Tunnel Digitalization Center – Beyond BIM in underground construction

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ABSTRACT: Digitalization opens the possibility of avoiding the waste of three very important assets. We can minimize the unnecessary loss of materials, time, and information by optimizing our use, presentation, and exchange of data.

The more complex a construction is, the higher the number of participants in a project are, the bigger the infrastructure network of which a tunnel is part of, the better the digitalization shows its advantages.

Digital continuity is the key for cross-phase and cross-divisional system solutions. With the help of 7 industry partners, under the coordination of the Swiss Center of Applied Technologies (SCAUT) the aim of the Tunnel Digitalization Center (TDC) is to showcase and develop new use-cases among very different stakeholders to innovate and demonstrate thirds the complex digital processes in a real environment. With this project, SCAUT aims to make an important contribution to the digitalization of the whole tunnelling industry.

From BIM and electromechanical equipment to operation and digital services in maintenance, several possible applications of the digital twin: at the TDC solutions across the entire value chain and life cycle are demonstrated. It allows demonstration and simulation in a realistic environment. Innovative uses cases, like cloud solutions, BIM and IoT for tunnelling are part of it.

In this paper the concept of the TDC is going to be presented, and the use cases shown there focusing on simulations, commissioning, operation, and maintenance.

1 INTRODUCTION

Even though an important development work has been done in the last years in the tunnelling industry, digitalization in tunnelling has still great further possibilities. A lot of communication among the different stakeholders is needed and a big amount of standardization processes must be done to profit of its full potential.

At the same time, for many players in the construction processes, digitalization is still too abstract to understand and needs deep explanation to be properly understood. It's especially true if it comes to complex connections.

On top of that, the more complex a construction is, the higher the number of participants in a project are, the bigger the infrastructure network of which a tunnel is part of, the better the digitalization shows its advantages. Digital continuity is the key for cross-phase and cross-divisional system solutions.

The Tunnel Digitalization Center Project of SCAUT enables exactly this cross-industry communication among the different stakeholders, that is needed to push the digital transformation in tunnelling. With its demonstrations, it aims to play an educative and eye-opener role for new technologies.

The Tunnel Digitalization Center was officially opened in October 2019 in the Hagerbach Test Gallery in Switzerland and is a project in permanent development since then.

2 THE TUNNEL DIGITALIZATION CENTER

2.1 *What is the Tunnel Digitalization Center*

In the Tunnel Digitalization Center (TDC), with the help of 7 industry partners, under the coordination of the Swiss Center of Applied Technologies (SCAUT) the aim is, to high-light and develop new use-cases among very different stakeholders to innovate and showcase third parties the complex digital processes in a real environment. With this project, SCAUT's intends to make an important contribution to the digitalization of the whole tunnelling industry.

The focus is on cross-phase and cross-divisional system solutions that span the entire value chain and life cycle of tunnel systems – from planning with BIM and the subsequent structural work and electromechanical equipment to the operating phase and digital maintenance services. New technologies and innovative concepts can be demonstrated on a scale 1:1, which leads to a better understanding of complex processes and procedures as well as a high level of cost-efficiency.

In particular, the interaction between different partners will be demonstrated using shared use-cases and presented live on site. In addition to reducing complexity, the Tunnel Digitalization Center focuses on saving time, optimizing efficiency, and increasing productivity. This goal is achieved with standardized, efficient engineering and a high degree of automation. As a result, tunnels can be put into operation earlier thanks to virtual commissioning, training, and simulations. The high level of safety and optimized maintenance also enable the tunnel to be operated sustainably and permanently.

2.2 *Stakeholders*

The Swiss Center of Applied Underground Technologies (SCAUT) is a competency center for the use of the underground space. It relies on high-end engineering, innovative solutions, and most advanced ICT to make a substantial contribution to the creation of underground spaces for the future and to provide relief for metropolises and highly populated urban areas.

The companies Amberg Engineering Ltd with its expertise in infrastructure construction, Siemens Ltd for automation, Elkuch Group Ltd as the expert for door systems and HBI Haerter Ltd for tunnel ventilation simulations, TLT Turbo Ltd as a fabricant of ventilators, Amberg Technologies Ltd, as a surveyor specialist and JES Elektrotechnik Ltd as a provider of environmental monitoring solutions for traffic applications such as tunnels were won as industrial partners.

2.3 *Main benefits of simulations, commissioning, operation, and maintenance with digital tools, state of the art today*

Monitoring large-scale structures such as tunnels has always presented significant challenges, particularly when localized damage needs to be detected and mapped. Traditionally, the only monitoring procedure allowing the detection and localization of damage such as leakages, settlements, cracks, or abnormal joint movements was periodic visual inspection. However, inspecting large structures regularly is a tedious and subjective procedure, which reveals issues only visible to the eye. The interval between inspections can be large, and it is difficult to obtain rapid feedback on the conditions of a structure during or immediately after an event such as an earthquake or a large storm. Permanent monitoring systems based on distributed optical fiber sensing technology, laser distance meters, and synthetic aperture radar have opened new possibilities to address these needs. They allow integrity monitoring with direct detection, localization, characterization, and immediate reporting of new local conditions. These systems are therefore able to not only measure strain and temperature (answering the “how much” question) but also localize possible damage areas (answering the “where” question). This makes them ideal for monitoring structures where the location of a possible instability or failure is unknown.

3 SIMULATIONS AND COMMISSIONING

3.1 *Ventilation and safety at the Tunnel Digitalization Center / Ventilation simulation*

In the Tunnel Digitalization Center one example of the demonstrated use-cases is for ventilation simulation, that has been developed by two of the consortium partners.

The aim is to be able to systematically test the tunnel ventilation control before the system is available and without blocking it. In addition, scenarios can be tested that are difficult to simulate in reality (e.g., traffic, fires). In this way, errors in the control system can be minimized.

The tunnel ventilation simulator is a digital twin of the tunnel system, which, based on external control commands to the ventilation system, calculates the air quality, air temperature and velocity, including any smoke development as well as flow velocities in real time. The effects of vehicles, wind, temperature, fires, etc. are automatically calculated.

Thus, a complete virtual commissioning can be performed. In addition, scenarios can be tested which cannot be tested in the tunnel, such as a tanker truck fire. Thanks to the automation possibilities, significantly more scenarios are tested than in a conventional commissioning.

The tunnel ventilation simulator is also used for operator training and during factory acceptance tests of the ventilation control system.

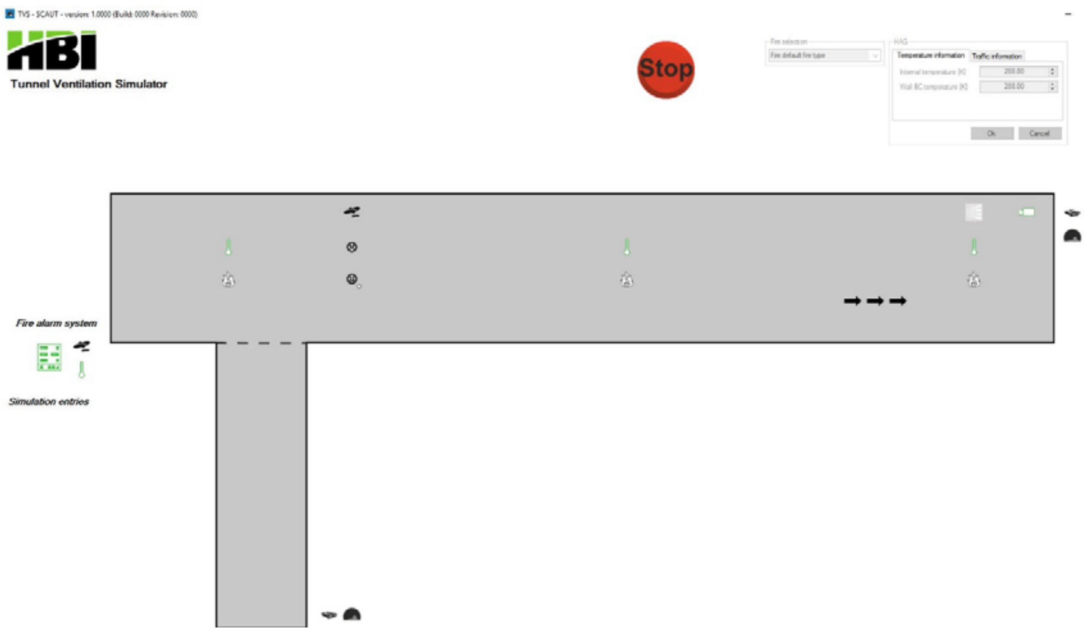

Figure 1. HBI Tunnel ventilation simulator.

3.2 *Ventilation and safety at the Tunnel Digitalization Center / Safety door*

The other safety-related use-case is the virtual commissioning of the tunnel door.

To shorten the commissioning time, we use the possibility of virtual commissioning.

Using the tunnel door as an example, a complete test of the setup can be shown. The control program of the door is tested in advance with a virtual twin of the tunnel door.

The physical behavior of the door is simulated and displayed. Different mechanical influences can be simulated. The control program must react correctly to these influences, such as a blockage of the door. Thus, a product is installed in the real plant that has been completely tested virtually beforehand. No more surprises during commissioning at the plant.

Elkuch with Siemens offers the possibility to equip the doors with various sensors. This makes it possible to monitor and control a wide range of environmental conditions, such as pressure and suction loads caused by trains passing, acceleration of the door leaf, temperature, humidity, air quality and degree of contamination. Based on the data obtained from the sensors and the electric drive, it is possible to calculate the maintenance intervals for doors and optimize the schedules for maintenance.

In addition, by digitizing the doors, the maintenance instructions, maintenance logs and spare parts lists can be accessed via a RFID-Chip at the door. Viewing the maintenance history simplifies the work to be performed. In addition, spare parts can simultaneously be ordered during maintenance, which results in a minimization of the administrative effort.

The fault-free functioning of escape doors is a critical factor for safe tunnel operation. Even the smallest malfunction of the doors during operation can lead to long interruptions of operation or even complete tunnel closures.

The conventional method of troubleshooting requires a free window of time to reach the door, diagnose the cause of the fault and rectify it. Response times therefore vary depending on the next available time window.

The digital connection of the door reduces the response time for troubleshooting and diagnosis. Troubleshooting can be simulated directly in the digital twin. Troubleshooting in the tunnel can thus be carried out in a targeted manner and in the shortest possible time.

Tunnel operation also does not have to be interrupted for the training of operator personnel. All functions of the door, such as normal opening sequence, blockages in opening and closing direction and behavior in case of power failure can be simulated in the digital twin.

Figure 2. 3D virtual twin of the safety door

Figure 3. Control interface of virtual door.

4 OPERATION

4.1 *Digital twin for operation, BIM/IoT implementation*

Getting information about the state of an existing structure is essential to plan its maintenance. Many structures in operation have measuring devices, which are manually checked on a regular basis. Due to higher efficiency and a lower response time, sensors are increasingly used to monitor structures. In either case, a measuring device, or a sensor only provides added values, if its data is regularly checked. Sensors connected to a server (e.g., via a SIM card) are often displayed on a web page and are thus easily accessible. It is often implemented that the person responsible for a structure receives a text message in case of alarming values, which considerably decreases the response time. As BIM plays an increasingly important role in construction projects, an inclusion of sensor data into a BIM-model visualization is a promising use case. The data of a sensor can be projected onto its corresponding element in real time and highlighted in color if an alarm value is reached.

The aim of this approach is not only to get a message, that the alarm value is reached, but also to provide context of the situation. If sensor data gives an indication that a construction element deforms more than a critical value, the surrounding elements can be visualized. This gives information whether the problem is local or whether the neighboring elements are also affected. Both problems can result in different measures to resolve the issue. This allows the user to understand the situation without having to analyze the data provided by the sensors, which takes time, and thus decreases the response time. Hence, this approach is particularly valuable for critical infrastructure, for which having the context earlier available is a great added value. Therefore, a more appropriate response may be found at an earlier stage, which can reduce disruption time, material usage and improve resource management.

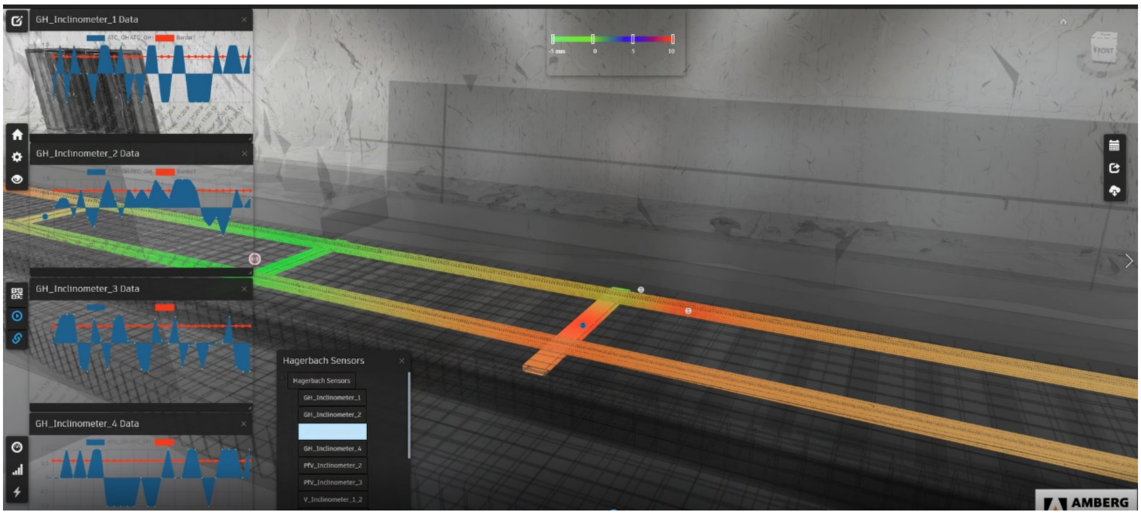

Figure 4. Heat map of sensor data about rail detorsions shown on the rail elements in the BIM model

4.2 *Sensor technology for the operational control and safety at the TDC*

The Tunnel Digitalization Center is equipped with several safety-related sensors, based on standards of a real tunnel project - from environmental monitoring such as air quality or air flow and sensors for the fire detection system to condition monitoring sensors for electromechanical equipment like jet fans or the escape door.

The sensor signals are processed collectively in a high-available PLC system, which ensures a failure-resistant operation of different safety-relevant automation tasks in the tunnel. On the other hand, it makes the signals available to a SCADA system, where the real-time status of the sensors is displayed.

Thanks to digital twins, all sensors can be emulated in a virtual environment to validate the PLC code or to simulate various scenarios using behavior models in an early project phase without having any tunnel hardware. As a result of this, the real commissioning at the plant can start based on a successfully pretested program.

Another use case within the context of sensor technology is the predictive maintenance of components, which are relevant for a safe operation of a tunnel. The data provided by condition monitoring sensors installed at electromechanical devices can be used for an early detection of failures or anomalies. This helps to increase the availability and reliability of the entire tunnel system.

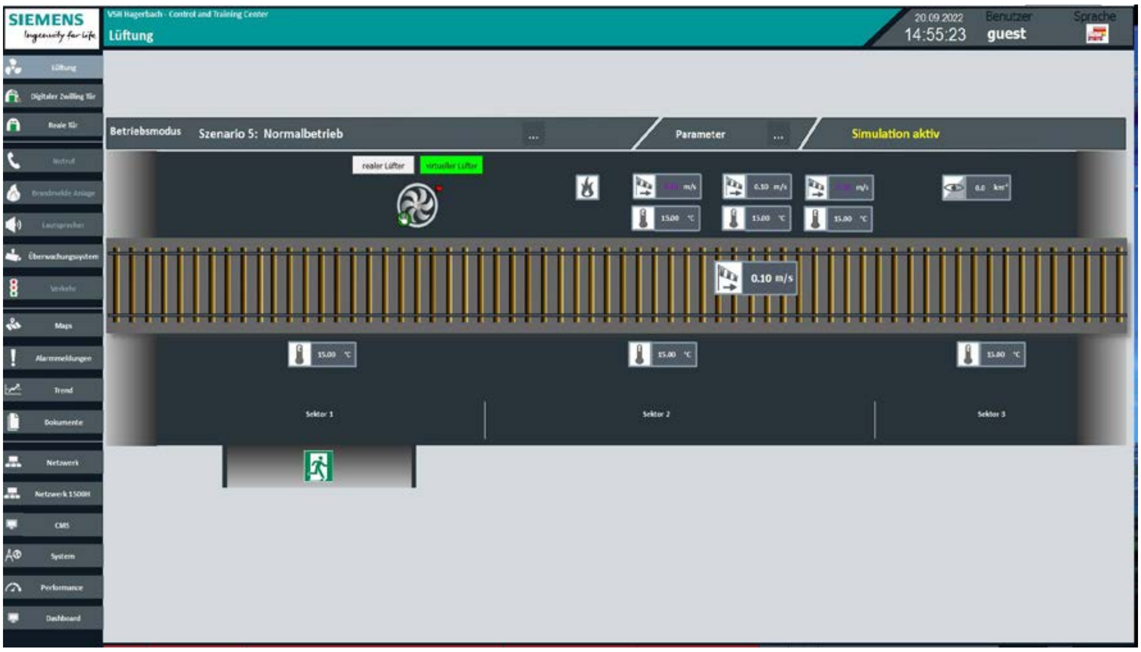

Figure 5. SCADA overview for the tunnel ventilation system and sensor technology.

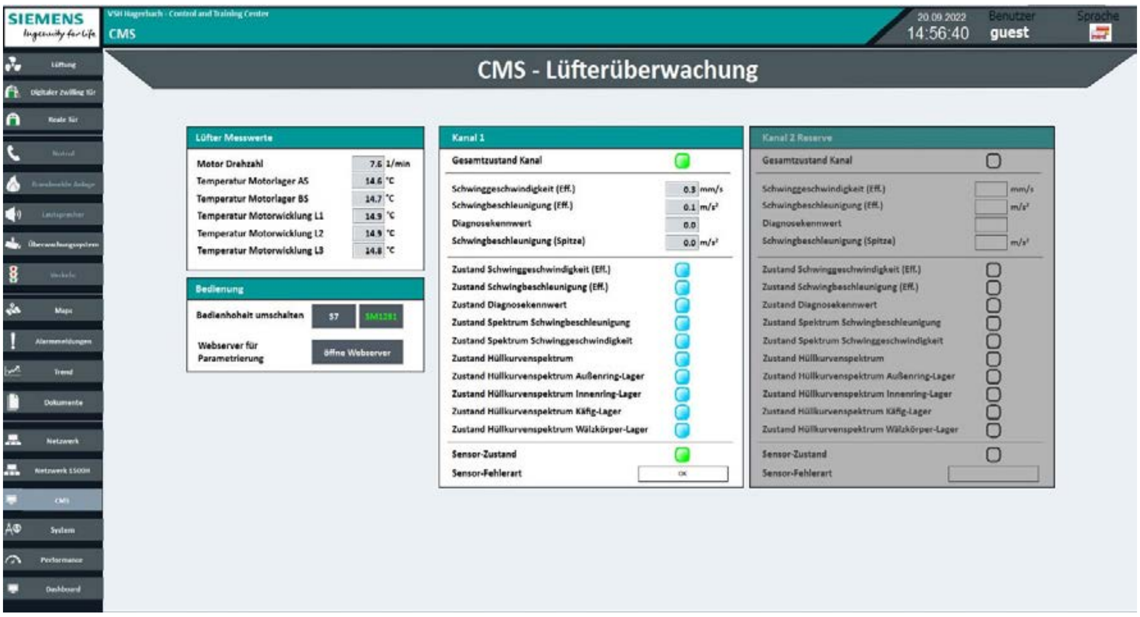

Figure 6. Overview of condition monitoring system for the jet fan.

5 APPLICATION OF THE ABOVE MENTIONNED TECHOLOGIES ON PROJECTS - THE SCHWAMEDINGEN TUNNEL

Noise, exhaust fumes and an almost insurmountable separation of their district – the traffic-plagued residents of Schwamendingen had had enough of all of this, and a project was launched to cover a part of the motorway. The tunnel will run from the Zurich East motorway junction to the Schöneich Tunnel, extending the latter by 940 m in length to 1.7 km. The ventilation system and the security features in the existing tunnel are to be renovated and modernised. The new tunnel will improve the connection between the two parts of Schwamendingen and protect the residents against noise and air pollution, while a large park on top of the construction will provide a recreational zone in the middle of the urban area.

The project managers have chosen Siemens to take care of the complex control tasks. A Simatic S7-1500 master controller and ten local controllers ensure the optimal operation of the tunnel ventilation systems. 52 ET200SP local peripheral devices are used to monitor and record the current status in the tunnel via sensors and to control the motors and jet fans, which are equipped with Sinamics G120X frequency converters.

A tunnel ventilation simulator has been developped, which was successfully used as a proof of concept in the collaboration with Siemens on the Roveredo bypass project. Thanks to its innovative modelling system, the HBI simulator allows for interaction with the controller and the real-time visualisation of the results. The advantages of using the digital twin for automation are also recognised. This is because it is not just the ventilation components that are being simulated – the controllers can also be mapped using the virtual PLCSIM Advanced controller in the TIA Portal. Various scenarios can thus be simulated and tested before the devices are installed on site.

Figure 7. Visualisation of the Schwamedingen Tunnel

Thanks to the virtual commissioning, the Swiss Federal Roads Office (FEDRO) does not have to close this busy motorway section at all. Markus Eisenlohr, a specialist in operating and security equipment at the FEDRO, emphasised how important this is, as any closure would have immediate far-reaching effects on all of the traffic in the North Zurich area. Last but not least, virtual planning and commissioning is an excellent supplement to the planning of a project using Building Information Modelling (BIM), something which is becoming increasingly common in complex building projects.

6 CONCLUSION

The Tunnel Digitalization Center is much more than a real environment showroom for the digital products of a consortium. It is also a place for cross-industry innovation for cutting edge technology. By working on digital continuity, predictive maintenance and digital twin technology for construction and smart cities, our activity contributes to more efficient future technologies. Mainly by enabling information exchange and immediate feedback possibility.

The work in the TDC has impact on social, economic, and environmental aspects. Digitalization opens the possibility of avoiding the waste of three very important assets. We can minimize the unnecessary loss of materials, time, and information by optimizing our use, presentation, and data exchange. That is why optimizing digitalization processes is very important to contribute to a sustainable future, and the Tunnel Digitalization Center insures a platform for this purpose.

This way, we contribute to the following sustainability goals:

- Responsible consumption and production: because we work on use-cases minimizing material losses
- Sustainable cities and communities: by working on digital twin technology for infrastructure and tunnelling and simulations for security
- Climate action:
  - by pushing toward a paperless construction site
  - better logistic processes due to simulations
  - using less material because of less planning errors
- Quality education: by regularly doing demonstrations for students
- Industry, innovation, and infrastructure: because we work on better construction and operation processes, and we are open about it

Above that, closing tunnels for construction or maintenance is very costly and disrupts the daily lives of their many users. By working on minimizing closure times and maintenance and operating costs, a fundamental benefit for society can be approved.

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