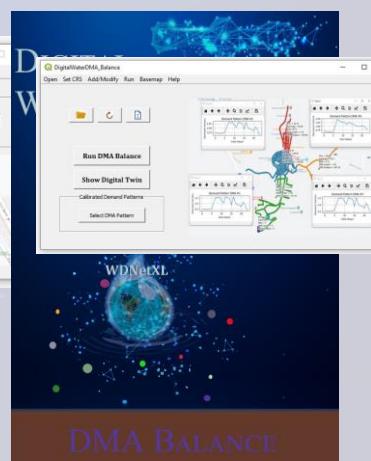
Conclusions

- **New opportunities from digital transitions in WDN**

- **A new connection between research community and technical world to boost innovation**

- **No blind translation of paradigms from other fields**

- **Exploit WDN Digital Twin for Digital Water Services**

- **New opportunities for education in the university courses**

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I was, am, will be forever Hydraulic Engineer
Loving technical and research contamination from different fields
Loving exploring the future on the shoulders of the past

Thanks for your attention
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