Towards a Sustainable Future: BIM, Virtual Reality and Simulation in a Giga Project

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Abstract. Sustainable energy is a key factor for the future prosperity and development of societies on our planet. Whereas the focus mostly is on energy production, the distribution of this energy, namely electricity, is crucial and often not perceived as well. In the energy transition of Germany, with a goal of 80% electricity from renewable sources in 2030, the current power grid is not capable of transmitting this amount of renewable electric energy across the country. Thus, a new backbone powerline of about 700 km is planned to transport the energy from wind farms up north to industry and households in the south. The capacity of this power line covers the electricity demand of about 10 million households. In this paper we describe how the integration of BIM, Virtual Reality, Augmented Reality, and simulation is used to plan and optimize a crucial part of this Giga project, a 5.2 km long tunnel during the design-, planning-, and currently pre-construction phase.

Keywords: BIM, Virtual Reality, Augmented Reality, Digital Twin

1 Introduction

Energy is crucial for all of us, our housing, our industry, our trade, our transportation, or in other words: our standard of living and future development. In 2021, Germany consumed about 2’500 terra watt hours of energy, thereof about 16% for trade, 29% for industry, 27% for transport, and 28% for households. In each of these sectors, more than 50% still were from fossil sources. The transportation sector unfortunately still consuming more than 90% fossil energy (Umweltbundesamt, 2023). To target climate change, in the 2016 Paris Agreement at the UN Climate Change Conference (COP21), 196 parties agreed to hold the global average temperature well below 2°C above the pre-industrial level (United Nations, 2023). Besides this urgent ecological necessity, the dependency on importing oil and gas over the last decades has shown itself to be politically and economically critical. The need for other energy sources is triggered in Germany also due to the fact, that after the Fukushima nuclear disaster, the German government decided to move out of nuclear power. The last German nuclear power plants were shut down mid-April 2023 with the need to replace this “missing” electric energy from other sources.

To solve all these requirements, the German government is setting the course for the accelerated expansion of wind and solar energy, to increase the percentage of renewable electric energy to 80% by 2030 (Die Bundesregierung, 2023). Given the geography of Germany, there is lots of wind power potential on- and off-shore in the countries’ north and northeast, whereas there is more solar power in the southern regions.

This change in the location of energy production as well as the continuously increasing consumption through heat pumps and electric mobility, poses large demands on the electricity grid infrastructure, which is even today not capable of handling the load in cases of lots of wind energy production. Under unfavorable conditions coal and gas powerplants have to be fired up in the south, and wind turbines in the north turned off due to transmission capacity shortage.

2 SuedLink and ElbX Project Description

To substantially improve the electricity grid from northern to southern Germany, the 10 billion Euros Giga project “SuedLink” (SuedLink, 2023), see figure 1, has been set up. Two 700 km long, 525 kV DC high voltage electricity lines are planned with a total capacity of 2 x 2 Gigawatt, covering the electricity demand of about 10 million households. Throughout most of the 700 kilometers, the four high voltage cables are buried below ground in standard open pit construction, about 1.5 meters deep.

In this routing, the crossing under the river Elbe close to Hamburg is one of the technically most challenging tasks in SuedLink. It has been decided to build a 5.2 km long tunnel under the river for the power cables (Seibitz, 2023) close to the city of Hamburg. This crossing of the river between the two federal states of Schleswig-Holstein and Niedersachsen is called ElbX. In the planning phase various technical options like overhead power cables, washing the cables into the riverbed, and others have been thoroughly analyzed. For multiple external reasons like minimizing environmental impact, tectonics, riverbed maintenance, and others, the final decision was to build a tunnel. The accessible tunnel solution was also preferred for optimal maintenance during operation.

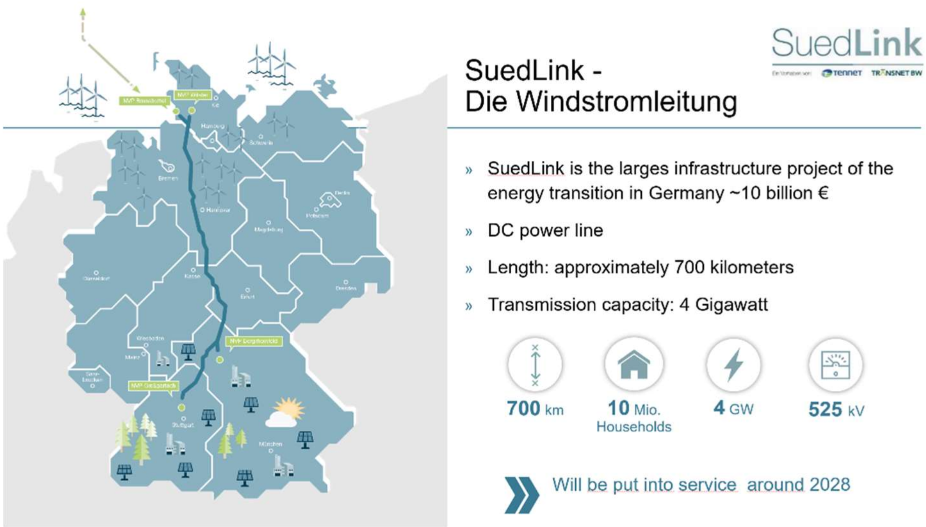

Figure 1. SuedLink map and project brief. Source: SuedLink, 2022.

The tunnel is positioned 20 meters below ground with an inner diameter of about 4 meters and made from concrete tubbings, At each end of the tunnel, similar shaft buildings are built.

Each one of the underground shaft buildings has an approximate outside dimension of length 85 meters x width 20 meters x height 26 meters. Only a small part of the shaft buildings with dimensions of about 24 x 15 x 8 meters is constructed above ground level and will be visible after completion. The main purpose of the shaft buildings is to guide the cables from land level to tunnel level, as well as the operation and maintenance services of the tunnel.

In this paper we describe our approach and experiences to support the design-, planning-, and currently pre-construction phase of this crucial section in Germanys largest grid infrastructure project with a combination of BIM, Virtual Reality (VR) and Augmented Reality (AR).

3 Visualizing and interacting with the BIM content

At the end of the initial design phase, the project manager of ElbX was looking for an option to make the BIM data - the 3D project data accessible to all project stakeholders for an in depth understanding of the project, as well as fostering discussion between the different stakeholders to further jointly improve the overall quality of the planning and project. After evaluating various options, Virtual Reality (VR) in a multi user environment for joint discussions was chosen. Typical single user experiences like head mounted displays (HMDs) were no option as they would not have enabled direct discussions.

Figure 2. Left: typical VR session in the CAVE with up to 12 participants.
Right: Mobile VR projection used in an onsite presentation. Source: Authors, 2023.

For organizational reasons like technical support, as well as to limit the necessary efforts, it was decided to mainly use the 5-sided CAVE (Cave Automatic Virtual Environment) at the High-Performance Computing Center Stuttgart (HLRS).

Since this environment allows teams of up to about a dozen people to explore the project jointly in a real world environment, interactively, and at 1:1 scale. A typical VR session in the CAVE is shown in figure 2 left. For various onsite PR events, setting up a CAVE would have been far too costly, so a large single screen back projection was used instead as can be seen in figure 2 right.

3.1 VR Sessions

As it took most of the participants a few hours to travel to the HLRS, the VR sessions had to be planned in a way to make the overall trip efficient. Quite unexpectedly most of the participants appreciated the “out of the office format”, since they jointly worked concentratedly on the well prepared topics not being distracted from every day’s work.

The VR session meetings were organized in a 2 x 3 hours format, so the same or also different teams could work concentratedly on specific topics in one of these 3-hour sessions. The focus of these meetings up to the current project state was:

- Session: Core team of the project: General understanding of the project and review of design status. Additional visualization of positions of pre-investigation boreholes to find potential overlaps with the tunnel pipe.
- Session: Cable manufacturers: How to install the 5.2 km long cables in one run, pulling of cables in the shaft buildings, and fixtures both in the shaft buildings and the tunnel.

- Session: HVAC team: HVAC optimization. Augmented Reality for presentation of air flow simulation data.
- Session: PR-Team: Video for internal and external publication.
- Session: SHE – Safety, Health, and Environment requirements. A complete walkthrough down to details like stairs detailing, evacuation routes and potential obstacles in operation.
- Session: Core team optimization 2
- Session: Communication technology and control: IT optimization for the project, spatial position, and design of ducts.
- Session: PR – communication update.
- Sessions: Mobile VR on site for official hand-ins for approval, public event to communicate project to politicians, the local public and within the whole SuedLink team.
- Session: Mobile VR “Maustag” - open house for kids and families at planning office.
- Sessions: Presentations for potential contractors, for tender, overview, and maximum transparency.
- Session: Maintenance team, operation of tunnel train for maintenance purposes.

For an effective integrated workflow, our focus is to minimize any additional work needed to visualize and interact with the BIM data in VR. VR should come as a byproduct. The VR system, as described later, is directly linked to the Revit project files, and visualizes additional data from various other project file sources. So, in each of the sessions, the current working status was visualized. Improvements discussed in earlier sessions were already incorporated using the “live” planning data. Minor changes then were implemented during the sessions, updating the Revit models accordingly.

Based on the positive experience in sharing the knowledge between all project stakeholders and fostering fruitful discussions, it is planned to support the project teams with further VR meetings in the current construction phase. Ongoing plans are, for example, to update all teams during the construction process, to use it for conflict resolution, as well as for training the future maintenance teams.

3.2 Augmented Reality, and 3D prints

The planning data used for Virtual Reality is used for Augmented Reality (AR) as well. As a base for printing the 3D model, the Revit data was converted to a printable STL file. Some wall thicknesses had to be extended and support structures added for 3D printing, otherwise the thin walls would have been lost in printing the model due to scaling.

For the Augmented Reality application as shown in figure 3, the live view of the model (on the left side) is captured by a webcam and the model position is tracked with two fiducial markers, one on the front and one on top. On the screen, on the right-hand side, the view of the model is overlaid with additional information like the tunnel geometry, the cables, as well as the simulation of airflow through the building. Even though this information can also be displayed in VR, in some discussions it is an advantage to discuss issues at model scale. As the same software system and data is used for both VR and AR, the added efforts to implement the AR visualization are minimal.

The open source software used for Virtual and Augmented Reality is COVISE (COVISE, 2023). The Augmented Reality system is based on the OpenCOVER plugin system and supports multiple underlying tracking libraries. These are: ARToolKit (Kato), ALVAR (Rainio) and ARUCO (Garrido-Jurado). The most stable tracking results so far can be reached with ARUCO which is part of the latest OpenCV library. To increase tracking accuracy, further marker arrays are now supported even for non-planar marker configurations. If multiple markers are in view at the same time, pose estimation is not only derived from the four corners of one marker but from all corners of all markers at the same time. Furthermore, the configuration system of OpenCOVER has been extended to support online modification of configuration files and storing of configuration entries.

Especially the AR system profits from these new features as the AR markers are now automatically added to the user interfaces, can be configured and stored through the user interface as well.

Figure 3. Dataset and simulation presented in Augmented Reality.
Source: Authors, 2023.

4 Technical background

4.1 Datasets

As shown in the sessions section, the project integrates most of the disciplines in the BIM planning process. Due to the wide variety of disciplines, a variety of data formats must be loaded into the VR software and displayed simultaneously. Some of the datasets used are:

- Both buildings as well as the tunnel were provided as native Revit files with materials assigned and building phases defined for all objects.
- MEP however was provided as IFC files.
- The cable systems were delivered as both DWG and IFC files. Both file formats posed issues when dealing with georeferenced coordinates and material information when importing them in Revit. Thus, they had to be converted manually.
- CFD: Star-CCM+ Simulation of the airflow in two directions by ROM, results are in Ensight Gold data format. The visualization was carried out in COVISE allowing to directly interact with the simulation and thus to analyze the air flow through streamlines, colored cutting planes as well as iso surfaces, anywhere in the building.
- Terrain: 1m resolution DTM model, raw LAS files and high-resolution imagery in .tif format. The DTM and imagery has been converted to an OpenSceneGraph tiled database by our own fork of VirtualPlanetBuilder which is part of the COVISE framework.
- LoD2 buildings in CityGML format, have been extended manually by higher resolution models of the neighboring farms, the former nuclear power plant and animated wind turbines.

4.2 Revit interface and project specific problems

A unique bi-directional interface between Revit and our Virtual Reality software system OpenCOVER is the core of the technical implementation for the BIM/VR workflow within this project. It is developed as part of the COVISE Framework (COVISE, 2023) and is available free of charge and Open Source under LGPL v2.1 license. The project is available on GitHub (COVISE Github, 2023) and prebuilt Windows versions are available. The Revit interface is described in detail in (Kieferle, 2015) and (Woessner, 2016).

This project posed several unique problems to the interface between Revit and the VR Software OpenCOVER, and its interface is continually extended to meet these needs. The two sides of the river are situated in two different federal states, Schleswig-Holstein and Niedersachsen. Both states are using different coordinate systems, requiring exceptional care when preparing the joint environment model, combining LOD 2 city models from both states with the Digital Terrain Model of the SuedLink routing corridor as well as models of landmarks such as wind turbines and the nuclear power plant “Brockdorf”, nearby. The BIM Models of the start and end of the tunnel and the tunnel itself have been modeled in three separate files. To be able to work with all of them in VR at the same time, they had to be combined into one Revit file by linking two files into one base file, the start building in Schleswig-Holstein.

The Revit interface was consequently extended to support linked documents. Previously, Revit objects have been identified through their numeric object id. This, however, is only unique within one document; hence the object identification has been changed to a tuple of both documentID and objectID throughout the whole Revit interface. This now enables addressing separate documents in one session but also hierarchically linked documents.

While linked documents have their own coordinate system, when loaded into a main document, all coordinates are relative to the parent document. On one hand, this simplifies working with multiple linked documents but on the other hand aligning modifications or clipping planes to local coordinates gets more difficult. This will have to be addressed in future versions of the interface.

In the design, the construction process is divided into 31 different construction phases in Revit, see figure 4. To visualize the temporal changes during construction, all objects sent to the VR environment have been extended by their construction and destruction time.

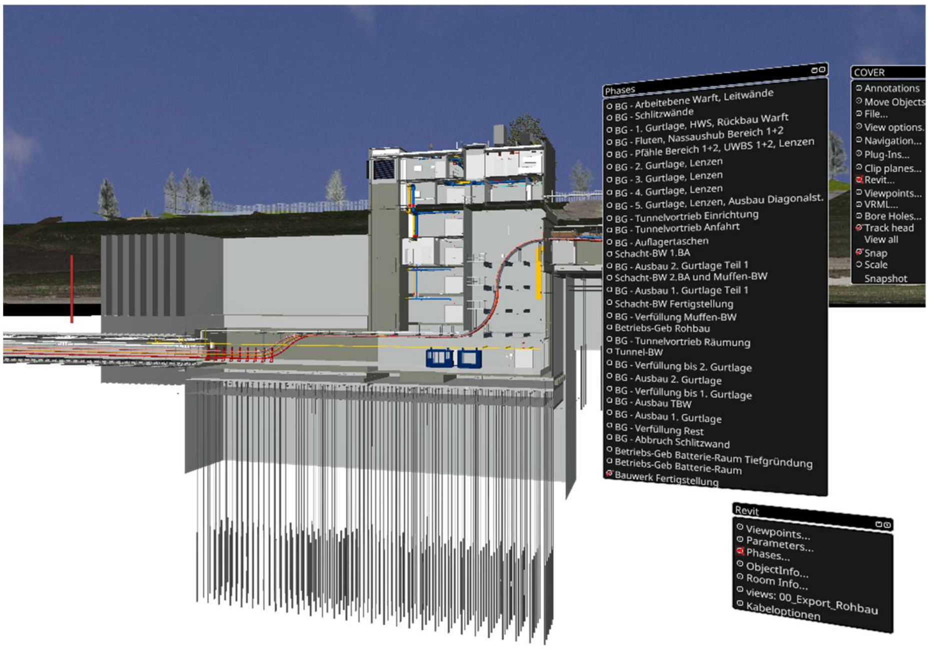

Figure 4. List of all building phases in the project. Source: Authors, 2023.

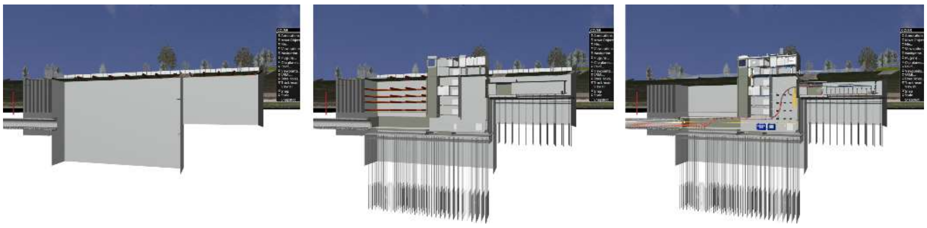

Figure 5. Examples: Three of the 31 building phases. Source: Authors, 2023.

Whenever one of the building phases is selected, all objects with a construction time later than, and a destruction time earlier than the selected phase are hidden, see figure 5, resulting in the correct rendering of that phase.

Not all objects in the scene, such as the cables, terrain, trees, and the tunnel vehicle are modelled or made available as Revit objects. These objects have been converted from various 3D geometry formats and added to the scene as VRML97 files. To display the correct building phase in these files, a custom VRML97 node has been developed which can both set and query the current building phase. This node creates an event whenever the building phase changes and thus VRML97 features can also be displayed in the correct state.

Like building phases, design options can be specified in Revit. All objects are attributed to one or more design options and displayed as necessary when the design option is selected.

The most important addition to the Revit interface is the ability to display object information of any available object in VR to query if needed in the discussion. The functionality changes depending on the selected family type. Basic functionality is available for all family types, such as selecting a different subtype for example. This for example allows quickly changing a single wing door to a double door. Added functionality is only available for selected family types. Windows and doors for instance can change their facing or handedness, see figure 6. These options are available selectively.

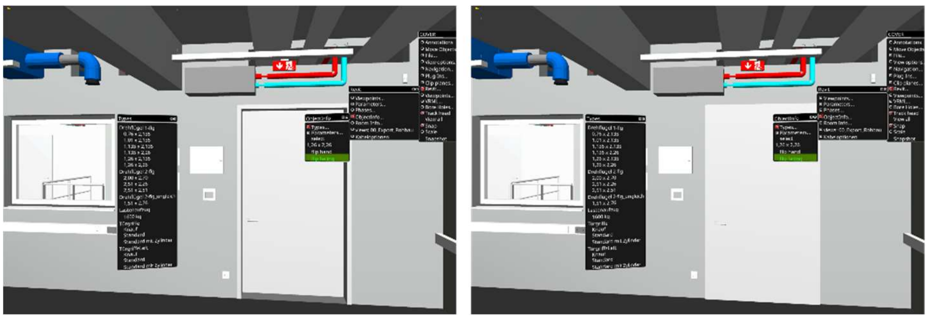

Figure 6. Object info showing family information and easy access to quick functions like changing facing and handedness, see door orientation. Source: Authors, 2023.

Figure 7. VR elevator with control implemented as plugin. Source: Authors, 2023.

The building hosts an elevator, see figure 7. We developed a set of classes to implement standard elevator functionalities. These include calling an elevator from every floor, automatic closing and opening of cabin and landing doors as well as selecting a destination floor in the elevator cabin. Unfortunately, there are no standard families for elevators and landing doors which would make it possible to automatically implement a working elevator within the Revit interface. Thus, the elevator is currently using VRML97 objects. In future versions we will adapt this to Revit families provided by major elevator companies such as Kone, Otis, Schindler, TKE and others.

4.3 Future work regarding the Revit interface:

Based on further experiences in a real life project, we would like to investigate whether there are standard Revit families for elevators that we could use to automatically generate working elevators from these families. Typical issues are cabin- and landing doors which are not modelled so that left and right panels can be distinguished while this is necessary for a correct animation. Buttons are also rarely part of the family. The goal is to design the interface in a way that the necessary features can be easily added to existing families, like the way doors are currently handled.

Another feature that was missed during the VR sessions is the ability to assign textures to materials. Often standard family types are used by the engineers, and project specific materials are not assigned. This should be easily fixed while doing a walk through in VR.

Object type modification should be extended to support sub-object types, such as handrails on stairs for instance. Furthermore pipe and duct editing is cumbersome in 2D views. This would benefit a lot from 3D interaction in an immersive VR environment.

In all these cases we do not try to implement all the functionality which is available in the native Revit but only select those interactions which are best suited for 3D interaction during virtual walk-through sessions. Due to the bi-directional feature of the interface, it is always possible to edit the model in Revit with the full set of modeling features concurrently.

5 Conclusion

VR as a communication and integration platform works very well during all project phases, even quite from the beginning. Experiencing the planned project in any scale up to 1:1 in the CAVE helps all project stakeholders to get a full understanding of the project by jointly immersing into it. Being able to experience it together in presence in the virtual environment, enables direct communication and discussions between all participants. One of the main benefits of this approach is that each of the stakeholders can get a deep understanding of the other's discipline and their constraints through the discussion directly in the virtual object. So, the overall quality of the BIM planning process and thus the quality of the project is improved using the presented method.

Though all stakeholders have been formally integrated into the planning process and continually asked for feedback throughout the planning phase, often, only during the VR meetings, crucial improvements have been identified and discussed by the joint teams. Improvements that otherwise might have come too late or even been lost after all.

For the productive joint discussions in a complex and dynamic infrastructure project like ElbX, it is crucial that the VR system can load and visualize data from various sources, so that the current and latest planning status can be discussed. To lower the hurdles to using VR for BIM projects, it should not be an add-on task but integrated as seamlessly as possible. An even closer integration for useful interactions with the model is our approach for the future.

Though in this paper we described the workflow in a real-life infrastructure project, the approach and workflow are directly applicable to any other architecture project as well.

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