Challenging Glass Conference Proceedings – Volume 10 – June 2026 – Louter, Bos & Belis (Eds.)
International Conference on the Architectural and Structural Application of Glass
Challenging Glass Conference 10 – 15-17 June 2026 – TU Delft – The Netherlands

An AAS-Based Digital Twin Framework for Load-Bearing Glass Structures under Seismic Testing

Julius Seifert [a], Nathalie Nießer [a], Geralt Siebert [a]

a University of the Bundeswehr Munich, Germany
julius.seifert@unibw.de, nathalie.niesser@unibw.de, geralt.siebert@unibw.de

Abstract

The integration of digital twin concepts into glass-intensive building structures offers new perspectives and challenges for structural validation and monitoring. This contribution presents an adaptation of the standardized Asset Administration Shell (AAS) to a full-scale experimental timber–glass building subjected to seismic excitation at the University of the Bundeswehr Munich (UniBw M). The structure features load-bearing glazing panels acting as horizontal bracing elements within a timber frame system. A hierarchical AAS-based architecture is introduced in which structurally relevant glass components are represented through semantically defined submodels capturing geometry, material properties, boundary conditions, load cases and sensor mappings. Building upon previous hybrid Digital Twin concepts for structural glass monitoring, the proposed framework establishes a structured linkage between analytical design models and experimentally recorded strain data. The prototypical implementation demonstrates how AAS-based digital asset modeling can be extended toward brittle structural components under dynamic loading, providing a foundation for component-level validation and future condition-based assessment strategies.

Keywords

Structural Health Monitoring, Load-Bearing-Glass, Asset Administration Shell (AAS), Smart Structures, Hybrid Digital Twin

Article Information

- Digital Object Identifier (DOI): 10.47982/cgc.10.777
- Published by Challenging Glass, on behalf of the author(s), at Stichting OpenAccess.
- Published as part of the peer-reviewed Challenging Glass Conference Proceedings, Volume 10, June 2026, 10.47982/cgc.10
- Editors: Christian Louter, Freek Bos & Jan Belis

1. Introduction

The digital transformation of the construction industry enables new approaches for the design, monitoring and assessment of structural systems. In structural glass engineering, sensor-based technologies allow the mechanical response of load-bearing glazing elements to be recorded under service and extreme loading conditions. This is particularly relevant for timber–glass assemblies, in which glazing panels contribute to global stiffness and horizontal stability. Recent studies on timber-glass hybrid systems have demonstrated that active glazing effectively contributes to global stiffness and lateral load resistance, including operational and seismic loading conditions (Žarnić et al., 2020).

Although high-resolution strain measurements (Haese, 2012; Neumer, 2018; Žarnić et al., 2020) and detailed BIM models are increasingly available, experimental data are rarely integrated into structured digital environments that allow traceable comparison with analytical design models. BIM typically represents geometric and semantic information of static design or as-built states, while Digital Twin concepts extend this approach by linking the physical structure with its digital counterpart and incorporating sensor data and analytical models for performance evaluation (Zhang et al., 2025).

A standardized and semantically consistent framework that systematically connects material parameters, boundary conditions and measured strain data for load-bearing glass systems is currently lacking. The Asset Administration Shell (AAS), standardized in IEC 63278, offers a modular and interoperable structure for the digital representation of assets and provides potential for bridging this gap (Treichel et al., 2025). Recent work has analyzed the Asset Administration Shell as a systematic foundation for digital twin engineering and examined its capability to fulfil common digital twin requirements across different AAS types (Treichel et al., 2025; Zhang et al., 2025).

Within a research project at the University of the Bundeswehr Munich, a full-scale timber–glass building is investigated on a seismic shake table. Load-bearing glass panels act as horizontal bracing elements and are instrumented with strain gauges and accelerometers. The objective of this paper is the development and prototypical implementation of an AAS-based hybrid Digital Twin architecture that enables traceable linkage between measured strains and structural design models, forming the basis for validation and condition-based monitoring of brittle structural systems.

2. Background – State of the Art

2.1. Digital Twins in Construction and Structural Engineering

Digital Twin concepts, originally established in manufacturing, are increasingly applied in construction and civil engineering. Recent review studies highlight the growing integration of Digital Twin technologies in structural health monitoring (SHM), particularly for damage detection, dynamic response analysis and predictive maintenance (Wang et al., 2025). The transfer of the AAS to civil engineering application has for example been achieved for bridge monitoring (Braml et al., 2022) and is currently being explored for further application in the construction industry (Wimmer and Braml, 2024).

As summarized in recent SHM-focused reviews (Wang et al., 2025), hybrid Digital Twin systems integrate sensor networks, finite element models and data-driven techniques to enhance monitoring accuracy and predictive capabilities. For brittle materials such as glass, whose structural performance is governed by local stress states and boundary conditions, this integration is particularly relevant for validating design assumptions under dynamic loading (Nießer and Siebert, 2024; Treichel et al., 2025).

While BIM provides a structured representation of geometry and semantics, it does not inherently incorporate operational response. A semantically structured framework that explicitly links structural verification models of load-bearing glass components with high-resolution experimental strain data is not yet established.

2.2. Monitoring of Load-Bearing Glass Structures and Research Gap

Experimental monitoring of laminated glass systems and hybrid timber–glass assemblies has demonstrated the feasibility of capturing stress distribution and load transfer mechanisms using high-resolution strain measurements (Neumer, 2018; Nießer and Siebert, 2024; Žarnić et al., 2020). Recent work has further introduced hybrid Digital Twin concepts for load-bearing glass façades, combining numerical sensor models with structural monitoring strategies (Nießer and Siebert, 2024, 2025a).

The Asset Administration Shell (AAS), standardized in IEC 63278-1, provides a formalized and interoperable framework for structuring asset-related information into semantically defined submodels. Although primarily developed for industrial applications, its hierarchical architecture offers potential for representing structural components, material properties, boundary conditions and sensor mappings within a unified digital environment.

To date, no approach provides a standardized AAS-based framework that explicitly integrates structural verification models of load-bearing glass panels with experimentally obtained strain data under dynamic loading. While recent studies provide analyses of AAS capabilities for hybrid digital twin engineering and bridge structures (Braml et al., 2022; Wimmer and Braml, 2024; Zhang et al., 2025), domain-specific adaptations for structural verification of load-bearing glass components remain unexplored. Addressing this gap forms the basis of the present contribution.

3. Experimental Setup

3.1. Test Facility and Dynamic Excitation

The experimental investigation is conducted on a full-scale timber–glass building mounted on a seismic shake table at the University of the Bundeswehr Munich. The structure is based on a “HUF-Haus” timber construction system and represents a residential-scale building with load-bearing glazing elements integrated into a timber frame. The load-bearing glazing panels are designed as double-glazed insulating glass units (IGU).

The test body measures approximately 7.8 m × 12.5 m with a ridge height of about 7.5 m and is supported by a steel substructure enabling controlled dynamic excitation. Unlike component-scale laboratory tests (which were also conducted in-house and by others (Žarnić et al., 2020) before construction of the facility), the setup represents a spatial structural system, allowing investigation of global load transfer mechanisms and interaction between timber frame and glazing panels under realistic boundary conditions.

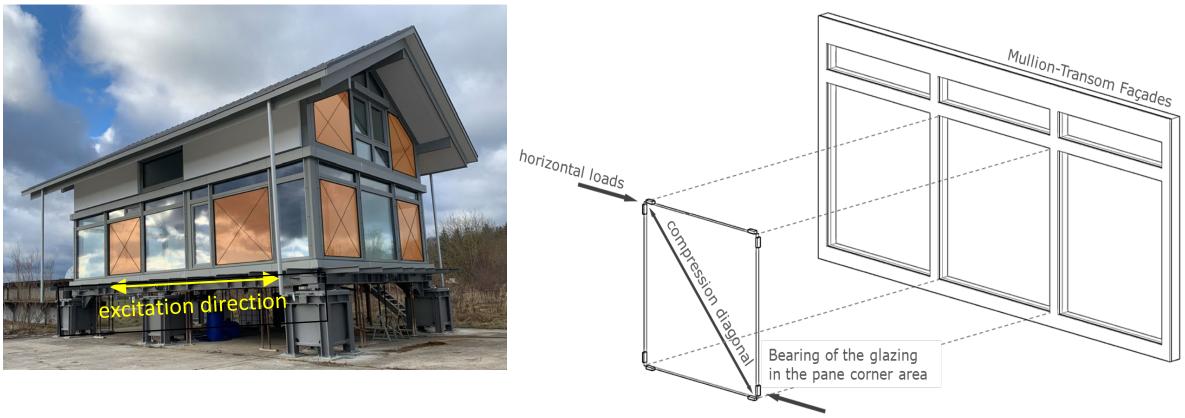


Fig. 1: Experimental setup with highlighted load-bearing glazing and main excitation direction (left) and schematic of the timber mullion-transom façade with load-bearing glazing (right).

On each façade side, two glass panels act as the only horizontal bracing elements. Horizontal excitation induces in-plane shear forces that are transferred through mechanical connectors from the timber frame into the glazing panels, which thus contribute to the global lateral stiffness of the building.

The shake table enables unidirectional excitation with a displacement amplitude of up to ±250 mm, simulating seismic-type loading scenarios under controlled laboratory conditions. The repeatability of excitation profiles permits systematic comparison between measured structural response and analytical design assumptions. While material behavior of timber, glazing and connectors has been examined in small-scale tests at UniBw M, the structural performance of the fully assembled system under dynamic loading remains the focus of the ongoing investigation.

3.2. Sensor System and Monitoring Concept

The structure is instrumented with a comprehensive sensor network capturing both structural response and environmental boundary conditions. The structural instrumentation currently includes conventional strain gauges and accelerometers; fibre-optic strain sensors are planned for future implementation and are currently subject to further investigation regarding their application in glazing systems (Nießer and Siebert, 2025b). The strain gauges are positioned on the load-bearing glass panels to record in-plane shear strains, while accelerometers capture the global dynamic response of the building during shake table excitation.

In addition, static pressure sensors are installed at the center of each load-bearing panel to measure local pressure variations. These sensors allow the direct recording of wind-induced load effects in terms of pressure changes acting on the glazing elements. Environmental monitoring further includes ambient temperature, pressure and humidity sensors in addition to localized temperature sensors to account for temperature- and pressure-dependent behavior in IGUs (Momeni et al., 2024). Lastly, wood moisture sensors are placed around the building to monitor timber boundary conditions. The selected sensor setup is displayed in Figure 2 – the presented fibre-optic sensor-layout is, as mentioned above, not yet final and still under development, thus the right image with an alternative option for fiber placement as explored in Nießer and Siebert (2025b).

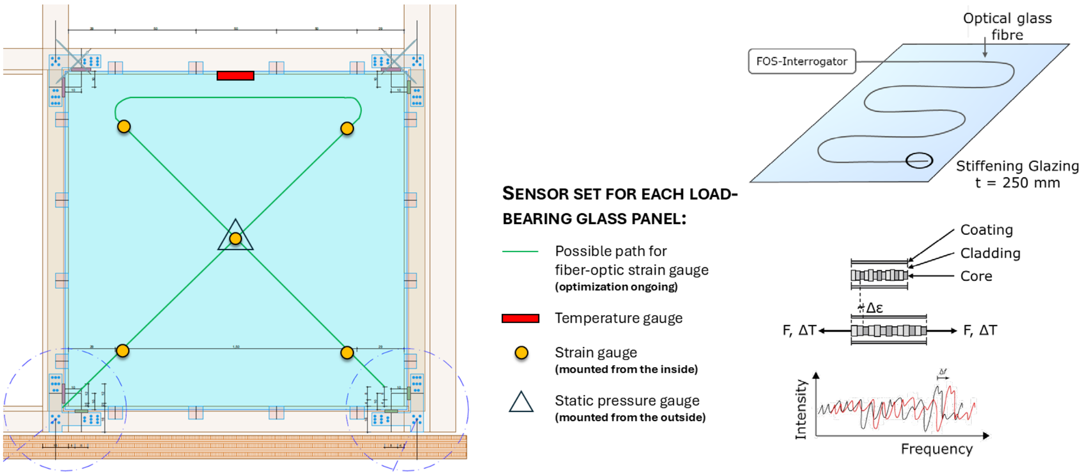


Fig. 2: Planned sensor set for each load-bearing glass panel and another possible application method of fibre-optic strain gauges as explored in (Nießer and Siebert, 2025b).

The sensor layout is defined with respect to anticipated shear load paths and connection zones between timber frame and glazing elements. By synchronizing shake table excitation data and wind pressure measurements with structural strain and acceleration data, the setup generates a high-resolution dataset linking loading conditions to component-level structural response. While the presented sensor setup primarily captures surface strains of individual panes, the integration into an AAS-based Digital Twin furthermore enables the consideration of coupled effects (like pressure-dependent displacement in IGUs) through semantic combination of sensor data for analysis.

This experimental configuration provides the physical basis for the development of a hybrid Digital Twin. While detailed BIM models and extensive measurement data are already available for the building, these datasets up until now existed in separate systems without a coherent semantic linkage between geometry, material parameters, loading states and measured structural behavior. For brittle structural materials such as glass, where peak stresses govern failure, such structured integration is essential for traceable validation and condition-based assessment. The presented test facility therefore forms the foundation for the AAS-based Digital Twin architecture introduced in the following section.

4. AAS-Architecture

4.1. Structural Decomposition and Asset Hierarchy

The development of a Digital Twin for a load-bearing timber–glass structure requires a clear structural decomposition of the physical system into digitally representable assets. In the present approach, the building is hierarchically structured according to its load-bearing components, for the purpose of this project with particular emphasis on the glazing elements acting as horizontal bracing members.

At the highest level, the complete building mounted on the shake table is defined as the primary asset. This asset is subdivided into façade segments corresponding to each building side and floor level. Within these façade segments, individual load-bearing glass panels are modeled as distinct structural assets. Each glazing panel is therefore assigned its own digital representation within the Asset Administration Shell (AAS) framework.

This hierarchical modeling strategy reflects the structural reality of the system: the global dynamic response of the building is governed by the interaction between timber frame and glazing elements, while local stress states and strain concentrations occur within individual glass panels. By assigning a dedicated instantiation to each structurally relevant glazing unit, the Digital Twin enables a component-level representation of structural behavior within a building-scale system.

The repeatable hierarchical asset structure furthermore establishes the basis for direct sensor addressing through GlobalAssetIDs, ensuring unambiguous identification of structural components and measurement points. This systematic identification is the foundation for automated strain-to-component allocation, traceable data processing and scalable evaluation strategies. It furthermore enables the display of sensor data through machine-readable means (e. g. QR-Codes) for convenient inspection.

4.2. Structural-Submodels for Load-Bearing Glass Components

Within the AAS framework, each load-bearing glass panel (itself an AAS) is described by a set of semantically structured submodels that capture its mechanical and contextual properties. The selection of submodels is driven by structural engineering requirements.

A geometry submodel defines dimensions, thickness configuration and positioning within the façade. A material submodel specifies glass type, lamination build-up and relevant mechanical parameters, including temperature-dependent properties where applicable. A boundary condition submodel represents support conditions and connection details, which are critical for the determination of stress distribution in brittle materials.

In addition, a load case submodel describes dynamic excitation parameters induced by the shake table, including displacement amplitudes and excitation direction. A sensor mapping submodel establishes the explicit relationship between measurement points and structural coordinates, allowing strain measurements to be interpreted in a mechanically consistent manner.

This structured representation transforms the glazing panel from a generic façade element into a digitally defined structural component whose behavior can be evaluated in relation to both design models and measured response.

4.3. Integration of Sensor Data and Hybrid Digital Twin Concept

The proposed architecture follows the concept of a hybrid Digital Twin, combining physics-based structural models with experimentally obtained sensor data. Hybrid Digital Twin approaches for load-bearing glass façades have previously been proposed to couple numerical sensor concepts with structural monitoring data (Nießer and Siebert, 2024). Analytical stress calculations and numerical simulations provide expected stress distributions and deformation patterns under defined loading scenarios. The sensor system delivers high-resolution strain data recorded during dynamic excitation of the structure. The present work extends this concept by embedding structurally relevant parameters within a standardized AAS architecture.

Within the AAS-based framework, measured strain values are semantically linked to the corresponding glass asset and associated load case. This linkage enables direct comparison between predicted and observed structural response. Measured strains can be converted into stress values using appropriate material models and subsequently compared with design stress assumptions or verification criteria.

The hybrid character of the Digital Twin arises from this bidirectional relationship: analytical models inform the interpretation of measured data, while experimental results provide feedback for validating and refining structural assumptions. Such a feedback loop is particularly valuable for load-bearing glass systems subjected to dynamic loading, where stiffness degradation, connector behavior and load redistribution may influence structural performance.

4.4. Digital Nameplate and Lifecycle Traceability

To ensure unambiguous identification and lifecycle traceability, each structural glass asset is equipped with a digital nameplate within the AAS. The digital nameplate contains standardized identification attributes, manufacturing information and classification data. This enables consistent referencing of individual glazing elements across design documentation, sensor systems and monitoring applications.

For structural glazing systems, lifecycle traceability is of particular importance. Glass panels may be replaced, retrofitted or subjected to changing boundary conditions during their service life. The digital nameplate ensures that sensor data and performance assessments can be consistently attributed to the correct structural component, even in the case of future modifications.

4.5. Methodological Contribution to Structural Glass Engineering

Building upon the general engineering perspective on AAS-based digital twins (Zhang et al., 2025), the present work introduces a structural template tailored to load-bearing glass components. Although implemented at a prototypical stage, the presented AAS-based architecture establishes a structured framework for integrating geometry, material properties, boundary conditions and sensor data of load-bearing glass panels within a unified Digital Twin environment.

By assigning semantically defined submodels to each glazing component, strain measurements can be explicitly mapped to structural coordinates and associated load cases. This enables traceable comparison between experimentally observed response and analytical verification models.

5. Prototypical implementation of the AAS

5.1. Instantiation of Structural Glass Assets

The previously defined structural AAS template was instantiated for selected load-bearing glass panels of the experimental timber–glass building. The implementation focused on the previously described façade elements acting as horizontal bracing components under dynamic excitation. Figure 3 illustrates the practical realization of the conceptual hierarchy and demonstrates the consistent digital representation of structurally relevant components within the overall system.

Each glazing panel was represented by an individual asset within the hierarchical asset structure introduced above. The building serves as the root asset, subdivided into façade segments and individual structural glass components. For each glass panel, the semantically defined submodels introduced in the architectural concept were instantiated and parameterized. These include geometry, material properties, boundary conditions, dynamic load cases and sensor allocation.

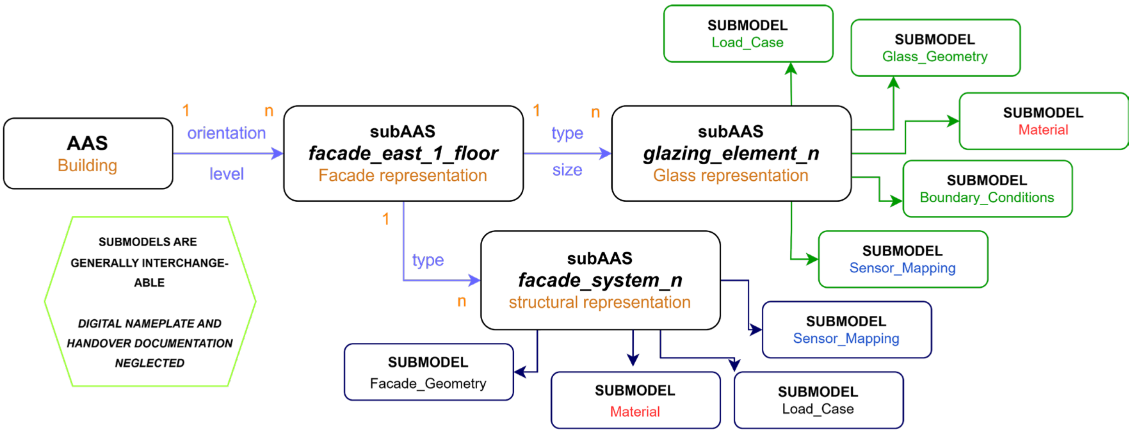


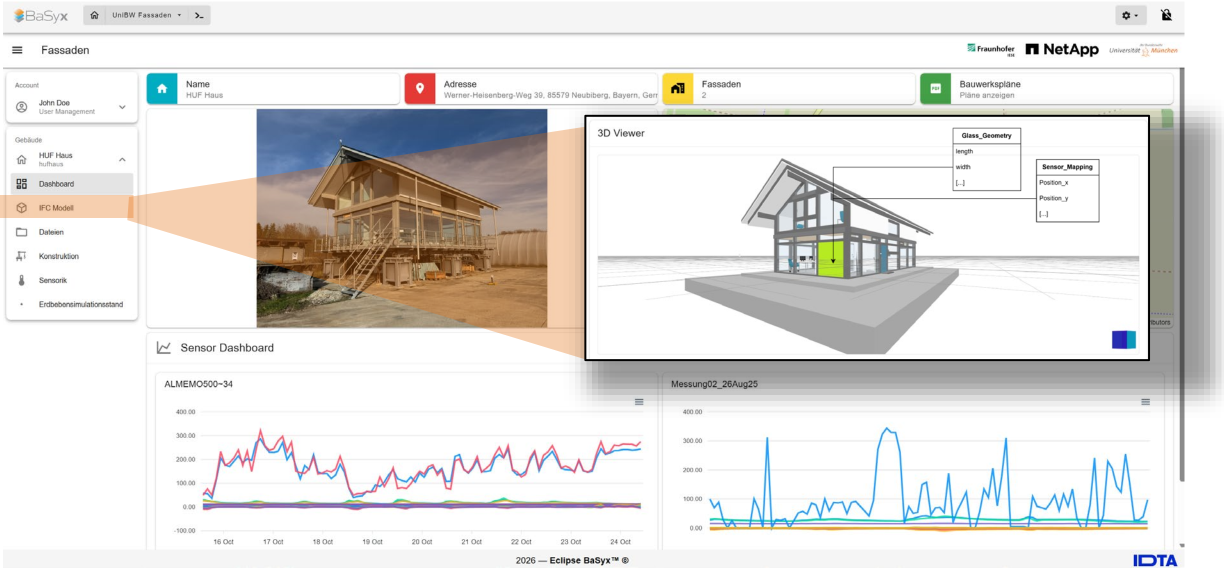
Fig. 3: The implemented AAS-template, only the relevant submodels for the load-bearing glazing are shown - colors correspond and show submodel interchangeability, light blue arrows indicate relationship/dependencies between instances.

5.2. Sensor Data Integration and Application

Based on the instantiated asset structure, the integration and evaluation of monitoring data is the next step of the Digital Twin implementation. The aim of the implemented Digital Twin demonstrator is not only the visualization of monitoring data, but its structured integration into an evaluation framework.

Measurement data from different sensor types, including strain gauges, accelerometers and environmental sensors, are mapped to their corresponding structural components through the AAS-based sensor mapping. This enables a direct assignment of measured structural response to individual load-bearing glass elements within the hierarchical asset structure.

The implemented dashboard allows simultaneous visualization of structural and environmental data and can be flexibly configured based on the underlying AAS structure. Since all assets, submodels and sensor relations are defined semantically within the AAS, relevant data streams can be combined, extended or restructured depending on the specific monitoring objective. The implemented AAS-interface is shown in Figure 4.


Name
HUF Haus

Adresse
Werner-Heisenberg-Weg 39, 85579 Neubiberg, Bayern, Ger

Fassaden
2

Bauwerkspläne
Pläne anzeigen

Fig. 4: Implemented AAS interface of the experimental timber–glass structure; the IFC-Viewer is also shown, where the respective instances can be inspected and edited.

Beyond visualization, this structured integration provides the basis for hybrid evaluation strategies in which measured data can be interpreted in relation to analytical or numerical models. For example, recorded strain values can be transformed into stress states using appropriate material models and compared with expected structural response under defined loading conditions.

This approach enables (i) validation of design assumptions, (ii) identification of deviations in structural behavior under dynamic loading, and (iii) the derivation of component-level performance indicators. In addition, the semantic linkage of different sensor types allows the consideration of coupled effects, for example in insulated glass units, by combining mechanical and environmental measurements within a unified framework.

5.3. Scope and Limitations

The present implementation demonstrates the feasibility of instantiating a structural AAS template for load-bearing glass panels within a building-scale system. However, real-time data integration, automated stress evaluation and continuous verification routines remain subjects of ongoing research. While the figures above provide an excerpt of the implemented interface, the complete hierarchical structure and interactive linkage between assets, submodels and measurement data extend beyond what can be fully conveyed in static illustrations and can therefore only be partially represented in this paper.

The established architecture nonetheless provides an interoperable and extensible foundation for future data-driven validation and condition-based monitoring of load-bearing glass systems under dynamic loading.

6. Conclusion

This paper presented the development and prototypical implementation of an AAS-based hybrid Digital Twin architecture for a load-bearing timber–glass structure subjected to seismic excitation. The focus was placed on structurally active glazing panels acting as horizontal bracing elements within a full-scale experimental setup.

Building upon recent advances in hybrid Digital Twin concepts for structural glass monitoring and general AAS-based digital twin engineering frameworks, the proposed approach extends these concepts by introducing a semantically structured asset template tailored to load-bearing glass components under dynamic loading. Unlike previous applications of the Asset Administration Shell in infrastructure contexts such as bridge monitoring, the presented architecture explicitly integrates geometry, material parameters, boundary conditions, load cases and sensor mappings required for structural verification of brittle glazing elements.

A hierarchical asset structure was defined in which individual glass panels are represented as distinct Asset Administration Shell instances with mechanically motivated submodels. This enables traceable linkage between experimentally recorded strain data and analytical design models at component level. The architecture therefore establishes a structured basis for validation, comparison of predicted and observed response, and future condition-based monitoring strategies for timber–glass systems.

Although automated sensor-data integration and real-time verification workflows are still under development, the implemented structural AAS template demonstrates the feasibility of embedding physics-based evaluation concepts within a standardized digital asset framework. The presented work therefore contributes an extension of AAS-based digital twin engineering toward brittle structural materials and dynamic loading scenarios.

Acknowledgements

This paper is supported by dtec.bw – Digitalisation and Technology Research Centre of the Bundeswehr, which we gratefully acknowledge as part of the project RISK.twin.

References

Braml, T., Wimmer, J., Varabei, Y., Maack, S., Küttenbaum, S., Kuhn, T., Reingruber, M., Gordt, A., Hamm, J., 2022. Digitaler Zwilling: Verwaltungsschale BBox als Datenablage über den Lebenszyklus einer Brücke. Bautechnik 99, 114–122. https://doi.org/10.1002/bate.202100094

Haese, A., 2012. Beitrag zur Bemessung scheibenbeanspruchter Stahl-Glas-Elemente. Universität der Bundeswehr München, Neubiberg.

Momeni, M., Bedon, C., Jordao, S., Cella, N., Lucia, P., 2024. Towards New Diagnostic Strategies and Monitoring Tools for Long-Term High-Performance Smart Facades, in: Challenging Glass 9. Presented at the Challenging Glass Conference, CGC. https://doi.org/https://doi.org/10.47982/cgc.9.587

Neumer, D., 2018. Beitrag zur Aussteifung von Gebäuden durch Glas - Konzentrierte Lasteinleitung im Eckbereich (Dissertation). Universität der Bundeswehr München, Institut für konstruktiven Ingenieurbau, Neubiberg.

Nießer, N., Siebert, G., 2025a. Integration of Digital Twins for the Preventive Monitoring of Load- Bearing Glass Facades. Presented at the IABSE Symposium, Tokyo 2025: Environmentally Friendly Technologies and Structures: Focusing on Sustainable Approaches, Tokyo, Japan, pp. 2961–2967. https://doi.org/10.2749/tokyo.2025.2961

Nießer, N., Siebert, G., 2025b. Evaluation of Real-Time Load Path Monitoring for Mullion-Transom Facades, in: Glass Performance Days Conference Proceedings. Presented at the Glass Performance Days 2025, Glass Performance Days, Tampere.

Nießer, N., Siebert, G., 2024. Design of a Numerical Sensor Concept as the Basis of a Hybrid Digital Twin for Monitoring Load-Bearing Glass Facades. Challenging Glass Conf. Proc. 9. https://doi.org/10.47982/cgc.9.519

Treichel, T., Zielstorff, A., Wimmer, J., Küttenbaum, S., Braml, T., Hamm, J., 2025. Smart Bridge Monitoring: Digital Twins and Sensor Technology Against Structural Aging. Jpn. Ger. Bridge Symp. 2025 Conf. Proc.

Wang, Q., Huang, B., Gao, Y., Jiao, C., 2025. Current Status and Prospects of Digital Twin Approaches in Structural Health Monitoring. Buildings 15, 1021. https://doi.org/10.3390/buildings15071021

Wimmer, J., Braml, T., 2024. Digital twins for engineering structures—An Industry 4.0 perspective. Struct. Concr. 25, 4202–4218. https://doi.org/10.1002/suco.202400683

Žarnić, R., Rajčić, V., Kržan, M., 2020. Response of laminated glass-CLT structural components to reverse-cyclic lateral loading. Constr. Build. Mater. 235, 117509. https://doi.org/10.1016/j.conbuildmat.2019.117509

Zhang, J., Ellwein, C., Heithoff, M., Michael, J., Wortmann, A., 2025. Digital twin and the asset administration shell: An Analysis of the Three Types of AASs and their Feasibility for Digital Twin Engineering. Softw. Syst. Model. 24, 771–793. https://doi.org/10.1007/s10270-024-01255-0

Challenging Glass Conference Proceedings – Volume 10 – June 2026 – Louter, Bos & Belis (Eds.)
International Conference on the Architectural and Structural Application of Glass
Challenging Glass Conference 10 – 15-17 June 2026 – TU Delft – The Netherlands

CGC 10

Platinum Sponsor

SAINT-GOBAIN

Gold Sponsors

EASTMAN

kuraray

NorthGlass®

sedak

seele

Silver Sponsors

Dow®

octatube

PERMASTEELISA GROUP

SEEN

Organisation

TU Delft

Technische Universität München

TUM

GHENT UNIVERSITY