

RETHINKING TUNNEL CONSTRUCTION: DIGITALIZATION IN THE BIM PILOT PROJECT TUNNEL HOLSTEIN

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ABSTRACT: The Holstein Tunnel in section BA 4.1 of the A44 Kassel–Herleshausen motorway is a pilot project for the application of BIM methods in German tunnel construction. Six BIM use cases (as-built documentation, construction progress monitoring, model-based billing, occupational safety, quality assurance, and defect management) are being implemented. A key role is played by the Construction Information System (CIS) developed by BEMO, which serves as the central ERP system and digital backbone of construction execution processes. The workflow from data acquisition through to the BIM use cases is described.

It becomes evident that the use of tailored digital solutions and model-based collaboration among all stakeholders can establish new standards for transparent, efficient and quality-assured tunneling.

1. INTRODUCTION

As part of the construction of the A44 motorway in Germany, the Holstein Road tunnel is being built on behalf of Autobahn GmbH, represented by DEGES. It consists of two tubes, each approximately 1,660 meters long, as well as cross passages constructed using both conventional tunneling and cut-and-cover methods. In addition to the tunnel tubes, extensive ancillary facilities such as operation buildings, firewater basins, ventilation separation walls, and various civil engineering structures are being realized.

The Holstein Tunnel was selected as a pilot project for the application of Building Information Modeling (BIM) in tunnel construction. The objective is to investigate how a conventionally designed infrastructure project can subsequently be transferred into the BIM methodology and used during construction execution to improve project delivery.

For this purpose, the design was subsequently modeled, attributed, and the discipline-specific models were merged into an overall model. These steps were initiated by the client prior to tendering, and the overall and discipline models were made available to the executing contractor after contract award (Brungsberg, T., Weißbrod, F. & Hanz, S. 2025).

Building on these design-phase services, the application of BIM methods during construction execution is expected to improve quality, risk management, project controlling, communication, and to increase schedule and cost reliability.

In the current phase of digital transformation in the construction industry, the quality of data also determines the quality of operational decisions. Information systems must not only store data, but also contextualize, structure, and make it analyzable. The Construction Information System (CIS) developed by BEMO meets this requirement by anchoring construction documentation directly at the point of data generation, thereby minimizing the gap between an event and its documentation.

2. CIS AS A CENTRAL PLATFORM

2.1 DATA QUALITY AND PROXIMITY TO THE SOURCE OF KNOWLEDGE

Data quality in construction cannot be created retrospectively; it arises at the moment of data capture. A system that delegates the collection of information to those who first perceive the situation systematically reduces information loss, transmission errors, and interpretative distortion. CIS enables site-based, practice-oriented data capture, structured by structural elements and chainage, transforming daily events into a consistent and analyzable format. The continuous input of structured primary data

forms the basis for timely evaluations, quality assurance, real-time controlling, and model-based downstream processes.

2.2 BASE DATA MODEL AND DATA CAPTURE IN CIS

Data capture in CIS includes, among other things, personnel data and working hours, RESS (required excavation and support sheet) with associated work steps and material consumption, as well as equipment usage and spatial allocation based on chainage or direct references to structural elements. The personnel planning module assigns individuals and teams to construction sites and enables visualization of shift plans, individual working time models, and absences. These data can be retrieved in subsequent processing steps and are used in automated evaluations, protocols, and reports.

The equipment module assigns construction machinery spatially and temporally, documents repairs, maintenance, and transport, and makes availability transparent.

This data can also be evaluated and analyzed in various reports. For the digital representation of a construction site, a wide range of basic information is required, such as client information, project-specific logos, building element designations, associated cost centers, and site-specific user rights management.

2.3 DESCRIPTION OF THE DATA CAPTURE PROCESS

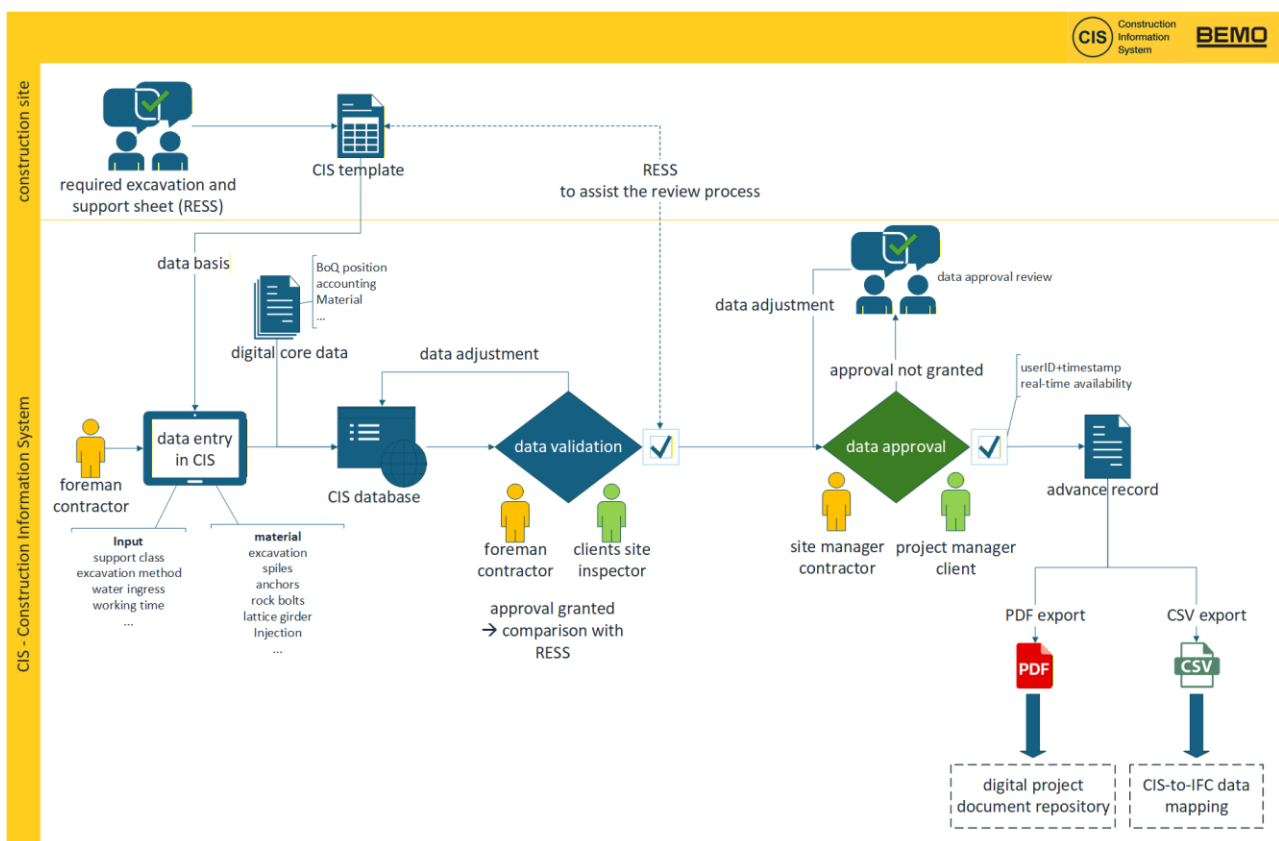


Figure 1: Workflow data capture, validation and approval

The process shown in Figure 1 illustrates data capture, validation, and approval underlying automated payment application. In tunnel construction, the process logically begins with the RESS for tunneling works. Standing at the tunnel face, the RESS can be created collaboratively between the client's representatives and the contractor via tablet. The jointly agreed parameters—such as round length, shotcrete thickness, selection of pre-support measures, and connection reinforcement—must be documented, as these data become relevant for automated payment application in subsequent steps.

In CIS, the RESS link structural elements, rounds, advance and consumption data, making them analyzable. All jointly agreed decisions already form the basis for automated, model-based payment application.

During tunneling operations, the contractor's foreman records the actually installed quantities in the so-called foreman's report. This report accesses the core data stored in CIS and enables a daily representation of executed construction activities. It includes recording of site teams and individual working hours, as well as predefined activities that can be individually and temporally assigned to personnel.

The digital cycle diagram, as the core element of the foreman's report, enables clearly organized, structural element- and station-related, and time-specific documentation of defined operational work steps.

CIS provides the familiar visualization of the cycle diagram in bar-chart form. At this stage, the major advantage of direct data input becomes evident, which can only be ensured by operational personnel. Material consumption data are attached directly to the cycle diagram by site staff, eliminating the risk of information loss associated with manual interfaces. These material consumptions generally reflect the materials previously agreed upon in the RESS with the client's representative.

The daily foreman's report also provides space to document irregularities and unforeseen events such as water ingress or stoppages, which are unavoidable in tunnel construction. The documented tunneling activities can then be compared by the client's representative with the originally planned RESS. If the foreman and the client's site inspector agree, approval can be granted by mutual consent. In the event of discrepancies and missing approvals, the relevant data cannot be exported and therefore cannot be further processed.

Data quality is achieved not only through capture, but through validation and governance. CIS supports approval workflows in which contractors, construction supervision, and/or clients jointly review and approve recorded data. Early validation by directly involved stakeholders on site increases trust in the data, accelerates downstream processes, and prevents the further processing of unapproved information that could otherwise lead to additional effort or disputes at a later stage.

All parties involved are obliged to grant approvals in a timely manner. Without approval, further processing within the system is not possible. This rule ensures the integrity of the overall system, as only approved information is further processed and made available for export within BIM processes. Particularly noteworthy is the resulting requirement for immediate clarification of discrepancies, fostering adherence to contractual procedures and ensuring traceability for both contracting parties.

Once mutual approval has been granted, a digital advance record reflecting the as-built state is automatically generated. This is provided both as a PDF for digital documentation and as a CSV export for transfer into the BIM model. The BIM model data not only reflects the actual tunneling values but also contain the contract-compliant payment application data.

2.4 MODEL-BASED PAYMENT APPLICATION

For model-based payment applications, the transformation of empirically recorded as-built values into theoretical billing quantities is crucial for many bill-of-quantities items. As part of the predefined support classes, digitally recorded materials, associated labor hour shares, billing units, and billing logics are defined. Legal allocation is ensured through the unique bill-of-quantities item of the construction contract. BIM-specific information completes the dataset at the level of the structural elements and represents the contractual framework within which billing rules, substitution rules, and conversion factors are applied.

CIS provides the necessary functions for this purpose. Materials recorded on a unit or quantity basis during execution can be replaced for payment application by model-theoretical quantities or converted using deterministic formulas. In this way, a consistent and contract-compliant billing quantity is created without impairing the simplicity of operational data capture. This approach enables systematic recording

of units identified by site personnel, such as specific quantities of construction materials, while ensuring objective, logical, traceable, and automated payment application in the BIM context.

By clearly separating operational data captured from the theoretical representation of model-based payment application, an unbiased planned-versus-actual comparison of consumption and effective controlling becomes possible.

2.5 INTEGRATION INTO THE SYSTEM LANDSCAPE

CIS ensures close integration with widely used software solutions across the construction and BIM value chain. Standardized exports enable the transfer of data into modeling, cost estimate, and common data environment (CDE) systems. This creates a consistent flow of information connecting planning, execution, and payment phases while minimizing discontinuities in media usage. This integration capability is already available and is continuously expanded through configurable interfaces.

2.6 ANALYTICAL EVALUATIONS AND REPORTS

A central objective of digital construction documentation is real-time analyzability. CIS generates automated daily construction reports that consistently combine personnel planning, activities, and equipment usage. Material reports condense consumption data by structural elements, time intervals, and activities, enabling analyses at both aggregated and detailed levels. Equipment utilization and downtime reports identify capacity bottlenecks, availability issues, and optimization potential in equipment management. Performance reports link progress indicators with cost calculation values and support internal management decisions. These evaluations are available in productive use and serve as interfaces to commercial and technical downstream processes.

2.7 CONCLUSION

CIS combines data-proximate capture, modular domain logic, and already implemented transformation mechanisms for model-based payment applications. By converting empirical as-built data into theoretical billing quantities, a payment application is created that combines efficiency, traceability, and auditability. The early involvement of the digitalization department ensures that bills of quantities and contract positions are modeled in a way that makes them digitally executable and billable. CIS thus forms the supporting foundation for an integrated, scientifically sound, and future-proof digitalization of construction execution.

Looking ahead, further coupling of CIS with external models aimed at pattern recognition and forecasting is expected. It remains essential that such models do not replace professional responsibility but rather support it. A robust digital foundation is created when data-driven methods are embedded in clearly defined roles, processes, and verification mechanisms. The architecture discussed here and the functions already developed provide the necessary basis and open further potential for standardization and scalability in construction execution.

3. IMPLEMENTATION OF THE USE CASES

3.1 MODEL CREATION

The modeling of tunneling activities is based on existing support class drawings and the bill of quantities. All geometric cross-sections and support elements are systematically captured and represented in adaptive Autodesk Revit component families. Such primary lining family, consisting of crown, temporary invert, bench, and invert, is shown in Figure 2.

These components are then placed along the three-dimensional tunnel axis at the respective stations. This is carried out automatically using a Dynamo script that reads all information relevant to model creation from an Excel file and assigns it to the model. Dynamo is a visual programming language used

as an extension of Autodesk Revit (Autodesk, Inc. (2024), enabling rule-based and automated creation and modification of BIM models.

The modeling workflow is illustrated in Figure 3. For both design and execution phases, it is ensured that all relevant adjustments can be represented in the model via parameter or geometry changes.

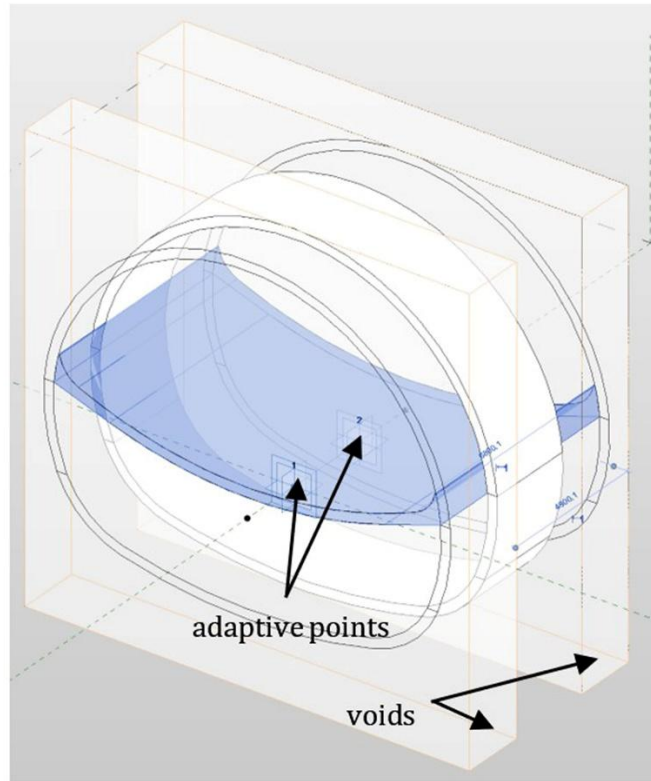


Figure 2: Adaptive Autodesk Revit family

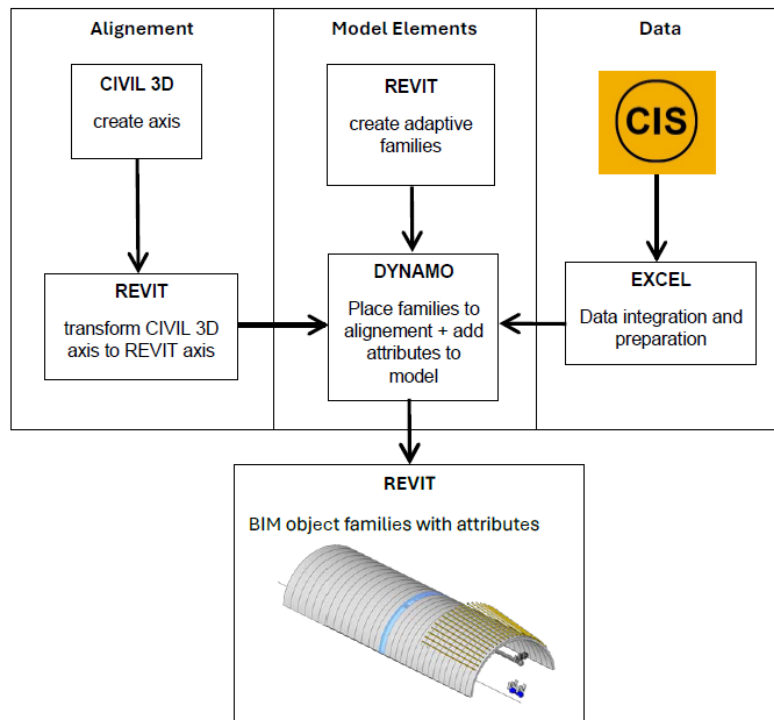


Figure 3: Workflow Modelling

3.2 USE CASE: AS-BUILT DOCUMENTATION

The input of installed support elements and materials is carried out in CIS using the cycle diagram directly on site. Each completed round generates an advance record in PDF format in real time, as well as a supplementary CSV file in which all rounds are fully documented. These files enable rapid joint review by client representatives and contractors directly on site and can be immediately confirmed in CIS. This procedure enables highly efficient coordination, ensuring that all subsequent processes benefit from verified and approved data.

3.3 USE CASE: CONSTRUCTION PROGRESS MONITORING

For this purpose, a planned, adjusted planned, and as-built model are created. The planned model is based on support class drawings, the bill of quantities, contractual advance performance, and approved execution parameters. Its objective is to create a reference for overall project planning. All cross-sectional geometries, support classes, and support elements are parametrically defined without considering actual deviations.

The actual advance duration and advance classes are represented in the as-built model. Forecasts for further work are based on planned model data adjusted to as-built dates.

The adjusted planned model is created analogously to the as-built model, with the difference that billable advance durations are represented instead of actually executed quantities and dates.

To integrate continuously adapted advance classes into the model, the model is recreated based on CIS data. Each element (i.e., each round) thus receives its construction time data, taking into account already executed or forecast construction processes.

Using DESITE MD (DESITE GmbH (2024)), these processes can be simulated and visualized. By cumulatively summing construction times, diagrams for the planned, adjusted planned, and as-built situations are generated, enabling transparent planned-versus-actual comparison and effective project controlling.

3.4 USE CASE: MODEL-BASED PAYMENT APPLICATION

Payment application is carried out using the estimating software iTWO (RIB Software GmbH 2024). The Revit model enriched with CIS data is imported into iTWO. The quantity take-off formulas required for model-based payment application in iTWO were reviewed and approved by the client prior to the first application. Services and materials not included in the bill of quantities are added subsequently. Not all bill-of-quantities items are suitable for model-based payment applications; these are recorded separately.

The Revit model contains objects that represent the tunnelling progress in dimensions. Each of these objects is enriched with semantic information containing all quantities relevant for model-based quantity determination. The quantities themselves are not derived from geometry but from CIS data linked via parameters.

These monthly generated models are appended to the existing payment model in the ongoing iTWO project, resulting in a cumulative quantity framework.

The contractor and the client's representatives work in parallel within mutually verified iTWO projects. These projects are identically structured, particularly regarding designations, keys, and project variants, ensuring a consistent and traceable verification process.

Payment application data and associated files are exchanged between contractors and client representatives via a collaborative SharePoint. As the final result of model-based payment application, the contractor provides the client's representatives with monthly quantities in the form of a priced bill of quantities. The payment status of individual objects is documented internally within the iTWO system.

3.5 USE CASE: OCCUPATIONAL SAFETY

Safety-relevant information such as escape routes, ventilation systems, and rescue facilities is captured and visualized in a model-based manner. BIM 4D simulations support risk assessment and communication with safety managers and emergency services.

For the implementation of the occupational safety use case, DESITE MD is used, based on the construction progress model. This model contains both as-built data on actual construction progress and forecasts data for future development. These time- and location-based data serve as the basis for planning and simulating occupational safety measures in tunnel construction, including ventilation ducts, fire water lines, transformer stations, rescue chambers, lighting, and emergency telephones. Objects are linked to the time-spatial construction progress model via predefined dependencies.

DESITE MD provides a simulation model that visually represents the current occupational safety situation in the tunnel. In addition, a one-month forecast of the expected safety situation is generated, based on the planned construction development up to the next reporting date.

The creation and maintenance of the model are the responsibility of the contractor. Explicit approval by the client is not required.

The simulation model is prepared monthly and presented to the client and emergency services. The objective is joint evaluation of the current occupational safety situation in the tunnel and the planned measures. The model serves as a central visual communication and planning tool.

4. CONCLUSION

The BIM pilot project Tunnel Holstein demonstrates how consistent digitalization and the development of tailored software solutions such as CIS can sustainably increase transparency, efficiency, and quality in tunnel construction. Model-based collaboration among all project stakeholders sets new benchmarks for the future of infrastructure construction.

REFERENCES

Brungsberg, T., Weißbrod, F. & Hanz, S. (2025): Praxiserfahrungen mit BIM in den unterschiedlichen Leistungsphasen im Tunnelbau. In: 61 Forschung + Praxis: STUVA-Tagung 2025, S. 404-410. Hrsg Studiengesellschaft für Tunnel und Verkehrsanlagen e. V. (STUVA), Köln (D)

Autodesk, Inc. (2024): Autodesk Revit. BIM-Software für Planung und Ausführung. Version 2024. San Francisco, USA. <https://www.autodesk.com/products/revit>

DESITE GmbH (2024): DESITE MD. Software zur 4D/5D-Simulation und Bauablaufplanung. Karlsruhe, Deutschland. <https://www.desite.com>

RIB Software GmbH (2024): iTWO. AVA- und BIM-basierte Abrechnungssoftware. Stuttgart, Deutschland.

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