

Virtual Exploration of Urban Spatial Changes due to Regional Tramway Line Construction

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1 ABSTRACT

For most large infrastructure projects, it is mandatory to assess their impact on the urban and rural environment before they are started. Many shareholders want to involve the public or even are obliged to do so due to legal provisions. For interactive exploration, a 3D viewer is needed that supports very complex scenes. They should be realistically rendered for sufficient credibility. Applied research on this topic (in close cooperation with industrial partners) resulted in GEARViewer, a geospatial rendering framework. It supports huge geospatial scenes consisting of large-scale terrain models, buildings, roads, tramways, railways, tunnels, vegetation and a skylight model. Everything is georeferenced. It can import GIS data and turn this into 3D objects. In the future, it will also support Building Information Modeling (BIM) standards. Furthermore, it also simulates traffic in a simplified way including cars, trams, trains and pedestrians. It was used for many planned projects in Austria and Germany.

In this paper, we describe one of the projects for the city centre of Innsbruck, created with the GEARViewer. It supported several stages of the segment wise planning and realization of a new regional tramway line over multiple years. Depending on progress, the project visualization incorporated varying levels of details into the existing city model, from graphic planning concepts during route optimization to detailed depictions of stops and road design shortly before constructional implementation. In this way, shareholders and citizens can experience the geospatial transformation and changes of the street network and traffic flow in the affected regions of the city. The system allows the regular creation of videos, screenshots, interactive online panorama tours and live demonstrations for publications and citizen information events. In order to fit the current state of planning, the system and model were constantly extended and updated. It supported the project progress and associated votes and discussions by supplying the display of variants, flexible viewpoints and realistic visualization.

Keywords: tramway, 3D city models, Spatial transformation, High performance visualization, interactive exploration

2 INTRODUCTION

The planning of infrastructure projects results in large projects with many moving parts and involved parties. It ranges from multiple different domain experts, planning and creating specific aspects and parts of the process pipeline, to different stakeholders making decisions or residents interested in how the planned project will change the topology of the environment. Traditionally this is done in a 2D environment, by drawing plans, architectural drawings, pre-rendered pictures or interactive visualizations with limited scope. Many tools have been created over the last decades to support specific stages of this process, therefore, they are very specialized to solve individual problems but are non-optimal for other tasks. GIS systems are powerful in creating, planning and comparing different scenarios. They generally work in 2D but lack an interactive, large-scale 3D visualization and are unsuited for the involvement of the general public.

Tools for visualization on the other hand have reached impressive visual fidelity in recent years but often only cover specific aspects of the requirements with high cost and time investment in creating and processing all necessary assets. Game engines and adjacent tools can display high fidelity and detailed objects in increasingly large areas, but often require very long development cycles and their data and scenes are highly specialized, processed and therefore changes can be very costly both in regards to resources and time. On the other hand tools more specialized for rapid prototyping and changing like in medicine and engineering, are often limited to specialized aspects or limited scene extends.

This leads to a situation where tools either allow the efficient planning and changing of data or the visualization and presentation of the data. Bridging this gap efficiently has become increasingly important to allow the involvement of experts from multiple fields but also non-experts, that have no detailed knowledge or experience in interpreting specialized tools. The projects and ideas can be better communicated, visualized and changes can be incorporated more easily, faster and cost-efficiently. According to our experience this can help with the addressing of unnecessary misunderstandings and fears and provide a common ground for all involved stakeholders for positive and productive discussions. Especially for planning and discussions, photo-realism is less important than the ability to explain complex relations, augment 2D planning data to a spatial 3D context and having a toolset to answer complex questions promptly. To help involved people really immerse themselves in the scene it is also helpful to allow for visual cues like, shadows, vegetation, street networks with driving cars and other animated parts.

In this paper we will present the GEARViewer an interactive geospatial planning and visualization tool developed at VRVis and Geoconsult in collaboration with large infrastructure providers and civil engineering consultants. After a discussion of related work, we will talk about the basic pipeline, involved data sources and provide detail about design decisions. Finally, we will describe how the GEARViewer is applied in a real-world use case, - a new tramline in the city centre of Innsbruck.

3 RELATED WORK

GIS are the most common tools to study how large-scale construction projects affect an urban or rural environment. They are a key asset of the planning process and efficiently allow to create and compare different alternatives. This is especially true for street, railway and tramway networks, which typically cover wide areas. Eliot (2014) gives a general overview on GIS concepts, services and resources. The book by Nyerges and Jankowski (2009) describes how GIS supports decision making in urban and regional scenarios. In Telega et al. (2021) GIS is used to measure the walkability of a city, which is an important indicator of the wellbeing of citizens and the sustainability of the urban planning. GISs are also important for collaboration and communication between different teams and stakeholders. Eikelboom et al. (2015) carried out user studies to evaluate how efficient different geo-design tools are for communicating stakeholder values. They found out that aggregation and ranking of such values are easier for expert users.

GIS are not well suited to inform the general public, which is an obligation in most large-scale construction projects. Most people are not familiar to interpret large area plans, let alone compare different layers representing planning variants or simply the status before and after the construction (see Figure 1). Sieber (2006) gives an overview of how GIS can be used for public participation in the planning process. They found out at the time of their publication that the efficiency of participation is low and the cost is relatively high. A more recent and very comprehensive study based on over 200 real life planning cases was presented by Kahila-Tani et al. (2019). Although public participation has several advantages, they identified problems with information overflow, the digital divide, data collection strategies and methodological challenges among others.

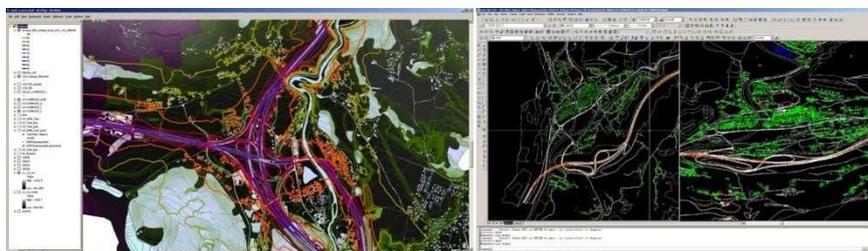


Figure 1: GIS system examples.

A major disadvantage of GIS is that it is based on maps and therefore restricted to 2D data. But a 3D visualization is essential to fully comprehend and experience the spatial effects of large-scale constructions. The support of 3D scenes in GIS has improved in recent years but many applications are still limited in their complexity. One of the first approaches was presented by Moser et al. (2010), where 3D city block models integrated into a GIS improves visibility and air flow analyses. Ferreira et al. (2015) introduced a decision support system for architects and city planners based on 3D models of buildings, whereby the focus is also on visibility analysis. Today ArcGIS by ESRI (2022) provides a 3D GIS that can handle large geospatial

scenes. InfraWorks by Autodesk (2022) visualizes infrastructure projects such as road construction in the environmental context and can derive virtual reality presentations from it.

Höhl (2020) presents an efficient open-source pipeline to generate 3D scenes from GIS data, which are optimized for XR applications. It only uses QGIS with a plug-in to extract terrain models and the Unity game engine with a plug-in that supports geo-references and CityGML for building models. Serious games could be a good alternative to engage the public and mediate information by edutainment. Brase et al. (2022) and Hemming et al. (2022) use the pipeline from Höhl (2022) to integrate open geospatial data into a game engine to create large game worlds. They authored a strategy game where players have to fight consequences of a flood.

Compared to these tools, the GEARViewer is able to cover even larger areas with high accuracy and many details that increases the realism of 3D scenes (see Figure 2). It makes analysis of planning variants highly efficient by enabling fast 3D model switching, like layers of a true 3D GIS. Furthermore, the GEARViewer allows to easily create media directly from the 3D scene, which has proofed to be well suited for a broad audience such as videos or interactive panoramas. These low-threshold media formats give nevertheless a realistic impression of planning variants and can be accessed in a web browser.



Figure 2: Render view showing visualization aspects.

4 DATA SOURCES & INTERACTIVE VISUALIZATION

In this chapter we will present a system overview of the toolset and some of its key aspects. To help with the visual immersion of the user it includes daylight illumination and adjustable illumination parameters (e.g. a rudimentary switch to night), shadows and other visual cues like vegetation and simple reflections. The whole scene can be explored either with a free fly camera or by imposing certain restrictions, like walking on the ground or driving along the street networks. While visualization is an important aspect of all viewers a more encompassing toolset helps with the presentation of the finished planning project. This includes measuring tools for distances and occlusions, a 2D map support for linked movement and positioning and the selection of scenes and toggles for parts of these scenes (see Figure 3).



Figure 3: Feature overview – GUI, projected textures, actors and annotations.

This is done by creating a digital twin of the existing project area and then supplementing or exchanging the planning stages and their variants and allow the switching between them for comparison.

4.1 Building a digital twin

The idea of a digital twin is the creation of a virtual replica of a physical object or system. Originally it was used in manufacturing to run simulations on complex constructs like motors before actual having to build devices. This idea has become increasingly important and prominent in many other fields. It moved beyond manufacturing and into interdisciplinary domains, artificial intelligence and data analytics. It gives professionals the ability to optimize their workflows at a conceptional level and create many what-if scenarios and variant analyses. The idea of a digital twin has therefore expanded from machine parts to include bigger, more complex but also sometimes more abstract systems.

It is also a system that lends itself well for complex infrastructure projects. Broo et al (2022) describes that there is an urgent need to make infrastructure systems more efficient, resilient and sustainable. Furthermore, they give an overview over multiple approaches and different aspects in which a digital twin can utilize real world data for planning and analysis. This includes physical and spatial parts and installed sensors, that relay a multitude of data to create a cyber-physical system.

The GEARViewer concerns itself at the most part with the spatial aspects, meaning the geospatial and visual representation of the real-world domain and its planning additions and variants. This ranges from producing a DGM representation from laser scans, orthophoto texturing from arial overflights to positioning data at the correct geo-referenced locations (e.g. trees from local cadastre data). Some smaller specialized projects within the GEARViewer framework extend this a little. A project with the Austrian Federal Railways (ÖBB) allowed for the on-the-fly update of digital signs on the Austrian autobahn. The definition of the scene and creation of the twin is done by employing a powerful XML based scene description that is loaded at startup. It defines a myriad of different nodes specialized to many of the mentioned visualization and planning tasks, from simple-geo referenced geometry with its rendering attributes to animation networks and how they are combined into scenarios (see Figure 4).



Figure 4: Finished digital twin with established scenarios and animation system.

4.2 Data sources

To build such a digital twin a lot of data from different sources is necessary to be processed, handled and displayed. To support the loading of the data, a flexible import mechanism is provided. On the most basic level it allows for loading of some mainstream geometric formats (e.g. OBJ) and some more specialized to the industry (e.g. VRML). In addition, it allows the loading of more abstract formats to be used in various different routines. This is an important aspect because most other real-time rendering systems require tedious detours to be able to handle these types of data.

- Geo-referenced imagery

This is an image file georeferenced with a world file. In most cases these are orthophotos created by aerial overflights or from some kind of tile-map (e.g. basemap). In principle this can be anything as long as it is a geo-referenced image. They can either be mapped to geometry such as the terrain, streets and building roofs or function as the data source for the 2D map.

- ESRI shapefiles

These are ESRI GIS specific file formats that are used to export or import point, line and polygon data with various additional attributes. This is one of the bridge gapping aspects of the tools. GIS systems are used for their powerful 2D based planning aspects and the shapefile output in turn is plugged into the GEARViewer for various different behaviours; Including the positioning of objects (trees, lampposts, ...), the definition of line geometry (power lines, annotation geometry, ...) and the use of property lines to automatically extrude buildings from them, which allows for a rapid inclusion of vast amount of building data needing little preprocessing work. Another rapid prototyping aspect is the placement of lines (e.g. noise protection walls) that are then procedurally converted into linear geometry defined by profile cutouts.

- Geometry data

Simple geometry data to be included in the scene. Common use cases are buildings, bridges, or sections of hand modeled terrain, that will replace parts of the existing domain. The formats mostly used in the tool are VRML and OBJ. A majority of tools used in infrastructure planning export their data in these formats.

- ArcGrid

A file format suitable for creating and exchanging large terrain models. It basically is a heightmap stored as an image that is used to automatically create terrain geometry with a level of detail hierarchy.

4.3 Variant Analysis

Another vital aspect of the digital twin is the possibility to create different what-if scenarios, compare, and analyse the different variants and permutations. A very important question in current infrastructure planning projects is answering the question in which way the project will transform urban and rural areas. First of all the elevation of the 2D planning steps into a 3D environment already gives experts and non-experts visual cues on how the process will spatially change the affected area. Supported by the digital twin aspects of the surrounding decoration domain, it's easy to recognize the area and therefore immediately get a feeling for the actual changes or additions in the project are in question.

To really help with analysing the impact on the project area, the system allows the definition of different scenarios, denoting important milestones over the lifetime of the project. It really helps to discern what structures or areas are affected when the changes can be viewed over time. In addition to changes over time, the scenarios also allow for the definition of variants of a certain point in the project (see Figure 5).



Figure 5: Variant analysis for an interchange. Only the relevant geometry and animation is exchanged.

Another important point that is addressed by variant analysis methods is doubts and concerns of residents, living in the affected project areas. A frequent occurrence in presentations with a more public character is stakeholders voicing concerns about how the changes transform the environment they are used to. Either on an emotional level or in regards to environmental concerns. It is possible to prepare expected scenarios as variants or in a more limited capacity create some structures, like noise-protection-walls on the fly to test other more favorable options (see Figure 6).

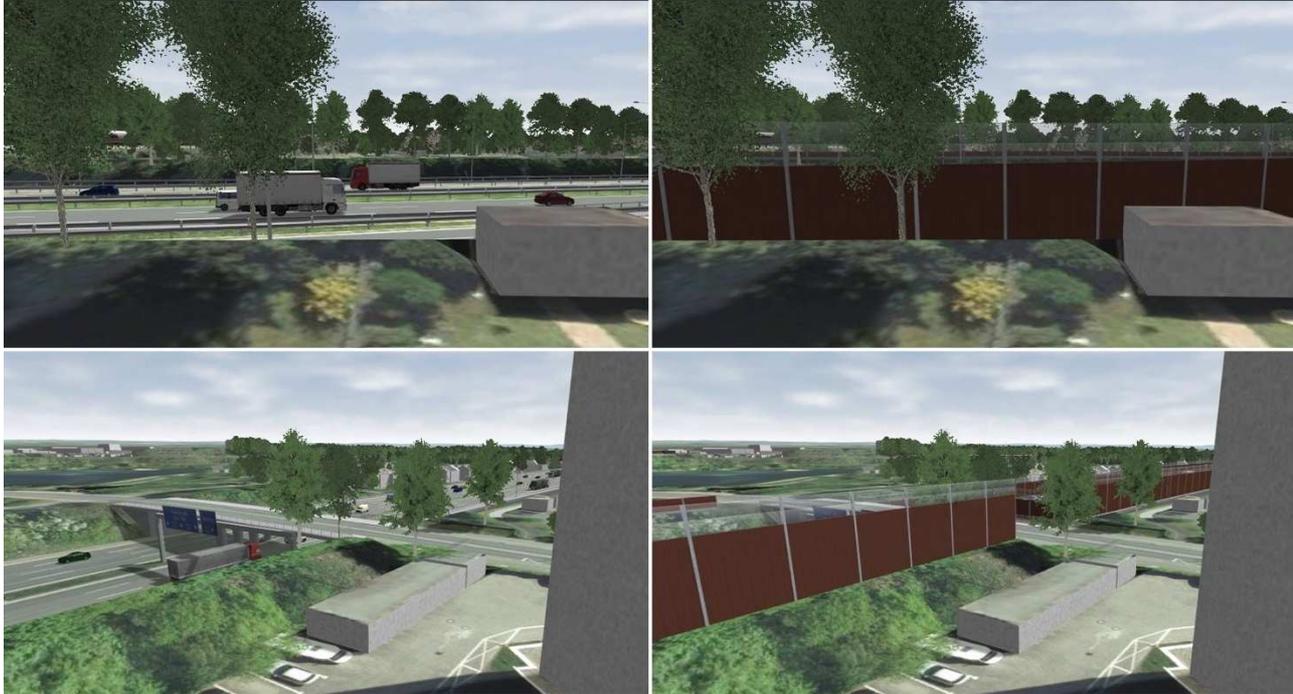


Figure 6: Inclusion of noise protection walls to address concerns of residents of the project area.

4.4 Presenting the finished planning projects

Another important aspect for this tool is the communication of the created scenarios and variants to the various different types of stakeholders. This can happen in different environments with changing requirements.

A common scenario is the presentation to a handful of people at events that provide sufficient hardware to use the viewer directly and employ all its visualization and presentation capabilities. This is where the 3D display of large project data and the variant management comes in really handy. It allows the display of the exact viewpoints and permutations currently required. Either by officials who need to make decisions about specific parts or residents who are interested in how the planned project would change the environment from e.g. their apartment window. Furthermore it allows the discussion of potential changes or alleviation of fears. Sometimes it is possible to change the opinion of residents by including a hill that obstructs the view on a new factory or by including a noise protection wall (see Figure 6). The ability to really understand these changes in an accurate 3D environment has often helped fundamentally in these scenarios.

Sometimes it is not possible, feasible or even required to employ the whole visualization capability. It is therefore possible to create various forms of output for further external use. This includes videos and screenshots at various resolutions. The screenshots can be geo-referenced for further accurate handling. Another aspect that has come in handy many times is the output in form of geo-referenced panorama images. These allow a low-cost 360 degree visualization of selected viewpoints. External tools allow the processing of batches of these panorama images to create a semi-interactive tour through the project area.

The last important output in terms of presentation is the ability to cutout an area from a project scenario, allowing a non-interactive lightweight 3D visualization of regions of interest or the further processing of the data with other tools.

5 INNSBRUCK USE CASE

This chapter explains how the workflows, pipeline stages and features come together in a finished real life use case. The process in question was a prestigious project commissioned by the City of Innsbruck a few years ago, with the goal to create a new regional tramline to connect the city centre with the periphery for better commuting and improving the access residents and tourists have to varying parts of the urban and surrounding area (see Figure 7).

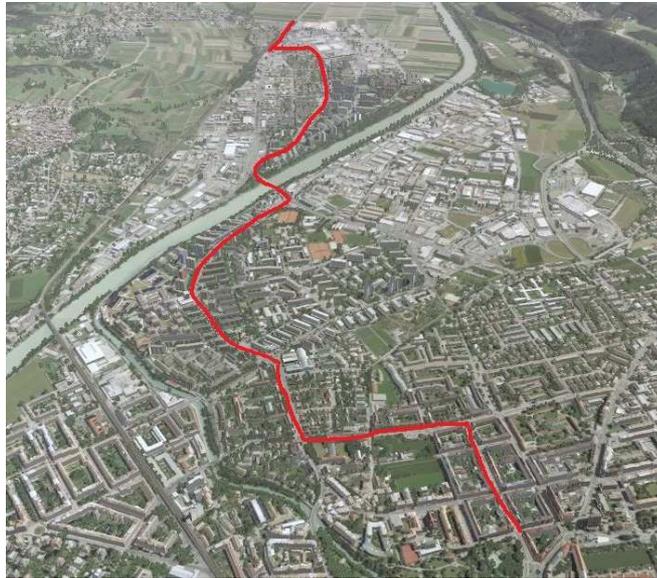


Figure 7: Project area depicting the planned regional tramline.

The whole process resulted in a multiple year spanning endeavour, planned and managed by a joined effort between the IVB (Innsbruck transport services), Geoconsult and VRVis employing the GEARViewer as one of the fundamental planning and visualization tools.

Depending on the progress the project was embedded into a stockmodel of the city in varying levels of detail. This process allowed the participating parties to plan for but also show the spatial transformation of the affected urban areas during frequent citizen information events and media articles. Figure 8 shows how two streets were efficiently connected during the planning process. This improved the traffic flow and enabled a more efficient access to public transportation in the area in question. In addition, the visualization placated residents by showing that it will still allow for trees and green areas without too much visual pollution.



Figure 8: Connection of inaccessible areas for traffic with a tramway station.

A disadvantage of a realistic rendering is that it sometimes distracts from important information by showing too much details. 3D scenes can also easily provide important annotations known from traditional 2D systems (such as GIS). Figure 9 shows how an integral and busy intersection is overlaid and annotated with colors to give stakeholders an easier understanding of how multiple interlocking parts will play out once finished. The yellow area depicts the sidewalk for pedestrians; the gray area shows the street while the blue area is a new area exclusive to the tramway. In addition, it shows residents that nature is also an important part of the urban environment with added green areas, where vegetation will be planted.



Figure 9: Use of colours for annotations to depict and explain complex changes to different stakeholders.

Furthermore, it was possible to account for refurbishing parts of the city by removing old and derelict buildings in favor of separate streets exclusively for the tramline, allowing for efficient public transportation without putting strain on narrow streets that cannot be extended otherwise (see Figure 10).



Figure 10: Addition of tramline exclusive tracks outside of the existing street by removing derelict buildings.

When planning a new public transportation system an important question is where to place and how to space out the stations, so that they make sense and allow access to important parts of the cities infrastructure. The visualization helped the various stakeholders to identify and visually communicate their placements. Figure 11 shows a youth hostel that was incorporated into the tramline network by including a dedicated station. In addition, this again allowed critique of residents during presentations to transform the urban area with additional green areas and trees.



Figure 11: Addition of a station to increase accessibility of a youth hostel. Addition of parking space and more green areas.

An interesting problem was presented by a similar but disjointed project about extending roads that progressed during the planning phase. It was situated at the outskirts of the project area but close enough that an inclusion was warranted. The solution to include the changes, without having to procure expensive but ultimately relatively unimportant geometric data, was to use orthophotos which needed to be created anyway and use the terrain texturing routines to switch between visual representation in the distance (see Figure 12).

In the process of finishing this project a plethora of outputs for presentation were created, including all mentioned output formats like screenshots, videos, cutouts and in person presentations. In addition, a panorama tour was created. We want to emphasize that everything you can see in the panorama tour can also be interactively explored in a 3D scene with the GEARViewer.



Figure 12: Progress of another project during the planning phase. Visualized as differing orthophotos of the relevant area.

6 CONCLUSION AND FUTURE WORK

The goal of the GEARViewer is to bridge the gap between the worlds of 2D GIS based planning and specialized 3D visualization and planning tools to allow the display of large scale and interactive digital twins, while giving the opportunity to augment them with changes needed for the infrastructure project at hand. The presented feature set supports a streamlined content creation workflow that natively supports different geospatial formats for many different use-cases that (semi) automatically create different forms of geometry. A variant analysis system allows the creation of different scenarios, the ability to switch between them and make comparisons. To allow stakeholders to recognize the project areas in question, the tool has an interactive 3D visualization and improves visual fidelity by including rendering aspects like shadows, vegetation and animation systems. It is possible to produce varying outputs for different requirements in regards to further processing and handling. This includes animation system simulations, cutouts from the project and material for media and presentations in the form of screenshots, videos and panoramas.

The original viewer was in development for over 10 years and therefore subjected to some limitations based on the underlying software. To allow for future state of the art improvements in different fields, the viewer is currently in the process of being migrated into the Visdom project, developed by VRVis. The focus of the Visdom framework is flooding simulations, but for that it also supports complex geospatial scenes covering wide areas. It also creates digital twins of urban and rural areas for physically accurate simulation. The resulting visualizations are highly interactive and are suitable for experts and non-experts alike. There are differences in the details of how the scenes are produced and the requirements of the people working on them; but many synergistic aspects can be found, which helps both projects in turn.

The most immediate goal is taking advantage of the newer nature of the framework and use its advanced rendering techniques to improve the performance and quality of the GEARViewer. Visdom supports the combination of geospatial data with application specific attributes, which are needed for the flooding simulation. Similar mechanisms could be used to extend the GEARViewer capabilities for the inclusion of BIM based aspects. Another aspect for future improvement is to enhance the digital twin by anchoring dynamic data into the geospatial context such as sensor measurements for traffic, railway, wind and many more.

Independent of the synergistic features a general goal is to continuously improve usability and react to additional requirements in regards to new or improved data source types. Furthermore, a goal is to utilize the new found potential in regards to the rendering software to including more state-of-the-art rendering techniques (e.g. day/night visualization with dynamic lighting and environmental effects, ...)

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