Making 3D City Models Dynamic

Thomas H. Kolbe
Chair of Geoinformatics
Technische Universität München
thomas.kolbe@tum.de

20th of October 2016

Joint 3D Athens Conference, Greece
Digital Models of the Built Environment

► On the scale of individual sites: Building Information Modeling (BIM, IFC)

► On the scale of city quarter up to entire regions: Semantic 3D City Models (CityGML)
Semantic Site and City Models as Cross Domain Integration Platform
Standardized Access to Semantic City Models

Mapping the state of a city at time $t_i$

Virtually carrying out planned actions by changing the city model accordingly

Energy Demand & Production Estimation
Noise Immission Simulation & Mapping
Real Estate Management & Urban FM
Vulnerability Analysis & Disaster Management
Multi-Simulations with 3D City Models

3D City Model + Application Domain Extensions

- Urban Climate Simulation (Air Pollution)
- Urban Climate Simulation (Heat Islands)
- Energy Simulation (Solar Potential Analysis)
- Energy Simulation (Building Heat Demand)
- Energy Simulation (Geothermal Energy Production)
- Environmental Simulation (Noise Immission)
- Energy Simulation (Geothermal Energy Production)
- Mobility Analysis (Traffic Flows)
- Energy Simulation (Building Heat Demand)
- Vulnerability Analysis (Detonations)
- Vulnerability Analysis (Flooding)
- Vulnerability Analysis (Failures of Critical Infrastructures)

Bold-framed boxes: projects that were carried out by or with participation of my teams so far
Motivating Example

Vulnerability Analysis (Detonation Simulation)
‘Controlled’ Blast of discovered unexploded Bomb from World War II
Detonation in Munich, District Schwabing, 2012

Unexploded American 500 lbs Bomb (120kg TNT)
Evacuation of 2500 citizens

Source: Google Maps

Source: Münchner Abendzeitung Bildzeitung
‘Controlled‘ Blast of discovered unexploded Bomb from World War II

Detonation in Munich, District Schwabing, 2012
Apollo Blast Simulator

► Developed by Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut (EMI) in Freiburg

► Computational Fluid Dynamics (CFD) simulation for
  ● Detonations
  ● Shock waves
  ● Gas dynamics

► Physical values
  ● Pressure, impulse

► Application areas
  ● Risk assessment
  ● Vulnerability analysis
Derivation of a Voxel Model from CityGML

- Selection of the simulation area
- Generation of a complete regular voxel grid for the simulation area
- Intersection of the voxel grid with the vector representation of the CityGML objects → occupancy grid
Detonation Simulation of a WW II Aircraft Bomb

► **Fictive scenario**: during groundworks an unexploded bomb from World War II is found in the courtyard of TUM; it cannot be defused and, hence, must be detonated on place

► **Real problem**: WW II ammunition is still found every day

► maximum danger zone is estimated based on the TNT equivalent using an empirical formula
Mapping the Simulation Result back to CityGML

- A vector of parameters is being computed by the simulator for each voxel
  - peak overpressure, probabilities for glass & façade breakage, death, eardrum damage etc.

- These parameters are aggregated and mapped back to the objects of the CityGML model (RoofSurfaces, WallSurfaces)

Probability for breakage of glass

70% max probability for breakage of glass
Comparison: Simple Estimation ↔ CFD-Simulation

Conservative method, peak overpressure

>20 000 Pa

>10 000 Pa

>5 000 Pa

CFD simulation, peak overpressure
Comparison: Simple Estimation ↔ CFD-Simulation

Conservative method, peak overpressure

Illustration of the overpressure on the facade

>20 000 Pa

CFD simulation, peak overpressure

Image: [Łukasz Ślaga 2013]
Linking Urban Simulations across Domains

► Output of one simulation can be the input for another one
  ● cascading simulations need lossless information handling

► Semantic 3D city models are well suitable data integration platforms
  ● source for simulation input data
  ● container for simulation output data

► Simulations often require and produce time-dependent data

► Smart City projects integrate sensors & observations
  ● observations are also time-dependent

► Time-variant object properties are not supported in City Models so far
Dynamic Data in Semantic 3D City Models
Properties of the Objects of a 3D City Model

- **Geometry**
  - Location, Shape, Extent

- **Topology**
  - Connectivity

- **Semantics**
  - Structure & Thematic Properties

- **Appearance**
  - Colors, Textures
Dynamic Data in City Models (1)

Which *properties of a city object* can be dynamic?

► **Spatial Information** (Geometry & Topology)
  - **Extent and form**: e.g. retrofitting, extension, (partial) demolition of sites; plant growth; watercourse during flooding
  - **Location**: e.g. for movable objects like vehicles or persons the position and orientation

► **Appearance Information**
  - Color, texture – e.g. change of the appearance of building facades within an RGB or Thermal IR image over the day

► **Semantic Information**
  - Thematic data like e.g. electrical power consumption of a building; room temperature; traffic density in a road; evaporation of a group of trees
Dynamic Data in City Models (2)

Which *types of dynamic behaviour* can be distinguished?

► **Slow Changes**
  - Creation and termination of objects (construction / demolition of sites, planting of trees; construction of new roads)
  - Structural changes of objects (e.g. raising of buildings)
  - Change of object status (e.g. change of building owner; change of the traffic direction of a road to a oneway street)
  - Few changes over a longer time period → *Evolution*

► **Fast Changes**
  - Time dependent / variant object properties (e.g. energy consumption, traffic density, pollution concentration, overpressure on building walls)
  - are the result of simulations or of measurements (sensor data streams)
  - Many changes over a short (but also longer) time period
Time-varying properties (1)

► Slow changes

- History or evolution of cities/city models
- Change of feature’s geometry over time
- Managing parallel or alternative versions over time
- Already published in 3DGeoInfo 2015, Kuala Lumpur, Malaysia

Source: Chaturvedi et al., “Managing versions and history within semantic 3D city models for the next generation of CityGML”. In 3DGeoInfo (2015)
Time-varying properties (2)

► Highly dynamic changes

- **Variations of spatial properties**: change of a feature’s geometry, both in respect to shape and to location (moving objects)
- **Variations of thematic attributes**: changes of physical quantities like energy demands, temperatures, solar irradiation
- **Variations with respect to sensor or real-time data**


Source: MOREL M., GESQUIÈRE G., “Managing Temporal Change of Cities with CityGML”. In UDMV (2014)
Modeling and Representing Dynamic Data

► **New data types for time-variant attributes** are required
  - Time series
  - Tabulation of timestamps + property values

► **Property values**
  - Simple numeric values, measures, physical quantities
  - Appearances (Textures, Colors)
  - Geometries

► Time variant properties of city objects can be represented by time series
  - Observation: only specific properties are dynamic → no general replacement of all simple data types by time series

► **Specific „dynamization“ using CityGML 3.0 Dynamizers**
CityGML Dynamizers
From the PhD Work of Kanishk Chaturvedi
Dynamizer – New CityGML Feature Type

► attributeRef refers to a specific property of a static CityGML feature which value will then be overridden or replaced by the (dynamic) values specified in the ‘Dynamizer’ feature.

► startTime and endTime denote time span for which the Dynamizer provides dynamic values

► Dynamizer composes of AbstractTimeseries:
  ● Allows representing time-variant values in different and generic ways
  ● E.g. Timeseries, Sensor observations etc.
Example Scenario

CityGML object

Source of dynamic data

<table>
<thead>
<tr>
<th></th>
<th>Estimated (in kwh)</th>
<th>Heat Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN-15</td>
<td>61578</td>
<td></td>
</tr>
<tr>
<td>FEB-15</td>
<td>52148</td>
<td></td>
</tr>
<tr>
<td>MAR-15</td>
<td>41011</td>
<td></td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>DEC-15</td>
<td>64984</td>
<td></td>
</tr>
</tbody>
</table>

Referencing of the object attribute using XPath

Dynamizer

```xml
<cityObjectMember>
  <Building gml:id = "building1">
    <gen:doubleAttribute name = "HeatDemand">
      <gen:value xxx /></gen:doubleAttribute>
  </Building>
</cityObjectMember>

<cityObjectMember>
  <dyn:Dynamizer>
    <dyn:attributeRef> //Building [@gml:id = 'building1']/doubleAttribute[@name = 'HeatDemand']/gen:value</dyn:attributeRef>
    <dyn:startTime> 2015-01-01T00:00:00Z </dyn:startTime>
    <dyn:endTime> 2015-12-31T00:00:00Z </dyn:endTime>
    <dyn:dynamicData>.. </dyn:dynamicData>
  </dyn:Dynamizer>
</cityObjectMember>
```
Integration of Sensors and their Observations

► By linking Dynamizers with Sensors

- Such links basically mean that a specific dynamic value for a city object property is measured by a specific sensor (service).
- Dynamizers represent these direct links to sensors and observations utilizing different requests.
  - In case of OGC SOS: DescribeSensor and GetObservation
- In order to get the dynamic data, requests to the sensor services must be performed.

► By including sensor observations within Dynamizers

- Sensor observations are typically encoded in OGC O&M format.
- Dynamizers provide explicit support of O&M, which allows representing sensor observation values.
  - Hence, the result of an SOS GetObservation request can directly be embedded (i.e. stored inline) within the Dynamizer.
Example for a Sensor Connection

Sensor (PV Panel)

Demonstration
City Models + Sensors
Integrating Dynamic Data and Sensor with Semantic 3D City Models

Queen Elizabeth Olympic Park
London

Thomas H. Kolbe, Kanishk Chaturvedi
Chair of Geoinformatics
Technische Universität München
Conclusions

► Semantic 3D City Models are a very suitable integration platform for multi-simulations
  ● Systems for managing semantic 3D city models could become the central data management component for simulators in the future

► Many properties of city objects are measured by sensors (important in Smart City scenarios)

► Handling of dynamics is mandatory for these purposes
  ● Slow changes / evolution
  ● Highly dynamic changes & sensor integration

► CityGML 3.0 will support both aspects
  ● Versioning / Historization
  ● Dynamizers