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Using Different Data Sources for New Findings in Visualization of Highly Detailed Urban Data

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1 ABSTRACT

Measurement of infrastructure has highly evolved in the last years. Scanning systems became more precise and many methods were found to add and improve content created for the analysis of buildings and landscapes. Therefore the pure amount of data increased significantly and new algorithms had to be found to visualize these data for further exploration. Additionally many data types and formats originate from different sources, such as Dibits hybrid scanning systems delivering laser-scanned point clouds and photogrammetric texture images. These are usually analyzed separately. Combinations of different types of data are not widely used but might lead to new findings and improved data exploration.

In our work we use different data formats like meshes, unprocessed point clouds and polylines in tunnel visualization to give experts a tool to explore existing datasets in depth with a wide variety of possibilities. The diverse creation of datasets leads to new challenges for preprocessing, out-of-core rendering and efficient fusion of this varying information. Interactive analysis of different formats of data also has to have several approaches and is usually difficult to merge into one application.

In this paper we describe the challenges and advantages of the combination of different data sources in tunnel visualization. Large meshes with high resolution textures are merged with dense point clouds and additional measurements. Interactive analysis can also create additional information, which has to be integrated precisely to prevent errors and misinterpretation. We present the basic algorithms used for heterogeneous data formats, how we combined them and what advantages are created by our methods.

Several datasets evolve over time. This dynamic is also considered in our visualization and analysis methods to enable change detection. For tunnel monitoring this allows to investigate the entire history of the construction project and helps to make better informed decisions in the preceding construction phases or for repairs.

Several methods are merged like the data they are based on enabling new ways of data exploration. In analyzing this new approach to look at heterogeneous datasets we come to the conclusion that the combination of different sources leads to a better solution than the sum of its parts.

Keywords: tunnel monitoring, heterogeneous data, visualisation, infrastructure, rendering

2 INTRODUCTION

The assessment and monitoring of tunnels and associated underground structures is the very core field of application of Dibit Messtechnik GmbH. Due to their needs, new methods for data representation and visualization had to be found. Visualization is the core field of VRVis. These two companies developed a long-term partnership in research and development for technologies needed for visualization of linear underground buildings. Over the years the need of Dibit to integrate additional data sources into high-performance 3D visualizations grew. Besides that, they wanted to integrate measurements from different tools. Another important point is to load and display raw data coming directly from laserscans such as point clouds. This combination of various heterogeneous data sources allows a more reliable visual analysis and leads to better informed decision. Every data type imposes different requirements for visualization demanding different solutions. After the integration of this highly heterogeneous information we realized the challenges which have to be met for the combination of these data types, which are further aggravated because performance and precision is crucial for our users.

Our solution for these problems described in this paper, is an approach that precisely combines several data types. After a short overview of related work, which handles similar problems, we analyze the different data types currently available in our application and the needs we had to meet, to visualize them. Based on this information we finally show the data combination, how we met emerging challenges, which techniques helped and how our solution enables the efficient and reliable exploration of heterogeneous datasets.

3 RELATED WORK

Our work is based on a long-time project described by Ortner et al. (2010). The basic concept is still the same but especially the acquisition of data has evolved significantly. The representation of point clouds was taken from other works (Hesina et al., 2009, Leitner and Hesina, 2011) where the visualization of huge LIDAR datasets is explained.

Ortner et al. (2016) presented a design study which shows the usage of multiple views for tunnel crack analysis. Based on this results they created a solution to support experts in tunnel maintenance tasks. Multivariant datasets were combined with a 3D-visualization to handle these complex problems efficiently.

It was surprising for us to find such a small amount of similar work. Especially research in tunnel visualization seems to be relatively rare. One example we found was presented by Stent et al. (2013), where they presented an automated system for visual changes in tunnel linings. It is basically used for maintenance of tunnels and shows a relatively cheap system for inspection which is able to reduce the workload. While our system fulfils a similar task with a higher amount of preparation, it is still more versatile and therefore not only usable for monitoring changes but also to analyze the construction of underground structures and handle additional information.

Figueiredo et al. (2014) present a Web application for the visual exploration of a cave model with decimated details. For the calculation of size or distances between objects, relevant for the user, the base model is used for higher precision. This work shows some of the problems of high resolution datasets of underground structures in a visualization application.

4 DATA SOURCES AND VISUALIZATION

We use several data sources in our application and therefore we need to describe the main data types in detail for deeper understanding. Our main 3D-models of tunnel scans are Ordered Point Clouds (OPCs), while unordered point clouds were added later with the requirement to combine it with the rest of the existing data. Vector based objects are needed for interaction and measurements. The overall impression, especially for presentations, can be improved by adding auxiliary 3D objects. Additionally, simple 3D objects are created to display geometry for analytical purposes such as cutting planes.

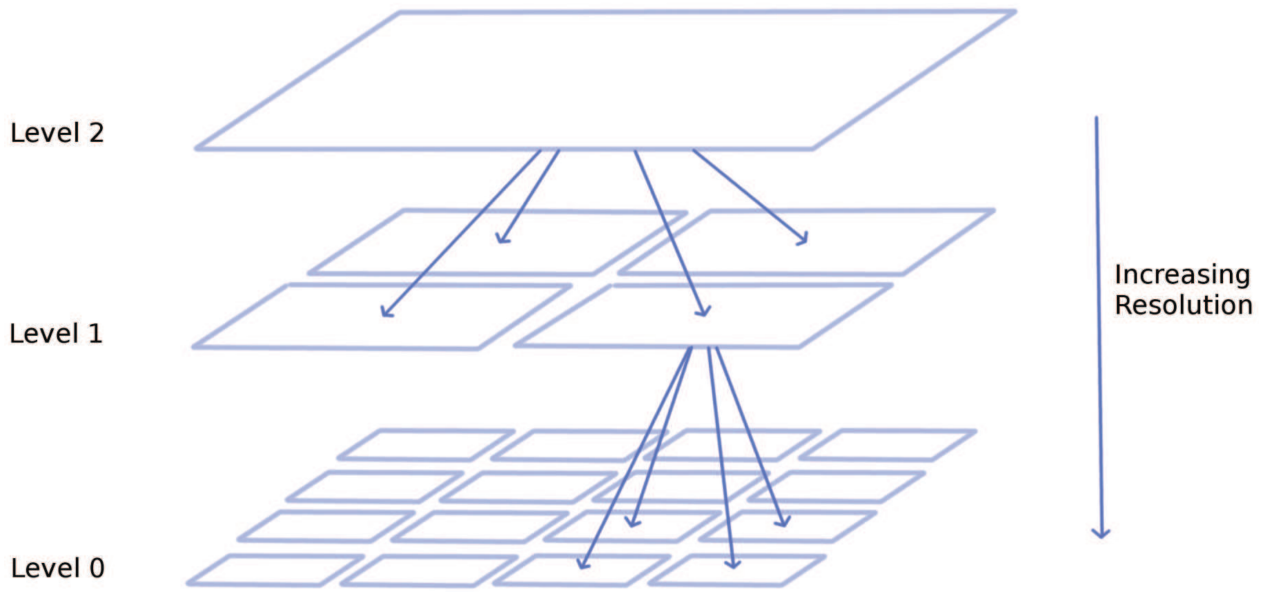

Fig. 1: Schematic LoD-Structure: Higher Levels with less detail encompass several lower level patches of higher detail

4.1 Ordered Point Cloud (OPC)

The OPCs are created from state of the art vision sensors like laser scanners as described by Ortner et al (2010). Camera images and laser scans are unified into the OPCs which are basically high tessellated 3D-meshes with high resolution textures. Tunnel data of several kilometers lengths with details in millimeter accuracy is created this way. Therefore a Level of Detail (LoD) approach (Luebke et al, 2002) is used to feed the render application with a manageable amount of data. In this way the whole dataset can be explored without any loss of information while only important data is shown which leads to proper performance.

For the beforementioned rendering techniques the whole dataset is already preprocessed in a special structure for the LoD-approach as described by Ortner et al (2010). The datasets are far too big for the graphics memory and therefore out-of-core data management is used. This means, that a strategy is created to decide, which parts of the data has to be shown and what amount of detail is required by the user. The data is split and every higher level of detail block includes the space of four lower levels with more data, as shown in Figure 1. Meanwhile the algorithm also decides, which data can be removed from memory to prevent that the needed amount of memory exceeds the existing resources.

In the last few years the power of computers highly increased but the algorithms created for this approach are still important. Scanning techniques have improved and with them, the amount of detail also increased. Therefore it is essential to use an optimized approach to meet continuously growing data volumes. Especially with the addition of more data types, performance requirements of our main data sources, the OPCs, has to be fulfilled without decreasing the possibilities of other, high resolution data like unordered point clouds.

4.2 Unordered Point Clouds

Laser scanners usually create irregular point clouds. No meta-information is added and therefore only positions of the points are known besides some color information and sometimes data of the reflection or classification of points. Many scans we got for visualization contain at least several million points. To explore such datasets efficiently in real-time, some preprocessing steps are needed. Still unprocessed point clouds are commonly used, because their acquisition is relatively fast and easy. The visualization still shows basic details without the need of highly advanced preprocessing algorithms as for OPCs. Without some steps to create an optimized data structure, presentation limits are easily reached.

Our approach for point rendering is loosely based on the work of Hesina et al. (2009) and Leitner and Hesina (2011). The whole point clouds are subdivided into blocks with an octree-approach to be prepared for LoD rendering similar to the scematic in Figure 1. Therefore the highest level with least details covers a larger area with the same amount of points than lower levels which only represent a part of its space. In this way the blocks seem to have a complete set of points when looked at from higher distances with details increasing when coming closer. When the camera in our rendering comes closer to a point block, the LoD-approach simply accumulates points of the lower levels. In this way exploration of the whole dataset is possible because only relevant data is rendered.

We use point sprites in our approach which is an efficient way to render points with current graphics cards as quads or, as in our example, as circles (Frank Luna, 2006). The main advantage of point sprites is that they need only a coordinate for visualization and the size of these sprites can be changed in the shader which is used to reduce the gaps between points. During preprocessing the average distance between points is calculated to set a point size value.

The rendering of point clouds is nearly as effective as the usage of OPCs. Still they are inferior because without informations of neighboring elements, many measurement techniques cannot be used on unordered point clouds. Additionally OPCs are visually richer and therefore easier to explore for the user. They can hold an increased amount of details based on high resolution textures which cannot be mapped onto point clouds which only use color values per point. Textures are well supported in current graphics cards to gain details for the visualization of datasets. Besides that, meshes are much easier to handle for many interactions such as measurements.

4.3 Vector based objects

In the presented approach geometry is not only used for the representation of existing objects but also for measurements and annotations. It is possible to select points on an OPC and check the distance directly or

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find it with a projection on the tunnel surface. For an improved visibility, geometrical tubes are used instead of lines to prevent them from disappearing inside other objects. Additionally, the line thickness depends on the distance from the camera so that the apparent thickness remains constant.

External data can also be specified as vector based objects and represented in the same way. If they are available as 3D datasets their coordinates are simply added, while 2D datasets are mapped onto surfaces with the beforementioned method. Different data types are handled with the same methods and lead to a high variety of sources which can be used in the application.

One issue with this polygonal approach is, that 3D tubes are many small geometries which can lead to performance problems. Therefore we use an algorithm to pack this high number of small parts into managabeable groups with bigger chunks of gemoetry which are easier to handle for the hardware but do not change anything for the user.

Besides measurements, the vector based objects can be used as markings to highlight cracks and building characteristics directly in the software or by external tools. It improves the possibilities to explore existing analysis, create new ones or present it in 3D space for visual verficication of tunnel irregulartities.

4.4 Smaller, additional data types

For interaction and presentation additional objects are needed. Therefore, 3D objects of well known data formats such as VRML can be imported. Traffic signs, lights or similar objects can be included into the tunnel for a more realistic impression.

3D objects are also used for further interaction and measurement methods. Cutting planes for OPCs create exact measurements along the tunnel axis. These cuts create polylines on the tunnel surface as mentioned in the chapter before.

Another important task is achieved by 2D reference profiles to find differences between the planned tunnel and the analyzed construction phase. This is accomplished by comparing the reference profile to tunnel profile slices of the 3D laserscans.

Finally a minimum clearance outline can also be integrated to find out, if objects like trains fit through a tunnel to prevent collisions.

4.5 Comparison of data types

The data types described include several advantages and disadvantages which have to be adressed for using them efficiently. Experts have to decide which data type is suitable for the users needs. Table 1 presents an overview of the main advantages and disadvantages of the different data types mentioned before.

Data type	Advantages	Disadvantages
Ordered Point Clouds (OPCs)	- fast rendering - completely meshed surface for precise measurements and selections - better details with high-resolution textures	- time consuming preprocessing
Unordered point clouds	- easy to acquire - fast render preparation	- points are more difficult to interpret - no surfaces for calculations and measurements
Vector based objects	- fast rendering and creation - visually clear visualization - user can create it easily in the application	- limited in use - manual preparation required
Common 3D objects	- wide variety of uses - easy to render - simple integration for additional details	- manually costly created or just already existing basic objects - usually not geo-referenced by default (manually set)

Table 1: Summary of advantages and disadvantages of the different, described data types

5 VISUAL COMBINATION OF DATA

Our main contribution is the combination of complex data in a software for visual exploration. Challenges are met with special techniques which lead to many advantages of this approach. In the end an application was created to meet the requirements of users for the analysis of tunnels during construction and for maintenance. The used techniques and advantages are decsribed first and demonstrated in our application description afterwards.

5.1 Challenges

While the basic visualization of the mentioned data is common knowledge for computer graphics specialists, the combination of the sources leads to additional challenges and problems. Keeping precision is already difficult for huge datasets. Common graphics cards use floating point precision only and therefore local coordinate systems have to be used for every dataset in the application. Every visualized dataset has to use their own coordinate systems to prevent floating point precision problems (Johnson and Hansen, 2004). The challenge is to find a way to join all datasets and keep the information in each of them while showing everything together.

The usage of the techniques described before leads to possible performance problems for combined datasets. It is easier to show a single huge dataset because the resource usage has not to be shared with so many functions in the application and is easier to handle. The memory management is the second significant challenge which has to be met for our requirements.

The next big challenge worth mentioning is the combination of interaction possibilities. Every dataset has to use its own kd-tree, a spatial data structure for efficient picking of objects in the application (Akenine-Möller et al., 2008), for interactive selection of its parts by the user. Communication between several data handling modules is also important to combine measurements across data sets. Combining of datasets also aggregates some interaction problems which occur with the usage of localized coordinate systems and different performance saving techniques. Calculations have to be done for every interaction to transfer the global data to the local coordinate systems and vice versa.

Additionally the same type of data may come from completely different sources. Preprocessing can be difficult if they differentiate in details. OPCs are properly prepared for rendering while other pointclouds are often just a bunch of coordinates without any further information but can also have colors or metadata for every point. Vector datasets which can be imported as vector based objects may come from different tools and therefore vary in detail. 3D models also originate from a wide variety of design software which leads to the same problems.

5.2 Techniques

The beforementioned challenges are handled in our work with different techniques. The basic approaches of high performance data visualization are still intact as mentioned in the chapter before but are tweaked in some details. Resource management is essential for all visualization modules presented. If any component of the solution does not work optimally, the whole system suffers from a severe decline in usability. Our approach keeps seperate parts as focused as possible and only unifies elements, where it is needed to create a seemless exploration experience for users.

For rendering all datasets at the same time a scenegraph is used. It is a higher-level tree structure which includes not only geometry, but also textures, transformations, levels of detail, render states, light sources and usually some more render information (Akanine-Möller et al, 2008). This way every part has its own properties and shaders but basic functions are the same for a larger substructure. For example the data handling of unordered points is highly different from OPCs or common 3D objects and therefore it is important to be able to handle the different types of geometry separately. In the presented approach a special scenegraph is used which handles semantic and rendering aspects cleanly separated (Tobler, 2011). It allows dynamic changes of every data type and adding new objects or nodes during runtime without influencing other parts of the visualization. Among other things, this scengraph is optimized to deal with out-of-core rendering of large scenes and multi-view rendering which is needed in our application.

All data is geo-referenced which leads to coordinates with a high number of digits. To keep precision and still use float values in the graphics card, datasets are split into blocks, where each has a local coordinate system and inherits an offset matrix into the global coordinate system. Individual blocks are rendered locally with the offset for the correct position. Users need the geodata for their tasks. Therefore every measurement and calculation is done in double precision and the offset is added or removed. This is especially difficult when common operations take place over several blocks. The selection of a part of a surface on an OPC or in a point cloud often has another local coordinate system and such differences have to be addressed to keep selections precise and consistent.

Another performance factor is the use of highly optimized out-of-core implementations, to stream data saved from the hard-disc directly into our application. Multiple threads handle separate datasets individually. The graphics card gets data to visualize while additional information is kept outside memory. It is prepared in a preprocessing step before or parallel in another thread at runtime. Data is subdivided into renderable blocks with their own, local coordinate system as mentioned before. Metadata is also created for LoD-decision hierarchies and kd-intersection trees.

5.3 Advantages

It is often emphasized that the combination of different data sources leads to more results than the mere sum of the parts. In the presented approach many examples are found to validate this statement.

The mixture of different tunnelscans leads to the most obvious advantage of the presented application. Unsorted point clouds from simple 3D-laserscans can be validated when they are exactly fitted into an OPC dataset of the same object. Other parts which are not preprocessed as a mesh and created with other scanners can easily be added to gain more information of a region inside a tunnel, to expand or update existing data. Datasets which are easier to acquire can be used for comparison with the complete current scans and to find changes on surfaces or in the geometrical structure.

The inclusion of vectorized polygonal data is essential for documentation of abnormalities and problems on the tunnel surface. It is also important for the ability to handle data of external tools to give users more flexibilities.

The tunnel surface can be analyzed by the usage of 2D-profiles on the tunnel axis. The comparison with the reference can bring additional insights of the boring and all other construction processes. The usage of a minimum clearance outline helps to detect potential collision hazards in the safe virtual environment of our application.

Several types of geometry like cutting planes also bring new, partly unexplored methods to measure distances on the tunnel surface which is often difficult but at least expensive in reality.

The use of 3D-models of real objects which might be added to the scene, supports planning of construction processes and might prevent unnecessary worksteps in the real tunnel.

Every data acquired in the virtual representation can save time and working hours. Expensive blocks of roads or railway tracks can be minimized without a loss of safety because of the high precision of the data which can be explored in real-time.

5.4 Solution description for visualizations and interaction

Visualization applications are usually easier to show than to describe. The application described in this paper is based on, as mentioned, the work of Ortner et al (2010) but highly extended. The main datasets are still OPCs as described in chapter 4.1. A 3D visualization needs a tunnel axis as basis to unify OPCs with other datasets. The data is shown relative to the tunnel axis and the navigation is bound to it, too.

Preprocessing is needed for some datasets before usage and can be started directly in the software. After preparations have been finished, the data is directly integrated into the visualization. The biggest datasets added to the usally huge OPCs, are often point clouds. For the user they are just added in a convenient way and as soon as the preprocessing is finished, the combined data is shown in the application.

The whole application works on usual computers with default graphics cards. All images are created inside the application where datasets can be explored in real-time. It shows the techniques described in sector 5.2 working together smoothly. Advantages described in sector 5.3 are shown in the following examples.

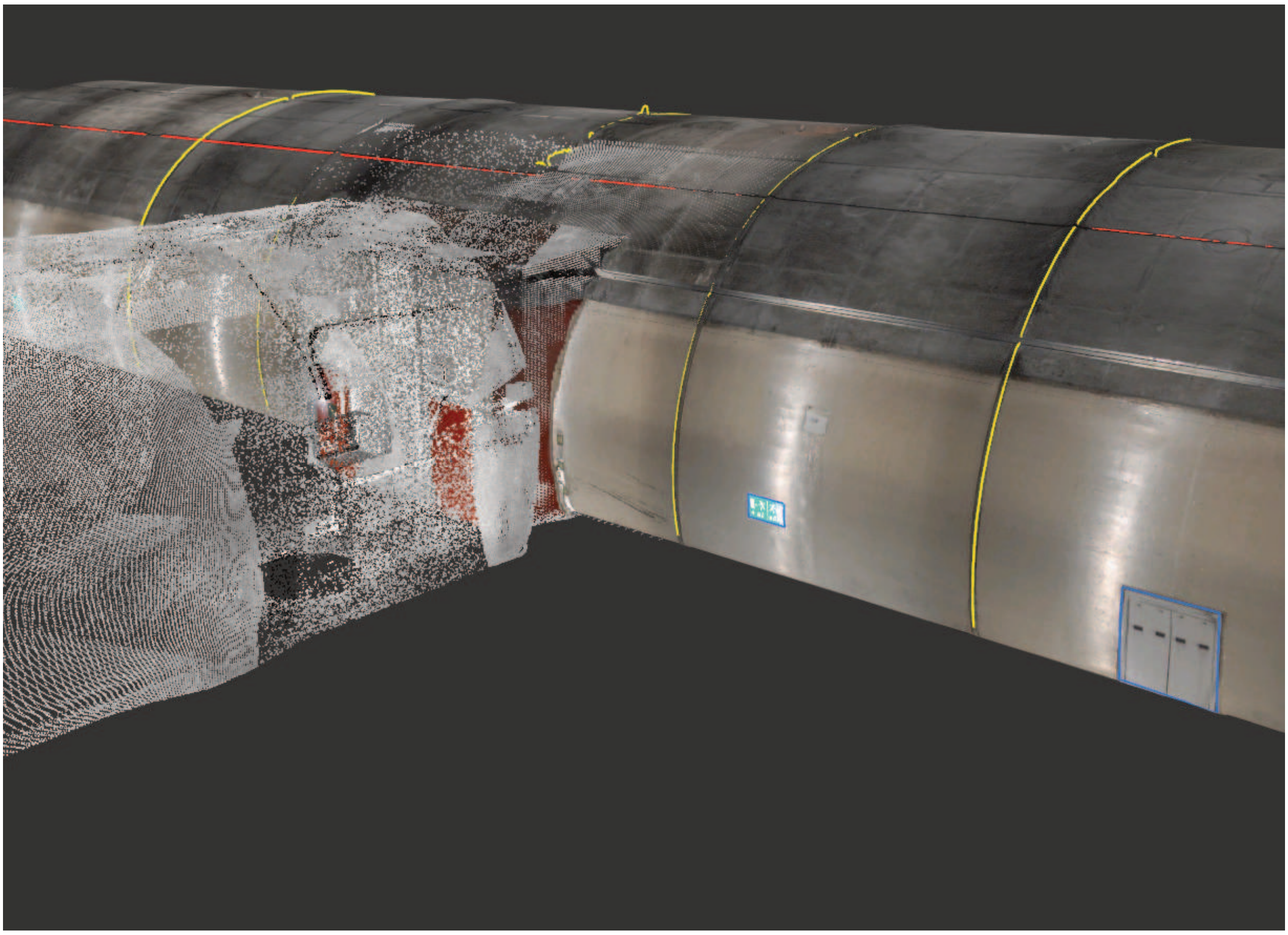

Figure 2: combination of OPC tunnel surface and point rendering

After such preparation, interactive visualization is possible. Figure 2 shows a laser scan from outside the tunnel combined with a side tube as an unordered point cloud. The section, where the two scans fit together is clearly visible. Additionally tunnel sections, the emergency exit sign and a door are marked with vectorized data in this figure. This shows the high precision of our approach for the combination of different data sources. The OPC datasets are created completely different from the point clouds which were added much later and still fit perfectly. Vectorized data give more information and highlight important structures while fitting seamlessly into the whole visual representation of the tunnel.

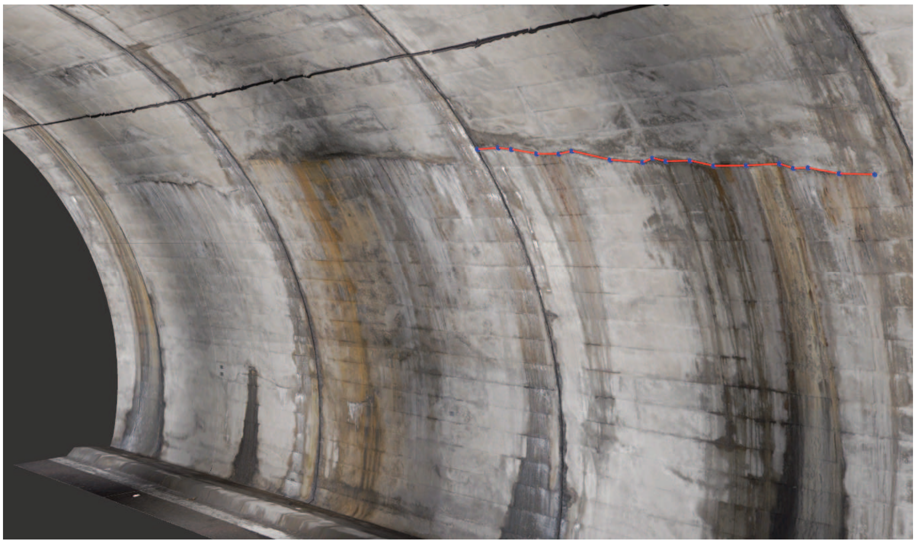

Figure 3: usage of vectorized data for crack tracing

Besides the use for highlighting, existing structures like mentioned before, vectorized data can also be created during runtime. Figure 3 shows the marking of a crack on the tunnel surface. The user defined lines

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are mapped directly onto the wall and kept for documentation. The use of tubes for vectorized data is also shown in this way. The selection on the surface created a line which perfectly fits onto the tunnel and would disappear in the visualization without the usage of tubes as described before. With the presented approach the visual representation of the line is differentiated and clearly identifyable from any direction.

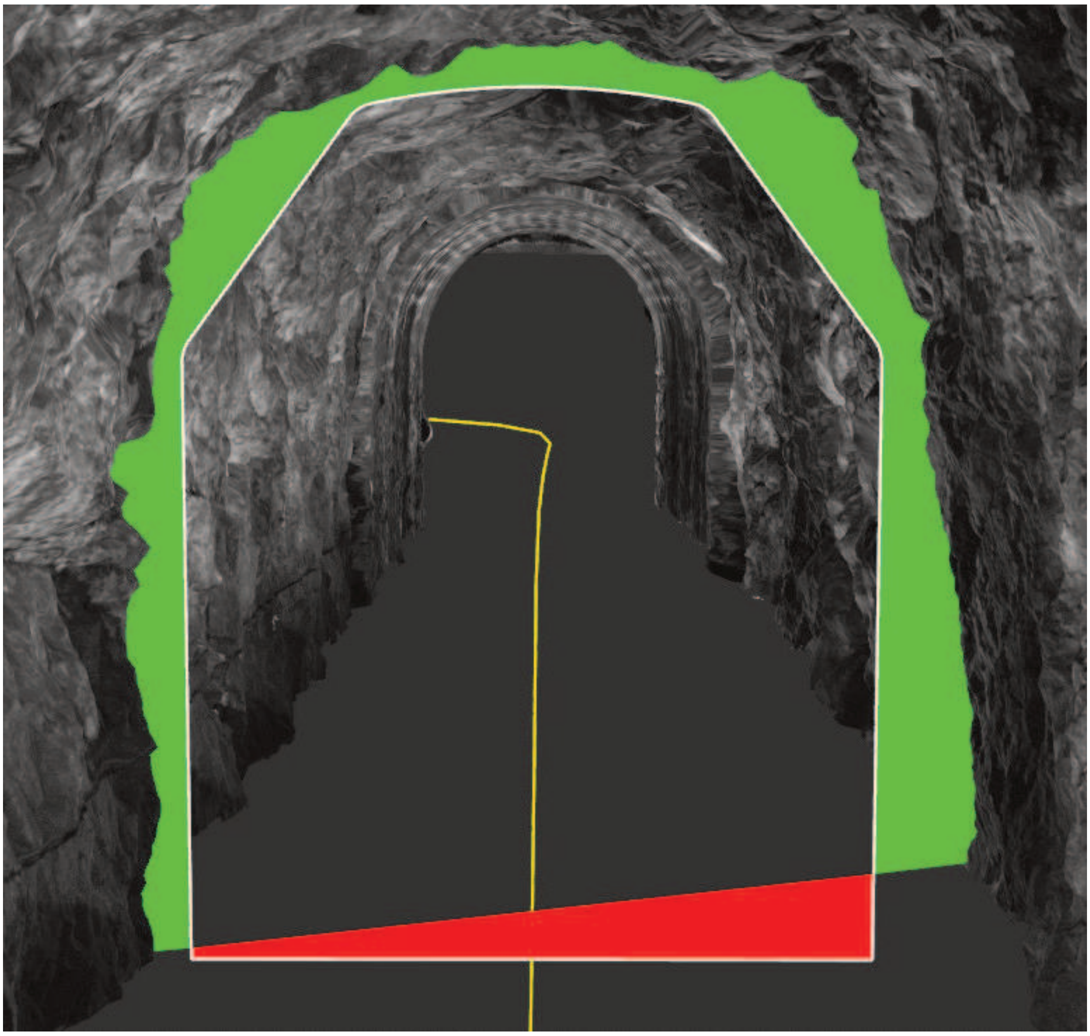

Figure 4: minimum clearance outline inside an early tunnel construction step

Figure 4 shows a minimum clearance outline inside a tunnel. The section on the plane, which does not belong to the outline, is highlighted, to recognize, how much space is between it and the tunnel surface. It is used to simulate if for example a train would fit through this tunnel without collision. Especially close collisions would not be noticed by the naked eye and therefore the visualization helps the user to identify possible threads.

Figure 5 shows an unordered point cloud with some measurements. Simple billboards are used for visualizing the distance between the clicked points. The structure is clearly identifiable but still not as precise as OPCs. The measurements can only be done betweeen points due to the lack of a surface. Still the addition of vectorized data helps to retrace measurements and shows the width of structures at a glance.

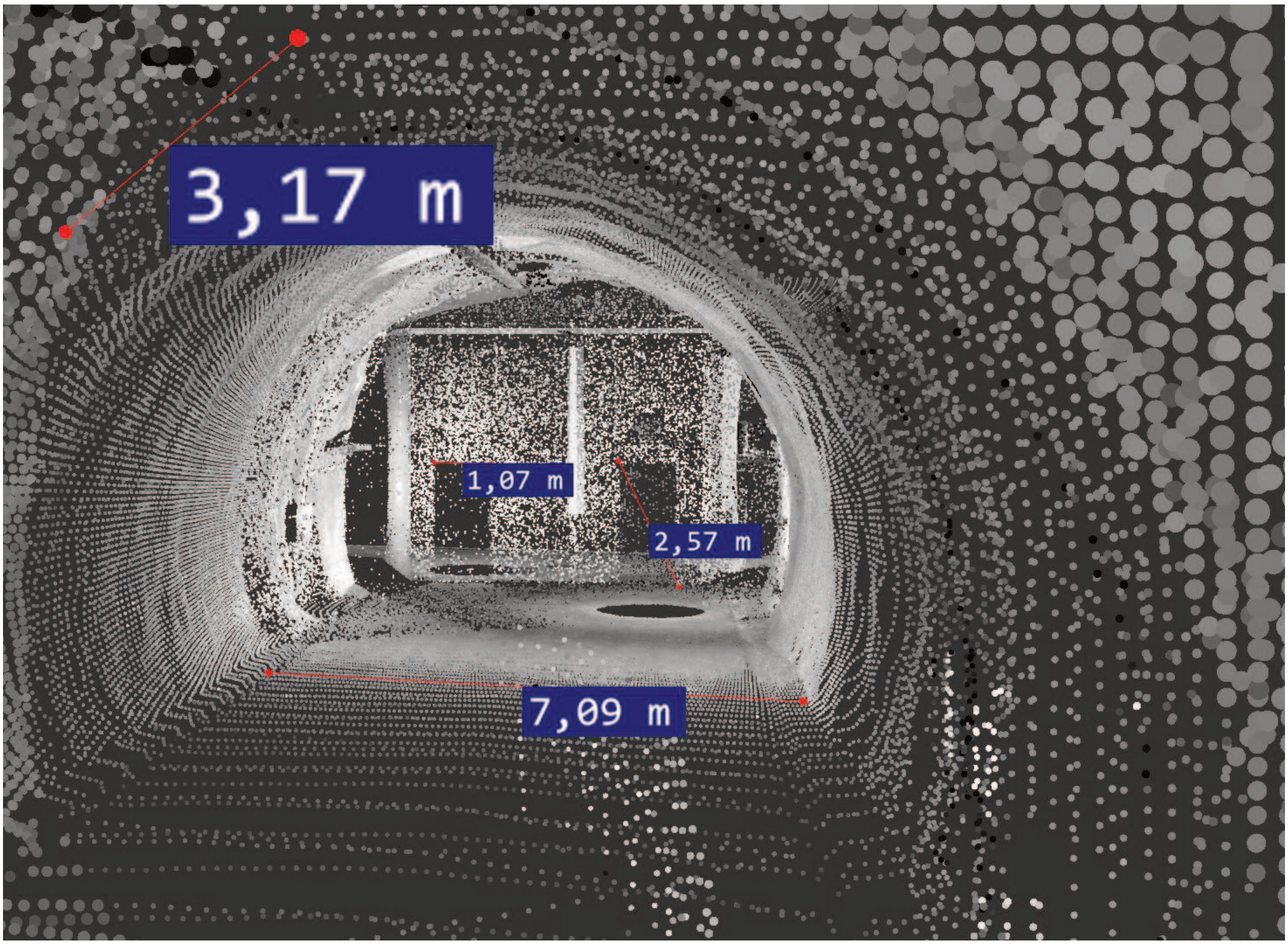

Figure 5: distance measurement in an unprocessed point cloud

These are some examples of the usage of the combination of data sources in our visualization application. Further possiblities were already described before and reach from usage of planes or surface structure for additional measurement and annotations to mainly optical improvements of the datasets.

6 CONCLUSION

We presented an application enabling a high-performance visualization of combined heterogenuous data sets resulting from tunnel construction projects. The integrated visualization of various data types in a consistent geospatial virtual environment allows a more efficient and reliable analysis than investigating the data sets separately by different tools.

Flexibility is one of the main advantages for the users of the presented work. Besides efficient real-time exploration, data comparison and interactive measurements leads to a working environment enabling an accurate and reliable visual analysis. Support of as many data sources as possible helps to serve a wide variety of experts with their tasks.

Still there are many interesting topics for research and development. Tunnel experts and geologists use our work together with a wide variety of other tools, which create new datasets. Not every data format can be supported and expending the range to more types is still possible. Flexibility will keep growing with new requirements from users.

Finding structures in unordered point clouds would lead to improved possibilities and could minimize the disadvantages of this data type compared to OPCs. This is still far from trivial and needs much more research and would still not fully meet the requirements to create a mesh out of every type of unordered point clouds.

Users asked for the integration of billboards for a wide variety of tasks. In this way geo-referenced photos of the tunnel can be integrated for further comparisons. Meta information might also be included in 3D rendering with a similar technique.

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Visualization of tunnel deformation with textures or maps which are used as base for displacements in the shader might lead to additional insights into the alterations between tunnel phases and several construction steps.

Performance is still an important issue for improvements. Continous Level of Detail approaches and the reduction of vertices without a loss of detail might be reached with the usage of hardware tessellation algorithms.

The possibilities for improvement seem limitless and our work for tunnel experts might show possibilities for the analysis of other areas of urban planning and maintenance.

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