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# An ontology-based digital architecture and modelling ecosystem for water-fit-for-reuse applications

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**Abstract:** With the water sector moving towards a circular and digital future, there is a need for a systemic approach to tackle multi-disciplinary and multi-objective challenges that the future brings. Developing holistic and large scale digital twins (e.g., for cities or industrial zones) provides a valuable tool for the stakeholders to improve their decision-making process. The heterogeneous and unstructured nature of the data and models in different sub-domains of the water system makes this development a challenging task which calls for an interoperable and transparent framework. WaterFRAME aims at developing such a framework for the water domain by using ontologies and knowledge graph to create a dynamic and interoperable digital twin that can provide a great opportunity for automated process optimization at a holistic scale.
**Keywords:** interoperability; digital twins; ontology; knowledge graph

## Introduction

The water sector is currently undergoing paradigm shifts. The transition towards a circular water and resource economy is inherently a multidisciplinary and multi-objective effort that implies bridging historical silo's (e.g., drinking water, wastewater, rainwater harvesting, etc). To develop a more systemic approach supported by holistic decision support tools, interoperability is a key challenge. Moreover, the digital transformation and the need for real-time simulations requires models/sub-models and data to communicate with each other in a more efficient and automated way. These challenges are more crucial when moving towards large scale systems where one develops holistic digital twins for cities, regions and/or industrial clusters. An interoperable framework allows heterogeneous sources of data (e.g., water quality, energy, etc.) and various models (e.g., for sewer networks, water/wastewater treatment, etc.) of the system to be connected to each other and communicate in an efficient and automated manner.

The current practice in the water sector is more focused on model integration and they mainly focus on offline use targeting the integration of specific, well established modelling frameworks (e.g., interfacing WWTP and Sewer models). Developing holistic decision support tools for large scale systems with vast amount of data from heterogeneous sources and with potential differences in temporal and spatial resolutions is still challenging as such tools should be generic, reusable and modular to allow for flexibility of the final model of the system and wide-spread applications. To achieve this goal, data standardization and model interoperability is crucial. Attempts have been made to develop such holistic interoperable frameworks [1-3]. However, most of the applications are in other sectors (like energy and mobility), and the water sector is still lagging behind in this regard.

In this study, within the context of the WaterFRAME project, we focus on developing a holistic decision support system for the water domain based on semantic models. Ontology and knowledge graphs are used as backbone for a dynamic multi-agent system [4] that provides holistic and

optimisation at large scale for tackling challenges within the water sector focusing on water reuse and circularity.

**Methodology**

WaterFRAME project aims at developing a generic, transferable digital architecture for the water domain. The digital framework is based on the semantic models and uses the concept of ontology and knowledge graph [5]. An ontology is a conceptual model of a system that defines its concepts, objects, and their properties as well as their relationships together. When coupled with data, a knowledge graph can be created that allows for advanced querying of various data from heterogeneous sources [6]. The WaterFRAME architecture has a multi-layer structure (Figure 1). It starts with bringing all unstructured data from heterogeneous sources in a standardized data model in which a common vocabulary can be shared between them. It then builds a library on ontologies on top of the data layer that aims at incorporating all important and relevant concepts and objects within the water domain. Ontologies are developed for rain water collection and storage, water/wastewater treatment processes, and water reuse applications to name a few. Various sources of data will be considered including water quality and quantity, cost and energy data. A dynamic knowledge graph is created by coupling the library of ontologies into the real data.

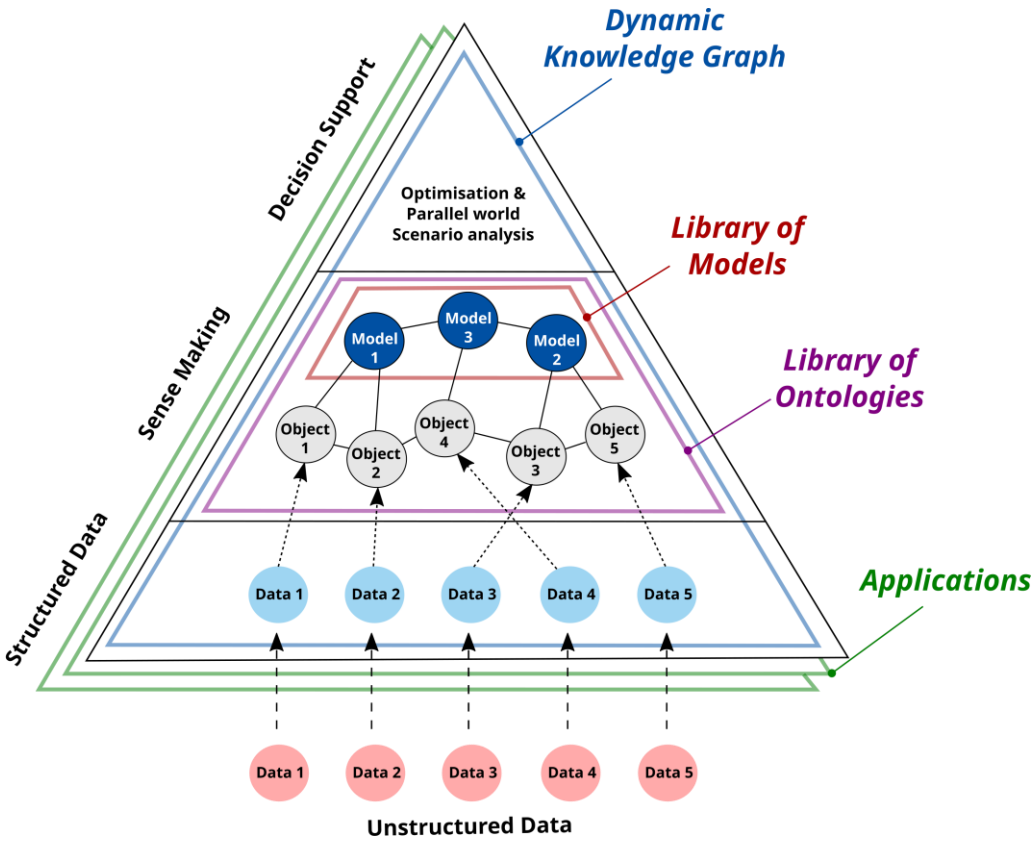


***Figure 1*** *The scheme of the WaterFRAME digital framework for holistic decision support in water domain.*

An important aspect of WaterFRAME architecture is the overarching optimization layer for decision-making processes. It consists of a multi-agent system facilitating automatic querying and reasoning over the ontologies and coupling the predictive models to the knowledge graph. Relevant indicators (e.g., related to process performance, environmental and economic

assessment) will be defined to provide tangible computational output from the knowledge graph. The knowledge graph is dynamic in a sense that it will update itself dynamically with new sources of data or new sub-models of the system. In the first phase of the project, a proof of concept is being developed for a virtual case focusing on decentralized water reuse management at the household level. This provides a foundation to build upon a generic and reusable modelling framework that can be easily extended and scaled. Two use cases are defined based on real data (in collaboration with the stakeholders) to test and demonstrate the potential use of the developed methodology for water-fit-for-purpose applications including the rain water management for the city of Antwerp, Belgium and tackling salinisation problem for an industrial harbour in the Gent-Terneuzen Canal, Belgium.

**Results**

A proof of concept has been developed based on the virtual case of the project focusing on the decentralized water reuse management at the household level. Figure 2 shows a simplified overview of the ontology developed for this case. It provides definition of all concepts within the boundary of the studied system such as different water tanks (e.g., rainwater, RW and potable water, PW) and treatment processes (e.g., reverse osmosis and membrane bioreactor) as well as the relationships between the components of the system. The semantic model is based on data standardization using Resource Description Framework (RDF) standards and Web Ontology Language (OWL) that ensures the interoperability and scalability of the semantic model. A multi-agent system acts upon this knowledge graph that consists of intelligent agents for querying information, running predictive models of the system, updating instances and restructuring the graph if necessary. An optimisation agent acts as an overarching component which provides holistic recommendations for decision making based on the information queried from the knowledge graph. The first version of the dynamic knowledge graph is capable of running different queries over the graph structure. This includes simple queries to get static information about the concepts (e.g., number of tanks in the system) as well as more complex queries to get dynamic information (e.g., current level of the tanks) about the system which might need running and coupling predictive models of the system.

The developed framework will be extended to more concepts and properties of the water domain including different external sources of data (e.g., for effluent wastewater, groundwater and surface water) and different models of the system (e.g., models for wastewater treatment plants and hydraulics). In addition, cost and energy models as well as life cycle assessment will be incorporated into the framework for provide tangible indicators for the large scale optimisation of water reuse and circularity.

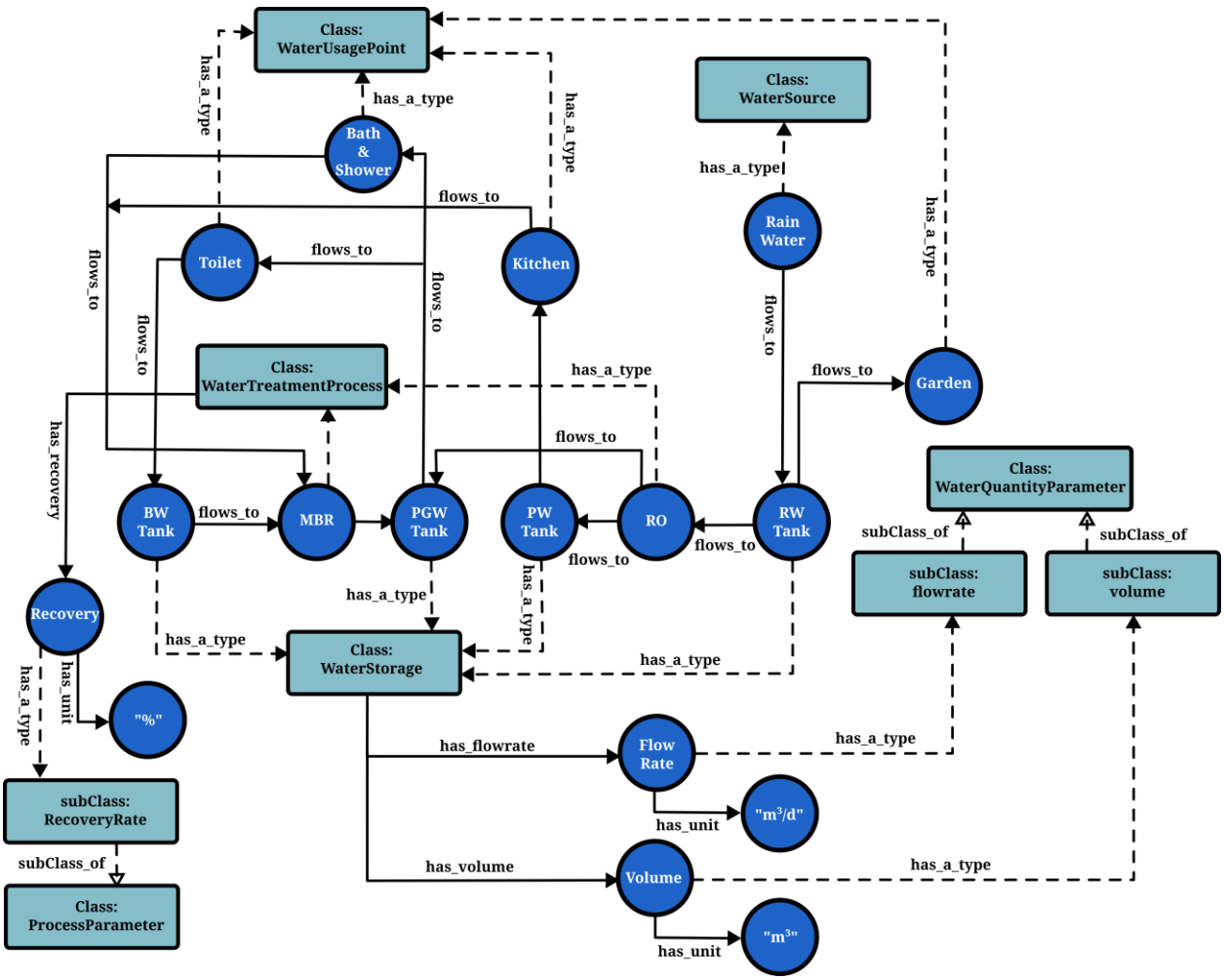


***Figure 2*** *A simplified scheme of the ontology developed for decentralized household water reuse management.*

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