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Dynamizers - Modeling and implementing dynamic properties for semantic 3D city models

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Abstract

Today, more and more cities worldwide are realizing the importance of semantic 3D city models. Various application areas of 3D city models such as simulations require the usage of highly dynamic and time-varying attributes, which are currently not supported by any standard. In this paper, we propose a new concept 'dynamizer', which extends static 3D city models by supporting variations of individual feature properties and associations over time. It allows to inject dynamic variations of city object properties into the static representation. In addition, the concept allows to model and study complex patterns representing dynamic variation of properties based on statistics and general rules.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—I.2.10 [Computer Graphics]: Vision and Scene Understanding—Representation, data structure and transforms

1. Introduction

Semantic 3D city models describe spatial, graphical and thematic aspects of the cityscapes by decomposing and classifying the occupied physical space according to a semantic data model. The relevant real world entities are represented by the ontological structure including thematic classes, attributes and their interrelationships [Kol09]. CityGML [GKNH12] is an international standard issued by the Open Geospatial Consortium (OGC). This standard facilitates the integration of heterogeneous data from multiple sources and allows the representation of the geometrical and semantic attributes of the city level objects along with their interrelationship to other objects. As a result, today, more and more cities worldwide are representing their 3D city models according to the CityGML standard.

Semantic 3D city models are proving to be useful and an important source of information for different types of simulations like environmental simulations, disaster management, and training simulators. Simulation specific data can be represented by specific geo-objects (features) and properties within the city models. Further, the results of simulations can be fed back to the original 3D city models for thematic enrichment and data fusion by data from different disciplines. In most of the simulations, time-varying properties play an important role. Such properties may either represent evolution of the city (slower changes); for example, change of the real property value of a building, change of ownership over time, or the construction of new buildings. They may also represent highly dynamic properties (comparitively faster changes); for example, variations of thematic attributes such as changes of physical quantities like energy demands, temperature, solar irradiation levels. The variation may also be with respect to spatial properties such as change of a feature's geometry, both in respect to shape and to location (moving objects). Such time-dependent and dynamic properties are currently not supported in semantic 3D city models. They only allow storing all time-dependent attributes as static values. Similar to OGC Observations and Measurements [OGC13], an explicit support for simulations is needed for semantic 3D city models.

In this paper, we introduce the concept of 'dynamizers' allowing tighter coupling of semantic 3D city models and simulations. The dynamizers extend the feature representations of city models to support variations of individual feature properties and associations over time. They may involve variations of not only spatial properties but also thematic attributes. In our approach, the dynamizers allow selected properties of city models to become dynamic. If an applica-

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tion does not support dynamic data, it simply can ignore dynamizer features. Furthermore, the dynamizers allow modeling patterns which represent dynamic variations of properties based on statistics and general rules. Such patterns are highly useful in many applications in comparison to the representation of dynamic data just by the tabulation of measured data. In the paper, we provide an implementation of this concept as an extension to the CityGML standard. The concept is also intended to be introduced in the upcoming version of CityGML (version 3.0).

2. Use cases and requirements

In relation to energy simulations, [KK13] explain the application of the CityGML standard in the project Energy Atlas Berlin for city-wide estimation of the energy demands of buildings. The Energy Atlas Berlin includes all data from the Solar Atlas Berlin including the rating of the suitability of all individual roof surfaces for each of the 550,000 buildings in Berlin for the production of photovoltaic and solar thermal energy. It also integrates methods for energy demand estimation (heating energy, electrical energy and warm water) and assessment of the energetic retrofitting possibilities on the individual building level (so far, for all residential buildings only). As shown in Figure 1, the authorities may explore the energy demand of individual buildings for different months of a year. However, such values can be stored within standards such as CityGML as static values only. The current version of CityGML does not allow to store such values varying with respect to time. In this application, one attribute for each month is explicitly modeled.

Figure 1: Visualization of estimated heat demand values of a building in Berlin. The screenshot is retrieved from 3DCityDB Webclient developed by TU München [YSKK14]

[Bil05] and [RBK07] mention the possibilities for application of semantic 3D city models in training simulators, especially concerning emergency car-driver training. The papers highlight the high usability of CityGML in different real-time simulations including flight, maritime and driving simulations. However, the usability will drastically be improved if such city modeling standards support real-time properties such as moving objects and sensor information.

Apart from semantic and spatial properties, appearances are considered an integral part of semantic 3D city models. Appearances are the observable properties of the surfaces and can be represented by material and textures. However, such appearances may also vary with respect to time. [MG14] demonstrate one such scenario of temporal evolution of a building as shown in Figure 2. Other scenarios may include switching of textures for variations according to day/night or summers/winters properties of energy demands, temperature of buildings and solar irradiation values. The current versions of city models do not allow supporting such variations in textures with repect to time. Other use case scenarios for modeling dynamic attributes within city models may include emergency route planning for indoor navigation [MRW06] and dynamic 3D flood simulation [SC08].

Figure 2: An example of texture temporalization. Image taken from [MG14]

Requirements

- The existing standards for semantic 3D city models only support the representation of static data, i.e., they support feature attributes of city objects as static values. However, in case of time-dependent feature properties, the new approach should allow to refer to a specific property of a static city feature whose value can be then overridden or replaced by the dynamic value specified by the source of dynamic data. As a result, only dynamic attributes would be changed, while static attributes would remain unaffected. There would be no need to make the entire model dynamic.
- The dynamic data may be provided by a means for the tabulation of measured data. However, it is not sufficient in many applications as they may require patterns to represent dynamic variations of properties based on statistics and general rules. Such periodic or repetitive patterns should be supported by the new approach.
- The dynamic data may also be provided by referencing Sensor Observation Services [OGC12], which are currently not supported by any of the standards. The new approach should support such real-time dynamic data such as moving objects and sensor information.

3. Related Work

3.1. Time-varying attributes in 3D City Models

There have been a number of studies in the past to develop the possibility of integrating time-varying values within semantic 3D city models. For instance in [PCDB13], the CityGML schema is modified to add temporal information on buildings. However, this method allows to register only definite states. CityGML schema modification and possible standardized exports are not discussed. [Fan10] develops an object-oriented spatio-temporal data model allowing storage and management of semantic and geometric changes of 3D building objects in a city. In this work, CityGML is extended to support such data models, containing an event model that describes events happened to building objects; and a hierarchical spatial data model that describes 3D geometries and semantics of building objects including their valid time span. Another method proposed is based on a modification of CityGML [MG14]. In this paper the authors propose to add two additional concepts to take into account the possibility for a city object to change and the time value which fixes this change in the city lifecycle. However, all of the mentioned approaches are oriented more towards evolution of the city (model). The highly dynamic time-dependent feature properties are not supported in any of the approaches yet.

3.2. Dynamic data support in standards

3.2.1. GML - Dynamic Features

The Geography Mark-up Language (GML) version 3.2 [GML07] allows expressing temporal developments of the features using the so-called history property. The history property of a dynamic feature contains a sequence of time slices, which captures the evolution of a feature over time. Since the city model standards such as CityGML are based on GML, this feature becomes the obvious choice to include dynamic features. However, this would require that we redefine all property data types of all features to use the GML dynamic data mechanism. That would result a total replacement of the existing model. The GML dynamic data schema would have to be generally supported by all systems, even if none or only very few attributes would have time varying properties. GML also has no support for patterns and sensor integration.

3.2.2. ISO 19123 - Schema for coverages

ISO19123 [ISO05] allows defining discrete and continuous coverages, which contain three components: a spatio-temporal domain set, a range set, and a coverage function. The range of a coverage is a set of feature attribute values (which may also be time-varying attribute values of geo-objects). The domain values are mapped to the range values values using a coverage function. The coverage functions within continuous coverages allow defining interpolation methods to derive feature attribute values. The coverage encodings (except continuous coverages) have already been specified using GML 3.2.

3.2.3. WaterML2.0 - Timeseries

WaterML 2.0 [Wat14] is a standard for the representation of hydrological observations data with a specific focus on time series structures. This standard is implemented as an application schema of the GML version 3.2.1, making use of the OGC Observations and Measurements standards. The standard allows defining timeseries as discrete coverages, which means, an instance of such a coverage would be a set of ordered time instances where each time instance is associated with a single value from the attribute space. This association is often represented using time value pairs or a domain range. It also allows to define interpolation types 'per point' within timeseries, establishing the relationship between time instants and the recorded values.

3.2.4. Cesium Language (CZML)

CZML [CZM15] is a JSON based schema describing dynamic properties of geospatial data in order to be visualized in web based virtual globes, in particular, Cesium [Inc15]. Since the work is already in progress for visualizing large scale semantic 3D city models on Cesium virtual globe [CYK15], CZML may prove highly useful in visualizing dynamic attributes of the city models.

4. Modeling time-dependent data variations

We propose a new concept called 'dynamizer' allowing modeling of time-dependent and dynamic variations within semantic 3D city models. A dynamizer is an object referencing a specific attribute of a specific object within a 3D city model providing time-dependent values to override the static value of the referenced object attribute. The dynamic data is given by tabulation of time/value pairs, patterns of time/value pairs or by referencing a Sensor Observation Service. The dynamizer can thus be used to inject dynamic variations of city object properties into an otherwise static representation. The advantage in using such approach is that it allows only selected properties of city models to become dynamic. If an application does not support dynamic data, it simply does not allow/include these special types of features.

4.1. Modeling timeseries interpolation methods

The proposed dynamizer approach has a close relation with ISO19123, where spatial or temporal values in the domain set are mapped to the specific values in the range set according to a mapping function. It allows dynamizers to map time points or timeseries to the specific time-dependent attributes, which may be spatial, thematic or appearance.

However, such mappings are discrete in nature resulting the mapping to be done in either time-value pair or domain-range fashion. Due to which, two important questions arise,

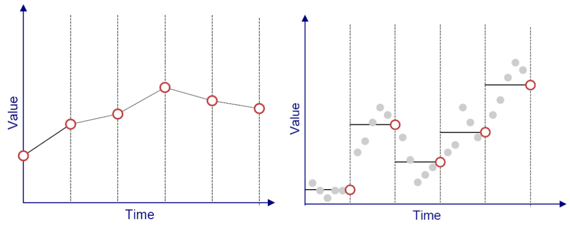


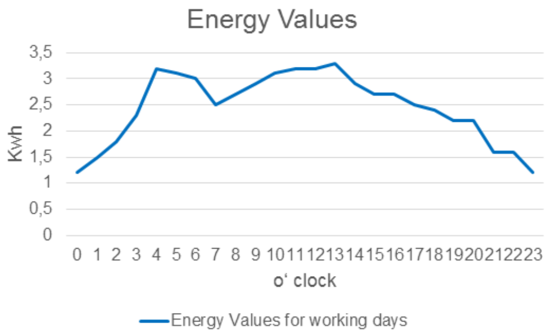
Figure 3: Representation of interpolation types supported within WaterML2.0 Timeseries. Continuous (left) and step functions (right). Image taken from [Wat14].

'How do we map the time points with missing values in the range set?' and *'How do we map the time points with multiple values in the range set?'*. These questions lead to explore the possibilties of interpolation and aggregation techniques in our approach. The standard WaterML2.0 defines a timeseries as a coverage whose domain consists of collection of ordered temporal elements and the spatial component relates to the feature of interest of the observation. Within the standard, the timeseries is a type of discrete coverages. It allows defining interpolation and aggregation types 'per point' within the timeseries as it is possible for this to change mid series. As shown in Figure 3, there are possible ways to define interpolation types within the timeseries. In our approach, the domain sets in the coverages are extended to support time series in the same fashion as the standard WaterML 2.0, allowing to map the missing or multiple values utilizing interpolation and aggregation techniques.

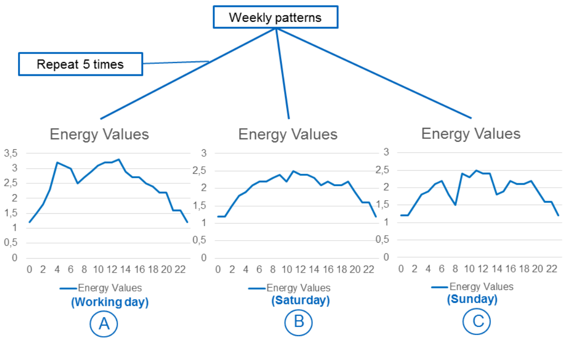
4.2. Modeling repetitive patterns

The dynamizers may have absolute start and end points, within which the attribute values can be mapped and can be represented as tabulation of measured data. One common example illustrating such scenario is mapping of energy values of a building (e.g. current energy consumption) for every hour in a day (see Figure 4a).

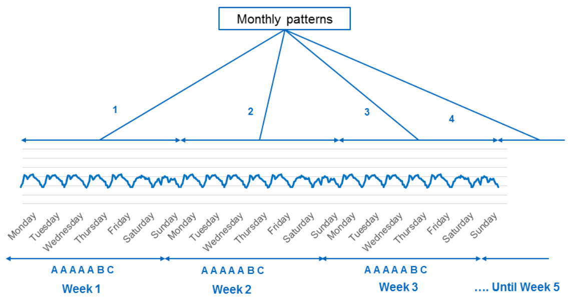
However, in many applications, it is not sufficient just to provide a means for the tabulation of time-value pairs. They may require patterns to represent dynamic variations of properties based on statistics and general rules. For example, in energy demand estimations, the energy values reflect specific patterns for individual weekdays and weekends. Such patterns can be modeled using composite timeseries. But, this would require to use relative time points, which is not clearly defined in any standard. ISO 19108 [ISO02] has no direct support for relative time points. The standard defines absolute time points in two ways, i.e. TMInstant and TMPeriod. TMInstant is a primitive that represents one position in time. The position can be associated with a single temporal reference system (e.g., Gregorian Calendar). However, it may allow to calculate a relative time point with respect to TMInstant, e.g., determining '1 Day' with respect to TMInstant (and not with respect to Gregorian Calendar). These composite timeseries may consist of nested ordered timeseries (having relative time points) for arbitrary depths. As shown in Figure 4b, an atomic timeseries can be defined for a working day, a Saturday and a Sunday (represented by A,B and C respectively). Then, the weekly energy consumption pattern can be composed by concatenating five times the weekday's energy consumption timeseries and the further two for Saturday and Sundays. Such complex behaviours are expressed using composite timeseries, wherein a weekly pattern can be defined containing the energy values for all



(a) Hourly energy values of a building (atomic timeseries)



(b) Example of composing atomic timeseries to a pattern



(c) Example of complex composite timeseries

Figure 4: Representation of complex patterns by atomic and composite timeseries.

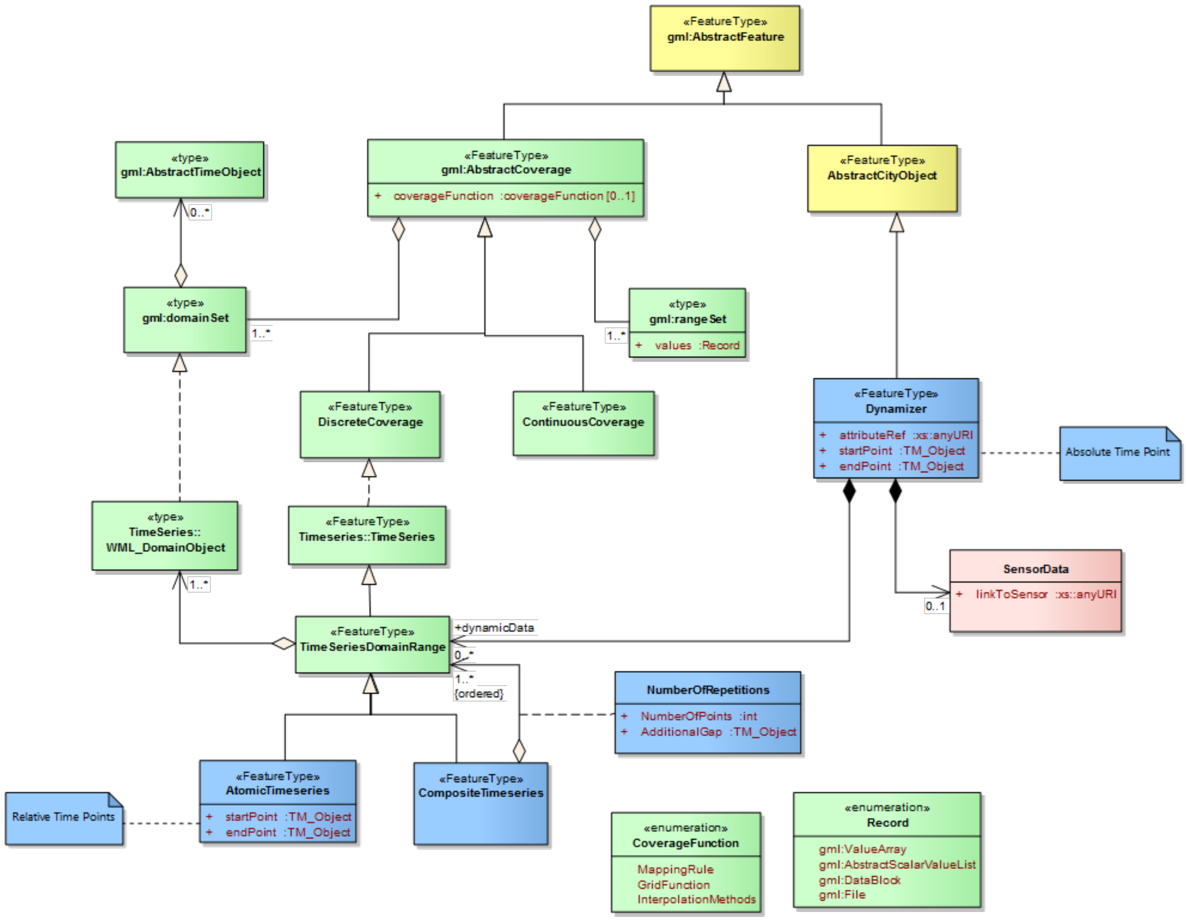


Figure 5: Dynamizer defined as UML model. Newly introduced classes are shown in blue and pink. Classes shown in green represent GML implementation of coverages [ISO05] and timeseries [Wat14]. Classes shown in yellow are from GML and CityGML respectively.

seven days of a week (represented as AAAAABC). The advantage in using such composite timeseries is that it allows the study of customized patterns; for example, patterns for only weekdays (AAAAA) or patterns of only weekends for four weeks (BCBCBCBC).In the similar fashion, even more complex patterns of arbitrary depth such as weekly, monthly and yearly, can be defined using the approach (c.f. Figure 4c).

5. Implementation

The mentioned concept of dynamizer is implemented as an extension to the CityGML standard. As shown in Figure 5, the dynamizers are defined as feature types consisting of attributes *attributeRef*, *startPoint*, and *endPoint*. The dynamizers utilize the GML implementation of ISO19123 *AbstractCoverage*. They consist of (i) a temporal *domainSet*, (ii) a *rangeSet* (having time-varying attribute values), and (iii) a *coverageFunction*, which maps the time values in the domain set to the range values accroding to a function. Since the *domainSet* is a *gml:AbstractTimeObject*, it is possible to have time points and time periods. The *rangeSet* may contain value arrays, scalar value lists, data blocks and external files. The value arrays are used for homogeneous arrays of primitive and aggregation values. Their value components may contain or refer to abstract values as well as spatial values allowing to express not only variations of thematic attributes but also variations of spatial properties both in respect to shape and to location (moving objects). The inclusion of external files in the range set allows to express variations of appearances (referencing textures) over time. The coverage functions map the time values in the domain set to the range values according to a function. The *attributeRef* in dynamizer, then, refers to a specific property of a static city model feature which value can be then overridden or replaced by the dynamic value specified in the dynamizer feature. It can be achieved utilizing XPath [Rec11], which is a W3C recommendation used to navigate through elements and attributes within an XML document. It allows to determine the position of the context item and replaces the attributes. The advantage is that by utilizing the XPath mechanism, this approach easily fits into the modularization concept of CityGML. The dynamizers currently support time-series domain whose values can be mapped to the dynamic attributes. This feature is further extended to support complex patterns utilizing composite design patterns. Furthermore, a first approach to link sensors to a city object is also shown in Figure 5. This approach will be useful in integration of city objects and real time sensor data, e.g. retrieved from photovoltaic production stations or smart meters.

6. Conclusions

In this paper, we present a new concept 'dynamizer', which allows representing dynamic and time-varying attributes within semantic 3D city models. This results in supporting time variations for spatial properties, thematic properties and appearances of the objects. An extension to CityGML is provided by defining a new dynamizer feature type, which stores dynamic variations and overrides the specific properties of the CityGML feature property. In addition, the proposed approach utilizes and extends the GML implementation of ISO19123 and WaterML2.0 Timeseries which enhances the dynamizer feature by supporting various types of timeseries and their mapping with spatial, thematic and appearance attributes of the objects. The approach even allows to map missing or multiple attribute values utilizing interpolation and aggregation methods. Furthermore, the timeseries can be extended to model and study complex patterns based on statistics and general rules. However, currently, such interpolation methods are only applicable for quantitative data (and not to thematic data).

The mentioned concept is intended to be proposed to become part of the next version of CityGML (version 3.0). However, the concept is general and can also be applied to other GML-based application schemas including the European INSPIRE data themes. In the future, it will be interesting to further investigate on linking the model with OGC Sensor Observation Services. It would allow supporting dynamic sensor information within 3D city models. The work is currently in progress to develop the mentioned approach as a CityGML Application Domain Extension (ADE) for CityGML 2.0 in order to test and evaluate it with current software systems ann applications.

References

[AIX10] AIXM: AIXM: Aeronautical Information Exchange Model, 2010.

[Bil05] BILDSTEIN F.: 3d City Models for Simulation and Training-Requirements on Next Generation 3d City Models. In *Proc. of the Int. ISPRS Workshop on Next Generation 3D City Models in Bonn, Germany. EuroSDR publication* (2005). 2

[CYK15] CHATURVEDI K., YAO Z., KOLBE T. H.: Web-based Exploration of and Interaction with Large and Deeply Structured Semantic 3d City Models using HTML5 and WebGL. *35. Wissenschaftlich-Technische Jahrestagung der DGPF und Workshop on Laser Scanning Applications* (2015). 3

[CZM15] CZML: CZML Guide AnalyticalGraphicsInc/cesium Wiki GitHub, 2015. 3

[Fan10] FAN H.: *Integration of time-dependent features within 3D city model.* PhD thesis, Technische Universität München, 2010. 3

[GKNH12] GRÖGER G., KOLBE T. H., NAGEL C., HÄFELE K.-H.: OGC City Geography Markup Language (CityGML) Encoding Standard, 2012. 1

[GML07] GML: ISO 19136:2007 - Geographic information – Geography Markup Language (GML), 2007. 3

[Inc15] INC. A. G.: Cesium - WebGL Virtual Globe and Map Engine, 2015. 3

[ISO02] ISO19108: ISO 19108:2002 - Geographic information – Temporal schema, 2002. 4

[ISO05] ISO19123: ISO 19123:2005 - Geographic information – Schema for coverage geometry and functions, 2005. 3, 5

[KK13] KADEN R., KOLBE T. H.: City-wide total energy demand estimation of buildings using semantic 3d city models and statistical data. *Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences 2* (2013), W1. 2

[Kol09] KOLBE T. H.: Representing and exchanging 3d city models with CityGML. In *3D geo-information sciences*. Springer, 2009, pp. 15–31. 1

[MG14] MOREL M., GESQUIÈRE G.: Managing Temporal Change of Cities with CityGML. In *UDMV* (2014), pp. 37–42. 2, 3

[MRW06] MÄS S., REINHARDT W., WANG F.: Conception of a 3d geodata web service for the support of indoor navigation with GNSS. In *Innovations in 3D Geo Information Systems*. Springer, 2006, pp. 307–316. 2

[OGC12] OGC: Sensor Observation Service | OGC, 2012. 2

[OGC13] OGC: Observations and Measurements | OGC, 2013. 1

[PCDB13] PFEIFFER M., CARRÈ C., DELFOSSE V., BILLEN R.: Virtual Leodium: From an historical 3d city scale model to an archaeological information system. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences II-5 W 1* (2013), 241–246. 3

[RBK07] RANDT B., BILDSTEIN F., KOLBE T. H.: Use of virtual 3d landscapes for emergency driver training. In *Proc. of the Int. Conference on Visual Simulation IMAGE* (2007). 2

[Rec11] RECOMMENDATION W.: XML Path Language (XPath) 2.0 (Second Edition), 2011. 6

[SC08] SCHULTE C., COORS V.: Development of a CityGML ADE for dynamic 3d flood information. In *Joint ISCRAM-CHINA and GI4DM Conference on Information Systems for Crisis Management* (2008). 2

[Wat14] WATERML: OGC WaterML | OGC, 2014. 3, 4, 5

[YSKK14] YAO Z., SINDRAM M., KADEN R., KOLBE T. H.: Cloud-basierter 3d-Webclient zur kollaborativen Planung energetischer Maßnahmen am Beispiel von Berlin und London. *Geoinformations system, proceedings of the Münchner GI-Runde* (2014), 24–25. 2