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Book of Abstracts

PATHWAY TO NET ZERO: DRIVING SUSTAINABLE TRANSFORMATION FOR THE FUTURE

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Abstract

The transition to Net Zero represents one of the most significant global challenges and opportunities of our time. Achieving this goal requires a holistic approach that integrates technological innovation, sustainable practices, policy support, and collaborative action across industry, academia, government, and communities. As nations and organizations strive to reduce carbon emissions and build climate resilience, the focus is shifting toward practical pathways that balance environmental responsibility with economic growth and social well-being. This keynote explores the key drivers, challenges, and opportunities in the journey toward Net Zero, highlighting the importance of innovation, digital transformation, and workforce capability in accelerating sustainable outcomes. The presentation will also acknowledge the role of initiatives such as ARC ITTC NØBEL in fostering research, collaboration, and knowledge exchange that support the development of future-ready solutions for a low-carbon and sustainable future

INTEGRATED BIM, BLOCKCHAIN, AND MULTIMODAL DATA-DRIVEN DIGITAL TWINS FOR AEC INDUSTRY DIGITALIZATION

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Abstract

This keynote addresses recent developments in leveraging blockchain and multimodal AI for data analytics to accelerate digitalization across the Architecture, Engineering, and Construction (AEC) industry. The construction sector's transition toward Industry 5.0 increasingly depends on the integration of Blockchain and the Internet of Things (IoT) as foundational enablers of automated, value-added workflows and intelligent data acquisition systems.

Drawing on a portfolio of research projects, the talk presents multimodal data-driven digital twins developed for the management and predictive maintenance of large-scale infrastructure, alongside blockchain-based solutions for digitising financial management processes in construction projects. It further explores the combination of IoT, blockchain, and BIM to support circular supply chains within existing building stocks, and showcases an open web-based prototype that addresses critical gaps in semi-automated tools such as COBie — tested across three case studies and evaluated against IFC-to-cloud data replication via linked SQL servers.

The keynote also examines advances in deep learning for infrastructure inspection, including a comparative study of eight CNN models for highway pavement crack detection, and the application of scarce and few-shot learning to enable AI-assisted decision-making in heritage assets where data access is limited.

Together, these projects offer a holistic, portfolio-level perspective on how digital technologies are reshaping AEC practice — providing researchers and practitioners with an integrated roadmap for embarking on this rapidly evolving journey.

INTELLIGENT PLATFORM FOR SHIELD CONSTRUCTION

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Abstract

This keynote presentation introduces a comprehensive Intelligent Platform for Shield Construction, designed to address the escalating complexities of extra-long and large-diameter underground infrastructure. As geological uncertainties in composite ground become increasingly challenging, the industry must urgently transition from traditional "field-based trial and error" construction to "science-based simulation and validation".

This platform realizes this critical paradigm shift through a sophisticated integration of Multi-Agent Systems (MAS) and multi-scale Digital Twins. The system architecture utilizes autonomous agents for core processes—including geological perception, adaptive thrust allocation, and automated segment assembly—enabling decentralized, real-time collaborative control. To rigorously substantiate these AI-driven algorithms, the platform is grounded by full-scale physical experimental apparatuses that simulate shield thrusting, highly precise segment erection, and the mechanical evaluation of novel metamaterial linings.

Furthermore, the platform incorporates advanced physics-data-driven models for real-time cutterhead wear prediction and an explainable AI-based "Smart Shield Black Box" for safety risk early-warning. Large Language Models (LLM), integrated via a Model Context Protocol (MCP), further optimize dynamic construction schemes through virtual-real interaction.

Preliminary field applications across major national projects, such as the Hutong Railway Wusongkou Yangtze River Tunnel, have demonstrated profound engineering impact, notably achieving a world-record monthly advance of 868 meters. Ultimately, this MAS-based platform provides a robust, highly resilient foundation for the next generation of fully autonomous Shield TBM operations.

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PHISHING RISK ASSESSMENT IN CONSTRUCTION PROJECTS: A BAYESIAN NETWORK FRAMEWORK

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Abstract

With the advancement of Construction 4.0, the construction industry is rapidly transitioning toward digitalized, networked, and platform-based operations. Owing to its domain-specific characteristics, however, the industry is particularly vulnerable to cyber threats. The involvement of multiple project stakeholders, the prevalence of temporary organizational structures, and the tight integration of on-site and cloud-based systems collectively expose construction projects to heightened cybersecurity risks. Among these threats, phishing attacks stand out because of their low cost, high stealth, and strong reliance on human behavior. Despite their growing importance, systematic and interpretable approaches for assessing phishing risk in construction remain scarce. Existing studies are often based on simulated datasets and rely on black-box models that offer limited transparency. To address this gap, this study proposes an interpretable Bayesian network (BN) framework for phishing risk assessment in construction projects. The model is trained on empirical data from 76 projects in China and the United Arab Emirates and captures the relationships among 16 technical, organizational, and behavioral factors and the likelihood of phishing attacks. The results demonstrate that the proposed BN framework outperforms several machine learning benchmarks in predictive accuracy while also providing transparent causal explanations and supporting rapid what-if analyses. Sensitivity analysis identifies authentication strength, project network type, and the degree of multi-project team involvement as the most influential factors. When deployed as a cloud-based microservice, the framework can integrate real-time project data to dynamically update risk probabilities and generate actionable mitigation recommendations. Although the current dataset is geographically limited, the proposed approach establishes a robust foundation for scalable and interpretable cyber risk assessment and management in the context of Construction 4.0.

Keywords: *Bayesian network, construction industry, cybersecurity, machine learning, risk assessment.*

3D SUBSURFACE RECONSTRUCTION FROM SPARSE BOREHOLES WITH A MULTI-SCALE LOCAL INFERENCE FRAMEWORK

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Abstract

Constructing high-fidelity 3D geological models from sparse and unevenly distributed site investigation data, such as borehole logs, remains a fundamental challenge in geotechnical engineering. The primary objective is to reliably infer unobserved stratigraphy across widely spaced measurement points. While recent data-driven volumetric modeling approaches introduce multi-scale iterative methods to mitigate extreme data sparsity, their application is often limited by the strict requirement of regular borehole grid layouts. To overcome this limitation, this study introduces a novel query-driven, multi-scale deep learning approach tailored for 3D subsurface reconstruction from highly irregular borehole distributions. The proposed methodology employs a progressive multi-scale scheme to hierarchically capture global-to-local stratigraphic features. Crucially, instead of relying on pre-defined rigid geometric templates, the approach implements a dynamic, query-driven neighborhood sampling strategy with quadrant-coverage constraints. This allows the model to effectively handle the scattered and irregular spatial distributions commonly found in real-world site investigation data. Geospatial features are processed using a specialized architecture that integrates a point-wise depth-sequence convolutional module with multi-layer perceptrons. Validation using real-world site investigation data demonstrates that the proposed approach effectively adapts to the geometric irregularity of field data. Consequently, it generates more accurate and globally consistent 3D stratigraphic boundaries, even under highly non-uniform data constraints.

Keywords: *3D geological modelling, deep feature fusion, multi-scale reconstruction, query-driven sampling, sparse borehole data.*

MULTI-SOURCE DATA FUSION FOR BUILDING CARBON EMISSIONS CONTROL USING ONLINE OPTIMIZATION

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Abstract

Building retrofits can significantly improve total energy performance and reduce carbon emissions. However, existing operational decarbonization strategies suffer from insufficient building performance data and improper equipment control patterns. This work constructs a systematical framework for operational building performance optimization. Firstly, a detailed digital twin model integrating heating, ventilation and air conditioning, and other electrical equipment is developed to simulate the actual building operation performance. Subsequently, the Tree-based Pipeline Optimization Tool model is used to predict carbon emissions and thermal comfort time series combining the simulated data and on-site data. Finally, NSGA-II is applied to dynamically optimize heating, solar gains, and ventilation. The proposed framework has been validated in a residential building in New Zealand. The results reveal that (1) The prediction model can accurately predict building carbon emissions and thermal comforts time series with the R2 are 0.993 and 0.934, respectively; (2) Online optimization algorithm can reduce 48.82% carbon emissions and 8.56% thermal comforts during a week period. The novelty of this work lies in combining physical data and simulation data simultaneously for building performance prediction and proposing an online optimization method to optimize equipment control for the national decarbonization goal.

Keywords: *Digital twin, Low-carbon building, Carbon emissions, Online optimization, Data-physics-driven*

OPTIMIZATION OF SUBCONTRACTORS PROCUREMENT

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Abstract

Project procurement is conceptually simple but labor-intensive and time-consuming, often relying on manual data entry and subjective judgment. Previous research has shown that AI-driven analysis can provide more accurate project estimates and improved risk management for small and medium-sized enterprises. Traditional project procurement methods are inefficient, as contractors manually decompose complex Bills of Quantities to identify and approach suitable subcontractors. This study examines whether a digitalized and automated approach can significantly reduce administrative effort while improving selection accuracy. An automated Python-based workflow using AI was developed to automate key procurement steps, including categorization of work items and generation of automated inquiries to potential providers. Data for testing was obtained from the Slovenian Public Procurement Portal. For a construction project for the new Faculty of Pharmacy in Ljubljana, a comparison was made between the new prototype application and the traditional methodology. By integrating a structured database and a user-friendly interface, the system provides a digital tool for managing employees' workload in project procurement. Future developments could further enhance the system by incorporating multi-criteria decision-making algorithms to optimize subcontractor selection or by introducing time standards for setting prices.

Keywords: *automation, process optimization, project procurement.*

EVALUATION OF MULTIMODAL GENAI FOR CONSTRUCTION DOCUMENTATION AND MONITORING

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Abstract

The increasing availability of multimodal generative artificial intelligence (GenAI) tools is enabling new data-driven workflows in construction management, particularly for transforming unstructured site information into actionable insights. However, the real-world capability and reliability of these tools for routine civil engineering workflows remain insufficiently characterized. This paper presents a capabilityfocused evaluation of GenAI-assisted processing of common construction site information across three data types: textual reports, photographs, and videos. First, we examine the extent to which AI can transform unstructured inspection reports into qualitative summaries, quantitative summaries, and risklevel assessments. Second, we assess image-based performance for core construction management tasks, including construction activity identification, progress monitoring, detection of execution defects, and safety-related observations. Third, we explore video-based summarization to generate a draft daily site log that captures temporally relevant events and supports structured documentation. The contribution of this study is an empirical assessment of current GenAI capabilities, typical error patterns, and practical limitations when applied to field data. The findings indicate where GenAI outputs can meaningfully support engineers under a verification-first approach, and where human review remains essential. The paper concludes with recommendations for responsible adoption, including quality assurance practices, minimal data standards, and guidance for integrating AI-generated outputs into construction reporting and project controls.

Keywords: *multimodal generative AI (GenAI); construction documentation; site monitoring; automated reporting; human-in-the-loop (HITL)*

DEVELOPMENT OF A SMARTPHONE-BASED, NON-CONTACT PHYSICAL CONDITION DETECTION SYSTEM USING FACIAL FEATURE INFORMATION FOR CONSTRUCTION SITE SAFETY

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Abstract

On construction sites, workers often continue their tasks even when they are tired, drowsy, or not feeling physically well. These conditions are not always easy to notice from the outside, yet they can lead to unsafe behavior and serious accidents. Although different health monitoring technologies have been developed, many of them depend on wearable or vital sensors. In actual construction environments, such devices can be uncomfortable, interrupt work, and are often not used continuously. In Japan, concerns about personal data and privacy further reduce workers' willingness to wear monitoring devices, making sensor-based solutions difficult to apply in practice. This situation highlights the need for a simple, non-contact health monitoring approach that can be easily accepted on construction sites. To address this issue, we developed a smartphone camera based physical condition detection system that analyzes facial and eye information captured through a mobile application. The system observes facial color changes by analyzing selected facial points in multiple color space models and evaluates eye related indicators such as blinking behavior and eye opening to estimate tiredness and drowsiness. In addition, workers provide basic health related information through a short questionnaire. All data are collected without using any wearable devices or vital sensors. The collected facial, eye, and questionnaire data are reviewed by medical professionals, and their expert feedback is used to train an AI-based judgment model that evaluates workers' physical conditions. The proposed system was tested in several construction sites as well as in office environments. Results from these trials indicate that the system can identify signs of drowsiness, tiredness, and physical unwellness and encourage workers to reflect on their own condition. This study demonstrates that a non-intrusive, vision-based approach can serve as a practical and socially acceptable tool to support proactive safety management and health awareness in construction practice.

Keywords: *computer vision, construction safety management, facial feature analysis, sensor-free monitoring, worker fatigue detection.*

EVALUATING ML MODELS TO PREDICT TRUCK TRAVEL SPEED IN CONSTRUCTION EARTHWORK OPERATIONS

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Abstract

Earthwork operations play a critical role in construction productivity and are characterized by high variability in equipment performance, particularly truck hauling speed. Traditional planning approaches often rely on simplified assumptions that fail to reflect real operational conditions. This study takes the initial steps and presents a data-driven evaluation of multiple Machine Learning (ML) models for predicting average truck speed using real construction data. Five ML models are compared, including linear regression, decision tree, random forest regression, neural network, and logistic regression. Performance is assessed using coefficient of determination (R^2), root mean squared error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE). To improve efficiency, the Interquartile Range (IQR) method is applied to remove extreme speed values and reduce the influence of outliers. Results show that tree-based ensemble ML models, particularly random forest, consistently outperform linear ML models. While the application of IQR filtering slightly reduces R^2 values due to variance compression, it leads to substantial improvements in error measures, indicating predictions that are more reliable.

Keywords: *construction, data-driven analysis, earthwork, ML Models, truck speed.*

GEMMS: A VISION–LANGUAGE FRAMEWORK FOR AUTOMATED CONSTRUCTION SAFETY AUDITING USING 360° SITE IMAGERY

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Abstract

The efficient identification and validation of safety hazards remain a critical challenge in the construction sector, largely due to its reliance on manual human inspection. This study investigates the potential of Vision–Language Models (VLMs) to automate safety auditing through a bio-inspired cognitive architecture that emulates human reasoning. We propose GEMMS, a hybrid framework that integrates high-fidelity object segmentation using Segment Anything Model 3 with semantic reasoning powered by the instruction-tuned Gemma 3 (27B). Rather than relying on conventional end-to-end detection, GEMMS employs a programmed Auditor Protocol grounded in industry safety regulations. This protocol executes a four-stage reasoning chain: Assembly Scanning to associate disjoint objects into functional units (e.g., stand + sign + cabinet); Ghost Scanning to detect missing or negative states, such as empty mounting brackets; Context Filtering to distinguish compliant activity from negligence; and Verdict Generation for final safety assessment. The experimental design evaluates two data sources: manually labeled focal images captured by site personnel during safety inspections and passive 360-degree imagery generated from OpenSpace scans of the same site. A two-tier validation process is applied, first benchmarking model performance against ground-truth focal images and then mapping 360-degree observations to corresponding focal views to assess detection transferability. Results demonstrate that passive 360-degree captures – despite lacking explicit hazard focus – can reliably support automated safety auditing when processed through the proposed framework. These findings indicate that existing virtual site documentation can be effectively repurposed for scalable, autonomous safety monitoring, reducing reliance on manual inspection and enabling continuous safety oversight in construction environments.

Keywords: *360-degree imagery, automated safety auditing, gemma 3, segment anything model 3, vision language models.*

DIAGNOSING EARLY STAKEHOLDER INTEGRATION IN CONSTRUCTION PROJECTS: DEVELOPMENT AND VALIDATION OF THE INTEGRIA MODEL

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Abstract

Early integration of stakeholders in construction projects is widely recognized as a critical factor for improving project performance. However, despite the proliferation of collaborative delivery models, digital tools, and academic research, a persistent gap remains between theoretical knowledge and its operational application during the early design and planning phases. In particular, few structured approaches enable project teams to diagnose the actual level of early integration and collaboration before critical project decisions are made. This paper presents IntegrIA, a diagnostic model designed to assess early stakeholder integration and collaboration during the initial stages of the construction project lifecycle. The study adopts a sequential mixed methods approach, combining a systematic literature review conducted under PRISMA 2020 guidelines with exploratory interviews with industry experts. The resulting variables were consolidated into a structured matrix encompassing conditions, enablers, practices, barriers, and indicators associated with early integration. The model is implemented through an artificial intelligence supported conversational system, which provides an enabling infrastructure for contextualized and structured diagnosis. Unlike maturity models based on quantitative scoring or benchmarking, IntegrIA adopts a qualitative diagnostic approach expressed through categorical maturity levels. This design choice avoids false precision in contexts characterized by high uncertainty and limited availability of early stage data. Initial validation was conducted through the application of the model to a large public hospital project, where the diagnostic outcomes were contrasted with the assessment of a panel of experienced practitioners. The results show strong convergence in the identification of critical integration gaps and demonstrate the model's ability to make explicit coordination and collaboration issues that typically remain implicit until later project stages. This study contributes an operational diagnostic framework that translates widely discussed concepts into a practical tool for early decision making, strengthening the connection between theory and practice in construction projects.

Keywords: *artificial intelligence, early stakeholder integration, project diagnostics, construction management, collaboration.*

BRIDGING DESIGN SAFETY PLANS AND SITE INSPECTIONS THROUGH A HYBRID NLP–LLM PIPELINE FOR STRUCTURED OBSERVATION STATEMENT GENERATION

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Abstract

Construction site safety management is hindered by a disconnect between design and execution. Safety prescriptions are expressed in descriptive, non-standard natural language that automated systems cannot interpret directly. As a result, the H&S Manager must manually and subjectively convert design requirements into operational inspection checks. This non-formalised cognitive process limits the traceability, comparability, and reusability of safety information across the construction site lifecycle. To address this gap, the present study proposes a hybrid NLP- and LLM-based pipeline for the automatic transformation of design safety prescriptions into structured, computable Site-Observation Statements (SO-Ss). The SO-S is formalised as a quadruple $S=\langle\sigma,\kappa,\rho,\gamma\rangle$, derived by selective projection from a seven-vector prescriptive grammar, and realised in a fixed canonical linguistic form that ensures objectivity, legal robustness, and semantic traceability. The pipeline combines BERT-based contextual embeddings, BERTopic topic modelling, and a schema-driven LLM generation stage constrained via prompt engineering and dynamic few-shot selection. Experimental evaluation on 183 prescriptions from an Italian design safety document shows that 62% of Zero-Shot outputs and 49% of Production outputs are directly usable or require only minor corrections, with fewer than 10% necessitating complete rewriting. A systematic misalignment between algorithmic metrics and human judgement is identified and analysed, revealing the inadequacy of text-overlap metrics for evaluating advanced syntactic transformations in technical-regulatory domains. The results demonstrate the feasibility of semantic standardisation as a prerequisite for automated compliance checking and machine-readable safety documentation.

Keywords: *Site-Observsation Statement (SO-S), Semantic formalisation, Construction safety documentation, Automated compliance checking, Large Language Models (LLM), Natural Language Processing (NLP).*

A FRAMEWORK FOR STEEL STRUCTURE WELD EVALUTION: EXPLAINABLE VISION EVIDENCE ENHANCE DIAGNOSIS AND PARAMETERS OPTIMIZATION

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Abstract

At current, the continuous quality optimization of steel structure automatic welding system is inseparable from reasonable quality diagnosis, while most small-scale visual language models (VLM) for quality diagnosis have disadvantages such as poor interpretability, insufficient ability to minor defects and vulnerability to illusion due to limited visual reasoning ability caused by edge deployment constraints. To address this gap, the research addresses the following question: *How to derive actionable guidance for quality diagnosis and welding parameter optimization through a synergy of explainable visual evidence and structured logical reasoning*? A novel steel structure weld defects identification and precise quality improvement framework is proposed, conbining: (1) A swin transformer discriminator with GradCAM used to identify the defect area, weld area boundary and the cause of the defect; (2) An explainable-vision-evidence-guided prompt engineering approach to construct a quality improvement scheme utilizing a small-scale VLM. The swin transformer discriminator can obtain high-quality explainable vision evidence with 0.877 defects labels classification F1-score and 0.0853 weld area recognition BCE. Moreover, the guidance of explainable evidence increases the BERTScore of the VLM output by 18 %. This study provides an efficient quality feedback technical route for improving the operation quality of steel structure welding robots.

Keywords: *Steel structure welding, Quality diagnosis, Visual language model, Explainable evidence, Prompt engineering*

M-SOS ARCHITECTURE FOR COMPLEX METRO MEP: BOTTOM-UP MODULAR RECONSTRUCTION AND INTELLIGENT LIFECYCLE APPLICATIONS

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Abstract

Urban rail transit mechanical, electrical, and plumbing (MEP) engineering represents a highly coupled system-of-systems (SoS). However, existing building information modeling (BIM) technologies predominantly focus on spatial geometric representation, lacking system-level logical topology and semantics. This gap severely hinders the transition from traditional on-site construction to off-site modular prefabrication and intelligent lifecycle operations, which rely heavily on structured networks rather than disorganized spatial coordinates. To address this problem, this study proposes a novel Metro System-of-Systems (M-SoS) architecture. This architecture establishes a three-level system decomposition framework comprising functional Blocks, Zone-Level systems, and Complete Connected systems. Based on this framework, the methodology employs a hybrid graph topological and geometric matching algorithm to automatically reconstruct complex MEP data from the bottom up into standardized, functionally independent Blocks. Specifically, a VF2-based graph isomorphism algorithm searches for standardized Blocks within the massive, disorganized BIM network, while an oriented bounding box (OBB) technique validates spatial geometric features to ensure accurate Block extraction. This process restructures scattered components into the aforementioned rigorous hierarchy. The results demonstrate that the proposed M-SoS intelligent hub can process subway stations with over 6,000 independent MEP components, achieving an extraction accuracy exceeding 99% in near-linear time complexity. This completely eliminates the need for hundreds of manual hours previously required for Block splitting and system sorting. The implications for the future of smart construction are significant. The structured M-SoS network directly empowers intelligent modularization by automatically exporting precise processing bills of materials for prefabricated Blocks, and enables millisecond-level topological cascade tracing for electrical faults during the operational phase, thereby establishing a new foundational paradigm for metro lifecycle management.

Keywords: *BIM, graph matching, modularization, MEP, system-of-systems, urban rail transit.*

NEW COMPETENCIES IN FACILITY MANAGEMENT IN THE AGE OF ARTIFICIAL INTELLIGENCE

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Abstract

Artificial intelligence (AI) is becoming increasingly prevalent in all areas, including the real estate sector and, within that, facility management. Facility managers of the near future will have to adapt to these new trends. Various professional organizations and educational institutions have defined in detail the expertise, knowledge, and competencies that facility managers must possess. However, in the age of AI, some of these competencies are no longer necessary, while other, new competencies are required. This article provides an overview of the current competency requirements for real estate operators and then revisits the competencies expected in the (near) future in line with the penetration of AI in specific areas. The article is part of a collaboration between the Budapest University of Technology and Economics (BME) and the Hungarian National Association of Facility Managers (LEO), which was established with the aim of launching a new, state-of-the-art MSc-level university program in Facility Management with a focus on Central Europe.

Keywords: *AI, Education, FM, MsC, Real Estate*

DVI-NET: BIDIRECTIONAL CROSS-MODAL ATTENTION FOR TUNNEL SEEPAGE SEGMENTATION UNDER ASYMMETRIC DEGRADATION

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Abstract

Automated semantic segmentation of water seepage in subterranean infrastructure is critical for structural health monitoring, yet it is fundamentally challenged by severe environmental interference. Particularly in drill-and-blast construction sites, sensor data suffers from extreme asymmetric degradation: visible-light (VIS) textures are physically occluded by dense suspended dust, while infrared (IR) thermography robustly detects thermal anomalies but suffers from inherent thermal blurring at boundaries. Traditional symmetric multi-modal fusion paradigms struggle in these environments, as they passively merge features and inadvertently propagate modality-specific noise. To address this critical gap, this study proposes DVI-Net, a novel dual-stream architecture explicitly engineered for synergistic VIS-IR fusion under asymmetric degradation. The core innovation lies in the proposed Cross-Modal Attention (CMA) module, which implements a robust purify-then-query mechanism. Unlike standard cross-attention, the CMA first executes intra-modal self-attention to purify features from domain-specific artifacts, followed by a dynamic, bidirectional interaction where reliable thermal representations actively query and guide the noisy visible modality, and vice versa. Furthermore, at the macro-architectural level, DVI-Net introduces an asymmetric skip-connection strategy. By exclusively forwarding high-frequency spatial features from the visible backbone to the decoder, the network rigorously bypasses infrared spatial noise, leveraging thermal data purely for robust semantic localization at the bottleneck while preserving high-fidelity geometric boundaries. Evaluated on a bespoke, expert-annotated in-situ dataset collected from an active tunnel construction site, DVI-Net achieves an outstanding Mean Intersection over Union (mIoU) of 98.63%. These results demonstrate significant superiority over existing single-modal and symmetric fusion baselines, providing a highly reliable perception algorithm for automated defect inspection in extreme subterranean environments.

Keywords: *asymmetric degradation, cross-modal attention, infrared-visible fusion, semantic segmentation, tunnel seepage.*

EXPERT PANEL VALIDATION OF FUZZY LOGIC AND LLM FOR MODERN METHODS OF CONSTRUCTION SELECTION UNDER MULTI-STAKEHOLDER DECISION-MAKING

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Abstract

The early-stage selection of Modern Methods of Construction is a complex multi-criteria decision shaped by technical, logistical, regulatory, and organisational constraints, as well as by the differing perspectives of project stakeholders involved in design and delivery. This study evaluates and compares two AI-based decision support approaches for MMC selection, a Mamdani Fuzzy Inference System and a large language model, under collective decision-making conditions. The research examines how both approaches perform when project inputs are not defined by a single evaluator, but by heterogeneous expert panels that reflect the multidisciplinary nature of real early-stage design processes. Two theoretical construction projects of contrasting typologies were examined, including a high-rise residential building and a low-rise residential building, through structured expert panels involving 46 construction professionals. Expert assessments were analysed to examine variability in project factor scoring, convergence in recommendation patterns, and the stability of outcomes across different panel sizes. Results indicated that, despite variation in selected factors, both approaches converged on the same modal MMC recommendation for each project, while recommendation patterns remained stable across expert inputs. The findings also suggest that panels of approximately 12 to 15 participants are sufficient to obtain reliable modal recommendations in this type of collective assessment setting. Building on these results, the paper proposes a five-step collaborative methodology to support early design workflows aligned with Lean Design and Design for Manufacture and Assembly principles. The study contributes evidence on the feasibility of AI-assisted multi-stakeholder decision-making for MMC selection and highlights the potential of comparing structured rule-based reasoning and natural language model interpretation to support more transparent, consistent, and practice-oriented decision processes in construction.

Keywords: *artificial intelligence, decision support, modern methods of construction, multi-stakeholder decision-making, offsite construction.*

INNOVATIVE MODELS FOR OPTIMIZING STEEL FORMWORK WEIGHT IN CONCRETE COLUMN CONSTRUCTION: A CASE STUDY

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Abstract

This study examines the optimization of steel formwork weight for concrete columns, focusing on key decision variables: sheathing thickness, beam cross-sectional size, and beam spacing. Two optimization models were developed using a genetic algorithm. The first divides the column into equal-height sections and calculates beam spans based on the maximum lateral pressure in each section. The second allows variable beam spacing along the column height to reflect pressure variations. This research also aims to determine whether formwork should be designed to withstand full hydrostatic pressure, thereby eliminating the need for contractors on-site to adjust casting data to suit the formwork. A sensitivity analysis on the decision variables was conducted. A case study of a 5.9 m-high column (baseline formwork mass 2,890 kg) illustrates the models' benefits. In the original project, the contractor had to significantly reduce the intended one-hour casting rate because the existing formwork would have collapsed at that rate. Using the same reduced casting rate, Model 1 and Model 2 reduced formwork weight by 27% and 29%, respectively. When the formwork was designed to resist full hydrostatic pressure, allowing any casting rate, Model 1 and Model 2 achieved reductions of 17% and 22%, respectively. Sensitivity analysis indicated that sheathing thickness and beam cross-sectional area are highly influential variables. Furthermore, designing formwork to withstand full hydrostatic pressure using the developed models yields a lower weight than the traditional design with constant beam spacing, while maintaining a reasonable casting rate. Therefore, the findings support the adoption of full-pressure design in practice.

Keywords: *construction engineering, formwork design, steel formwork, optimization, genetic algorithm.*

ORIENTATION FOCUSED ENVELOPE MICRO RETROFITS AND DATA-DRIVEN CALIBRATION OF NIGHT VENTILATION IN EDUCATIONAL BUILDINGS

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Abstract

This paper presents an integrated monitoring and simulation methodology for evaluating targeted passive retrofit strategies in an existing elementary school building located in a hot-arid region of Israel. The study combines long-term environmental monitoring, empirical ventilation measurements, and calibrated building energy simulation to assess the effectiveness of orientation-sensitive envelope improvements and naturally driven night ventilation.

The proposed approach is based on two complementary passive strategies: selective envelope insulation informed by measured facade thermal asymmetry, and night ventilation schedules derived from in-situ CO_2 decay experiments. Distributed surface temperature monitoring identified significant thermal imbalance between facade orientations, with south-facing walls and the roof exhibiting substantially higher thermal exposure during peak summer conditions. These findings were used to define a targeted insulation strategy focused on the most thermally stressed envelope components rather than applying uniform insulation to the entire building envelope.

Ventilation performance was evaluated experimentally under different window-opening configurations using the CO_2 tracer decay method. The measured air-change rates exceeded standard prescriptive assumptions commonly adopted in simulation practice, demonstrating the importance of empirical ventilation characterization for accurately predicting passive cooling performance in naturally ventilated educational buildings.

All retrofit scenarios were implemented in a calibrated Design Builder model validated against monitored indoor environmental data in accordance with ASHRAE Guideline 14 criteria. Results indicate that orientation-focused insulation combined with empirically calibrated night ventilation can substantially improve indoor thermal comfort while significantly reducing seasonal cooling demand. The targeted retrofit strategy achieved performance levels comparable to more extensive uniform insulation approaches while requiring a considerably smaller intervention area, thereby improving construction efficiency and reducing retrofit scope.

The findings demonstrate that monitoring-informed micro-retrofit design and data-driven ventilation calibration provide a practical and cost-effective framework for improving energy efficiency and thermal resilience in existing school buildings under hot climatic conditions.

Keywords: *Building energy efficiency, School retrofitting, Envelope insulation, Night ventilation, Construction management.*

FRAMEWORK FOR EVALUATING THE ECONOMIC FEASIBILITY OF WIRELESS CHARGING PAVEMENT

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Abstract

Wireless charging pavement systems are emerging as an innovative approach to support the expansion of electric vehicles by providing in-motion charging without the need for stops. Despite their potential benefits, these systems face challenges related to high installation costs, uncertainty in maintenance requirements, and a lack of standardized economic evaluation methods. An organized framework is needed to guide researchers, planners, and policymakers in assessing the feasibility of such systems. This study proposes a structured framework for conducting an economic assessment of wireless charging pavement. The framework defines the key cost categories, including construction, installation, operation, and maintenance, and establishes the economic parameters required for analysis, such as discount rates, service life, and residual values. The goal is to enable consistent evaluation of the costs and benefits, facilitate comparative analysis with alternative charging strategies, and support decision-making for sustainable transportation infrastructure. The framework is designed to serve as a guideline for future research and implementation studies, ensuring that the economic dimension of wireless charging pavements is addressed alongside technical and environmental considerations...

Keywords: *electric vehicles, financial feasibility, life-cycle cost analysis, wireless charging roads.*

AUTOMATING CIRCULAR DESIGN ASSESSMENT THROUGH BIM CHECKING RULES

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Abstract

The construction industry, which accounts for about 50% of all extracted material and is responsible for over 35% of the EU's total waste generation and 36% of GHG emissions. Identified as a priority sector in the EU Circular Economy Action Plan, the construction industry has started its transition from a linear to a circular economy (CE) with the aim to reduce its environmental impact while contributing to create economic value State of the art research explores various circular design strategies that aim to narrow, slow down, and close resource loops (e.g. Design for adaptability and reversibility). The building design stage is crucial for implementing said circular design strategies by optimizing resource usage and consequently enhancing circularity scores. Several circularity assessment methodologies and frameworks exist but lack Building Information Modeling (BIM) interoperability. Furthermore, professionals are still missing the necessary tools to design and evaluate architectural concepts against existing circularity assessment methodologies. This paper proposes a BIM-based methodology that aims to provide designers with automated ways to incorporate circularity assessments aligned with the targeted strategies into their architectural projects throughout the design process. The study first analyzes the circularity metrics for buildings from the literature and then reports on the methodology for the development of BIM checking rules supporting the building circularity assessment. The results of a test of the proposed rules on a case study of a building in Luxembourg using the Solibri Model Checker are presented. Based on initial findings, limitations and gaps are identified, and a set of generalized BIM checking rules is proposed that can be integrated into existing BIM checking workflows. Ultimately, the proposed methodology seeks to automate the assessment of circularity and leverage the widespread use of BIM in the industry for a better integration of CE strategies in the built environment.

Keywords: *Building Information Modeling, Circular design strategies, Circular economy, Design process, Rule-based model checking.*

ECONOMIC ASSESSMENT OF DYNAMIC WIRELESS CHARGINGPAVEMENT SYSTEMS

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Abstract

Dynamic wireless power transfer (DWPT) enables in-motion charging of electric vehicles and has the potential to extend driving range without increasing battery capacity. However, the economic feasibility of this technology remains uncertain due to high capital costs and limited deployment experience. This study presents a structured economic assessment of DWPT infrastructure based on a discounted cash flow framework consistent with National Institute of Standards and Technology (NIST) guidelines. The analysis considers the incremental cost of roadway electrification over a 40-year period, including installation, operation and maintenance, periodic replacement, and salvage value. A representative roadway segment is evaluated on a per-kilometer basis, corresponding to infrastructure deployed in both directions of travel, to quantify lifecycle cost and examine the contribution of individual cost components. Results indicate that lifecycle cost is dominated by capital-intensive elements, particularly initial installation and system replacement, while operation and maintenance costs accumulate over time. The study also highlights the need for normalization based on energy delivery to enable meaningful comparison with conventional charging systems such as direct current fast charging (DCFC), including determination of the equivalent DWPT roadway length required to deliver a full charge. Although exploratory, the analysis establishes a baseline for future scenario analysis and supports future comparative analysis of charging infrastructure alternatives.

Keywords: *electric vehicles, financial feasibility, life-cycle cost analysis, wireless charging road*

MANAGING FLOW OF MATERIALS IN NEW BUILD - TECHNOLOGICAL OPPORTUNITIES

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Abstract

In the EU countries, companies, local authorities and citizens have become more aware of the climate mitigation value in reusing building materials, motivated also by EU legislation. The effort comes in many forms and with different targets. Here the focus is on the flow of materials in new build: Coming in, being opened and dismantled, being (partly) assembled and leaving again as waste or as recycled materials. Packaging materials such as plastic is a case in point. Voices ask for better planning and purchasing, but here the focus is how stronger sorting and organizing processes on site could transform materials viewed as waste into valuable resources. So we ask

How can sustainable sorting on site be organized and supported? And what are the technological opportunities?

A framework of understanding for a circular process of new build is developed, appreciating circularity as social, material and commercial.

As the issue is relevant across Europe and beyond, a literature and document search and review on EU activities was carried out, using Webster and Watsons thematic review method.

The findings show numerous initiatives of new ways of handling building materials in different phases of the circular, using technologies such as AI, robots and sensor, but little attention is given to technologies for structuring data. And tendencies of inventing the wheel in parallel "town by town" is apparent. Moreover, most initiatives on site and afterwards at recycling spaces. Very few initiatives appear to incorporate the issue in planning, design and purchasing. With a view to acceleration of the climate change mitigation it is suggested to further develop site and recycling activities rather, including a cost and efficiency aspect better, possibly through establishing metrics for the respective processes.

Keywords: *Circularity, EU, recycling material, site, sorting.*

BEYOND HARD HATS: REIMAGINING SAFETY IN HUMAN-ROBOT COLLABORATION FOR CONSTRUCTION THROUGH A TOE PERSPECTIVE

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Abstract

Human-robot collaboration (HRC) in construction is increasingly recognised as a promising approach to enhance productivity and safety; however, its effective implementation remains a complex socio-technical challenge. This study demonstrates that HRC safety is not determined solely by technological capabilities but is shaped by the interaction of technological, organisational, and environmental factors through Technology-Organization-Environment (TOE) framework. While advances in sensing systems and adaptive control enable safe human-robot interaction, their performance is constrained by dynamic and unstructured construction environments. Organisational factors, including workforce training, safety culture, and workflow integration, play a critical role in influencing how these technologies are adopted and trusted in practice. In addition, environmental conditions, like regulatory limitations, site complexity, and industry constraints, introduce further uncertainty and variability. The study highlights the need for integrated, context-aware frameworks and construction-specific standards to support the safe and effective deployment of HRC systems.

Keywords: *human-robot collaboration, review, safety, TOE framework, construction industry.*

STRUCTURING REGENERATIVE DATA

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Abstract

Poor interoperability costs the building industry in value creation, quality and productivity. Many tools and technical solutions are provided, yet to establish efficiency in bridgebuilding between the parties of the crosscutting building processes it is necessary to acknowledge the collaborative, organizational and societal aspects of interoperability. This diagnosis is toppled by the emergence of a need for buildings that respect planetary boundaries, regenerative buildings.

The recognition of the importance and costs of interoperability issues related to sustainability data is only just emerging. The dual transition of climate and digitalization is often portrayed as a new opportunity in construction, yet few demonstrate integrative proposal and many invent new proprietarian island solution.

This project views crosscutting data integration as a sociotechnical phenomenon. It aims to expand knowledge of data structuring and develop systematic understanding of the possibilities and challenges of future sociotechnical data structuring in regenerative building. The paper carry out a systematic literature review on data structuring, classification, and regenerative buildings, including failed national data standardization attempts. In doing so the paper adopts Science Technology and Society concepts.

Preliminary results show that where the discussion among professionals have tended to focus on features of the standards as sorting and classification tools, it is rather the importance of diversity of professional domains of data and the need for collaboration and organizational integration that comes through as important and less so new technical smartness. This even concerns commencing use of AI, which appears to fail encompassing large recurrent data structure in the built products and to over emphasize quick configuration of new ad hoc structures-

Learnings include shifting focus to bridgebuilding and interaction between domains of data with discrete structures and adopting organization and managerial ways of integration. The paper commence a journey of identifying particular leverage points I regenerative building data exchange.

Keywords: *regenerative building, data structuring, classification, collaboration, leverage points.*

DYNAMIC RESOURCE ALLOCATION METHOD FOR CIRCULAR FACILITY MANAGEMENT - MINIMIZING LCC AND ESTABLISHING OPTIMAL STOCK STRATEGY VIA CASCADING UPDATES

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Abstract

The transition to a circular economy is a pressing societal demand. In the construction and facility sectors, there is an urgent need to minimize waste and effectively utilize existing stock. However, a lack of clear criteria regarding quality assurance and economic rationality remains a barrier to implementation. Addressing this issue, this study proposes a "Cascading Update Model" to achieve dynamic optimization of facility resources within building portfolios. It systematically clarifies the economic rationality and operational conditions for this model. Specifically, this study adopts a four-stage verification process. First, using a physical model that temporarily ignores economic factors, we quantify the life-extension effect and saturation point of introducing external supply stock. This confirms the fundamental validity of resource circulation. Second, focusing on the "Value-Performance Gap"—the difference between the exponential depreciation of market value and the linear degradation of actual performance—we identify the Optimal Zone for used components. Using exhaustive simulations under practical constraints like fixed installation costs, we pinpoint where Return on Investment (ROI) is maximized, clarifying the boundary conditions for economic superiority over new procurement. Third, we extend this to a spatial allocation problem. We construct a multi-stage cascading algorithm that leverages the gradient of requirement levels across different areas. This verifies the maximization of resource utilization efficiency beyond simple component replacement. Finally, we evaluate the model's robustness using Monte Carlo simulations that incorporate equipment failure probability distributions and supply-demand uncertainty. We demonstrate that statistically significant Life Cycle Cost (LCC) reduction effects are achievable even when considering contingent risks, aiming to establish a practical dynamic optimization protocol. In conclusion, this study presents a new stock utilization theory that resolves the trade-off between environmental responsibility and economic rationality, contributing to a transformation in decision-making for sustainable building asset management.

Keywords: *Circular Economy, Facility Management, Component Reuse, Building Stock Management, Life Cycle Cost*

DESIGN AND OPTIMIZATION OF AN ADVANCED MULTIROTOR UAV SYSTEM FOR SMART MONITORING AND MAINTENANCE IN RESIDENTIAL BUILT ENVIRONMENTS

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Abstract

Efficient monitoring and maintenance of residential apartment environments remain challenging, particularly in hard-to-access zones and densely built areas. This work presents the design and performance evaluation of an advanced multirotor unmanned aerial vehicle (UAV) intended for integrated building-level applications such as environmental inspection, intrusion detection, localized sanitization, honeybee mitigation, and traffic observation within apartment premises. The study combines computational fluid dynamics (CFD), finite element analysis (FEA), and vision-based sensing to examine both aerodynamic behavior and structural response of the UAV under realistic operating conditions. A multirotor platform with a wheelbase of 0.48 m and a payload capacity of 1.5 kg is developed and analyzed. CFD simulations carried out in ANSYS Fluent are used to investigate rotor-induced airflow and spray dispersion for wind speeds between 0 and 8 m/s. The results show that a nozzle inclination of 38° at an operating height of 1.9 m improves surface coverage by 30.8%, while maintaining droplet uniformity within ±10%. The rotor downwash produces an average velocity of 6.3 m/s, which is sufficient to displace insect clusters without direct contact. Structural assessment indicates a maximum von Mises stress of 65 MPa and a deformation of 1.27 mm, yielding a safety factor of 2.7 under combined loading conditions. The onboard vision module demonstrates detection accuracies of 95.1% for human presence, 93.2% for insect activity, and 94.4% for obstacle identification. The proposed system provides a practical and scalable approach for enhancing monitoring and maintenance operations in residential buildings.

Keywords: *Multirotor UAV; Smart building monitoring; CFD spray optimization; FEA structural analysis; Facility maintenance; Vision-based detection.*

COMPARATIVE LIFE-CYCLE COST ANALYSIS OF RESIDENTIAL GREYWATER REUSE SYSTEMS UNDER URBAN UTILITY CONDITIONS

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Abstract

Greywater reuse systems have emerged as a potential strategy for reducing potable water consumption and alleviating pressure on centralized urban water infrastructure. However, the long-term economic feasibility of residential greywater systems remains uncertain due to differences in technology complexity, maintenance requirements, and utility pricing structures. This study presents a comparative life-cycle cost analysis (LCCA) of five representative residential greywater systems evaluated under a common urban utility environment using Chicago, Illinois, as the reference case. The analysis incorporates initial investment, operation and maintenance (OMR), replacement, energy, and utilityrelated costs over a 40-year analysis period following established National Institute of Standards and Technology (NIST) life-cycle costing principles. Results indicate that simple diversion-based systems achieved the lowest life-cycle costs due to reduced capital and maintenance requirements, while advanced treatment systems incurred substantially higher long-term costs because of elevated replacement and operational expenses. The findings also demonstrate that existing utility billing structures significantly influence economic performance by failing to account for reduced wastewater discharge associated with greywater reuse. The proposed framework provides a structured basis for comparing residential greywater systems and evaluating their long-term economic viability under urban utility conditions.

Keywords: *greywater reuse, life-cycle cost analysis, residential infrastructure, urban water systems, wastewater reuse.*

ECONOMIC SENSITIVITY OF HOUSEHOLD GREYWATER SYSTEMS TO KEY FINANCIAL PARAMETER VARIATIONS

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Abstract

Greywater constitutes the largest fraction of the domestic wastewater stream, presenting a significant opportunity for water reclamation in regions experiencing water scarcity. While household-scale greywater reuse systems can substantially reduce potable water consumption and associated utility expenditures, their widespread adoption is contingent upon their economic viability under uncertain operating and market conditions. This study develops and applies a quantitative framework to assess the financial performance of these systems through a comprehensive sensitivity analysis. Using a life-cycle cost analysis (LCCA) methodology, we evaluate the economic feasibility for a representative single-family residence in Chicago, IL, with commercially available treatment systems serving as reference cases. The analysis systematically quantifies the influence of variations in key input parameters, including capital installation costs, maintenance and replacement costs, dynamic water pricing, and discount rates, on critical economic performance indicators such as total life-cycle cost (LCC), net savings, savings-to-investment ratio (SIR), and adjusted internal rate of return (AIRR). The resulting framework provides a structured and robust basis for evaluating the economic attractiveness of residential greywater infrastructure. It serves as a critical decision-support tool for homeowners, engineers, and policymakers, enabling a rigorous assessment of system viability across a spectrum of plausible future scenarios and fostering the adoption of sustainable water management solutions.

Keywords: *greywater, life cycle cost analysis, sensitivity analysis, sustainability, wastewater treatment.*

DESIGNING FOR ADAPTABILITY: REGULATORY APPROACHES TO OFFICE-TO-RESIDENTIAL CONVERSION IN A CARBON-CONSTRAINED ERA

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Abstract

The structural transformation of the office market and the high carbon intensity of the construction industry together pose a new challenge for the sustainable use of the urban building stock. Due to the spread of digital technologies and hybrid work arrangements, demand for office space is declining permanently, while a significant portion of the existing building stock is difficult to convert to other uses. Based on an analysis of international literature and market data, this study highlights that the adaptability of office buildings is largely rooted in the original design decisions.

An examination of the Budapest office market confirms that conversion constraints also arise at the local level. In response, the study proposes a regulatory approach that requires, already during the design phase, an assessment of the feasibility of converting to residential use and an estimate of the associated costs.

The proposed model could contribute to the development of a more flexible, adaptable building stock, reducing the need for demolition and reconstruction, as well as the carbon footprint of the built environment.

Keywords: *Budapest, Office market, Real Estate, Residential transformation, Sustainability.*

TECHNICAL AND FINANCIAL FEASIBILITY OF SENSOR-BASED, DATA-DRIVEN DIAGNOSTICS FOR LIFE-CYCLE VALUE PRESERVATION OF HUNGARY'S PREFABRICATED BUILDING STOCK

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Abstract

The aim of this research is to examine how sensor-based, data-driven building diagnostics can be made technically and financially viable to protect the long-term value of Hungary's prefabricated building stock. We start from the premise that the most critical risks of panel buildings—such as corrosion, water leakage, and hidden joint defects—are concentrated in hard-to-access structural zones, while their economic consequences may escalate exponentially due to delayed intervention.

First, we ranked critical areas based on damage potential, detectability, and expected loss, drawing on Hungarian-language literature on panel construction failures. The analysis identified three priority areas: flat roof waterproofing defects, balcony corrosion, and joint sealing failures.

Second, we examined the underlying technical mechanisms (moisture ingress, corrosion processes, and sealing deficiencies) and developed a minimally invasive, cost-effective sensor concept applicable to all three focus areas. Investment and operating costs (CAPEX, OPEX) were determined for the proposed system.

Third, we conducted a life cycle cost analysis over a 15-year horizon, treating sensor-related costs as expenses and prevented damage as savings. To quantify avoided damage, we adapted the expected loss formula from bank credit risk analysis. Two interrelated damage scenarios—optimistic and pessimistic—were constructed to provide lower and upper loss estimates. Each damage event was priced individually, and annual avoided damage values were calculated; the average of the two scenarios provided the annual estimate.

In the next phase, deterministic NPV/IRR calculations will be complemented by a probability-based decision framework. Monte Carlo simulation will estimate building-specific damage distributions, followed by a 15-year decision tree analysis of maintenance strategies. A Bayesian Value of Information analysis will further assess how sensor data reduces decision uncertainty and quantify its financial benefit.

The ultimate goal is to develop a decision support tool for condominiums and operators, enabling predictawble, value-preserving, data-driven maintenance of Hungary's prefabricated building stock.

Keywords: *large-panel system housing, life cycle cost analisys, maintenance strategy, risk analysis, sensor-based monitoring*

RESISTANCE, RISK ASSESSMENT AND MITIGATION OF TUNNELLED SMR NPP EXPOSED TO BLAST SHOCK WAVES

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Abstract

The research analyses the vulnerability of electric power generating NuScale SMR (small modular reactor) Power Plant assumed to be built in chalk rock tunneled cavern in order to withstand blast shock waves. The dimensions and material properties of the SMR were reversed engineered, and were used for hydro-dynamic simulations (Ornai et al. 2022) of two blast scenarios (Scenario A – buried explosion of 300 KG TNT, Scenario B- buried explosion of 2400 KG TNT). Analytical empirical dynamic analyses were compared to numerical hydrodynamic simulations and were found to be similar. In order to keep the cavern's cracking threshold at Peak Particle Velocity (PPV) of 1 m/sec, the distances between the assumed deeply buried explosions and the cavern's top were set to 32m and 64m for scenarios A and B respectively.

The average mean spectral peak accelerations caused by the blast shock waves, inside the reactors building (RXB) of 5.2g for scenario A and 3.45g for Scenario B were found to be higher than the allowed High Confidence of Low Probability of Failure (HCLPF, a capacity level where there is a 95% confidence of less than 5% failure probability) of 0.88g. Thus the in-structure motions of the RXB and its systems and components incompliance with the US NRC safety goals of less than $1 \cdot 10^{-4}$/year for Core Damage (CD) and $1 \cdot 10^{-6}$/year for Large Release (LR). The RXB failure is determined due to non-compliance with the US NRC 2nd structural level demand, despite the compliance with the 3rd systems and components level demand.

To meet the safety requirements, several alternatives are available, such as improving the existing configuration of the RXB within the tunneled cavern, by separating it from the cavern side walls. Assuming that only the RXB foundation experiences the in-structure motions caused by blasts, the spectral accelerations of scenarios A and B are 0.16g 0.4g respectively, which are lower than the HCLPF of 0.88g, thus a-priori fulfilling the NRC safety demands. Another option is upgrading the RXB shock absorption within the tunneled cavern by adding appropriate base isolators and dampers, while reducing the transfer of ground motions to the structure and preventing structural damage.

The three levels of probabilistic risk assessment (PRA) of a nuclear power plant including the SMR that should be checked according to the US NRC are:

- Level 1 PRA: Models plant responses to initiating events that challenge plant operation, called accident sequences. These sequences depend on whether systems operate properly or fail, and on operator actions. Some sequences result in no damage, while others may lead to a Core Damage (CD). The frequency of each CD sequence is estimated, and the total CD

frequency is calculated, which feeds into the Level 2 PRA.

- Level 2 PRA: Focuses on the plant's response to accident sequences that lead to CD (severe accidents). It examines how containment structures respond and the amount/type of radioactive release. The risk of radioactive release is measured here and becomes the input for the Level 3 PRA.

- Level 3 PRA: Estimates the consequences of radioactive release from severe accidents, assessing short- and long-term health effects, such as injuries or diseases, from radiation exposure to the surrounding population.

Risk Mitigation: The research goals of risk mitigating the excessive in-structure motions (maximum accelerations of ~90 g) to less than the allowable acceleration of 0.88 g were achieved by using certain base isolators. Their cost ~30,000$/unit, and 324 base-isolators are required for the whole RXB BaseMat foundation, meaning a total cost of 9,720,000$. The annual maintenance costs of this installation are estimated at 5% of the establishment cost. The annual Life Cycle Costs of the dynamic mitigation system (assuming annual Rate of interest of 5%) is estimated at 1.207 M USD. Assuming a reinstatement cost of the NuScale SMR of 6-7 billion USD, this solution will not affect the economic viability of the project.

Furthermore, a deterioration model for tunneled critical infrastructures, especially SMR (small modular reactors), was developed. It connects between the physical state of the RXB and the surrounding rock and their shock wave resistance. It may serve as a basis for building a data base of Israel’s caverns and tunnels in rock, with and specific validated machine learning model. It will enable to maintain the critical infrastructures safe, robust, and resilient.

***Keywords**: Critical Infrastructures, Vulnerability Curves, Integrated Fragility Model, NPP, Power Supply, SMR, Resilience.*

ANALYTICAL PROBABILISTIC FRAMEWORK OF HV POWER TRANSMISSION LINES RESILIENCE

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Abstract

Reliable power transmission is essential for maintaining economic stability, industrial productivity, public safety, and continuity of critical infrastructures. High-voltage (HV) power transmission lines are increasingly exposed to operational disruptions resulting from equipment degradation, technical faults, environmental disturbances, maintenance limitations, and geographically distributed failures. While conventional reliability assessments typically emphasize outage frequency and restoration metrics through indicators such as the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI), comparatively limited attention has been devoted to the statistical characterization of outage consequences and their probabilistic behavior. Energy Not Supplied (ENS), which reflects both outage duration and interrupted power demand, provides a more comprehensive indicator of outage severity and transmission-network vulnerability because it captures the direct operational consequences of interruptions and their implications for continuity of power supply.

This study presents an analytical–probabilistic reliability framework for resilience assessment of a high-voltage transmission network based on historical overhead transmission-line outage records. The proposed framework integrates statistical reliability analysis, distribution fitting, exploratory data analysis, regression modeling, and extreme-event characterization to investigate the probabilistic structure of outage consequences and identify the principal operational drivers governing ENS severity. The study is based on 44,528 historical outage records collected from the Israeli HV overhead transmission network for the period 2010–2020, complemented by annual outage data spanning 2017–2022, including information regarding outage duration, interrupted power, spatial location, and fault causes.

A structured methodological framework was developed to support resilience-oriented reliability assessment. The research method included data preprocessing, statistical exploration, feature characterization, probabilistic distribution fitting, and multiple linear regression analysis. Exploratory data analysis (EDA) was carried out to investigate variable relationships, identify distributional characteristics, and reveal patterns associated with outage severity. Descriptive statistics, histograms, correlation heatmaps, scatterplot analyses, and categorical distributions were used to evaluate operational variables associated with ENS. Particular emphasis was placed on identifying statistical irregularities such as skewness, outliers, long-tailed distributions, heteroskedasticity, and potential multicollinearity effects, which frequently challenge conventional reliability modeling assumptions.

The statistical analysis revealed that ENS exhibits pronounced heavy-tailed behavior characterized by strong right skewness and extreme outlier dominance. Most outage events correspond to relatively low ENS values, whereas a small number of severe interruptions contribute disproportionately to cumulative system consequences. This behavior suggests that

outage severity in transmission systems is governed not by gradual deterioration alone, but rather by rare, high-impact events capable of dominating overall reliability risk. Such findings are consistent with cascading-failure dynamics reported in complex infrastructure systems, where infrequent disruptions may propagate through interconnected networks and result in disproportionate socioeconomic consequences.

To quantify the statistical behavior of ENS, probability density estimation, cumulative distribution function (CDF) analysis, complementary cumulative distribution function (CCDF) analysis, and extreme-value modeling were employed. Several probability distributions were evaluated to characterize outage severity and tail behavior, including conventional statistical distributions and composite tail representations. Among the candidate models, a Composite Lognormal–Generalized Pareto Distribution (Lognormal–GPD) framework provided the most suitable representation of ENS behavior by capturing both the central outage population and the extreme-event tail. This probabilistic representation enables more realistic characterization of severe outages and improves understanding of the mechanisms governing rare but catastrophic interruption events.

A multiple linear regression framework was further implemented to quantify the influence of operational and geographic factors on ENS severity. Independent variables included outage duration, interrupted power intensity, fault causes, district-level spatial variability, and temporal effects. Results indicate that outage cumulative duration is the dominant physical driver of ENS, highlighting restoration time as a primary determinant of outage severity. Interrupted power was found to significantly amplify outage consequences but exhibited comparatively lower explanatory influence than restoration duration. Furthermore, fault-cause analysis revealed that technical and maintenance-related failures constitute the dominant share of interruptions, suggesting that infrastructure condition and maintenance strategies may exert greater influence on system reliability than environmental hazards in the analyzed network. Spatial and temporal interactions also revealed evidence of regional variability and correlated reliability changes across districts.

The findings demonstrate that ENS cannot be adequately described using traditional average reliability indicators alone because rare extreme outages dominate system consequences and distort central tendency measures. Consequently, resilience-oriented transmission planning should explicitly account for heavy-tailed outage behavior, uncertainty, and the probabilistic nature of severe service interruptions. The proposed framework contributes to reliability engineering by integrating outage statistics, probabilistic modeling, and operational interpretation into a unified resilience assessment methodology capable of identifying vulnerability drivers and supporting continuity-oriented decision-making.

Beyond statistical characterization, this work establishes a methodological foundation for future artificial intelligence (AI)-based forecasting applications aimed at early identification of abnormal outage escalation patterns and prediction of severe interruption scenarios. By combining probabilistic reliability analysis with predictive modeling, the proposed research direction may support proactive maintenance prioritization, resilience-informed operational planning, and enhanced preparedness against rare, high-consequence transmission failures.

Keywords: *Energy Not Supplied (ENS); Extreme Events; Overhead Transmission Line; Reliability; Resilience.*

TRANSFORMING DEGRADED AREAS INTO FLOOD CONTROL FACILITIES: THE SHKHORET QUARRY CASE STUDY

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Abstract

Critical Infrastructure (CI) in desert regions is increasingly vulnerable to flood damage as climate change intensifies the frequency and magnitude of sudden, extreme flood events. This case study examines the design, planning, and implementation of a flood-control and landscape rehabilitation project in the Shkhoret Stream, located in the hyper-arid Arava Valley in southern Israel. Although rainfall in this region is rare, extreme storm events generate destructive flash floods that pose substantial risks to infrastructure, public safety, and downstream urban systems.

The objective of this case study is to document the transformation of an abandoned quarry situated within an active riverbed into a functional flood-control facility that both mitigates flood hazards and rehabilitates a degraded desert landscape. The project repurposes abandoned mining pits from the former Shkhoret Quarry into an integrated flood-control system covering approximately 270,000 square meters. Two regulating reservoirs, with a combined storage capacity of approximately 450,000 cubic meters, were constructed to attenuate flood peaks, reduce downstream discharge rates, and suspend flood-wave propagation. This suspension enables early warning of flood hazards for downstream critical facilities near the entrance barrier to the regional center of Eilat. An additional benefit of the system is groundwater recharge, as captured floodwater infiltrates through the reservoirs and contributes to replenishing the local aquifer.

The system is supported by a concrete conveyance canal and overflow slides, as well as surface treatments using locally sourced granite to reduce flow velocity and dissipate hydraulic energy. Extensive earthworks were undertaken to restore the site in accordance with a comprehensive landscape architectural plan, ensuring integration with the surrounding desert environment.

The project was carried out in 2020, and observations from 2021 to 2025 indicate a significant reduction in downstream flood risk and enhanced resilience of critical infrastructure, including energy, water, and transportation systems. This case study demonstrates how engineering-led adaptive reuse of disturbed industrial sites can provide robust, cost-effective, and environmentally responsive flood-control solutions in hyper-arid regions facing increasing climate-driven hydrological extreme events.

Keywords: *Case Study, Critical Infrastructure, Extreme Events, Flood-Control, Landscape Rehabilitation.*

HEALTH-RESPONSIVE SMART FLOORING: INTEGRATING LOW-VOLTAGE HEATING AND PRESSURE SENSING FOR RETROFIT SAFETY AND COMFORT

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Abstract

This paper presents the design and integration of an adaptive smart flooring system that combines low-voltage radiant heating with pressure-sensitive sensing to enhance energy efficiency, occupant comfort, and safety in residential retrofits. Operating on a 12–24 V DC bus, the system connects directly to solar or battery microgrids, minimising conversion losses and supporting off-grid operation. The flooring incorporates zonal radiant heating to maintain stable comfort while reducing peak loads, aligning with established principles of low-temperature radiant systems. Embedded piezoelectric sensors detect presence, inactivity, or impact events, enabling privacy-preserving fall detection without cameras or wearable devices. A smart control hub coordinates predictive heating responses and automated safety alerts. Developed through a design-science methodology, the study synthesises validated thermal, biomechanical, and energy parameters to define a framework for simulation and future prototyping. By unifying energy management and health monitoring within a single retrofit-ready layer, adaptive smart flooring offers a pathway toward health-responsive, energy-adaptive homes that support safe and dignified ageing in place.

Keywords: Smart flooring; Low-voltage radiant heating; Energy efficiency; Occupant safety; Health-responsive design; DC microgrids; Ambient assisted living; Retrofit technologies.

FROM FIELD SURVEYS TO STRUCTURAL SIMULATIONS: AN INTEGRATED METHODOLOGY FOR CULVERT LIFECYCLE OPTIMIZATION

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Abstract

This research aims to establish an integrated framework for culvert maintenance optimization through empirical deterioration evaluation and numerical simulations. Since culverts represent highly vulnerable components of roadway infrastructure, the study intends to advance lifecycle management and inform better decision-making in maintenance planning.

Field inspections provided the data required to calibrate a deterioration model, with an exponential decay trend identified as the best fit ($R^2 = 0.94$). Culvert performance evolution was described using a transition probability matrix. A local–global simulation framework was performed to capture the processes of structural degradation, including critical bending moments, peak shear forces, and load combinations of live, dead, soil, and water loads. Finite-Discrete Element Method (FDEM) analysis results were employed to determine the level of stress caused by corrosion, which resulted in the formation of cracks over time.

The originality of this research lies in combining local-to-global numerical simulations with empirical deterioration models to improve culvert maintenance. This research work advances culvert maintenance by using empirical models of deterioration.

Keywords: *Optimal Maintenance Strategy, Roadway Drainage Structures, Infrastructure Management, Corrosion Progress, Crack Propagation, FDEM, Local-Global approach.*

IFC2MATERIAL - BRIDGING IFC SEMANTICS AND MATERIAL DATABASES: AN AI-BASED MATERIAL MATCHING APPROACH

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Abstract

The inconsistent and highly abstract naming of materials and material layers in BIM and IFC models still poses a key methodological challenge for advanced calculations such as life cycle assessment, material flow analysis, or material building passports. In practice, generic material categories such as “concrete”, “insulation” or “wood” dominate, without a clear assignment to specific material definitions, products, characteristic values or standardised datasets. These material designations are also highly context-dependent and are used differently depending on particular discipline standards, project environments or national regulations, which leads to high semantic variance and significantly hinders the automated and consistent processing of IFC data. At the same time, material-based evaluations have so far relied largely on manual interpretation and expert judgement. This article presents IFC2Material, an AI-based, automated material matching process that captures material-generic IFC designations and systematically links them to material databases. The aim is to connect generic material specifications with clearly assessable reference materials and associated characteristic values, thereby establishing a methodologically robust interface between IFC semantics and database-compatible material entries. The workflow is based on a two-stage, constraint-supported matching process in which material designations are first assigned to parent reference classes via keyword identification and subsequently mapped to suitable reference materials (child level) using AI-proposed constraints. This enables the derivation of concrete material products or representative reference values with associated performance indicators from abstract IFC specifications. The applicability of the approach was demonstrated using material ecoindicator databases as an example, on the basis of which a life cycle assessment was conducted following the methodology of the Austrian Institute for Healthy and Ecological Building. A workshop with domain experts was conducted to validate and refine the AI-derived constraints of the material matching process. A systematic comparison with fully expert-based matching is defined as future work. The workflow thus forms a robust foundation for the automated coupling of IFC models with material-based assessment methods.

Keywords: *AI-based material matching, IFC semantics, BIM data enrichment, constraint-based matching, life cycle assessment (LCA).*

DEVELOPMENT OPTIONS OF ROBOTIC END-EFFECTORS REGARDING SOME REQUIREMENTS OF THE ROBOT-ORIENTED DESIGN IN THE CASE OF CONSTRUCTION WITH SMALL BLOCKS

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Abstract

Robot-based technologies are increasingly applied across various fields of the construction industry. The set of traditional construction technologies is continually being supplemented by a growing number of new technologies, such as robotic concrete prefabrication, robotic welding, robotic-arm-based processing of carved-stone architectural decoration elements, robotic façade construction, robotic bricklaying, and additive construction technologies, such as 3D concrete printing. Initially, the basic set of end-effectors was developed in other industries and adopted by the construction industry; later, some types were developed specifically for construction applications. However, in both cases, the end-effector systems should be optimized according to the principles of Robot-Oriented Design. It means that the design of the end-effectors, the shaping of the construction elements, and the application of the sensor systems should be developed together, taking into account the characteristics of the robotic environment and considering the possible options of modularity. In this paper, an overview of existing end-effector solutions of small construction block-based technologies and an analysis of possible directions for future development are presented.

Keywords: *small construction blocks, robotic end-effectors, robotic bricklaying technology, robot-oriented design.*

WORKFLOW FOR ESTIMATING CONCRETE VOLUME DURING PLACEMENT USING IPAD LIDAR POINT CLOUDS

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Abstract

In concrete construction at building sites, the required quantity of concrete is calculated in advance by construction managers, and orders are placed with concrete plants. Particularly during the final stage of concrete placement, accurately determining the remaining volume to be placed is critical. Currently, this quantity is estimated on site by construction managers using tape measures. However, this approach leads to material shortages or over-ordering, resulting in increased material costs, environmental burdens, overtime labor, and quality degradation.

Conventionally, accurately calculating the remaining volume of concrete has been challenging. Quantities estimated in advance from design drawings inherently contain errors and cannot adequately reflect the as-built condition of the construction. Moreover, performing calculations that account for the complex shape of already placed concrete is difficult. Furthermore, the calculated results depend on the experience of individual construction managers, causing variability in estimated quantities.

To address these issues, this study proposes a quantity estimation method based on point cloud data. Using this method, quantities that directly reflect the shape of existing concrete can be calculated based on consistent Gili LIFSHITZ computational logic, enabling stable and reproducible results. However, point cloud data acquired by LiDAR scanning of concrete placement areas include elements unnecessary for quantity calculation, such as reinforcing bars, workers, pipes, and temporary structures, making the accurate identification of relevant point clouds challenging. Therefore, this study aims to develop point cloud extraction and processing methods to address this issue. Furthermore, a point cloud–based method suitable for estimating the remaining volume of concrete during placement is proposed. Finally, the capability of the proposed system and its on-site validation are discussed.

Keywords: *Point Cloud Data, LiDAR Scanning, Volume Estimation, Construction Management, Concrete Placement*

RESEARCH ON LIFTING OPERATION METHODS FOR TOWER CRANE ROBOTS BASED ON MULTI-MODAL DATA REPRESENTATION AND FUSION ANALYSIS

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Abstract

With the in-depth development of new-type building industrialization, tower cranes, as core equipment for vertical transportation, are increasingly widely used, significantly enhancing operational efficiency and construction safety. However, in complex construction environments characterized by multi-modality, dynamism, and uncertainty, collaborative operations between personnel and tower crane robots still face numerous challenges. These primarily include high uncertainty in the working environment, limited intelligence of the equipment itself, bottlenecks in collaboration efficiency, and safety risks that are difficult to fully eliminate. To address these issues, this study constructs a multi-source perception and unified spatiotemporal representation system for complex construction scenarios. By integrating multi-modal data such as BIM models, LiDAR point clouds, visual images, and wireless sensor networks, a high-precision environmental modeling and real-time data acquisition system is developed. This system achieves accurate identification and dynamic modeling of construction scenes, lifting targets, tower crane robot poses, and dynamic obstacles. Building on this, a multi-modal state unified representation method suitable for tower crane robot operations is proposed, creating a semantically rich dynamic high-precision map. This provides a unified and reliable data foundation and spatiotemporal perception framework for intelligent collaborative control and real-time safety warnings.

Keywords: *Tower Crane Robot; Multi-modal Data; Representation and Fusion Analysis; Lifting Operation Methodology;High-Precision Environmental Modeling.*

DESIGN FOR MANUFACTURE, ASSEMBLY, AND IMPROVED PRODUCTIVITY IN BRIDGE CONSTRUCTION

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Abstract

Design for Manufacture and Assembly (DfMA) has been proven in the manufacturing industry as a method of improving productivity by integrating knowledge of downstream processes with design. Productivity in the construction industry is poor, and literature promotes DfMA as a route to achieving productivity gains through increased off-site manufacture and reduced on-site activity. However, there is an apparent divergence between the construction industry's perception of DfMA as a prefabrication concept and the manufacturing industry's application of DfMA as a systematic design optimisation process. Prefabrication is only one of several capabilities of DfMA, yet the literature remains skewed towards this focus. Designers have substantial influence over the application of DfMA during the design stage, but their perceptions and current practice do not realise this. Using a case-study approach based on a portfolio of 19 bridge design projects, a qualitative study was conducted. Semi-structured interviews with 14 participants and thematic analysis identified key themes relating to prefabrication, design optimisation, collaboration, and 3D modelling. Five primary themes were identified: (1) DfMA is perceived as a prefabrication concept, (2) designers are already applying the principles of DfMA, (3) designers strive for design optimisation based on experience, (4) behaviours are key for collaborative relationships, and (5) 3D modelling is helpful when the project team is allowed to use it to suit their needs.The findings of the study suggest the term DfMA is misleading, and 'Integrated Design for Optimised Construction' is proposed. Improved site experience and clearer client intentions for BIM are required to avoid a skills gap and maximise benefits.

Keywords:*, bridge design, design for manufacture, prefabrication, productivity, semi-structured interviews.*

MULTIMODAL FEEDBACK FOR TAKEOVERS IN AUTOMATED TOWER CRANE TELEOPERATION: AN FNIRS INVESTIGATION

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Abstract

In automated tower crane teleoperation, relying solely on visual Takeover Requests could lead to cognitive bottlenecks and performance delays. To address this, this study evaluates the effectiveness of supplementary auditory and haptic cues by analyzing behavioral performance, subjective workload, and functional near-infrared spectroscopy (fNIRS) data across four modalities (Visual, Visual-Auditory, Visual-Haptic, and Visual-Auditory-Haptic). The results demonstrate that multimodal configurations significantly enhance operational performance and subjective experience compared to the single modal visual feedback. Specifically, fNIRS data reveals that incorporating haptic cues reduces occipital activation, while moderation analysis confirms that multimodal feedback effectively decouples objective visual processing demands from subjective cognitive overload. These findings provide a practical system design reference to mitigate teleoperator fatigue and enhance operational safety, supporting the advancement of reliable tower crane teleoperation automation in the construction industry.

Keywords: *functional near-infrared spectroscopy, takeover, teleoperation, tower crane, multimodal feedback.*

WEAVING OF CONTINUOUS EXTREMELY MODULAR TRUSS-Z STRUCTURES

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Abstract

For millennia, traditional weaving techniques have served as the foundation for semi-rigid structures that derive stability from tendon tension or inter-fiber friction, while allowing for controlled deformation (as exemplified by nomadic tents or historical curragh boat hulls). Although textiles served for load-bearing roles since antiquity, the final two decades of the 20th century brought fully rigid woven constructions capable of sustaining loads without geometric alteration. A pivotal achievement in this domain is the development of three-dimensional (3D) textiles, which, when integrated with a matrix, form rigid structural composites.

From a structural perspective, solutions based on 'wire weaving' (matrix-free) are of particular interest: crimped meshes, rigid architectural panels, 3D welded trusses, and Wire-Woven Bulk Kagome (WBK) trusses.

Truss-Z is an innovative Extremely Modular System (developed in 2010), composed of a single hybrid truss-frame unit (and its mirror image), which enables the creation of ramps of arbitrary shapes and constant inclination. This paper presents a concept for the reduced-scale manufacturing of a continuous Truss-Z structure utilizing weaving technology.

Keywords: *matrix-free weaving, truss fabrication, wire bending, welding.*

MONOCULAR RGB-BASED WORK-AREA RECOGNITION AND CAMERA POSE ESTIMATION FOR AUTOMATED FIREPROOFING SPRAY

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Abstract

Fireproofing spray in construction sites is essential for ensuring the fire safety of steel structures; however, the need for robot-based automation has been increasing due to various hazards such as dust, chemical exposure, and high-elevation work. For autonomous robotic fireproofing, it is fundamental to accurately identify the work area and estimate the camera pose of the robot. However, prior studies on work-area recognition and camera pose estimation often rely on RGB-D sensors, which, compared to RGB cameras, increase hardware cost and require additional depth-processing steps such as point-cloud generation and planar segmentation. This can limit applicability in construction sites where real-time operation is important for schedule control. To address these limitations, this study proposes a monocular RGB method that combines multiple deep learning models and computer vision techniques to extract precise boundaries of steel structures. Using these boundaries, the method jointly segments the work area and estimates the camera pose. Experimental results show that the proposed method achieves a mean Intersection over Union of approximately 0.95 for work-area recognition and an average camera pose estimation error of about 5%, indicating performance comparable to an RGB-D-based approach. These findings confirm that work-area recognition and camera pose estimation at a level suitable for field deployment can be achieved using only a monocular RGB image without a depth sensor.

Keywords: *fireproofing robot, monocular RGB, work area recognition, camera pose estimation*

SIMULATION-BASED OPTIMIZATION OF SPRAY STRATEGY FOR FIREPROOFING SPRAY ROBOTS

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Abstract

The fireproofing spray process often exhibits non-uniform thickness due to variations in workers' skills and changing site conditions, which can lead to regions below the target thickness or excessive deposition. In addition, fireproofing work is categorized as a high-risk operation because it involves work at height and exposure to heavy dust. Although robotic fireproofing has been studied to mitigate these quality and safety issues, methods for quantitatively assessing how spray toolpaths and process settings affect thickness distribution and uniformity from a robotic operation perspective remain limited. This study proposes a simulation method that generates a thickness map by modeling spray distribution and accumulating overlapped deposition along a robot spray toolpath. Thickness quality is evaluated using metrics including the under-coverage ratio, thickness uniformity, and the over-coverage ratio, and including a localized build-up effect that can occur near direction changes due to deceleration. Using the proposed simulation, we identify an optimal spray strategy on a planar target surface by optimizing toolpath and process settings to balance work time with thickness-quality metrics. The proposed framework provides a simulation-based evaluation basis for selecting spray toolpaths and examining key process settings, including path spacing, standoff distance, and nozzle half-angle, for robotic fireproofing.

Keywords: *fireproofing spray robot, spray deposition modeling.*

PERT-BETA DISTRIBUTION REVISITED

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Abstract

The PERT method traditionally models project activity durations using the PERT-beta distribution, whose key parameters (mean and standard deviation) are derived from three-point estimates (optimistic, most likely, and pessimistic durations). Although this assumption has been the subject of considerable criticism, neither the theoretical validity nor the inadequacy of the PERT-beta distribution has been convincingly demonstrated.

This study presents, to the best of our knowledge, a novel approach to determining the probability distribution of activity durations. We assume that the actual completion time is shaped by multiple uncertainty factors acting simultaneously relative to a neutral baseline state, and that the combined effect of these factors determines the resulting distribution of activity durations. The joint impact of the uncertainty factors on activity durations is modeled using Monte Carlo simulation, and the resulting empirical distribution is subsequently fitted to several theoretical probability distributions.

The results indicate that, among the distributions examined, the PERT-beta distribution provides the poorest fit to the empirical distribution generated by the Monte Carlo simulation, whereas the inverse Gaussian distribution provides the best fit. These findings fundamentally challenge the widely accepted assumption that activity durations can be adequately represented by the PERT-beta distribution.

The results open several avenues for further research, including extending the model to incorporate one-time risk events, deriving the actual distribution analytically, and investigating how the use of distributions that more accurately approximate the true distribution affects the distribution of overall project completion time compared with calculations based on the original PERT-beta distribution.

***Keywords**: PERT, criticism of Beta distribution, analytical approach, invers Gaussian distribution*

SIMULATION-DRIVEN SCHEDULING AND OPTIMIZATION OF VERTICAL MATERIAL TRANSPORTATION IN HIGH-RISE CONSTRUCTION

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Abstract:

Vertical material transportation is a critical factor influencing the construction progress and operational stability of high-rise buildings. Existing transportation plans are often based on experience, lacking quantitative evaluation and comparison in advance. Inefficient transportation schemes can lead to delays, congestion, and decreased efficiency. To address this challenge, this paper presents a simulation-based decision support system for vertical material transportation. The system formalizes the key components and standard operational units of the transportation process, clarifying resource allocation, task logic, and performance metrics. It integrates discrete-event simulation with agent-based modeling to develop a flexible model capable of representing different organizational arrangements. The model enables the prediction and scenario analysis of key performance indicators, including transportation efficiency, waiting time, and resource utilization. Building on this foundation, a genetic algorithm is employed to explore and optimize critical parameters, such as resource input levels and scheduling rules, allowing quantitative comparison and selection of alternative transportation strategies. A case study of secondary-structure concrete transportation in a high-rise building is conducted to validate the proposed approach. The results demonstrate that the model can effectively reproduce the spatiotemporal patterns and key performance characteristics of the transportation process, while identifying potential bottlenecks. When combined with heuristic optimization, the system enables automated exploration and selection of alternative resource configurations. The proposed approach provides a data-driven decision paradigm for scheduling optimization and project control in complex transportation, supporting the transition of construction on-site logistics management from experience-based configuration to quantitative decision-making.

Keywords*: high-rise construction; vertical material transportation; on-site logistics scheduling; hybrid simulation; multi-objective optimization; intelligent decision support*

A BIM-BASED FRAMEWORK FOR ASSESSING CIRCULARITY IN BUILDINGS

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Abstract

The construction industry is among the largest consumers of raw materials and generators of waste worldwide, making the transition toward a circular economy a critical challenge. Although numerous circularity indicators for buildings have been proposed in the literature, their practical application remains limited due to fragmented data structures, insufficient standardization, and weak integration with digital design environments. Building Information Modeling (BIM), as a data-centric representation of buildings, offers a promising foundation for translating circular economy principles into measurable design parameters across the building life cycle.

This paper proposes a conceptual and methodological BIM-based framework for assessing building circularity by explicitly linking circularity indicators to BIM information structures. Based on a structured review of existing circular economy metrics and BIM-enabled sustainability approaches, key indicators are identified and categorized according to material reuse potential, recyclability, demountability, and life cycle performance. The framework defines indicator-specific BIM data requirements, clarifies the required level of information development, and introduces a step-by-step assessment logic that can be embedded within early design and planning workflows.

The proposed framework positions BIM as a unified decision-support platform for circularity evaluation and discusses current implementation barriers, including data availability, model granularity, and interoperability limitations. By focusing on data-driven indicator mapping rather than project-specific or numerical quantification, the study bridges the gap between theoretical circular economy concepts and their operationalization in building design practice. Furthermore, the proposed framework establishes a robust foundation for future research on automated and AI-supported circularity assessment and design optimization.

Keywords: *building information modeling (bim), circular economy, circularity indicators, decision-support framework, life cycle thinking.*

DELIVERABLE-DRIVEN AGILE MANAGEMENT ENHANCED BY 4D CHRONOGRAPHICAL SPATIOTEMPORAL MODELING FOR CONSTRUCTION PROJECT CONTROL

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Abstract

Traditional construction project management, reliant on activity-based tools like MS Project, often lacks flexibility in handling site uncertainties, leading to inefficiencies. This paper proposes a paradigm shift to deliverable-driven agile management, integrated with the Last Planner System (LPS), Lean Construction, Earned Value Management (EVM), and 4D chronographical spatiotemporal modeling. By focusing on milestones, work packages, and visual spatiotemporal representations, the approach enhances agility, reduces waste, and optimizes resource and space utilization. A hybrid optimization combining graphical, procedural, and algorithmic techniques prioritizes critical spaces over paths, ensuring linear production and site occupancy. Case studies demonstrate improved coordination, performance evaluation, and project outcomes for building projects.

Keywords: *Agile management, Construction, Chronographical modeling, Spatiotemporal planning, 4D BIM, Lean Construction, Scheduling.*

IMPACT OF BASALT DUST ON THE FRESH AND MECHANICAL PROPERTIES OF ULTRA-HIGH-PERFORMANCE CONCRETE

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Abstract

Ultra-high-performance concrete (UHPC) is recognized for its exceptional mechanical strength and durability, yet its production demands large cement quantities that contribute to significant carbon dioxide emissions. This study investigates the potential of basalt dust, a quarry by-product, as a partial cement replacement in UHPC mixtures. Two replacement levels, 10% and 20% by weight of cement, were evaluated against a control mixture. Workability was assessed using slump flow, while compressive strength was measured at 7 and 28 days. Results showed a progressive reduction in slump flow from 92 cm in the control to 87 cm and 82 cm in the 10% and 20% mixtures, respectively, with all values remaining above the self-consolidating UHPC threshold. Compressive strength testing indicated that the 10% replacement slightly outperformed the control, reaching 120 MPa at 7 days and 153 MPa at 28 days compared with 116 MPa and 152 MPa for the control. The 20% replacement achieved 115 MPa at 7 days and 137 MPa at 28 days, representing a moderate reduction that remained within the UHPC range. These findings confirm that basalt dust can be incorporated as a sustainable supplementary material in UHPC production without compromising essential performance, while supporting cement reduction and waste valorization.

Keywords: *Concrete; Basalt Dust; Ultra High Compressive Strength; Sustainability; Waste Material*

EVALUATING RED MUD AS A SUSTAINABLE PARTIAL CEMENT REPLACEMENT IN ULTRA-HIGH-PERFORMANCE CONCRETE

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Abstract

The environmental burden of Portland cement production has intensified the search for sustainable alternatives in advanced concretes. Red mud (RM), a byproduct of alumina refining, presents potential as a partial cement replacement due to its fine particle size and latent reactivity. This study evaluates the compressive strength of Ultra-High-Performance Concrete (UHPC) incorporating RM at 10% and 20% replacement levels. Compressive strength tests were conducted at 7 and 28 days to assess both early and standard age performance. Results show that UHPC with 10% RM demonstrated comparable strength to the control mix, while 20% replacement maintained high strength with only minimal reduction relative to the control. These findings suggest that RM can be used to replace a significant portion of cement in UHPC without compromising structural performance. The study underscores RM's potential as a sustainable binder for high performance concretes, offering both environmental and material efficiency benefits..

Keywords: *Concrete; Red Mud; Ultra-High-Performance Concrete; Sustainability; Waste Material*

THE BIM COST DISEASE: RETHINKING PRODUCTIVITY IN CONSTRUCTION

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Extended Abstract

The observation that productivity in construction stagnates while other industries improve has been frequently cited. For more than two decades, Building Information Modelling (BIM) has been presented as the technological lever capable of closing construction's productivity gap with manufacturing. Yet aggregate statistics remain stubborn: productivity growth in construction has been flat in most OECD economies, while manufacturing and other tradable sectors have recorded sustained gains (McKinsey Global Institute 2017; OECD 2023). This persistent divergence is commonly described as a "construction productivity paradox" (e.g., Murray 2015; McKinsey Global Institute 2017).

The paper argues that this framing is incomplete. The paradox is not primarily technological, nor uniquely construction-specific. It is structural. The stagnation of productivity in construction is better understood as the combined effect of (1) Baumol's cost disease and (2) the sector's incomplete industrialization. BIM does not fail; it operates within macroeconomic and institutional constraints that prevent its benefits from translating into measurable total factor productivity (TFP) growth.

The construction and BIM communities have paid limited attention to what is known in economics as Baumol's (1967) theory of unbalanced growth. In sectors where labor input per unit of output cannot be dramatically reduced - due to heterogeneity, site specificity, safety requirements, and coordination complexity - wages nonetheless rise in line with economy-wide productivity gains. Prices increase, but real output per labor hour does not. Because TFP strips out price effects and measures real output relative to inputs (Solow 1957), rising costs without proportional quantity increases manifest as stagnant or even declining productivity. Construction exhibits many characteristics of such a sector: project-based production, one-off outputs, local regulation, and limited repetition. In this macroeconomic sense, weak productivity growth is not anomalous—it is expected.

At the same time, empirical studies consistently document project-level benefits of BIM: reductions in rework and change orders, improved clash detection, enhanced coordination, and greater schedule predictability (Sacks et al. 2010; Bryde, Broquetas, and Volm 2013; Barlish and Sullivan 2012). These gains are real. Yet they rarely translate into aggregate productivity growth. The explanation lies in the structure of measurement, rising labor costs, and in the absorption of efficiency gains elsewhere in the system.

The second mechanism is organizational rather than macroeconomic. Digitalization in construction has not resulted in the industrialization of construction. BIM enhances information flows within projects, but productivity growth requires complementary structural changes: capital deepening, standardization, prefabrication, integrated project delivery, and stable learning environments. Without these complements that are consistent with the broader IT productivity literature (Brynjolfsson and Hitt 1998; Brynjolfsson, Rock, and Syverson 2017)

digital tools act as informational overlays on a fundamentally craft-based production system. Where industrialization is advanced - such as in off-site manufacturing, modular construction, and highly standardized infrastructure segments - productivity growth is observable (McKinsey Global Institute 2017). These are not counterexamples to the paradox but confirmations of the theory: digitalization increases productivity only when embedded in industrial logic.

We therefore propose the concept of the “BIM cost disease.” The term captures a structural condition in which digitalization improves coordination and reduces friction but fails to alter the labor-capital ratio or outputs sufficiently to overcome Baumol effect. The absence of measurable productivity growth does not imply technological failure; it reflects the interaction between macroeconomic cost structures, institutional incentives, and measurement conventions.

This reframing carries implications for both research and policy. First, evaluating BIM solely through aggregate productivity statistics risks misdiagnosing the problem. Second, productivity restoration requires systemic transformation - procurement reform, contractual integration, lifecycle-based metrics, and capital investment in industrialized production - not merely software adoption. Third, scholars should explicitly connect construction management research with macroeconomic growth theory rather than treating the productivity puzzle as sector-specific.

In short, construction suffers from a structural condition in which digital tools alone cannot escape the gravitational pull of cost disease. Productivity growth in construction will emerge not from BIM adoption per se, but from its integration into an industrialized production regime.

The future should bring about not increments to Construction 4.0 but “Construction X.0”, inspired by high-learning-rate engineering firms such as X, SpaceX and Tesla. We should examine whether first-principles engineering, vertical integration, and a shift toward industrialized production, all this coupled with reorganized decision rights and lifecycle feedback loops, can convert digitalization from mere informational gain into measurable productivity growth.

Keywords: *Construction productivity; BIM; productivity paradox; Baumol’s cost disease; total factor productivity; industrialization; digitalization; project-based production*

A CODIFIABILITY FRAMEWORK FOR SMART-CONTRACT MILESTONE PAYMENTS IN CONSTRUCTION PROJECTS

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Abstract

This paper introduces a codifiability framework to scope smart-contract milestone payments in construction projects. Rather than proposing another payment architecture, the study addresses a prior question: which milestone payment clauses can be encoded as deterministic, auditable rules, and which must remain human-governed due to judgement, change, or off-chain evidence. We conduct a systematic mapping of research on blockchain-enabled payments, construction contract administration, and BIM-enabled progress verification to extract recurring requirements, failure modes, and oracle-related constraints. The resulting framework has two components. First, a codifiability rubric scores payment clauses along five dimensions: measurability, verifiability of evidence, oracle reliability, sensitivity to variations, and reversibility safeguards (retention, correction, clawback). Second, a reference workflow specifies minimal governance for automated release of funds, combining multi-party approval, explicit review windows, and a dispute-pause state that suspends execution while preserving an immutable audit trail and escalation path. The framework is examined through scenario-based walkthroughs covering routine certification, partial completion, defects within the defects liability period, and scope changes, and through a traceability matrix linking literature-derived requirements to framework elements. The paper provides researchers and practitioners with a decision-support basis to design realistic levels of automation for milestone payments, reduce administrative friction, and target future work on empirical validation, legal alignment, and interoperable oracle integrations.

Keywords: *bim, blockchain, codifiability, construction contracts, smart contracts.*

IMPLEMENTATION OF CONSTRUCTION 5.0: CHALLENGES AND OPPORTUNITIES IN THE CONSTRUCTION INDUSTRY

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Abstract

Technological progress has driven the construction industry toward a new paradigm associated with Construction 5.0, which seeks to integrate technological development with the principles of human-centricity, resilience, sustainability, and ethics. Although this approach has gained increasing visibility in recent years, its effective implementation across the sector still faces significant challenges. In this context, this paper analyzes the state of the art of Construction 5.0 and identifies the main barriers to its implementation reported in the international literature, while also examining their relevance to the Chilean context. Methodologically, the study was conducted as a structured literature review based on an adapted PRISMA principles (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The analysis revealed that, despite the existence of technologies, approaches, and strategies aligned with the principles of Construction 5.0, their widespread adoption remains limited. At the international level, the main barriers identified are related to human capital, technological affordability and economic factors, regulatory frameworks, and organizational culture. In the Chilean case, additional context-specific challenges were identified, particularly those associated with the quality of training and skills, as well as operational barriers, together with several of the limitations already reported in the international literature. The findings suggest that the transition toward Construction 5.0 depends not only on technological progress, but also on an ecosystem that combines training, regulation, investment, organizational culture, and strategies adapted to the local context. Consequently, its implementation requires coordinated efforts among academic institutions, companies, governments, and workers to support the effective adoption of Construction 5.0 principles.

Keywords: *human-centric construction, implementation barriers, local adaptation, resilience in construction, technological affordability.*

STRUCTURING BIM INFORMATION FOR UNIT-PRICE CONTRACTS: CONCEPTUAL FOUNDATIONS AND RISKS

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Abstract

Building Information Modeling (BIM) has become an essential enabler of digital transformation in the construction industry, offering opportunities for improved data integration, collaboration, and lifecycle management. However, while BIM methodologies have been effectively employed within the context of lump-sum contracts, their application in unit-price contractual frameworks poses significant challenges. The principal difficulty arises from the conceptual and structural gap between BIM models—organized according to spatial, functional, and design logic—and the Bill of Quantities (BoQ), which is structured according to standardized measurement rules and contractual cost breakdowns.

This paper introduces a conceptual framework for transforming BIM-derived data into a BoQ structure that supports the requirements of unit-price contracts. It examines the information hierarchy, classification standards, and data semantics necessary to achieve consistency, traceability, and contractual reliability. Additionally, the research outlines potential risks associated with this transformation process, including information loss, model misinterpretation, and discrepancies between digital and contractual representations. The proposed framework establishes theoretical foundations for integrating BIM data within cost management processes, contributing to more transparent and digitally aligned procurement strategies.

Keywords: *bill of quantities (boq), building information modeling (bim), digital construction, information modeling, unit-price contracts.*

TOTAL COST OF OWNERSHIP ANALYSIS OF AUTONOMOUS AND CONVENTIONAL DUMPERS: DECOUPLING PRODUCTIVITY AND COST

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Abstract

Autonomous construction equipment is expected to improve productivity and mitigate labor shortages, yet its economic viability remains largely uncertain due to fundamental shifts in cost structures from labor-intensive operating costs toward capital-intensive investment and ownership costs. This raises a key question for construction management: Does lower productivity at the project level necessarily imply inferior economic performance over the useful life of the equipment? This paper addresses this question by applying a Total Cost of Ownership (TCO) perspective to an autonomous dumper in earth-moving operations. A prior evaluation using a Robot Evaluation Framework developed by Stanford showed a 20% increase in cycle time for the autonomous dumper under identical boundary conditions. Building on a structured TCO framework, we analyze ownership and operating costs over a four-year lifecycle, extending the prior project-based productivity comparison to a lifecycle-oriented economic assessment. This analysis is complemented by an output-oriented assessment based on the total volume of material moved. The results reveal a clear shift in cost structure, with ownership costs approximately 21% higher but operating costs approximately 36% lower for the autonomous system, primarily due to reduced labor requirements. This shift results in an overall TCO of approximately €409k compared to €592k for the conventional alternative, corresponding to a 31% cost reduction. When normalized by total moved material volume, the autonomous system achieves a lifecycle cost of approximately 9.5 €/m³ compared with 10.3 €/m³ for the conventional alternative, a ~7.8% reduction. The findings demonstrate that economic performance and operational productivity are not necessarily aligned and highlight the importance of lifecycle-based, output-oriented cost assessment. Applying TCO-based evaluations rather than project-level productivity assessments fundamentally changes how economic performance is assessed and represents a key lever for the adoption of autonomous construction equipment by making economic benefits transparent.

Keywords: *autonomous construction equipment, total cost of ownership, construction robotics, lifecycle cost analysis*

GOVERNANCE-BASED SAFETY RISK RECOGNITION FOR CUSTOMER ENERGY RESOURCES DEPLOYMENT IN NEW SOUTH WALES, AUSTRALIA

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Abstract

The large-scale deployment of Customer Energy Resources (CER) in New South Wales (NSW) is exposing limits in traditional electricity safety governance. Although CER supports energy transition and consumer participation, it also creates new safety challenges that do not fit well within traditional electricity governance built around centralised generation and one-way power flows. This paper examines CER deployment in NSW as a governance-based safety problem. Using a qualitative case study and document analysis, the study maps the governance landscape across device compliance, installation practice, and network and system integration, and then applies domain-based safety analysis and systematic risk recognition to identify key vulnerabilities. The results show that CER safety in NSW is governed through a dense but segmented institutional environment. Device safety is organised around standards, testing and product recognition; installation safety is organised around licensing, accreditation, connection rules and reporting; and network and system integration is increasingly organised around digital identity, data exchange, visibility and operational coordination. The main finding is that safety risk arises not only within each domain, but also at the interfaces between them, particularly where accountability is fragmented, visibility is incomplete, and formal compliance does not fully guarantee safe operational behaviour. The paper contributes a governance-based framework for recognising CER safety risks and clarifying where stronger coordination is needed to support safer large-scale CER deployment.

Keywords: *Customer energy resources, energy governance, network and system integration, safety risk recognition, system coordination.*

METHODOLOGY FOR ACCIDENT PREVENTION OF SCAFFOLDINGS USING AI EXPERT SYSTEM

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Abstract

The objective of this research is to develop a framework for enhancing construction safety performance of scaffolding, particularly Tube and Coupler Scaffolding. The proposed methodology integrates data from the pre-construction and construction stages using technologies such as the YOLO computer vision framework for real-time identification and detection of scaffolding components, and the Python Darts Library for analyzing displacement and force measurements. A monitoring application is also proposed to provide safety status of scaffoldings to site officials.

Key milestones in this research include the proposal of an "Overall Safety Score" measurement, sensor-based scaffolding monitoring, risk detection using machine learning, and the detection of scaffolding components using computer vision. The research highlights the benefits of an expert system that integrates computer vision, physical measurements, and data from the Building Information Modeling (BIM) for control of scaffoldings works safety.

The proposed methodology combines AI modules with human knowledge to improve safety. The findings of this research can benefit the construction industry, particularly in working with temporary structures and scaffolding. The dedicated application for control of scaffoldings safety can detect new risks and facilitate communication between the site foreman, scaffolding builders, and construction engineers.

Ultimately, this research highlights the distinct benefits of utilizing an expert system that integrates computer vision, physical measurements, and BIM data to manage and control works on temporary structures. While implementing these state-of-the-art AI modules is crucial, the methodology recognizes that a robust safety culture also plays a vital role in ensuring site safety. By combining an Integrated Comprehensive Safety Score with human knowledge both before and during construction, this framework offers advantages that could extend to other areas of the construction industry.

Consequently, this research offers a valuable contribution to the construction industry, providing a scalable framework to mitigate scaffolding critical site hazards and enhance life-safety outcomes.

Keywords*: Artificial Intelligence, Computer Vision, Construction Safety, Scaffolding, TensorFlow Framework, YOLO Framework.*

MAPPING DATA EXCHANGE AND SKILLS FOR CONSTRUCTION 4.0: A SYSTEMATIC REVIEW TO OVERCOME ON-SITE IMPLEMENTATION BARRIERS

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Abstract

Construction 4.0 has advanced the Architecture, Engineering, and Construction (AEC) industry by integrating a range of technologies and concepts designed to improve productivity, safety management, and cost efficiency. However, despite growing awareness among project stakeholders, the full potential of Construction 4.0 remains largely unrealized, especially during the construction phase. A significant barrier to effective implementation is the knowledge gap, which is evident in the shortage of relevant operational skills. This gap is exacerbated by a lack of skilled labor and insufficient understanding of the data and information flows required by Construction 4.0 drivers during both construction and design phases. This review paper examines the limitations in the utilization of Construction 4.0 drivers, with particular emphasis on the input and output data necessary for construction workers to enable the effective integration of each driver within the Construction 4.0 framework. The methodology involves a comprehensive review of articles indexed in the Web of Science and Scopus databases. Through synthesis of the existing literature, the paper clarifies the input and output data required for successful implementation of Construction 4.0 drivers during the construction phase and identifies the corresponding worker skills needed for each driver. The findings indicate that effective data exchange between management and workers, primarily through Building Information Modeling (BIM), is essential for successful implementation. BIM models at the 400 Level of Development (LOD) serve as data extraction sources that require tailored interpretation for workers, while achieving LOD 500 involves data collection by workers and subsequent integration into the BIM model by management. The process has not yet achieved a high level of automation, but the results demonstrate the synergistic benefits of employing additional Construction 4.0 drivers, supporting the transition of traditional construction workers to Construction Workers 4.0.

KEYWORDS: CONSTRUCTION 4.0, DRIVERS, WORKERS, WORKFORCE SHORTAGE, DATA EXCHANGE.AN ANALYTICAL EMPIRICAL MODEL AND ROOT CAUSE ANALYSIS AND MITIGATION OF CONSTRUCTION ACCIDENTS

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Abstract

Construction work remains one of the most hazardous industries in Israel, with accidents leading to severe injuries, fatalities, and long-term disabilities. This study investigates the root causes of construction accidents by systematically identifying and prioritizing the factors that most strongly contribute to severe outcomes. The analysis is based on a national dataset of 716 documented construction accidents that occurred between 2017 and 2019. These data were examined to characterize direct accident causes, hazardous workstations, unsafe site conditions, fall-related incidents, and contextual variables such as worker age and day of the week. In parallel, a structured questionnaire was distributed to construction professionals to capture industry perceptions regarding dominant accident causes and effective prevention strategies.

The Pareto principle was applied to focus the analysis on high-impact contributors across three dimensions: accident causes, accident locations, and unsafe work conditions. Results indicate that five accident categories account for the most severe and fatal injuries: falls from height, being struck by falling or moving objects, excavation collapses, structural failures, and electrocution. The most hazardous workstations were identified as scaffolds, roofs, open pits, shafts, and ladders. A detailed examination of fall incidents revealed that the vast majority were associated with absent or inadequate safety measures, particularly missing guardrails and insufficient fall protection systems.

Based on these findings, the study proposes a worker-centered visual safety training and inspection model to avoid exposure to critical hazards. The model integrates Pareto-based risk priority setting into daily visual self-inspections, enabling early hazard detection and digital reporting at the site level. By translating empirical accident data into workstation-specific visual checklists and prioritized safety actions, the proposed framework operationalizes existing safety requirements and stimulates proactive worker participation. Although further field validation is required, the model offers a data-driven approach for improving construction safety management and targeting resources toward the most consequential risks.

Keywords: *Construction Safety, Fall from the Height, Fatal Accidents, Preventive Activities.*

MODELING THE ESCALATION POTENTIAL OF NEAR-MISS INCIDENTS INTO WORKPLACE ACCIDENTS IN THE CONSTRUCTION INDUSTRY USING MACHINE LEARNING

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Abstract

This study proposes an interpretable machine learning system for identifying events with a high potential for escalation in the construction sector, based on historical data on near misses and workplace accidents. The research problem concerns the early prevention of workplace accidents by identifying near-miss events that, despite lacking injurious consequences, exhibit a feature structure similar to events that resulted in injury at the workplace. The aim of the research is to support proactive occupational safety management through model-based assessment of the escalation near misses based on historical data.

Classification models were trained on a dataset of events recorded between 2015 and 2023, encompassing information on causes and organizational, technical, and human factors. Three complementary models were developed and compared: logistic regression, a linear Support Vector Machine model, and a decision tree model, designed to identify events with a heightened potential for escalation. The training process employed an approach that accounted for the asymmetry of classification error costs and validation procedures ensuring the separation of the training, decision threshold selection, and final evaluation stages. The results confirmed the high discriminatory power of the models, with ROC AUC and PR AUC values exceeding 0.8 and sensitivity above 80% for the accident class. Simultaneously, the model maintained high specificity for the class of potentially hazardous events, exceeding 80%.

A significant result of the study is the possibility of quantitatively assessing the escalation potential of events and the model-based interpretation of factors contributing to the escalation of near misses into workplace accidents. The decision tree model also allows for the formulation of clear decision rules, which facilitates the practical application of the results in proactive occupational safety management systems in the construction industry.

Keywords: *occupational safety, construction, classification models, machine learning, near-miss events.*

COPING STRATEGIES FOR MANAGING JOB STRESS AMONG OFFICE-BASED CONSTRUCTION PROFESSIONALS IN THE UNITED STATES

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Abstract

Due to the fragmented and time-sensitive nature of construction operations, office-based construction professionals must manage demanding psychosocial work conditions. Despite this reality, very little is known about how they manage job stress in day-to-day practice, specifically, US-based construction professionals. This study investigates coping strategies used by home-office construction professionals in the U.S. Southeast and examines whether coping patterns differ across estimating/preconstruction, virtual design and construction (VDC), project management, and executive roles. The objectives include investigating: (1) which coping strategies are reported for managing job stress; (2) how coping patterns vary by role; (3) how self-reported coping compares with coping behaviors respondents observe among coworkers; and (4) whether coping patterns show notable differences across demographic strata. Using a structured Qualtrics survey informed by practitioner input and prior research, respondents: (1) selected all coping activities they personally use and those they observe among coworkers, (2) identified their single most common and most helpful coping activity, and (3) reported how often they engage in each with open-ended options provided to gather more detailed insight. After data-quality screening, an analytic sample of approximately 141 respondents was retained. Analyses will present ranked coping profiles overall and by role using within-role percentages, contrast “most common” versus “most helpful” choices and their frequencies to distinguish routine from occasional coping, and summarize self vs coworker gaps that may reflect workplace norms or stigma. To keep inference defensible and within the scope of this paper, role differences will be tested only for a limited set of high-prevalence behaviors or grouped coping domains (e.g., work-structuring, social support, physical/recreational, digital, psychological regulation, time off, and substance-related strategies) using chi-square or exact tests. The study provides an evidence-based coping profile for home-office construction work that can guide role-sensitive supports and practices aligned with how professionals actually manage job stress.

Keywords: *construction, mental health, coping strategies, construction professionals, psychosocial hazards.*

JOB STRESSORS AMONG OFFICE-BASED CONSTRUCTION PROFESSIONALS IN THE UNITED STATES

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Abstract

Studies on mental health in the construction industry have primarily focused on field crews and field-based professionals. However, many job-related stressors in construction project delivery also originate on the office side, where estimating, preconstruction, VDC, project management, and executive functions shape workload, coordination, decision-making cycles, and performance pressures. This study examines the prevalence and role-specific patterns of job stressors among office-based (home-office) construction professionals, specifically in the Southeast U.S. This study investigates: Which job stressors are most commonly experienced in these roles, and to what extent do stressor profiles differ across roles? A sequential mixed-methods research design is used in which stressor themes are first elicited from both eight skilled trades (or craft) workers and thirty-two office-based construction workers, and then operationalized in a structured cross-sectional survey with open-ended sections. The instrument captures respondent demographics and work context, perceived stress duration, perceived spillover effects, and a 19-item select-all checklist of job stressors spanning work organization (e.g., staffing and time pressure), coordination and information flow, resource constraints, interpersonal climate, and performance/accountability demands. Analyses will report overall stressor prevalence and within-role percentages to produce a clear role-resolved stressor profile. To support statistically defensible role comparisons given the multi-select format, each stressor will be analyzed as a respondent-level binary indicator (selected vs. not selected), and role differences will be evaluated using stressor-level chi-square or exact tests, as appropriate, alongside reporting of practical effect sizes and false-discovery-rate control to reduce false positives across multiple stressors. The contribution is a role-resolved stressor map for office-based construction work that can help organizations move beyond generic wellness efforts toward targeted, role-appropriate interventions focused on modifiable work design and organizational practices, such as staffing and deadline governance, coordination protocols, decision authority clarity, and supervisory support.

Keywords: *construction, mental health, job stress, construction professionals, psychosocial hazards.*

STRUCTURED SYSTEMATIC APPROACH FOR AUTONOMOUS SCAN-TO-BIM: A CASE STUDY ON HONG KONG PUBLIC RENTAL HOUSING

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Abstract

Existing Scan-to-BIM systems are often limited to geometric fitting, producing unstructured meshes that lack architectural semantics and editability. To address this, we propose an autonomous framework implemented in Unity, structured into three synergistic modules. **The Knowledge-base Module** formalizes the parametric rules and structural syntax of Hong Kong's public rental housing (HKPRH), providing foundational constraints. **The Perception Module** serves as the sensory processor, utilizing an enhanced PointNet++ network and projection-guided DBSCAN to achieve component-level semantic segmentation from point clouds, further enriched by aligning high-resolution UAV facade images. Finally, the **Autonomous Modeling Module** acts as the central decision-maker, integrating perception outputs with structural priors to execute a sequence of discrete modeling actions—including component instantiation and parameter adjustment—to iteratively minimize the error between the digital state and physical scan. This workflow effectively bridges the gap between low-level geometric reconstruction and high-level BIM creation, providing a scalable and interpretable solution for the digital twin modeling of urban infrastructure.

Keywords: *building information modeling, scan-to-building information modeling, autonomous agent, structured editable model generation, point cloud segmentation*

AUTOMATED SCAN-TO-BIM METHOD FOR CONSTRUCTION PROGRESS MONITORING OF PAVEMENT STRUCTURAL LAYERS

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Abstract

Characterized as linear engineering projects, roads are vital infrastructure for industrial and residential activities, and the management of road construction progress is critical. Traditional monitoring methods rely on manual inspections, which are both labor-intensive and time-consuming. Recently, low-altitude Unmanned Aerial Vehicles (UAVs) have emerged as a powerful tool, but monitoring road construction progress still depends on manual interpretation of UAV imagery, resulting in limited efficiency improvements. To address this, it is necessary to transform point cloud data into as-built Building Information Model (BIM) and compare it with as-planned BIM to calculate progress. This paper proposes an automated Scan-to-BIM method for construction progress monitoring of pavement structural layers (PSLs). Firstly, a local coordinate system is established via the Minimum Area Bounding Rectangle (MABR), and PSL boundaries are extracted by combining quantile-based method with the Ramer-Douglas-Peucker (RDP) algorithm. Subsequently, the point cloud data is constructed into 3D quadrilateral mesh by planar quadrilateral mesh generation and elevation interpolation. Finally, as-built BIM is constructed in Revit using Dynamo to generate adaptive components based on the 3D quadrilateral mesh. Case study results demonstrate that this method offers an effective method for the automated construction of as-built BIM for PSLs.

Keywords: *adaptive family, construction progress, pavement structural layer, Scan-to-BIM, UAV point cloud.*

DESIGN FOR MANUFACTURE, ASSEMBLY, AND IMPROVED PRODUCTIVITY IN BRIDGE CONSTRUCTION

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Abstract

Design for Manufacture and Assembly has been proven in the manufacturing industry as a method of improving productivity by integrating knowledge of downstream processes with design. In comparison, productivity in the construction industry is poor, and literature promotes DfMA as a route to achieving productivity gains through increased off-site manufacture and reduced on-site activity. However, there is an apparent divergence between the construction industry's perception of DfMA as a prefabrication concept and the manufacturing industry's application of DfMA as a systematic design optimisation process. Prefabrication is only one of several capabilities of DfMA, yet the literature remains skewed towards this focus. Designers have substantial influence over the application of DfMA during the design stage, but their perceptions and current practice present a gap in knowledge.

Qualitative research was conducted using a case-study approach based on a portfolio of bridge design projects. Semi-structured interviews and thematic analysis identified key themes relating to prefabrication, design optimisation, collaboration, and 3D modelling. The findings suggest the term DfMA is misleading, and 'Integrated Design for Optimised Construction' is proposed. Improved site experience and clearer client intentions for BIM are required to avoid a skills gap and maximise benefits.

NAV & SNAP BASED LOCALIZED INDOOR PHOTOGRAPHY AND NERF DRIVEN 3D MODEL GENERATION FOR CONSTRUCTION DIGITALIZATION

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Abstract

In construction sites, a large number of photographs are taken every day to document work progress, verify construction quality, and support communication among project stakeholders. However, most of these images are stored without reliable spatial information, making it difficult to understand where they were captured or how they can be effectively reused during later stages such as facility management and maintenance planning. As a result, valuable visual data collected during construction often remains underutilized. This study proposes a practical framework that combines a smartphone-based indoor positioning system, Nav & Snap, with Neural Radiance Field (NeRF) technology to enable location-aware photo documentation and three-dimensional (3D) model generation in indoor construction environments where GNSS signals are unavailable. Nav & Snap captures highly accurate indoor-localized images with x, y, z coordinates and latitude and longitude values stored in the image metadata, allowing photographs to be spatially organized and easily retrieved. These localized images are then used as inputs for NeRF-based reconstruction, where the positioning information provide camera pose information and reduce dependence on SfM-based pose estimation and enhance reconstruction stability in complex indoor scenes. Experimental evaluations conducted in real indoor environments demonstrate that the proposed approach achieves positioning accuracy suitable for typical construction workflows. Furthermore, it enabled successful NeRF reconstruction in a straight-line image acquisition case where conventional SfM-based pose estimation failed. By transforming routine construction photography into spatially structured digital information, the proposed framework supports better visualization of construction conditions, improved spatial understanding of built assets, and more efficient digital twin creation for lifecycle information management. The study highlights the potential of combining lightweight smartphone sensing with AI-based neural rendering to promote scalable digitalization in construction projects.

Keywords: *construction digitalization, digital twin, indoor positioning, neural radiance fields, photo localization*

A STUDY ON BIM DATA COLLABORATION BETWEEN DESIGNERS AND CONTRACTORS

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Abstract

This paper examines the current state and challenges of BIM data collaboration between designers and contractors in Japan's building construction process, based on survey results conducted with general contractors. While the use of BIM in construction projects is progressing, differences in modeling purposes between design and construction departments create barriers to collaboration. Contractors prioritize ensuring consistency in design BIM data and expect coordination across the three main disciplines—architecture, structure, and MEP. On the other hand, the current situation reveals that the use of quantity and attribute data is less utilized compared to geometric data. The survey highlights gaps between expectations and reality in the use of design BIM data, identifying issues in the separated contract system and its application during the construction phase. Finally, this study aims to strengthen collaboration between designers and contractors and provide recommendations for optimizing the building process through the use of BIM. This includes ensuring interdepartmental consistency, promoting effective information use, and establishing institutional frameworks.

Keywords: *BIM, consistency , data collaboration, designer, general contractor.*

SPATIAL DEVIATION ANALYSIS FOR FIT UP QUALITY ASSURANCE IN HETEROGENEOUS AS-BUILT–TO–BIM ASSEMBLIES

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Abstract

The construction phase in the Architecture, Engineering, and Construction (AEC) industry frequently encounters design–build discrepancies that lead to cost overruns, delays, and quality issues. Conventional Scan-to-BIM workflows typically compare an as-built state to its own design intent, but do not explicitly support quality control for fitting a newly designed structure to an existing one. This paper addresses this gap by introducing a spatial deviation–driven quality control framework for assemblies where two heterogeneous models must be brought into fit: (i) an as-built laser scan of a host structure and (ii) a designed BIM model of a structure to be affixed (e.g., retrofits, extensions, prefabricated additions). The proposed framework is demonstrated on a steel frame extension to be attached to an existing reinforced concrete structure. Terrestrial laser scanning was used to capture the as-built concrete host and a BIM model for the designed steel extension. After registering the as-built point cloud to the BIM coordinate system, critical assembly components are extracted from the BIM-designed structure (e.g., connection coordinates, plate geometries), and their geometric attributes are computed. An iterative convergence-driven procedure is implemented to refine displacement estimates until stable spatial deviations are obtained. These deviations are then evaluated against predefined tolerances to support quality control decisions aimed at minimizing on-site adjustments and rework. Results are presented as color-coded 3D visualizations and comprehensive QC reports summarizing classification outcomes, deviation statistics, and representative interface conditions. The framework enables fit-up–oriented quality control that systematically reduces clashes and rework while improving accuracy, productivity, and sustainability in construction.

Keywords: *As-built scans, BIM, Construction, Design, Quality Control.*

DRIVING SUSTAINABILITY FORWARD: BUILDING INFORMATION MODELING (BIM) INTEGRATION IN PROJECT MANAGEMENT

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Abstract

The adoption of smart technologies offers significant opportunities to enhance sustainability in construction by enabling real-time data analysis, optimizing resource use, and facilitating predictive maintenance. This research evaluates BIM's impact on sustainable management practices (SMPs) throughout the project lifecycle. Findings highlight eight key applications of BIM including but not limited to its role in understanding project schedules, budgets, and potential design conflicts prior to construction and in facilitating early selection of design charrette experts. This study contributes to construction management literature by highlighting the vital role BIM plays in developing effective strategies, ultimately leading to better outcomes for sustainable projects.

Keywords: *Building Information Modeling (BIM), construction management practices, smart technologies, sustainable construction.*

FROM DISCIPLINARY BOUNDARIES TO GENUINE COLLABORATION: AN INTERDISCIPLINARY MODULE BASED ON SUSTAINABILITY CHALLENGES

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Abstract

Addressing sustainability challenges in the built environment requires professionals capable of collaborating across disciplinary boundaries. This paper presents a qualitative pedagogical case study of an interdisciplinary module that brought together Civil Engineering and Spatial and Object Design students through three sustainability-oriented challenges: a thermal performance prototype, a bioclimatic window for a children's hospital room, and a circular-economy merchandising project. The module was developed with the support of ExploraTec UDD, an institutional platform that facilitates interdisciplinary technology-based learning between Engineering and Design. Data were drawn from instructor participant observation, student deliverables, assessment activities, and reflective comments. The analysis identified four main implementation issues: logistical coordination, disciplinary language differences, hybrid assessment criteria, and the role of institutional support. The findings suggest that sustainability challenges can serve as pedagogical boundary objects when they are carefully framed, jointly assessed, and actively mediated by the teaching team. The paper contributes practice-based insights for designing interdisciplinary learning experiences in construction-related education.

Keywords: *circular design, Design-Engineering integration, interdisciplinary collaboration, project-based learning, sustainability education.*

INNOVATION AND DESIGN OF SMALL CONSTRUCTION ELEMENTS: EXPERIMENTAL COURSE TASK FOR THE EDUCATION OF CONSTRUCTION TECHNOLOGY AND MANAGEMENT

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Abstract

Sustainability is a key aspect of contemporary requirements for both education and innovation in the construction industry. Among the sustainable development goals, Nr. 8 “Decent work and economic growth”, Nr. 9 “Industry innovation and infrastructure”, and Nr. 12 “Responsible consumption and production” are strongly related to the development of the construction industry. A system of small construction elements with dismountable joints enables the later reuse of the elements on high embodied energy level. In the introduced project, our educational purpose was to strengthen sustainable development goals and the option of innovation in our students' design thinking. In the demonstrated course, students had to develop a modular construction system, according to established requirements of small modular elements with dismountable construction joints, and apply it in their own design in the form of a small garden facility or exhibition composition. An additional elective task was to formulate the elements and joints in the spirit of the robot-oriented design.

Keywords: *small construction elements, sustainable design, dismountable joints, modular construction*

BOARD GAME BASED LEARNING FOR TEACHING CONSTRUCTION MANAGEMENT IN CIVIL ENGINEERING

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Abstract

Construction management education requires students to understand planning, sequencing, resource allocation, and decision-making in contexts that are difficult to reproduce through conventional classroom instruction. To address this challenge, this study presents Build Race, a board game designed to foster experiential learning in a Civil Engineering course. In Build Race, students assume the role of project managers responsible for delivering residential building projects through key construction stages, including excavation, foundations, structural works, and finishes. Throughout the game, they must allocate resources, respond to decision-making situations, and coordinate actions within a collaborative and competitive setting. The game applies board game-based learning principles with physical and visual elements such as a board, 3D-printed figures, laser-cut tokens, and dice, creating an interactive simulation of construction project management. The game was implemented in the course Construction Management Workshop with 25 undergraduate students, of whom 24 completed the post-activity questionnaire. Student perceptions were assessed through a survey measuring satisfaction, motivation, engagement, and perceived learning. Results were highly positive: all students gave the maximum rating to the items related to class engagement, active participation, and willingness to use similar games in other courses. In addition, learning-related items received consistently high scores, and the activity obtained a mean overall rating of 6.72 out of 7. Open-ended responses highlighted planning, construction sequencing, resource management, and decision-making as key learning outcomes. These findings provide initial evidence of the perceived educational value of board game-based learning for bridging theory and practice in construction management education.

Keywords: *Board game-based learning, civil engineering education, construction management, experiencial education, gamification.*

PEER LEARNING ACROSS BORDERS: DEVELOPING MANAGEMENT CAPABILITY THROUGH A GLOBAL ONLINE ENGINEERING MANAGEMENT MSC

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Abstract

The development of management capability among (construction) engineers remains a persistent challenge, particularly for those transitioning from technical roles within complex, globally distributed project environments. Although online postgraduate education has widened access less is understood about how globally diverse cohorts contribute to learning outcomes in engineering management.

This research explores peer learning within an online MSc in Engineering Management that has been delivered since 2019 to a large, international cohort of mid-career professionals, many from the construction sector. The programme's rolling-entry, modular structure supports study alongside full-time work, resulting in a continually evolving learning environment.

The approach draws on programme-level evidence, including the design of modules, sequencing of assessments, and observed patterns of student interaction across collaborative and reflective activities. Particular attention is given to how peer learning is structured and enacted through group work, discussion forums, and a sequence of formative and summative assessments that progressively support the transition from technical expertise to managerial capability.

The findings indicate that peer learning across geographical, disciplinary, and organisational contexts functions as a social learning mechanism that, not only broadens participants' understanding of management practice, but also enables more creative, context-sensitive approaches to problem framing. This is especially relevant for construction professionals engaging with perspectives beyond their immediate project and organisational environments. The findings also highlight interrelated design and delivery factors that shape capability development, showing how these simultaneously support peer learning while also bringing some structural and pedagogical tensions.

This work contributes to the literature on construction management education by demonstrating how global peer engagement can act as a mechanism for capability development, while also identifying design and delivery considerations necessary for sustaining success in large-scale online programmes.

Keywords: *capability, construction management, peer learning, online programmes, postgraduate.*

FUZZY LOGIC FRAMEWORK FOR CONVERTING INFRASTRUCTURE PERFORMANCE MEASURES INTO LEVEL OF SERVICE

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Abstract

Infrastructure performance is often assessed using discrete condition ratings (e.g., A–E) or qualitative descriptors such as Good or Poor. While widely used, these categorical approaches can introduce ambiguity, particularly when measured values lie near the thresholds between rating classes. To address this limitation, this study presents a fuzzy logic–based framework that transforms raw performance measures into a continuous and objectively interpretable Level of Service (LOS) score. In the proposed approach, each performance indicator is modeled using fuzzy membership functions to explicitly represent uncertainty associated with linguistic grading. The fuzzy outputs are subsequently defuzzified to obtain continuous indicator scores, which are then aggregated using a simple weighting scheme to compute an overall LOS value. The resulting LOS score retains the variability of the underlying measurements, mitigates subjectivity inherent in categorical rating systems, and enables more consistent comparison of infrastructure conditions across assets. Overall, the proposed framework provides a practical and transparent methodology for enhancing the reliability and credibility of infrastructure performance evaluations.

Keywords: *Fuzzy logic; Infrastructure performance; Level of service ; Linguistic variable; Asset management*

COMPARISON OF 3D OBJECT SEGMENTATION ACCURACY USING VERTEX DATA AND BSP TREE ALGORITHMS

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Abstract

Photographic information is the most convenient way to manage crack damage during the maintenance period of a construction structure. However, the limitations of 2D images hinder their usability in BIM-based maintenance systems. To link damage information in 2D photographs to a 3D-based BIM model during the maintenance phase, a process is required to align the 2D photographic information with the damage information in 3D objects. To improve the accuracy of the inter-object alignment coordinates during this alignment process, the 3D model can be divided into objects of a certain size and aligned accordingly. This study analyzes algorithms for dividing 3D models into objects of a certain size and verifies the accuracy of various segmentation methods to present a highly reliable methodology. To compare segmentation accuracy, the study compares and verifies a vertex-data-based segmentation method using Revit software's Dynamo with a BSP (Binary Space Partitioning) algorithm. To verify the model's X, Y, and Z-axis segmentation, the two segmentation methods are compared based on the results of dividing the object into eight equal parts, and the most accurate object segmentation method is selected. This study divides bridge pier structures into circular and rectangular shapes, applying two methods to segment them. The segmentation accuracy is then compared by comparing the volumes of the segmented objects. The initial BIM model created during the design phase requires segmentation of objects depending on their intended use during the construction and maintenance stages. The comparison of segmentation accuracy of 3D objects presented in this study can be helpful in assessing the appropriateness of the segmentation method.

Keywords: *3D model, Vertex data, Binary space partitioning, 3D object division*

STAKEHOLDER ENGAGEMENT IN PROJECT MANAGEMENT - A COMPARATIVE ANALYSIS OF EXISTING FRAMEWORKS

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Abstract

The increasing complexity of modern projects has elevated the importance of stakeholder engagement, not only in sustainable project management and social responsibility. The contemporary challenges of significant investments inevitably include environmental and social issues. Therefore, a paradigm shift is needed in project management where stakeholders are viewed not merely as risk factors or information sources, but as active partners in value creation and decision-making. Traditional, instrumental models often lack the flexibility required to address these environmental and social demands, highlighting the need for integrated approaches that foster legitimacy, innovation, and trust. The primary objective of this study is to identify, classify, and compare existing stakeholder engagement frameworks. The research seeks explicitly to evaluate how these models support inclusive, adaptive, and equitable decision-making processes and to understand their role in the evolution of responsible project management. To ensure a rigorous and transparent analysis, a systematic literature review was conducted following the PRISMA methodology. This approach enabled comprehensive mapping and a deep comparison of relevant models in the current academic literature. The analysis reveals a significant distinction between general project management (PM) frameworks and specific stakeholder engagement (SE) frameworks. PM frameworks often treat engagement instrumentally: focusing on risk mitigation, compliance, and short-term efficiency. At the same time, specific SE frameworks view engagement as a strategic partnership essential for long-term sustainability, knowledge, and value co-creation. The findings indicate that effective frameworks rely on adaptive communication and continuous feedback loops to integrate stakeholder needs systematically. Ultimately, the study outlines a clear transition in the field: shifting from traditional stakeholder management towards deep-level engagement.

Keywords: *project management, stakeholder engagement, framework.*

ARTIFICIAL INTELLIGENCE-BASED PROCESS INTEGRATION AND DECISION SUPPORT IN AGILE PROJECT PLANNING

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Abstract

This study investigates the system-level integration of artificial intelligence (AI) within agile project management, focusing specifically on the preparation and planning phases of the Scrum framework. The research aims to embed AI agents into daily workflows to alleviate the cognitive load on project managers by automating the processing of unstructured information. Utilizing a two-pillar methodology, the study combines a PRISMA-based systematic literature review of 50 Q1 publications with a technological case study within a large enterprise ecosystem. Results demonstrate that the "Human-in-the-loop" model achieves a 50% time saving in administrative tasks, with the most significant breakthrough being the automated processing of meeting minutes. Furthermore, AI functions as extended intelligence, enabling real-time predictive analysis of Scrum metrics to improve decision-making accuracy. The paper concludes that while AI structures data and enhances efficiency, human oversight remains essential for contextual validation and strategic decision-making. The study proves that AI is not merely a technological supplement but a vital efficiency-enhancing component of modern agile processes.

Keywords: *agile project environment, artificial intelligence, AI-based process integration, predictive modeling, scrum automation,*

INVESTIGATING ARTIFICIAL INTELLIGENCE FOR TIME-BASED PREDICTIONS IN DIVERSE PROJECT MANAGEMENT ENVIRONMENTS

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Abstract

Predicting project timelines with precision remains a formidable challenge in the engineering and construction sectors due to inherent uncertainties and external dependencies. This research explores the potential of machine learning (ML) algorithms to enhance schedule reliability by analyzing historical performance data. We conducted a comparative assessment of three distinct regression models—Linear Regression, Random Forest, and Gradient Boosting—across diverse dataset environments, including Agile software development, organizational resource tracking, and traditional Waterfall-based projects. The study aims to identify which algorithmic approach offers the highest accuracy for time-related predictions in real-world corporate settings. Our findings reveal that while Gradient Boosting generally yields the lowest error rates, the applicability of these models is heavily dictated by the project context. In structured environments like Agile, where tasks are granular and iterative, the models performed with high reliability. Conversely, in Waterfall scenarios characterized by complex external dependencies and rigid sequential phases, predictive accuracy diminished significantly. The paper concludes that while AI-driven tools are powerful for short-term, well-defined estimation tasks, they cannot yet fully replace expert judgment in high-uncertainty construction phases. To maximize value, organizations should adopt a hybrid strategy: leveraging ML for data-rich, repetitive task estimation while retaining human oversight for managing external risks.

Keywords: artificial intelligence, construction management, machine learning, predictive modeling, time estimation.

INTEGRATING RANDOM FOREST AND GIS FOR RISK ASSESSMENT OF HIGH-SPEED RAIL DELAYS UNDER FREEZING RAIN HAZARDS

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Abstract

To address the complex uncertainties associated with high-speed train delay risks under freezing rain disasters, this study proposes a risk assessment method that integrates random forest and geographic information systems (GIS). The proposed method employs a random forest model to evaluate the delay risk of trains under multi-factor coupling conditions and identifies the key factors influencing the severity of delays. Building upon this, GIS is introduced to spatially visualize delay risks, thereby effectively identifying vulnerable areas and risk clustering characteristics within the high-speed rail network. The method is validated using the high-speed railway network of Hubei Province as a case study. Results demonstrate that the model exhibits strong predictive performance, achieving an accuracy of 0.997. The primary contribution of this study lies in the development of a high-speed train delay risk assessment method that integrates data-driven modeling with spatial analysis, providing scientific support for railway operation management and risk-based decision-making under freezing rain disasters.

Keywords: *random forest, geographic information system, high-speed rail, freezing rain, risk assessment.*

A BIM-INTEGRATED SITE DIGITAL TWIN PROOF-OF-CONCEPT FOR EARLY SCHEDULE DEVIATION DETECTION

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Abstract

Delays on construction sites rarely arrive as a single event - they build up through small productivity losses that are often recognized only after the planned finish is already missed. This paper analyses whether a BIM-enabled site digital twin, fed with frequent progress updates, can surface schedule risk earlier than periodic manual reporting. We present a proof-of-concept for the structural works of a typical building floor, covering slab, columns, and core walls, where execution activities are linked to BIM element sets via unique identifiers and monitored against a baseline schedule. Instead of relying on field sensors, we use a reproducible, time-stamped progress stream that is replayed as near-real-time input at 30-minute resolution. The digital twin continuously updates the execution state and flags schedule risk through two transparent checks: a gap between expected and reported progress and a simple completion-time estimate derived from recent progress rates. The approach is tested in two scenarios: an on-time baseline and a disruption in slab reinforcement (S-R) that propagates to slab concreting (S-P). In the delayed scenario, the digital twin signals schedule risk 2.0 hours before the planned finish of S-R, while the final delay reaches 2.5 hours and propagates to S-P; in the on-time scenario, no alerts are triggered. These results suggest that even a minimal digital twin logic can improve the timeliness of deviation detection and provides a practical, reproducible basis for future work with real site data and decision support.

Keywords: *bim, construction monitoring, digital twin, progress tracking, schedule deviation detection.*

AUTOMATED TRANSLATION OF KOREAN DESIGN STANDARDS INTO EXECUTABLE CODE USING TEMPLATE-BASED LLMS FOR AUTOMATED CODE CHECKING

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Abstract

Engineering design standards prescribe quantitative requirements that must be rigorously verified during design. However, these standards are predominantly text-based and are typically applied through manual interpretation and hand-coded implementation. Implementing BIM-based Automated Code Checking (ACC) therefore requires translating natural-language regulations into executable computational rules, a process that is inherently difficult to scale and vulnerable to ambiguity. This study presents an automated pipeline that translates Korean Design Standards (KDS) from PDF documents into validated, executable Python code. The proposed approach integrates hierarchical document extraction, two-stage computational rule filtering combining regex-based screening and LLM-based semantic validation, rule deduplication to ensure atomic rule granularity, template-based few-shot code generation, and multi-level code integrity verification. The system was evaluated using KDS 11 50 15 (Deep Foundation Design Standard) and applied to the entire document without preselection. Experimental results showed that the pipeline achieved complete structural validity, while functional correctness reached 85.71% under type-aware validation. The automated process successfully recovered all manually implemented reference rules and discovered 1.5× more executable computational rules beyond expert implementation (17 vs. 11), with the discovered rules achieving higher functional correctness than the manually implemented set (94.12% vs. 72.7%). In cases where generated code diverged from manual implementations, the differences were primarily attributed to ambiguity in the source specifications rather than generation failure, with LLM-generated code reflecting conservative or explicit engineering interpretations. These results demonstrate that structured few-shot prompting combined with systematic computational filtering can reliably automate the translation of engineering standards into executable, verifiable code, supporting BIM-based ACC.

Keywords: *Template-based Code Translation, Korean Design Standards, Large Language Model, Automated Code Checking, Few-Show Learning*

MACHINE LEARNING-DRIVEN PROCESS SIMULATION FOR PROACTIVE CUTTER MAINTENANCE IN MECHANIZED TUNNELING

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Abstract

Cutter maintenance is a critical source of downtime, safety exposure and cost in hard-rock shield tunneling, yet fixed-distance inspection and passive replacement cannot properly accommodate the stochastic evolution of cutter wear and construction disturbances. This paper develops a compact machine learning-driven process simulation framework for robust proactive cutter maintenance. Wavelet packet decomposition and path-wise inverse reconstruction are first used to transform non-stationary tunneling parameters into physically interpretable multi-scale features. A Gaussian process regression surrogate is then trained under small-sample conditions to predict the overall cutterhead wear state and quantify predictive uncertainty. The surrogate is embedded into an AnyLogic discrete-event simulation model that reproduces excavation, regripping, ring erection, maintenance operations, technical failures and logistic delays. Monte Carlo simulations are conducted to obtain distributional indicators of monthly advance rate, intervention frequency and maintenance cost, and a coupled grey relational analysis and TOPSIS model is adopted to rank candidate strategies. A case study on the Shenzhen Metro Line 14 shows that the GPR model achieves an LOOCV R2 of 0.932 with an RMSE of 0.032. The process simulation reproduces the observed monthly advance rate with a relative error of -1.70%. The condition-based opportunistic strategy S8 achieves the highest closeness coefficient of 0.796, demonstrating balanced advantages in efficiency, risk control and cost robustness.

Keywords: *cutter maintenance, discrete-event simulation, gaussian process regression, process uncertainty, shield tunneling.*