Extending Spatial Data Infrastructures 3D by Geoprocessing Functionality

3D Simulations in Disaster Management and environmental Research

Georg Walenciak Beate Stollberg Steffen Neubauer Alexander Zipf
Department of Geography
University of Bonn
Bonn, Germany
{walenciak,stollberg,neubauer,zipf}@geographie.uni-bonn.de

Abstract— **The quite new Web Processing Service (WPS) specification of the Open Geospatial Consortium (OGC) is increasing the value of Spatial Data Infrastructures (SDIs) by offering a standard for the actual processing of spatial data. The interface is already used in a range of projects, but up to now mainly in connection with 2D spatial data. In this paper we want to demonstrate that the standard can also be applied in a 3D environment which increases the potential of such 3D-SDIs. We implemented two use cases of disaster management and environmental monitoring and discuss the benefits and drawbacks of applying geoprocessing functionality in 3D. The scenarios were integrated and visualized in a Web3DServer (W3DS) viewer and demonstrate how useful it is to present the outcomes of such simulations in the third dimension.**

3D geoprocessing; 3D simulations; Spatial Data Infrastructures; Web Processing Service

I. Introduction

Today, Spatial Data Infrastructures (SDIs) are primarily used to share, access and visualize distributed 2D spatial data. However, the usefulness of SDIs can be improved by developing web services that are also capable of handling 3D data which offer much more sophisticated applications. The main goal of our project GDI-3D (Geo-Spatial Data Infrastructure 3D) is to find best practices for 3D data exchange, data preparation, service chaining, and user interaction. The test case is the city of Heidelberg in Germany. In that context we are implementing and improving the most recent services of the Open Geospatial Consortium (OCG) that are currently under discussion. Together with the established and successful services for conventional SDIs these offer new possibilities for web-based and interoperable applications using 3D city models and 3D landscape models. The goal is also to investigate extensions to the existing specifications in order to fulfill the special requirements of 3D data exchange and display [1].

Within the project a 3D-SDI has been set up based on relevant OGC services like Web Feature Service (WFS), Web Map Service (WMS), Catalogue Service for the Web (CS-W) and Web Coverage Service (WCS) using open source tools and frameworks. These are supplemented with our implementations of an OGC Web3D Service (W3DS) – serving 3D scenes, accompanied with a specialized 3D viewer [2], and the needed software for preprocessing, generating and managing the 3D landscape and city models in a 3D database. But a range of further services have been realized and added, in order to be able to realize more complex scenarios and user workflows in an interoperable manner.

Some quite new specifications of the OGC are increasing the value of SDIs by offering standards for the actual processing of spatial data and the use of dynamic or real-time spatial data. These are especially the new Web Processing Service (WPS) interface [3], the specifications of the Sensor Web Enablement (SWE) Initiative [4] and the Open Location Services (OpenLS) standards [5]. All these new specifications are already used in a range of projects, but up to now mainly in connection with 2D spatial data. In this paper we want to demonstrate that these standards can also be applied in a 3D-SDI. As argued by [6] this increases the potential of development in SDI technology, as it allows new kind of applications compared to the existing 2D applications to be realized in a standard-based way and supported by the modular, Service Oriented Architecture (SOA), which is a common paradigm for realizing applications not only in the general IT-world, but in the Geographic Information (GI) business in particular. Some first examples of the possible uses and current issues related to this approach with 3D data have been presented in [2].

Within this paper we now focus on the use of the WPS specification for perform 3D simulations in the context of disaster management and environmental research. Some of the arising questions are - how to use the WPS in the context of 3D GI applications, what are the benefits and drawbacks, and if the current specification needs more specific support for 3D. In order to investigate these issues and discuss the outcome of these, we have implemented two use cases. More precisely we integrated two specific scenarios of disaster management and environmental monitoring (simulation of air pollution) within the GDI-3D project. The simulations have been realized using the WPS interface. For integrating dynamic data the Sensor Observation Service (SOS) [7] - which is part of the SWE standards - has been applied, too, in the latter use case.

This paper is structured as follows: First we give a short introduction how to provide geoprocessing functionality in 3D based on open standards, then we explain and discuss the two scenarios in the domain of disaster management and environmental research. By means of the use cases we indentify similarities of 3D simulation and provide therefore a basis for the future development of a WPS profile for such 3D simulations. Finally the paper ends with a summary and outlook.

II. GEOPROCESSING FUNCTIONALITY IN 3D

A. *OGC WPS Interface*

The goal of the WPS interface was to add geoprocessing functionality to the spatial web. The specification defines three mandatory operations for a WPS. These are *GetCapabilities*, *DescribeProcess* and *Execute*. The response to a *GetCapabilities* request is an XML-document containing metadata of the WPS and all available processes. A detailed process description as well as input and output parameters are provided for every process as response to a *DescribeProcess* request, also in form of a XML-document. The final process execution is carried out when an *Execute* request is send to the WPS.

Unfortunately the actually specification allows any kind of processing functionality. Even in the context of Geographic Information Systems (GIS) it may provide simple calculations (e.g. the calculation of Thiessen polygons) as well as complex computations (e.g. the generation of a geomorphologic model). Due to this fact the specification can be applied to a wide variety of domains and tasks. Some examples include disaster management [8], forest fire analysis [9], generalization [10], hydrological models [11], housing market analysis [12], biodiversity research [13], time series analysis [14], precision farming [15] etc. All these applications are based on 2D data.

Further use of the WPS specification on the basis of 3D is emerging at the moment. E.g. within the project SDI-Grid[1] different representative scenarios are implemented where 3D data are processed by Grid computing technologies. These scenarios include flood simulation as well as noise propagation modeling and they will be provided by the WPS interface.

B. *3D Visualization in Disaster Management*

3D processing and 3D visualization can be used in the field of disaster management for a rapid assessment of the current situation including detailed building models, terrain, vegetation, and other objects. The immersive nature of the visualization allows also inspecting building complexes such as airports for which 2D footprints are sometimes difficult to understand. Internal structures, e.g. rooms and corridors, pipes for water and fuel, sewers, cables, ventilation shafts, and the like, can be better analyzed in 3D. Due to the possibly vast amount of details, high performance visualization at interactive frame rates is preferred which can be achieved using W3DS. The better the representation of the space affected by a disaster, the better is the support for decisions taken by the operation control.

C. *Use Case Bomb Finding*

In our here implemented scenario which was already set up in 2D [8] a bomb was found. This can be either an “old” bomb from World War II or a “ticking” bomb from a current attack. All persons within a specified radius around the bomb, namely within the “danger zone”, must be evacuated. A second, larger buffer must also be defined around the bomb, namely the “security zone”. These radii can be calculated based on the explosive force of the bomb which expresses the degree of destruction around the bomb finding place. The 2D visualization of the result of this scenario could look as shown in figure 1.

The realization of this use case within a 3D-SDI environment promises a more sophisticated visualization. In particular in situations with complex building configurations – e.g. airports, train stations, factories this can give more detailed information about the affected places. This is of course in particular true, if a complex physical model for estimating the effect on the surrounding buildings is used. This could also be encapsulated by a WPS in general. For our purposes the very simplified approach with the circular danger and security zones was used and also supported by the real end users (firemen).

So based on the earlier 2D scenario, a new 3D-WPS process “BombThreatScenario3D” was developed. It takes two input parameters, namely the location of the bomb in 3D coordinates and the explosive force in kg. The process was integrated into our W3DS viewer. This now allows an end user to pick the location of a found bomb within the 3D scene and send that location together with the explosive force (which can be filled in a form) to the WPS. The WPS executes the process which calculates the security and the danger zone according to the explosive force. As a result the WPS generates two transparent spheres expressing the calculated areas around the bomb. These spheres are stored as Virtual Reality Modelling Language (VRML) file and a reference to this file is sent back within the WPS Execute response to the W3DS viewer, which is so able to visualize the result. This visualization is shown in figure 2.

Figure 1. Visualization of the bomb threat scenario in 2D.

[1] http://www.gdi-grid.de

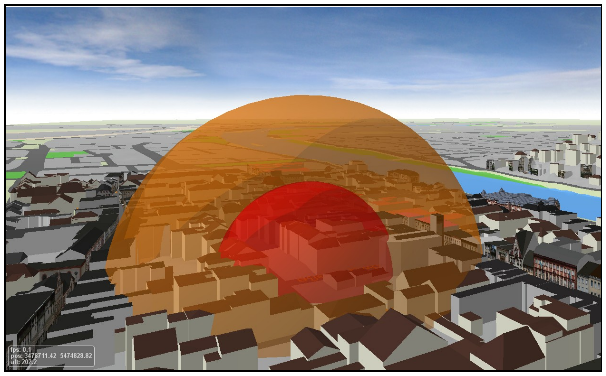

Figure 2. Visualization of the bomb threat scenario in 3D.

The approach allows the 3D viewer to be a relatively thin client, as it only displays the pre-processed geometry. The use of VRML as an exchange format provides a means to put the processing task mainly to the server side. In the given use case the presented solution was sufficient, and provides a very elegant possibility of adding new functionality to the client with minimal effort or changes needed within the client software. But there are different use cases conceivable where it might be advantageous to shift the processing task to the client side. In this case there would be more interaction with the 3D object possible. The user may change the object within the client which requires a fast on-the-fly visualization.

Furthermore VRML is a very simple format which does not allow integrating a semantically richer model. So there is no possibility to attach attributes to the 3D object which limits the opportunity to further work with these attributes as it would be possible by using different data exchange formats like the Geography Markup Language (GML). Another example in this context would be the visualization of sensor data within the client (e.g. temperature values of a distributed sensor network within the city). These data are changing permanently and respectively the visualization (e.g. labeling of the values). In this case it makes no sense to request, process and store these data on the server. Instead it would be useful to directly request, process and visualize them on-the-fly within the client.

However, the 3D visualization of the result offers a lot of advantages compared to the 2D representation. Rescue teams must evacuate people within the defined zones, streets have to be blocked and the bomb must be disarmed. Different units are involved in the use case like the police, fire brigade, medical teams and so on. All of them must be coordinated by an operation controller which is the user of our implemented scenario. The 3D visualization within the 3D viewer offers the possibility for him to “move” within the scene and to detect a lot of details at first sight. He is able to estimate how many buildings must be evacuated and which kind of buildings these are. For example it makes a huge difference if skyscrapers are affected or just small buildings with a low number of people. Furthermore the user is able to capture information about street widths which are important for the transportation of heavy equipment to the affected area. This “moving” within the 3D scene is therefore much more revealing compared to having a “simple look” at a 2D presentation.

D. Use Case Eemission Spread

In our second use case we assume that a gas leakage was detected and the gas - which might be toxic - is spreading. This might affect (or even be a threat to) both the environment and human beings. So this scenario is very much dependent on what type of gas or substance we talk about. In case of a toxic gas which is a danger for the human population it can be classified as a disaster to manage. But in general it is a typical example of environmental simulation. The user in this scenario wants to know where the gas will be within the next hour, e.g. in the domain of disaster management for estimating which region and how many people are affected by the propagation. As the spreading is dependent on the actual wind speed and wind direction we have to obtain this relevant information from a weather sensor. For using the data in an OGC compliant way we store the received sensor data in regular intervals in a PostGIS database and provide it by an OGC Sensor Observation Service.

We developed a new 3D-WPS process “ToxicGasScenario3D” that uses this sensor information. The process takes two input parameters, namely the location of the gas leakage in 3D coordinates and time duration. Once more the process was integrated into our W3DS viewer where it is now possible to pick the location within the 3D scene and sends it within an Execute request to the WPS. The process in turn sends a GetObservation request to our SOS for retrieving the actual wind speed and direction. According to these values the process generates a transparent cloud expressing the gas spreading within the requested time duration, e.g. 60 minutes.

As the implementation of this scenario is also meant to demonstrate the potential use of a 3D-WPS within 3D-SDIs, of course a quite simple approach has been taken that does not take a specific physical gas spreading model into account or even the 3D city model for parameterize that simulation model. For more sophisticated environmental simulations it would be useful to integrate an atmospheric propagation model in consideration of the surrounding buildings.

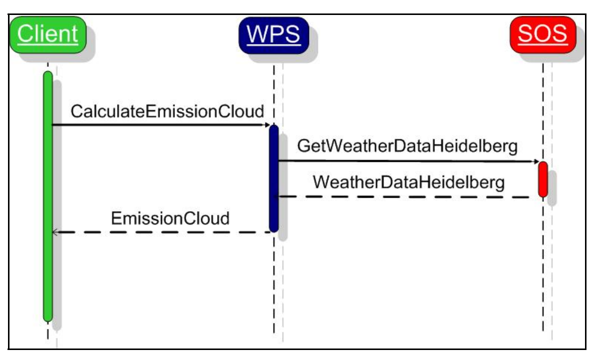

Figure 3. Sequence diagram of the services involved in the emission spread scenario.

Furthermore it is assumed that wind speed and direction are not changing significantly within the next hour. In addition the information about the wind conditions is derived from a single weather sensor available in Heidelberg which is again a quite simple approach. A denser sensor network which allows sophisticated predictions for regions within the city would be beneficial. In that case in a first step the sensor closest to the incident needs to be determined – this is a spatial search on the usually known location of the individual sensors.

Just like in the bomb finding scenario, the cloud is again stored as a VRML file and a reference to this file is sent back within the WPS Execute response to the W3DS viewer which is so able to visualize the result. An example of such visualization is shown in figure 4.

III. IDENTIFYING SIMILARITIES OF 3D SIMULATIONS

The WPS interface has been consistently coming under criticism for its openness because the specification makes it possible to use it as a facade for any kind of processing, providing geo-processing functionality or not. For this reason it is important to develop so-called profiles by user communities to agree on defined WPS processes. Within particular domains, it is imperative that standardized geo-processing functionalities are agreed upon in order to solve interoperability problems. In [16] a beginning was made to classify 3D operations in general. Furthermore it became obvious that it is useful to distinguish between basic geoprocessing functionality (e.g. spatial buffer, intersection etc.) and domain specific functionality which may in turn rest upon such basic operations.

Here we try to identify common statements for 3D processing in the field of disaster management and environmental research which we want to summarize as 3D simulations. For each 3D simulation a data basis is needed which might be a city or terrain model. The actual processing is based on a computational model which is exchangeable for each scenario.

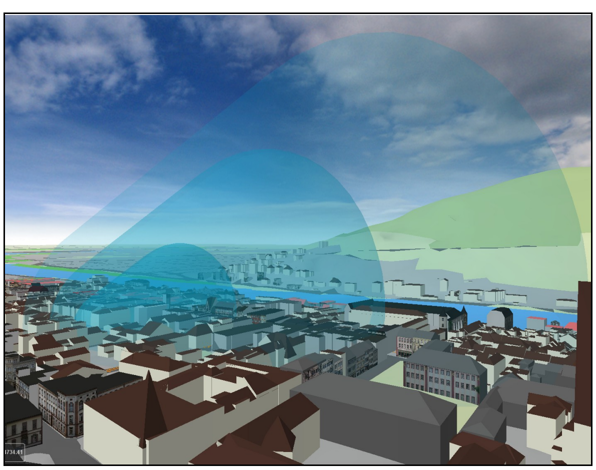

Figure 4. Visualization of the emission spread scenario in 3D.

In the case of our example of gas emission this might be a physical spreading model dependent on a specific type of gas. For the bomb finding scenario a model can be used which is computing the degree of damage by means of a city model. Furthermore any simulation is of course related to space whereby we distinguish between the location of an event (e.g. the location of a gas leakage) and the area we want to observe within our simulation (e.g. a whole city or just a defined area around the location of an event). As every simulation is performed for a specific duration also a time parameter must be introduced. For example in the emission use case the user is interested in the spreading for the gas cloud within the next 60 minutes. In addition we also define the output format as a parameter for a 3D simulation process for creating a flexible application that is capable of being integrated into different 3D visualization tools. In any scenario we are interested in the following questions:

- How? (Model of processing)
- Where? (3D city/landscape model, Location of event, Area of simulation)
- When? (Time)
- Visualization? (3D city/landscape model, Output format)

For this reason we identify six common input parameters which are also transferable to other 3D simulations. These are:

- Computational model for the actual processing
- 3D city/landscape model
- Location of event
- Area of simulation
- Time
- Output format

For giving another example we are looking at a flooding scenario. Assuming that a dike overtopping takes place we use a city model as data basis, a flood model for the actual computation, the position of the specific dike as location of event, the whole city as area of simulation, 24 hours as time and e.g. VRML as output format.

The six identified common input parameters for 3D simulations provide a basis for the development of a future domain independent WPS profile for 3D simulations. The underlying processing model on the other hand is domain dependent and may be provided by another WPS process requiring specific input parameters. For the development of domain specific profiles for these models expert knowledge is required. However, the first step in direction of interoperable simulations is made because it is now possible to provide these functionalities by a well-defined interface with easy exchangeable processing models. These models can be quite simple as in our example implementation or sophisticated, but in both cases a simple gateway is provided to the end user.

IV. SUMMARY AND OUTLOOK

In this paper we demonstrated how 3D-SDIs can be extended by geoprocessing functionality. We implemented two specific use cases in the field of disaster management and environmental research as WPS processes within a 3D-SDI. The results are visualized by a W3DS viewer and demonstrate how useful it is to present the outcomes of such simulations in 3D. For the sake of simplicity no specific computational models (e.g. a propagation model for gas emission) were used but it would be easy to integrate them into our system. For this reason we appreciate the new WPS interface which makes it now possible to integrate geoprocessing functionality within SDIs in a standardized way.

We assume that there exist a range of readily implemented computational models for 3D simulations but up to now it was not possible to use them in connection with other OGC standards behind a well-defined interface. Of course this also demonstrates the openness of the specification which allows hiding any kind of processing functionality behind a WPS facade. But the fact that it is now possible to offer existing GIS processes by means of the interface promises a huge benefit for SDIs. Now it is also possible to share GIS functionality besides "traditional" spatial data or maps.

As the WPS specification is already used in a number of projects in connection with 2D data we wanted to demonstrate that the interface is also a benefit for 3D applications, e.g. in the field of disaster management and environmental research. Furthermore we identified six general input parameters for 3D simulation processes which are in our opinion transferable to a range of domains. So the first step is made in direction of an interoperable 3D-SDI including geoprocessing functionality.

Future work has to deal with expert knowledge of domain specific processing models (e.g. in the domain of environmental research) and the integration of them into SDIs. Sophisticated computational models provided by an easy accessible interface as the Web Processing Service would be a great benefit for SDI users.

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