Semantic modeling of wastewater treatment plants towards international data format standards

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Building information modeling (BIM) is a methodology for managing structures by digitally sharing information related to all phases of the structural lifecycle. BIM requires standardized data formats for information exchange, such as the Industry Foundation Classes (IFC), which are the only open standardized data format used for BIM. However, currently BIM cannot be applied for managing water infrastructure, as water infrastructure is not covered by IFC. Thus, the IFC schema needs to be extended to support water infrastructure. In this paper, a basis for the IFC extension is presented, following two steps, (i) identification of reliable knowledge sources, such as software packages and standards and (ii) semantic modeling. In addition, a case study on an Italian wastewater treatment plant (WWTP) is presented. For illustrative purposes, the WWTP is expanded following Italian and, hypothetically, German legal and technical regulations, to be reflected in the semantic model and in the IFC extension. A comparison between Italian and German regulations reveals that both countries require similar design procedures, which can formally be described on a common superset of parameters. In conclusion, the semantic model proposed in this study can serve as basis for extending the IFC schema for describing water infrastructure.

Keywords: Building information modeling (BIM), Industry Foundation Classes (IFC), information modeling, metamodeling, semantic modeling, wastewater treatment plants

1 Introduction

Building information modeling (BIM) has become increasingly important on a European level since single member states have been introducing BIM in their legislation, requiring BIM in construction works due to the European Union Public Procurement Directive. The Italian Ministerial Decree n.560/2017 demands all public contracting authorities to use "digital instruments and processes" for infrastructure management and for building modeling in public procurement procedures (MIT 2017). In Germany, the Federal Ministry of Transport and Digital Infrastructure requires BIM to be used in all publicly financed infrastructure projects by the year 2020 (BMVI 2017).

Besides legislative demands, the employment of BIM is also driven by practical reasons. Given the complex nature of water infrastructure (BENEDETTI 2006), the use of standards is essential for a fully integrated management and for reaching efficient levels of interoperability and communication (LAAKSO & KIVINIEMI 2012, EDMONSON et al. 2018). For example, "open BIM" is a universal approach to collaborative design, realization, and operation of buildings based on standardized data formats. Open BIM provides a common language allowing project members to participate regardless of software packages (KIVINIEMI 2015). The Industry Foundation Classes (IFC), which are described by the IFC schema, represent the only open standardized data format for BIM.

The need for specialized extensions of the IFC standard has been highlighted in several infrastructural domains resulting in the development of IFC-Alignment, IFC-Bridge and IFC-Road/IFC-Rail (buildingSMART 2018). Also, specialized extensions have been proposed for describing sensor-based structural health monitoring systems (THEILER & SMARSLY 2018). To extend the IFC schema for modeling domains without IFC-dedicated objects, proxy elements and property sets have been employed, representing a quick solution towards extending the IFC (WEISE et al. 2009). However, the same authors have indicated that using proxy elements and property sets leads to a loss of semantic information.

The need for an IFC extension supporting water infrastructure has been illustrated by SÖBKE et al. (2018) and EDMONSON et al. (2018). IFC extensions have to be applicable worldwide. Therefore, this paper exemplarily analyzes the requirements for water infrastructure in two EU countries (Italy and Germany) to define a common semantic model, which can serve as basis for the IFC extension. The production of this semantic model is intended to be viewed as a "*prototyping*" activity, i.e. a combination of explicit knowledge as in the Socialization, Externalization, Combination, Internalization SECI model proposed by NONAKA & KONNO (1998), where the knowledge sources to be considered are tangible, codified documents. The knowledge sources considered in this work are documents with normative (and similar) value, such as standards or software packages.

Defining business requirements is the first step of the IFC development cycle (LIEBICH 1999, WEISE 2009), the IFC schema being an object-oriented tool for requirements representation. This work therefore utilizes methodologies for requirements elicitation well established in the field of object-oriented system development (JACOBSON 1992, SOMMERVILLE 2017, BRUEGGE & DUTOIT 1999). In the second step, the semantic model is defined to be implemented as IFC schema extension. Accordingly, in the second section of this paper, the legal knowledge sources for dimensioning wastewater treatment plants available in Italy and in Germany are analyzed summarizing the parameters needed for the preliminary design level. In the third section, the preliminary design of the wastewater treatment plant (WWTP) located in Maglie, Italy, is presented as case study. The fourth section proposes a semantic model of the WWTP describing the preliminary design of the WTTP based on the knowledge sources studied in the second section. The paper ends with a summary and conclusions.

2 Knowledge sources for WWTP design

This section summarizes the knowledge sources used for developing the semantic model. First, the knowledge sources from Italy are given, followed by the knowledge sources from Germany.

2.1 Italy

The main Italian legislative reference for wastewater treatment plants is the Legislative Decree April 3, 2006, n°152 (TUA 2006), *Norme in Materia Ambientale. Testo Unico Ambientale* (TUA) and its updates, better known as *The Environmental Code*. The Environmental Code defines values of a set of parameters to be met by the effluent of the plant (Table 1). Moreover, the Italian legislation confers territorial planning activities guiding the full lifecycle of water infrastructure on local authorities. Local planning instruments define the influent load to a WWTP in terms of Population Equivalent (P.E.) of a given area. The construction, management and maintenance of the works is entrusted to a specific local "Managing Body", i.e. a local governmental authority. The design documentation is organized in three levels according to the Public Procurement regulation: preliminary, detailed and executive. The TUA (2006) identifies four plant capacity classes, expressed in terms of P.E. (Table 2). In addition to the national legislation, each Italian region has its own set of regulations regarding effluent parameters and guidelines for the design of wastewater treatment plants. In this paper, the regulation in force in Italy's Apulia region is analyzed.

Table 1: Effluent limitations (Included (o) and not included (-) in the regulation; sources: Italy: Table 1 and Table 2 of TUA (2006), Germany: AbwV (2017))

Parameters (daily average)	**Unit**	**ITA**	**GER**
BOD5 (no nitrification)	mg/L	o	o
COD	mg/L	o	o
Suspended solids	mg/L	o	-
N-NH4	mg/L	-	o
Total phosphorus	mg/L	o	o
Total nitrogen	mg/L	o	o

Table 2: Categorization of wastewater treatment plants according to the capacity (unit of size ranges: 1000 P.E, German figures derived from average BOD5 load per P.E.) (Sources: Italy: TUA (2006), Germany: AbwV (2017))

Categorization	**1**	**2**	**3**	**4**	**5**
ITA ("Type")	< 2	2 - 10	10 - 50	> 50	-
GER ("Size categories")	< 1	1 - 5	5 - 10	10 - 100	> 100

2.2 Germany

The legal basis for planning wastewater treatment plants in Germany is the *Abwasserverordnung* (AbwV) (AbwV 2017). AbwV is a regulation on national level and contributes to dimensioning of wastewater treatment plants by defining size categories and requirements regarding the effluent. Size categories are defined depending on WWTP capacity measured in P.E. Further regional regulations may tighten, but not loosen the requirements for the effluent. AbwV does not regulate specific treatment procedures; instead, it is stated that treatment has to be performed according to "generally recognized rules of technology". The German Association for Water, Wastewater and Waste (DWA) is one of the authoritative organizations that define generally recognized rules of technology. The DWA is in charge of specifying standards for sustainable water infrastructure, such as the "A 131 – Dimensioning of Single-Stage Activated Sludge Plants" (ATV-DVWK 2003).

3 Case study of a wastewater treatment plant in Maglie, Italy

This section focuses on the preliminary design of the WWTP located in Maglie, a town in Apulia, Italy, currently serving around 70.000 P.E. First, the dimensioning procedure according to the Italian and Apulian regulation is presented. The preliminary design document produced by the competent regional Managing Body, i.e., "*Acquedotto Pugliese*" (AQP), is referenced as knowledge source, being a public document with legal validity. Secondly, the preliminary design of the Maglie WWTP according to the German regulations is carried out, using the software package *Active Sludge Expert* (FRÖSE 2012) as knowledge source. The WWTP located in Maglie performs an oxidative treatment process with activated sludge and anaerobic digestion. The plant is currently undergoing a process of expansion from 73.630 P.E. to 110.263 P.E.

3.1 Introduction to the regional Apulian regulation

Urban wastewater treatment plants are subject to a specific local regulation in the Apulia region, the R.R. n.13, May 2017 (PUGLIA 2017). This regulation defines the content of the design documentation and explicitly mentions the application of BIM to the development of new plant projects (PUGLIA 2017). Art.B3 of Annex B of PUGLIA 2017 contains general guidelines for dimensioning, which are applicable to new plants as well as to activities related to expanding, refurbishment, process improvement, and layout modification of existing plants. The parameters used for dimensioning are person load, influent flow (design value), daily average dry weather flow, influent load, average daily flow, average daily volume, and plant capacity (PUGLIA 2017).

3.2 Preliminary dimensioning of the WWTP Maglie in the documentation of the Managing Body

Table 3 lists the design parameters identified by the preliminary design document determined by AQP (AQP 2015). The document outlines the status of the plant, its layout and the modifications needed to meet national and regional regulations for the new technical capacity of the WWTP. Design simulations have been performed with *ASCAM* (Activated Sludge Computer Aided Modelling) (TOMEI & RAMADORI 2002), a software package for dimensioning activated sludge wastewater treatment plants applying dynamic models. Further, the parameters describing the pollutant load in the wastewater have been specified in the preliminary design document (Table 3).

3.3 Preliminary dimensioning according to German regulations

The software *Active Sludge Expert* implements the steady-state model described in the DWA standard A 131. Table 1 lists the parameters required for the preliminary design level of the WWTP expansion and the parameters available in the official preliminary design document for the WWTP Maglie. The software allows manually selecting the basic components of the plant, and then it requires the parameters for calculating both hydraulic and polluting loads of the influent. Most parameters requested by the preliminary design document are available, except total nitrogen (Ntot). The parameters chemical oxygen demand (COD), COD dissolved, NO3 and alkalinity are not directly requested by the regional regulation but can be derived from other parameters.

3.4 Comparison between the Italian and the German regulations

Both regulations indicate minimum effluent requirements for different capacity classes (size categories). However, the Italian regulations expresses these requirements in terms of P.E., while the German legislation adds a definition in terms of 5 days biochemical oxygen demand (BOD5) load. There are few differences between both regulations in terms of parameters for the effluent characterization. The German regulations adds the parameter alkalinity, the peak factor for carbon respiration and the peak factor for ammonium oxidation. No specific methodology for the preliminary design is indicated by the Italian regulations or by comparable knowledge sources. Nevertheless, the preliminary design document references the use of software for dynamic modeling and lists the kinetic parameters needed for this modeling along with values to be adopted.

The main difference observed from the comparison is between the design models suggested by the knowledge sources of the two countries. The regulation adopted in Germany proposes a steady model and software for implementing it, while in Italian practice using dynamic models is widespread.

4 A semantic model for wastewater treatment plants

In the preliminary design, a draft layout of a WWTP must be assembled according to both the Italian and the German regulations as a first hypothesis of the chain of treatments expected to be performed by the WWTP. Both regulations require a set of parameters describing the quality of the influent and define a set of values to be met by the parameters describing the effluent of the WWTP. At this level of design, values characterizing the flow are also given for different sections of the WWTP (e.g., inlet flow of the anaerobic mixing tank, inlet flow of the secondary clarifier). Taking into account the aforementioned definitions, the semantic model illustrated in the UML diagram of Figure 1 is proposed.

The model in Figure 1 shows the superclass `WastewaterTreatmentPlant` which has a set of `AbstractWWTCompontent`. The set of components varies depending on the specific layout of the WWTP. The regulations examined in this papers determine the characterization of the influent of the first component and the effluent from the last component. To this end, stereotyped anonymous subclasses `FirstComponent` and `LastComponent` are given. The regulations give few other parameters related to middle components, such as the secondary clarifier, represented in the model as the subclass `SecondaryClarifierComponent`. The `FirstComponent` has a `PSetInfluentLoad` class with all the attributes requested by the regulations to characterize the influent. Similarly, the `LastComponent` has a `PSetEffluentRequirementClass` and the `SecondaryClarifierComponent` a `PSetInfluentRequirements`.

Table 3: Parameters for influent and effluent characterization (Included (o) and not included (-) in the regulation; sources: Italy: AQP (2015), PUGLIA (2017), Germany: FRÖSE (2012))

Parameter Group	Parameters	Unit	ITA	GER
Influent: Hydraulic load	Person load	P.E.	o	-
	Water supply	l/P.E./d	o	-
	φ return flow rate		o	o
	Average influent daily volume	mc/d	o	o
	Daily average dry weather flow	mc/d	o	o
	Two-hour-top dry weather flow	mc/d	-	o
	Average flow after equalization Design inflow at the screening Peak flow after the first pumping station	mc/h	o	-
	Temperature	C°	o	o
Influent: Pollutant load	BOD	kg/d	o	o
	COD	kg/d	o	o
	Dissolved COD	kg/d	-	o
	TSS	kg/d	o	o
	$N\text{-}NH_4^+$	kg/d	o	o
	TKN	kg/d	o	o
	Phosphorus	kg/d	o	o
	Alkalinity	mmol/l	-	o
Effluent: Pollutant load	BOD5	mg/l	o	o
	COD	mg/l	o	o
	TKN	mg/l	o	o
	TSS	mg/l	o	o
	Ammonia nitrogen	mg/l	o	o
	Phosphorus	mg/l	o	o
	E. Coli (colony- forming units per 100 milliliters of water)		o	-

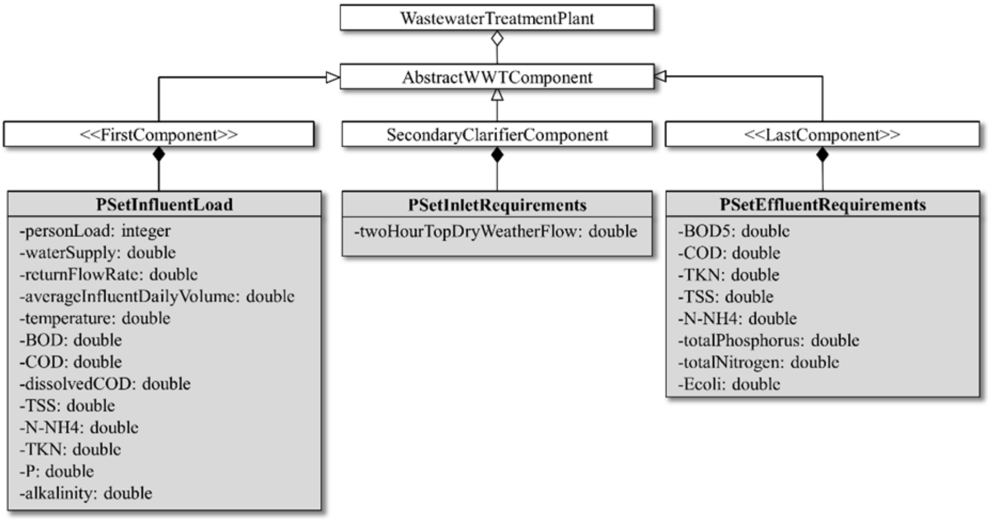

Figure 1: UML diagram of classes needed at preliminary design level to model a WWTP

5 Summary and conclusions

The lack of standardized data formats for water infrastructure has been hindering the applicability of open BIM approaches to water infrastructure. IFC is the only open international standardized data format for applying BIM. However, the IFC standard has limited applicability. To provide an IFC extension for water infrastructure, the requirements from different national regulations have to be considered, due to the international character of the standard. In this paper, a semantic model for water infrastructure has been developed to serve as a basis for IFC extension. Exemplarily, the legislations for constructing wastewater treatment plants in Italy and in Germany have been compared to serve as reliable knowledge sources towards IFC extension. Requirements from the regulations for the characterization of influent and effluent have been determined using an Italian document implementing preliminary WWTP design and a German software package for WWTP design; both have been semantically merged and transformed into a semantic model. The comparison between the regulations from the two countries has yielded differences in the design processes. However, it was possible to identify supersets of the parameters relevant to WWTP design. For the definition of an IFC extension, it is concluded that IFC property sets have to be filled selectively with parameter values in accordance with the national design process.

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