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Abstract Booklet

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ENHANCED CGMD PERFORMANCE USING A NOVEL FINNED-FEED DESIGN

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History shows us that water can both create and destroy civilizations. The Nile's annual floods turned African desert soil into rich farmland, sustaining one of the longest-lasting empires in history, the Egyptian civilization. In contrast, the Classic Maya civilization eventually collapsed largely due to repeated and severe droughts that damaged their water systems and agricultural practices. Today, our modern cities are no less at risk of this truth. In the United States, the Colorado River is shrinking because of climate change and years of drought. Its two main reservoirs, Lake Mead and Lake Powell, have dropped to historic lows. The river supports seven U.S. states and Mexico, with Arizona and California being the most heavily reliant on it. As rivers continue to decline, desalination has become an increasingly important solution to supply fresh water from the sea. Several desalination technologies exist, including reverse osmosis, multi-effect distillation, and membrane distillation (MD). Among them, MD stands out for its ability to use low-grade or waste heat, operate under atmospheric pressure, and produce high-quality freshwater. MD is a heat-driven desalination process that uses a membrane to let only water vapor pass from hot salty water to a cooler side, producing fresh water efficiently. It has several configurations, which mainly differ in what fills the gap between the hot and cold sides. In this study, the focus is on the conductive-gap membrane distillation (CGMD) configuration, where the gap is filled with a conductive material that transfers heat efficiently between the two sides. Most CGMD studies focus on enhancing system performance by testing new gap materials or modifying the cooling side, while paying less attention to modifying the hot and cold stream channels. In this study, a novel finned-feed CGMD (FF-CGMD) configuration is proposed by adding cylindrical fins in the hot stream channel. This modification addresses the issue of thermal boundary layer buildup in CGMD, which reduces the effective driving temperature difference for heat and mass transfer. The modified system is modeled numerically using the Engineering Equation Solver (EES), and its performance is compared to that of a baseline CGMD system without fins. The results showed that the introduction of fins reduced temperature polarization by up to 97% and increased water production by approximately 14%.

TOWARDS SUPPRESSING RING OPENING IN TEMPO CATHOLYTES FOR AQUEOUS REDOX FLOW BATTERIES

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TEMPO-based molecules are among the most promising organic catholytes for aqueous redox flow batteries (RFBs), yet their charged oxoammonium state ($TEMPO^+$) suffers from rapid chemical instability. In the widely used 0.5 M TEMPOL/MV^{2+} chemistry, the cell retains high coulombic efficiency (~98%) but loses ~70% of its capacity within 155 cycles due to fast catholyte degradation. This work systematically investigates the fundamental decay pathways of $TEMPO^+$ and introduces molecular design strategies to suppress them.

We combined electrochemical cycling, temporal NMR, EPR, GC-MS, and LC-MS to resolve the structural evolution of $TEMPO^+$. Our mechanistic study reveals two dominant decomposition routes: (i) oxoammonium-driven oxidation of the hydroxyl group, generating carbonyl species and releasing protons, and (ii) β-hydrogen deprotonation followed by ring-opening, forming alkene intermediates that further oxidize into carbonyl and CO_2-containing products. These reactions provide a molecular origin for the severe electrolyte acidification observed during cycling and explain the rapid loss of redox-active material.

To mitigate these degradation pathways, we evaluated two modified TEMPO derivatives. The anionic SPrO-TEMPO reduces membrane crossover but still undergoes β-H–initiated ring opening. In contrast, the hydroxyl-free cationic derivative TMA-Ac-TEMPO, designed to eliminate the reactive –OH functionality and suppress β-H extraction, demonstrates significantly improved performance. A 0.5 M TMA-Ac-TEMPO/MV^{2+} cell shows only ~32% capacity loss after 275 cycles, compared to ~70% loss after 155 cycles for TEMPOL under identical conditions. The reduced acidification (catholyte pH maintained near ~3) further confirms suppression of decomposition.

Overall, this study provides direct molecular-level evidence linking $TEMPO^+$ degradation to hydroxyl-mediated oxidation and β-H–driven ring-opening pathways. Our results establish clear design criteria for stabilizing TEMPO-based catholytes and demonstrate that eliminating both the hydroxyl group and β-hydrogens is essential for enabling long-lifetime organic RFB systems.

DYNAMIC WARPAGE METROLOGY OF THERMAL GREASE DEGRADATION

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The miniaturization and power densification of modern semiconductor devices have intensified the need for reliable thermal management solutions. Thermal interface materials (TIMs) play a vital role in facilitating heat dissipation between components within an electronic package. However, mismatches in the coefficients of thermal expansion (CTE) among constituent materials can induce thermo-mechanical stresses, leading to warpage, void formation, and progressive TIM degradation. While previous studies have investigated TIM performance under static or idealized flat interfaces, real packages experience dynamic warpage during operation due to temperature cycling and manufacturing-induced stresses. Understanding how such dynamic deformations influence TIM degradation is essential for improving long-term reliability.

This study introduces a novel metrology framework that enables controlled investigation of dynamic warpage effects on TIM behavior. The system comprises a flexible metallic substrate, a thermal grease layer, and an optically transparent top substrate. A precision linear actuator cyclically bends the bottom substrate to simulate dynamic warpage while a resistive heater replicates operational thermal conditions. The surface curvature prior to cycling is characterized using high-resolution shadow moiré interferometry, a non-contact optical method that reconstructs three-dimensional warpage profiles. During cycling, a laser displacement sensor verifies the cyclic warpage amplitude, and an optical microscope continuously monitors the evolution of the TIM layer.

Results reveal that thermal grease degradation intensifies under cyclic warpage, with void regions expanding with cycles. These findings demonstrate that cyclic mechanical deformation significantly accelerates the degradation of TIMs, underscoring the importance of accounting for real-time warpage in reliability assessments.

The proposed metrology establishes a foundation for next-generation dynamic warpage characterization of thermal interfaces. By bridging thermal and mechanical reliability testing, this approach enhances the predictive evaluation of TIM performance and informs the design of more robust thermal management architectures for advanced electronic packaging.

RECONSTRUCTIONS ON DISORDERED SURFACE ALLOYS: STRAIN-CONSISTENT FIRST PRINCIPLES TREATMENTS FOR HETEROGENEOUS CATALYSIS

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High entropy alloys (HEA's) have attracted significant attention as candidates for improved heterogeneous catalysts, and their compositional flexibility allows an almost limitless number of catalyst structures to be explored. However, while the bulk structures of HEA's are generally acknowledged to consist of crystalline lattices with a random distribution of elements between lattice sites, considerably less understanding of the molecular structure of the surfaces, which controls catalytic properties, exists. To address this question, we present a first principles-based approach to investigate the thermodynamic behavior and surface properties of disordered alloys, focusing on CoMo bimetallic systems, which are well-known catalysts for ammonia synthesis and decomposition, as a model for more complex high entropy alloys (HEAs). Using density functional theory (DFT) calculations and a custom film generation algorithm, we explore the stability of a large number of surface compositions and configurations, including both pseudomorphic and non-pseudomorphic (Moiré pattern) structures. Our analysis reveals that thermodynamically stable surface compositions can differ significantly from the bulk, with Co_6Mo, Co_2Mo, and $CoMo_6$ being particularly stable. Further, non-pseudomorphic structures, which reduce the magnitude of strain fields near the surface, are often found to be more stable than pseudomorphic patterns of the same composition, highlighting the relevance of Moiré-type surface reconstructions on disordered alloy surfaces. These fundamental insights into the interplay between surface composition, structure, and stability in disordered alloys lay the groundwork for understanding more complex multi-element systems such as HEAs, in turn providing a pathway to an accurate and systematic evaluation of HEAs' catalytic properties.

MATERIAL SELECTION BASED ON LIFE CYCLE ASSESSMENT WITH APPLICATION TO HOUSING DESIGN TO REDUCE ENVIRONMENTAL IMPACT AND ENHANCE DISASTER RESILIENCE

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The construction industry is a major contributor to global carbon emissions, responsible for approximately 40% of the total. To address increasing concerns about climate change, environmental degradation, natural disasters, and diminishing natural resources, sustainable constructive materials and manufacturing could be used as an alternative in communities with high environmental risk to build resilience and mitigate the social and economic impacts of weather-related natural disasters. Herein, we will focus on how the use of life cycle assessment (LCA) combined with material selection charts can support decision making of building materials to mitigate natural disasters' consequences on the housing sector. To compare different building elements, a tiny house (TH) accommodating a family of four people was designed for the Southwestern region of the United States to be used as a functional unit. This study reviews material physical properties and LCAs to assess the environmental impacts (cradle-to-gate LCA, covering extraction and manufacturing stages) and determines the advantages of using different materials in early design-stages of the housing sector threatened by natural disasters. The results of different perspectives indicate that, for the Los Angeles area, compressed earth blocks (CEB) lightly stabilized with cement (10%), settled with polymeric mortar, complemented with frames in wood, and thermoplastic polyolefin roofing was the combination that satisfies the TH project in a wildfire scenario. This evaluation considered price, durability, mechanical strength, thermal conductivity, fire resistance, acidification, ozone depletion, and carbon footprint, and revealed that this combination of materials achieved good physical and thermal performance that allows its users more time for safe evacuation for new disaster occurrences, while generating the least environmental impacts.

SIGNIFICANT NANOPARTICLE EMISSIONS AND EXPOSURES FROM DRY SHAMPOO PRODUCTS

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The objective of this presentation is to emphasize the importance of considering everyday products, like dry shampoos, as significant sources of indoor air pollution potentially impacting human health. Dry shampoos, hair care products marketed for their time-saving features, are potent sources of indoor air pollution as they release significant concentrations nanoparticles (6 to 500 nm) and volatile organic compounds (VOCs) that interact with the indoor atmospheric environment and impact human health. Real-time studies on the emitted aerosols from propellant-based hair care products and associated health impacts remain limited. This study conducted 14 full-scale emission experiments, using five commercially available hair care products in a controlled laboratory environment inside of the Purdue zEDGE Test House. Using a High-Resolution Electrical Low-Pressure Impactor (HR-ELPI+) and a photoionization detector (PID), we measured nanoparticle size distributions and total VOC (TVOC) mixing ratios, respectively, directly from the user's breathing zone during realistic hair care routines. Data analysis revealed that dry shampoos produced airborne nanoparticle concentrations ranging from 75,000 to 650,000 cm^{-3} with most particles ranging between 80 and 200 nm. The TVOC peak concentration found for dry shampoos during source periods were between 2,500 and 4,000 ppb. Interestingly, the only dry shampoo product without label-listed siloxanes, a commonly used VOC in hair care products, displayed the lowest nanoparticle and TVOC concentrations, suggesting that product formulation may have a great impact on aerosol emissions. It is known that prolonged exposure to nanoparticles have potential health outcomes associated with oxidative stress, decreased lung function, heart disease, breast cancer, and prostate cancer. Similarly, long-term exposure to VOCs has been linked to cardiovascular disease, neurological disorders, and risks of cancer. These findings are valuable as they contribute to the body of knowledge regarding indoor air pollution from propellant-based hair care product use and human health that was previously underexamined.

PROTEIN DIFFUSION IN COLLAGEN-HA GELS: AN IN-VITRO PLATFORM FOR MIMICKING THERAPEUTIC DIFFUSION IN THE VITREOUS HUMOR

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Intravitreal administration of IgG-type therapeutics is essential for treating age-related ocular diseases and their transport in the vitreous humor is driven by diffusion. The vitreous humor is a viscoelastic gel predominantly composed of water (>98%), collagen fibrils and hyaluronic acid (HA) interspersed in a network of type II and type IX. Age-related changes in the viscoelasticity of the vitreous humor is due to vitreous liquefaction, which is characterized by simultaneous increase in liquid vitreous (HA content) and aggregation of collagen fibrils.

In our previous work, we developed an in-vitro platform to screen protein therapeutics by tracking the movement of unlabeled bovine IgG (b-IgG) in an in-vitro HA matrix, simulating the diffusion of therapeutics in the vitreous humor of individuals < 65 and > 65 years of age. The measurement was done by activating the tryptophan residues of b-IgG at 280 nm and capturing the inherent fluorescence at 384 nm. We also determined the effect of age-related viscosity changes of the liquid vitreous on b-IgG diffusion.

In our current work, to improve the reliability of our in-vitro screening tool, Type II collagen-HA gels were used to better replicate the primary components of the vitreous humor. The collagen-HA composite gels were prepared with varying mesh sizes and HA concentrations, in which HA was dispersed within the interfibrillar space of the collagen fibers. The next step is to utilize Alexa Fluor-labeled b-IgG and monitor the spread of the fluorescence signal over time to predict the diffusion coefficient. Since diffusion in polymeric environments can deviate from Fickian behavior, this approach will also be used to detect whether the b-IgG diffusion is anomalous. Additionally, the effect of the collagen-HA gel mesh size on b-IgG diffusion will be evaluated.

This work provides an updated version of our previous in-vitro screening tool. It aims to establish a better correlation between the diffusion properties of therapeutics and the viscoelasticity of the vitreous humor and potentially offer improved insights into the intravitreal therapeutic transport across different stages of vitreous liquefaction.

EGROWING STRUCTURED DATA: EVALUATING AGRICULTURAL ONTOLOGIES FOR FIT TO ORGANIC TOMATO VARIETY DATA

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Though more data has become available through the internet, its deluge has created new challenges for extracting insights to inform decision-making. Standards for data modeling and transfer in agriculture have not been established, contributing to the growing data crisis - data siloing, information overload, and heterogeneity in data sets have become barriers to some dimensions of agricultural research and development. Computational ontologies provide a starting point for data modeling and may serve to bridge the gap between massive sets of data and the needs of researchers.

Here, we describe a human-in-the-loop curation workflow to map a set of terms from experimental metadata to ontologies. This workflow uses a custom-built BERT-style semantic matching engine and an informal ontology engineered to bridge between the dataset terminology and the ontological classes. Our test data set includes 47 terms from organic tomato breeding research; matches are made using the term names and definitions between the test data set and the five major agricultural ontologies. The semantic matching engine leverages cosine similarity to calculate a similarity score between terms. Vectorization of terms is carried out through the use of Hugging Face's MiniLM-L6-v2, a sentence transformer model with a dimensionality of 384. Using this workflow, we will assess the fit of the ontologies against the data set.

We also aim to demonstrate a quick, effective estimation for mapping an ontology to a set of research data terms. Additionally, our process offers researchers a time-optimized alternative to online ontology annotation tools available as a PyPi Python package, Owlchemy. This package may be implemented by other researchers to annotate their data, thereby allowing them to structure their information for their own purposes or for contributing to online repositories.

TIAM1, A CAMKII SUBSTRATE, AND ITS ROLE IN THE CA2+-DEPENDENT SIGNALING EVENTS OF THE EGG- TO-EMBRYO TRANSITION IN MAMMALIAN EGGS

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Calcium (Ca2+) signaling is a fundamental element of life, being involved in intracellular signaling pathways that are known for maintaining cellular homeostasis. In mammalian eggs, Ca2+ signaling mediates the egg-to-embryo transition, a developmental event composed of a series of events that transform a mature oocyte (egg) into a developing embryo following fertilization. Increased cytosolic Ca2+ induces key developmental events including the completion of meiosis, progression to embryonic mitosis, and the establishment of the egg's preventative mechanisms that block fertilization by more than one sperm (known as blocks to polyspermy). Calcium ions exert their effects through calcium-dependent effector molecules, and Ca2+/Calmodulin-dependent kinase II (CaMKII) is directly involved with exit from metaphase II stage and mediating events in early embryogenesis. It is known that the gamma isoform of CaMKII (CaMKIIγ) mediates multiple events of the egg-to-embryo transition, as evidence from studies that CaMKIIγ knockout female mice are infertile due to egg activation defects. Furthermore, CaMKII has numerous downstream effectors, including T-cell lymphoma invasion and metastasis 1 (Tiam1), a Rac1 guanine nucleotide exchange factor (GEF) phosphorylated by CaMKII in other biological systems such as neurons. Tiam1 activates small G-proteins Rac1 and Cdc42, which places Tiam1 as a potential mediator of membrane block establishment for actin cytoskeleton remodeling. Despite Tiam1 transcript being enriched in mammalian eggs and testes in mice, there are no known roles of Tiam1 in the mammalian egg-to-embryo transition. Here, we investigate the Ca2+-dependent activation of Tiam1 and its association to CaMKIIγ throughout meiosis and early egg activation stages. Expression of Tiam1 protein in oocytes was evaluated using immunoblotting and immunofluorescence, and Tiam1/CaMKIIγ co-localization was analyzed through proximity ligation assays (PLA). We detected both Tiam1 and CaMKIIγ (control) protein presence in egg lysate through immunoblotting. Immunofluorescence images show Tiam1 presence in both cytoplasm and cortex in Prophase I, Metaphase II, and fertilized eggs, and PLA for Tiam1 and CaMKIIγ in fertilized eggs indicate a promising mechanism for studying the co-localization of both Tiam1 and CaMKIIγ. These studies will elucidate the factors and pathways of Tiam1 and CaMKIIγ that contribute to the Ca2+ -dependent signaling events in the egg-to-embryo transition.

A HIGH-THROUGHPUT PLATFORM FOR INVESTIGATING TRANSPORT OF INTRATHECALLY INJECTED NANOPARTICLES

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Intrathecal injections are the least invasive way to deliver drugs to the brain while bypassing the blood-brain barrier. Upon intrathecal injection into the subarachnoid space, nanoparticle-based therapeutics interact with the surrounding injection environment: 1) forming a surface coating of proteins originating from the cerebrospinal fluid (CSF) called a biocorona and 2) binding to the extracellular matrix of pia mater, the tissue located between the subarachnoid space and brain parenchyma. While interactions between nanoparticles and the surrounding environment are known to occur, in vitro models to study the impact of CSF and extracellular matrix interactions on nanoparticle transport are limited. Investigating how nanoparticles interact with proteins in biological barriers (e.g., CSF and pia mater) is key for understanding how to improve nanoparticle drug delivery to the brain. Here, we develop a high-throughput platform for investigating nanoparticle transport through CSF and tissue matrices.

In this work, we investigate how albumin in artificial CSF (aCSF) alters the transport of nanoparticles with various surface chemistries through pia mater using a modified Transwell recovery assay. This model consists of two layers: 1) a solution of nanoparticles and aCSF, mimicking intrathecal injection microenvironment and 2) a pia mater mimic. By varying the amount of albumin in aCSF, we evaluate how albumin biocorona, and thus disease state, impacts nanoparticle transport. When adding albumin into the aCSF solution, nanoparticle transport is impacted differentially depending on the nanoparticle surface chemistry. There was an increase in transport of unmodified, carboxylated, and aminated nanoparticles with an increase in albumin due to decreased aggregation of nanoparticles in aCSF. PEGylated nanoparticles had a rapid decline in their ability to traverse through collagen with albumin.

The results indicate that nanoparticle surface chemistry and nanoparticle albumin biocorona are key factors that impact how a nanoparticle can traverse across collagenous barriers, such as pia mater. Additionally, a comparison to pig and human CSF was performed, allowing us to observe that nanoparticle transport through CSF is modeled better with aCSF containing albumin than aCSF without albumin. Diffusion of nanoparticles is dependent on the interactions between nanoparticle surface chemistry, albumin in the biocorona, and collagen in the extracellular matrix.

ERGONOMICS MEETS HERITAGE: MOTION CAPTURE OF INDIGENOUS DANCE FOR CULTURAL PRESERVATION

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IHuman ergonomics plays a vital role in how we interact with the world around us, and it is important to explore the different facets of this field, particularly cultural ergonomics. According to Lin et al 2014, "Cultural ergonomics is an approach that considers interaction- and experience-based variations among cultures". Developing a deeper understanding of cultural ergonomics is essential not only for engaging effectively within cultural contexts but also for creating interactive user experiences. This approach broadens our comprehension of cultural significance and enables us to apply this knowledge in the research, design, and evaluation of everyday products.

Hence, this project focuses on understanding the biomechanics and kinesiology of an African dancer from the Igbo tribe using the Move4D motion capture and dynamic body scanner system. This research project is the interweaving of African cultural heritage and cutting-edge technology to explore the interaction between the world of humans and technology. One of the primary outcomes of this project is to leverage modern motion capture tools to create a comprehensive digital library of Indigenous dance movements. This digital archive will provide a more precise and accessible format for learning about these movements and ensuring their preservation. The goal is to contribute to cultural sustainability while also creating a platform for cultural ergonomics in the dance movement.

The findings from this work can foster greater inclusivity and serve as a lasting resource for cultural exchange and understanding. The goal is to use this project as a stepping stone to move forward and expand who contributes to, and who benefits from, ergonomics study using advances in 3D motion capture technology.

C3-D SIMULATION OF IGNITION OF A REACTIVE STARTING HOT JET INTO A CH_4–H_2/AIR MIXTURE

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The ignition of premixed flammable mixtures can be effectively initiated by the injection of a sudden pulse of hot combustion products into a colder reactive environment. This process is of great relevance to advanced combustion concepts such as pre-chamber ignition and pressure-gain combustion, where rapid ignition must be achieved under transient and highly turbulent conditions. In this study, the ignition mechanism is examined for a starting jet of hot combustion products entering a quiescent CH_4–H_2/air mixture. Upon injection, the jet establishes two distinct flow regions: a high-speed trailing jet in the near-field and a leading vortex ring in the far-field. The leading vortex ring is of particular significance due to its universal dynamics, strong entrainment capability, and complex mixing processes, all of which strongly influence ignition. Entrainment occurs primarily through large-scale engulfment, followed by gradual molecular diffusion across the scalar interfaces. These mixing mechanisms lead to the development of spatially distributed ignition kernels, with the vortex ring often serving as the dominant ignition site.

To capture the unsteady processes of mixing and ignition, Large Eddy Simulation (LES) is employed. The jet composition corresponds to equilibrium combustion products from a rich premixed CH_4–H_2 fuel (equivalence ratio $\phi = 1.1$), injected at its adiabatic flame temperature. The inflow is introduced through a circular orifice of diameter D = 6 mm into a rectangular enclosure with a width-to-diameter ratio of W/D = 4 and a length-to-diameter ratio of L/D = 5, respectively. The injection velocity is Uj = 360 m/s, producing a strongly compressible and transient flow. Parametric variations of the main-chamber equivalence ratio and fuel blend are examined to evaluate their impact on ignition initiation and flame development. The results provide insight into the fundamental role of vortex-ring dynamics in jet-induced ignition and establish a framework for understanding ignition in practical combustion systems.

EFFICIENCY EVALUATION OF DIFFERENT METHODS FOR NITROGEN REMOVAL IN MUNICIPAL WASTEWATER TREATMENT PLANTS: AN INTEGRATIVE REVIEW

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Domestic wastewaters present high nitrogen levels due to the urea and ammonia, which are excreted into urine. Municipal wastewater treatment plants (WWTP) normally face some challenges in keeping their treated wastewater at a low total nitrogen concentration, since the majority of their wastewater is domestic. Low nitrogen levels in the treated wastewater are important to avoid increasing eutrophication of the receptor body, which receives the treated wastewater. This work presents an integrative review considering studies related to denitrification in domestic WWTPs published from January 1, 2018, to April 30, 2023. This review aims to identify the most effective methods for nitrogen removal in municipal WWTPs. The studies were classified based on the used technique: biological, chemical, electrochemical and statistical process control (SPC). They were evaluated according to their total nitrogen removal efficiency. Only reports with efficiency higher than 75% were included in this review. In total, 7 studies were analyzed, and their data correlated. It was possible to conclude that the most common approach used for nitrogen removal in WWTPs was the chemical addition, seeing that it is hard to treat domestic wastewater due to its low carbon/nitrogen (C/N) ratio. So, an efficient technique is using a chemical substance to increase the carbon source. The four most efficient solutions to remove total nitrogen in WWTPs according to the present review are: increase the source of electron donor for the denitrification process by adding acetate, methanol, or ferrous ion Fe(II) and H by microelectrolysis and inoculation of temperature-tolerant heterotrophic nitrifying-aerobic denitrifying bacterium Klebsiella sp. (KSND) seed culture.

FEEL THE BURN: A SYSTEM-OF-SYSTEMS APPROACH TO AERIAL FIREFIGHTING TACTICS AND FLEET COMPOSITION

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Wildfires have the potential to harm property, livelihoods, and human health. Studies have found that climate change has led to an increase in wildfire season length, wildfire frequency, and burned area. According to the National Oceanic and Atmospheric Administration, between 1980 and 2023 the United States had 22 wildfire events that individually caused more than $1 billion in damage; 18 of those have occurred since 2000. Over the past few decades, the United States has routinely spent more than $1 billion per year to fight wildfires, including $3.5 billion in 2022. These efforts have resulted in the deaths of hundreds of firefighters. Even in communities far downwind, wildfire smoke has been directly linked to poor air quality that can lead to significant health effects and costs to society (emergency department visits, hospital admissions, and deaths, often due to respiratory ailments). Aerial firefighting is known as a pivotal management practice in curbing the frequency and intensity of wildfires; in some cases, it is the only option for fire suppression. However, it is a very costly solution: effectiveness of this method has received a lot of criticism, with some analyses showing a loss of between 60 and 95%. In a study done by the U.S. Department of Agriculture assessing aerial firefighting use, the potential of predictive models to help managers evaluate the probability of success and determine efficient aviation strategies was noted, in which analytics are embedded into existing operational decision support systems. The RAND National Model and the RAND Local Resources Model have historically been used to predict fleet composition for initial attacks, however, little is known about the effectiveness of these aircraft against fires that are already large. Operationally, aerial firefighting is limited to times when aircraft have clear visibility - otherwise, pilots run the risk of flying into terrain or colliding with other aircraft. Developing Unmanned Aircraft System (UAS) technologies could overcome this limitation by enabling responders to remotely monitor and suppress these fires during nighttime and low visibility conditions. This work integrates a system-of-systems approach with a network flow framework to produce an evaluation tool that can be used to study aerial firefighting use and effectiveness, by determining fleet composition for large fires and predicting the cost benefit of introducing novel UAS airframes to fire suppression efforts.

MAPPING MEDIA FRAMES IN CIVIL CONFLICTS: A CROSS-NATIONAL ANALYSIS WITH CONFLIBERT

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Media framings of civil wars have long shaped public opinion, thereby influencing international responses and intervention decisions. While existing studies have relied primarily on qualitative evidence or focused on a single war dyad, less is known about how specific media framings affect civil conflicts more broadly using cross-national data. To address this gap, we introduce the Conflict Framing Dataset, a new resource that enables systematic, large-scale analysis of how international media framing influences civil war dynamics.

Our approach integrates natural language processing with conflict studies to quantify the framing of news coverage across thousands of international media articles. Using ConfliBERT, a transformer-based model pre-trained on conflict-related texts, we fine-tune the classifier to identify civil war dyads mentioned in news articles and categorize their dominant framing as humanitarian-focused or politically-focused. We further validate the model through manual annotation and inter-rater agreement to ensure classification reliability.

Our dataset contributes to the growing effort to quantify the global information space. By quantifying media narratives at scale, our dataset makes it possible to empirically test theoretical claims regarding media framing effects that have traditionally relied on qualitative evidence or single-dyad analyses. Integrating domain-adapted language models such as ConfliBERT, we offer a transparent and replicable framework for studying the global information environment.

Beyond building a dataset, this research demonstrates how computational text analysis can bridge data science and political science. By capturing large-scale patterns of media narratives, the Conflict Framing Dataset provides a foundation for exploring how different framings correlate with conflict intensity, international interventions, and humanitarian outcomes. Therefore, this research contributes to understanding how global media ecosystems shape state and non-state behaviors during civil wars, offering a scalable framework that can be extended to other domains of international communication and crisis analysis.

POINT-OF-CARE WOUND HEALING USING A HANDHELD COANDA-DRIVEN CENTRIFUGAL SPINNING DEVICE

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U.S. emergency departments treat about 7-9 million lacerations each year. Burns cause millions of injuries worldwide, and surgery adds postoperative wounds at risk of infection, with about 110,800 inpatient surgical-site infections in the United States each year. The costs are substantial - Medicare spends an estimated $28-$97 billion annually on wound care, each surgical-site infection adds about $12,000-$42,000 to a hospitalization for a national total of roughly $3.3-$10 billion and burn inpatient care averages about $9,000 per day.

Sutures, staples, and strong adhesives can be painful, leave visible marks, and often require skilled application. Fibrous bandages have emerged as promising alternatives that can protect tissue, deliver therapeutic agents, and support faster healing. However, while the raw materials used in these fibrous systems are not inherently expensive, the fabrication methods - often involving high voltage, tight environmental control, or harsh solvents - make current solutions costly and difficult to scale. These constraints limit their speed, portability, and suitability for point-of-care applications.

I developed a handheld device that forms and lays down dry, porous fibers directly onto the skin from a biopolymer solution. The spinner uses airflow and rotation to stretch a small jet into continuous fibers and to guide those fibers onto the wound. It avoids high voltage and extreme conditions, fits in one hand, and is designed for low-cost manufacturing and reproducible use.

The device is intended to enable rapid bedside closure and protection by creating a conformal, breathable barrier that can be removed or naturally resorb. The platform can be tailored to carry drugs or simple sensors. Planned evaluations include deposition rate and uniformity, adhesion under gentle motion, barrier performance and breathability, cytocompatibility, and time to functional closure compared with standard dressings.

PLGA-BASED IMPLANTS FOR LONG-ACTING GLAUCOMA THERAPY

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Glaucoma, a leading cause of irreversible blindness, results from increased intraocular pressure (IOP) that damages the optic nerve, essential for transmitting visual information to the brain. With more than 2.7 million people in the U.S. currently affected - a figure expected to increase to 4.2 million by 2030 - advancing effective glaucoma treatments has become increasingly urgent. Current therapies, primarily eye drops and oral medications, face challenges including poor patient compliance, rapid drug clearance, off-target side effects, and high recurring costs. Despite advancements like ILUVIEN and Durysta implants, limitations such as side effects and a lack of implants for carbonic anhydrase inhibitors persist. Our research focuses on developing a novel, biodegradable ocular implant to address these issues. Our methodology involves systematically investigating the effects of polymer composition and drug loading on release kinetics. Previous findings indicate that polymer chemistry and concentration are critical in modulating the drug release profile. The implant's ability to maintain therapeutic levels of the drug while minimizing systemic exposure has significant implications for patient outcomes. By incorporating dorzolamide, a carbonic anhydrase inhibitor (CAI) drug into a biodegradable poly(lactic-co-glycolic acid) (PLGA) matrix, our implant aims to release the drug over 6-12 months, reducing dosing frequency and enhancing patient compliance. PLGA, already FDA-approved for various medical applications, degrades into lactic and glycolic acid, which are naturally metabolized by the body. Our innovative approach leverages hot-melt extrusion, a solvent-free technique ensuring consistent drug-polymer mixing and controlled drug release. The significance of this work lies in its potential to improve glaucoma management by providing a sustained-release implant using dorzolamide, a carbonic anhydrase inhibitor drug often prescribed for glaucoma treatment.

Our research aligns with global healthcare goals by offering a long-term, cost-effective glaucoma treatment that could decrease vision loss rates and enhance quality of life. The development of this implant supports the overarching aim of reducing the burden of irreversible blindness worldwide. Future work will include optimizing the release profile and mitigating the effects of terminal sterilization on the final product to ensure safety and efficacy.

EFFECT OF DISCHARGE CURRENT RATES AND COOLANT TYPES ON LITHIUM-ION BATTERY DEGRADATION IN IMMERSION COOLING

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As electric vehicle adoption rises, lithium-ion batteries (LIBs) have become critical to global green energy goals. Current research on LIB degradation often examines factors like temperature and cycle count using constant charge/discharge rates. These static test methods, however, fail to capture the dynamic, variable loads of real-world driving. Consequently, the impact of random, high-variability discharge profiles on battery health remains largely unexplored. This research addresses this gap by experimentally evaluating battery degradation under a randomized discharge profile. It concurrently investigates the effectiveness of static immersion cooling, a prominent thermal management strategy, during dynamic operation. The study compares two distinct commercial LIB types cooled by one of four media: air and three different dielectric fluids (deionized water (DIW) and two oil-based coolants with one commercial product and the other from our collaborator). To establish a baseline, cells are first cycled at constant 3C, 4C, and 5C charge/discharge rates. Subsequently, they are tested using a dynamic protocol mixing 1C, 2C, 3C, 4C, and 5C rates with a constant 1C charging rate to simulate real-world use. Throughout all experiments, cell degradation and thermal performance are quantified by tracking discharged capacity, cell voltage, and temperature. Preliminary results from the constant-rate tests revealed distinct thermal performance: cells cooled by deionized water (DIW) exhibited the lowest surface temperatures, while air-cooled cells were the highest. The oil-based coolants yielded intermediate temperatures. A clear degradation trend emerged for the air-cooled cells due to the temperature effect, where discharged capacity decreased as the discharge rate increased. In contrast, cells immersed in DIW and oil-based coolants did not show a clear correlation between discharge rate and capacity. This suggests that a more precise comparison requires further refinement of the charging protocol to ensure identical charged energy with the same charging rate across all cells.

A DAILY NEWHALL SIMULATION MODEL FOR DEPTH-SPECIFIC SOIL MOISTURE ESTIMATION

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Soil moisture is a critical variable in the hydrologic cycle that governs processes such as infiltration, evapotranspiration, and runoff. Reliable soil moisture information enables effective water resources management, including flood and drought prediction as well as vulnerability assessment. However, the availability of depth-specific soil moisture data is limited. In situ measurements are spatially sparse, and satellite products have coarse spatial resolutions and are largely restricted to the surface layer. While many hydrologic models incorporate soil moisture processes, their vertical coupling is limited, so updates primarily affect the surface. Consequently, antecedent rootzone moisture, which is critical for groundwater recharge and runoff generation, is not adequately represented. This study proposes a simple, rule-based Newhall Simulation Model (NSM) for depth-specific soil moisture estimation using only precipitation and temperature. The monthly NSM is extended to a daily time step by expanding the soil water storage capacity to include saturation storage, adopting the Daily Thornthwaite method for daily potential evapotranspiration, and implementing a one-year spin-up to stabilize initial states. The model integrates depth-specific soil properties from the Gridded Soil Survey Geographic (gSSURGO) dataset and is evaluated using daily soil moisture observations from the U.S. Climate Reference Network (USCRN) at 45 stations from 2010 to 2016. Evaluation shows strong correlation ($r \approx 0.7$) and low unbiased root mean square error (ubRMSE ≈ 0.04) for both the surface and rootzone layers. These results demonstrate the feasibility of scaling the daily NSM from point stations to global applications when coupled with gridded meteorological inputs. The Python-based daily NSM can serve as a practical tool to improve initial soil moisture conditions for hydrologic models and enhance flood and drought prediction capabilities.

RDEVELOPING AN AGENT-BASED MODEL FOR SIMULATING FOOD ACCESS: A TIPPECANOE COUNTY CASE STUDY

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Food systems are subject to sudden disruptions, rapidly changing markets and emerging trends. Policymakers addressing food security are expected to consider potential effects of their decisions in a highly uncertain environment. Moreover, the impact of their decisions are non-trivial. Simulation models can be useful for testing systems-scale interventions to address such challenges that would otherwise be unethical or too costly to study in real life. While there is a shift towards more data-driven approaches, current technologies for food security remain descriptive, often presenting static poverty or food insecurity rates.

This study aims to develop an agent-based model (ABM) that captures dynamic food distribution and access behaviors in a local community. The ABM is implemented through a geospatial ABM Python library, Mesa-Geo. The model contains two decision-making agents, Food access sites and Consumers, and one passive agent, Bus stops. The Consumer agents' objective is to maximize food levels by acquiring them from Food Site agents, while Food Site agents can decide how to manage their operations.

This talk presents the method of development including model design choices, verification and validation. It will cover five ABM constructs: the spatial environment, the temporal scale, the agents' attributes, behaviors and rules governing their interactions. We discuss strategies of representing real life by seeding agent behaviors in empirical data from U.S. Census and other government data sources. Local-scale data on the built environment is incorporated for improved data resolution. We then demonstrate two simulation scenarios (one of a food system disruption and another of a food policy intervention) using Tippecanoe County, Indiana as a case study area.

The goal is for the ABM to allow policymakers to explore various scenarios and evaluate their potential impacts on our food system's food security metrics. The code is open-source, modular and easily adaptable to invite researchers and developers to tailor the ABM to their local communities.

NUMERICAL MODELING FOR ASSESSMENT AND EVALUATION OF NEW AND RETROFITTED BRIDGE RAILS UNDER IMPACT LOAD

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Bridge railings/barriers are critical safety components designed to contain and redirect vehicles during collisions, thereby preventing severe damage to the bridge structure and ensuring public safety. Their performance evaluation is traditionally based on full-scale crash testing in accordance with the AASHTO manual for Assessing Safety Hardware (MASH), a process that, while reliable, is both costly and time-consuming. Moreover, such tests are often limited in scope and cannot efficiently address modifications or retrofits to existing railing systems. To provide an efficient and reliable alternative, this study focuses on developing a high-fidelity numerical modeling framework to assess the impact performance of new and retrofitted bridge railings.

The research to date has concentrated on the development and validation of three-dimensional finite element (FE) models capable of capturing the dynamic behavior of bridge railing anchorages and concrete under the impact loading. Preliminary analyses have been conducted to evaluate single and group anchor behavior under varying loading rates and geometric configurations. The initial results demonstrate the potential of the proposed modeling approach to replicate realistic failure mechanisms and quantify the influence of key geometric features, boundary conditions and loading parameters on anchorage and concrete performance. Future work will extend this numerical framework through experimental validation at both anchor and sub-assembly levels.

The outcomes of this research will provide transportation agencies with robust, reliable and cost-effective analytical tools to evaluate both new and retrofitted railings, thereby reducing the reliance on expensive full-scale crash testing, accelerate design approvals, and enhance roadway safety.

UNDERSTANDING HOW REPRESENTATION ALIGNMENT EVOLVES DURING DEEP LEARNING TRAINING

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Deep neural networks routinely achieve strong performance in practice, yet we still lack a precise understanding of the internal mechanisms that enable efficient training. In particular, classical conditioning theory often predicts slower or less stable convergence than what is empirically observed. My research studies training through the lens of Neural Tangent Kernel (NTK) alignment to examine how architectural choices and optimizer dynamics shape the formation and evolution of internal representations during learning. This raises the main question: what properties of model structure and optimization cause alignment to emerge in a way that supports fast and stable training?

To investigate this, I conducted experiments across multiple neural architectures MLPs, CNNs, ResNet18, and Convolutional Kolmogorov-Arnold Networks (ConvKANs), computing per-layer NTK alignment, gradient loss norms, and weight drift. Using PyTorch and functorch, I compared the dynamics under SGD, momentum-based SGD, and Adam. My results indicate that alignment growth often corresponds more consistently with observed convergence behavior than classical conditioning metrics alone. Furthermore, optimizer and architectural choices systematically change the geometry of representation evolution, suggesting that alignment is not an accidental byproduct but an active mechanism shaping learning.

These findings have implications for both theory and model design. If we can predict when a configuration will align well before full training, we can reduce repeated trial-and-error runs, lower compute resource usage, and design neural networks that are inherently more efficient. This perspective supports an emerging viewpoint that alignment-based properties may be a more accurate descriptor of training efficiency than conventional conditioning metrics. Ultimately, understanding alignment dynamics could contribute to a more principled way of constructing models that train faster, require less experimentation, and scale more responsibly.

DATA-DRIVEN SAFETY ANALYTICS FOR LITHIUM-ION BATTERIES

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Accurate prediction of thermal runaway is crucial for optimizing the reliability and safety of Lithium-ion batteries (LIBs) across various applications. Traditional physics-based models often fall short in predictive accuracy due to the complex multi-scale-multi-phase interactions involved during thermal runaway events. To address such limitations, we present a comprehensive data-driven framework that utilizes a machine-learning approach to predict the thermal stability of LIBs. The study employs experimental data from accelerating rate calorimetry (ARC) experiments to analyze and predict critical safety characteristics such as thermal runaway onset temperature and exothermic heat release for a diverse set of cells. These cells exhibit differing state-of-charge (SOC) levels, electrode compositions, anode/cathode chemistries, aged under different operating conditions, etc., allowing the model to reflect real-world heterogeneity. By integrating a machine-learning model, our framework captures nonlinear relationships within metadata and ARC-derived observations, enabling scalable and accurate prognostics of commercial cells. From the ARC data, we extract four critical thermal safety metrics: self-heating onset temperature (T_1), thermal runaway onset temperature (T_2), peak runaway temperature (T_3), end temperature of learning window (T_w). These metrics provide a holistic view of the cell's thermal behavior during abuse scenarios. Input features include metadata and specific experimental ARC observations, enabling reliable thermal safety predictions despite the limited availability of training data. This study combines time-series prediction with data fusion of in-house experimental measurements and physics-based modeling, providing a versatile pathway toward real-time, reliable and efficient battery safety assessment. Our results highlight the potential of data fusion and time-series prediction as a viable alternative to purely physics-based approaches. Our ML-based Long-Short Term Memory (LSTM) model pipeline provides a scalable and accurate alternative to traditional thermal models, paving the way for advanced diagnostic tools and design optimization strategies. This work highlights the transformative role of data-driven methods in accelerating the development of inherently safer batteries and informing industrial practices and regulatory frameworks as the world transitions toward a more electrified and energy-resilient future.

LEFT VENTRICULAR KINETIC ENERGY AND ENERGY LOSS IN CHILDREN: A SECONDARY ANALYSIS OF THE PHN ECHO Z-SCORE PROJECT

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Background: The standardization of pediatric cardiac care remains challenging due to the continued reliance on adult-derived protocols and the wide variability in existing pediatric reference values. This lack of pediatric-specific guidelines leads to inconsistencies in clinical decision-making and compromises the accuracy of cardiovascular assessments in children. To address this limitation, we are characterizing age-dependent variations in intracardiac flow dynamics across the pediatric population. By establishing developmental benchmarks of healthy cardiac flow, our goal is to improve the precision and consistency of pediatric cardiac evaluations.

Hypothesis: We hypothesize that intracardiac flow dynamics significantly change with age, reflecting developmental adaptations in cardiac structure and function, and that the age-specific flow patterns observed in our initial cohort will be consistently reproduced in the larger, independent dataset. Validation of these developmental trends will confirm their utility as reliable benchmarks for pediatric cardiac assessment.

Methods: Apical four-chamber color Doppler echocardiograms from 571 healthy participants in the Pediatric Heart Network Echo Z-Score Project (median age 0.2 years, 54% female; ranging from newborns to 18 years) were analyzed. Velocity fields were reconstructed using Doppler Velocity Reconstruction (DoVeR), which applies mass conservation while allowing for rotational flow to resolve chamber velocity. Given rapid growth in infancy, linear regression models were performed on log-transformed variables.

Results: Kinetic Energy (KE) and Energy Loss (EL) showed exponential trajectories, with steepest changes in early infancy. KE rose progressively with development, while EL peaked in newborns and declined to lowest values in young adults. In multivariable models, both KE (R^2=0.43) and EL (R^2=0.49) were positively related to E-wave velocity, Left Ventricular (LV) ejection fraction and inversely to LV mass-to-volume ratio; but only EL was inversely related to body surface area.

Conclusion: This study provides the first pediatric LV reference values for KE and EL, identifies diastolic filling, contractility, and ventricular geometry as key determinants, and highlights inverse remodeling of KE and EL during developmental stage.

THERMAL COMFORT PREDICTION

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Predicting thermal comfort with high accuracy is critical for maintaining healthy indoor conditions and optimizing energy performance of HVAC systems. However, the effectiveness of predictive models is often constrained by the amount of training data available. In this regard, this study aims to investigate and compare various regression-based machine learning algorithms to predict thermal comfort in an educational building using a limited dataset. The data were collected by distributing the questionnaire from the occupants in an educational building. Furthermore, Synthetic Minority Over-sampling Technique for regression (SMOTER) and Genetic Algorithm (GA) are employed to balance data and improve machine learning efficacy. GA is employed to optimize the hyperparameters of the machine learning models, enhancing their predictive accuracy and reducing model bias. Five machine learning algorithms including support vector regression (SVR), artificial neural network (ANN), random forest regression (RFR), Extreme gradient boosting (XGBoost), and K-Nearest Neighbors (KNN) were trained using indoor air temperature, outdoor air temperature, relative humidity, metabolic rate, air velocity and clothing insulation as inputs. The results demonstrated that XGBoost model achieved the best performance with MAE of 0.204, RMSE of 0.301, and R2 of 0.8. Moreover, a feature importance analysis is conducted to identify the most influential parameters on TSV prediction. The results revealed that indoor air temperature, outdoor air temperature, and relative humidity were the three most significant factors affecting the occupants' thermal sensation vote.

DESIGN AND VALIDATION OF MODULAR MECHANO-BIOREACTOR FOR CHONDROCYTE EXTRACELLULAR MATRIX PRODUCTION

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Osteoarthritis (OA) is a musculoskeletal disease that affects more than 350 million individuals worldwide. One of the hallmarks of OA is the degeneration of the articular cartilage, the soft tissue at the end of bones in a diarthrodial joint that functions to cushion the bones during everyday motion. Due to the aneural and avascular nature of cartilage, the chondrocyte cells within the cartilage are responsible for maintaining the structure of the cartilage through integrating mechanical and chemical cues from their environment to upregulate or downregulate the production of extracellular matrix (ECM) components. While it has been proven that physiological mechanical loading can upregulate the production ECM, the mechanisms through which this occurs remain poorly understood. One of the barriers in studying mechanical loading effects on chondrocyte ECM production is the need for an easily replicable in vitro model that can recapitulate physiological loading effects with high throughput while maintaining cell viability. In this study, a modular, hot-swappable bioreactor designed for chondrocyte loading studies is validated through displacement verification, cell viability testing, and ECM production measurement. Displacement and frequency from the loading device were verified using digital image correlation. Following displacement verification, bovine chondrocyte-seeded, collagen-agarose hydrogels were loaded for 1, 3, and 7 days and tested for cell viability and ECM production. We found that gels loaded with this device showed increased sulfated glycosaminoglycan content, a major ECM component, compared to unloaded gels and the modular functionality of the device does not interfere with the cell viability. Results from this study offer an easily replicable device that can be used to better understand mechanisms of chondrocyte mechanotransduction in vitro and inform future treatments for OA.

LEVERAGING CLASSICAL AND QUANTUM COMPUTING FOR PROCESS SYSTEMS ENGINEERING APPLICATIONS: DECOMPOSITION ALGORITHM WITH ISING SOLVERS FOR EFFICIENT DISCRETE LANDSCAPE EXPLORATION

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Conceptual process design is a crucial aspect of chemical engineering that involves process synthesis, considering the various process phenomena. Mixed-integer nonlinear programming (MINLP) offers a powerful framework for modeling such design problems by combining discrete and continuous variables; however, the combinatorial complexity of discrete choices, coupled with nonlinearities, makes MINLPs challenging to solve as monolithic problems. Various simulation and mathematical optimization tools have been developed, often utilizing decomposition strategies that break the original problem into more manageable subproblems. Discrete subproblems can potentially benefit from quantum Ising solvers, while simulators and nonlinear solvers offer powerful tools for handling nonlinearities. To fully exploit recent advances in computational hardware, we propose an integrated approach that decomposes MINLP problems into discrete and continuous components and solves each subproblem using the most suitable computational method. Two case studies are presented: an illustrative example involving the selection of an ionic liquid and its process design, and a more complex problem of drug substance manufacturing process optimization. The discrete subproblem in each case is formulated as an integer programming and solved using a commercial classical optimization solver. For comparative analysis, the problem is reformulated as a quadratic unconstrained binary optimization and solved with simulated annealing (SA), quantum annealing (QA), and entropy quantum computing (EQC). The continuous subproblem is solved using Gurobi and a simulator-based optimization approach, respectively. In both examples, Gurobi achieved the shortest runtime, whereas EQC took the longest, followed by QA and SA, in reaching feasible and optimal solutions. The heuristic methods demonstrated advantages in solution diversity compared to Gurobi's global search approach, identifying all or most of the feasible solutions in a single run and better capturing a broad solution space. In contrast, Gurobi provides a global optimality guarantee and speed. This comparative analysis highlights

the distinct strengths of each method and underscores the potential of this heterogeneous computing approach, which enables the use of different methods to address practical optimization problems.

CYCLE-LEVEL ENERGY AND PERFORMANCE MODELING OF DIRECT AIR CAPTURE SYSTEMS

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Achieving global sustainability targets and limiting warming to 1.5 °C will require not only deep emission reductions but also dioxide removal (CDR) technologies to address unavoidable residual emissions from hard to abate sectors such as aviation, agriculture, and heavy industry. The IPCC Sixth Assessment Report (2022) states that all 1.5 °C warming scenarios involve some degree of CDR, and that without these technologies, most models cannot generate viable net-zero pathways. Direct Air Capture (DAC) is a promising approach, but large-scale deployment is limited by high energy demands and uncertainties about efficiency under real-world conditions. This study develops a cycle-level modeling framework to evaluate both energy consumption and CO_2, removal performance of DAC systems.

The model quantifies energy requirements across the distinct operational phases: adsorption, vacuum purge, regeneration, and cooling. It also estimates the mass of CO_2, captured per cycle, allowing direct comparisons of carbon removal potential against energy input. Simulating weather conditions demonstrates how ambient temperature, humidity, and pressure influence both energy consumption and capture efficiency. Preliminary results show that energy use is unevenly distributed across DAC phases, with regeneration accounting for the largest share of the demand. Variations in weather conditions also alter capture performance, revealing the importance of plant location considerations.

This cycle-based approach offers a method to assess the tradeoffs between energy input and carbon capture in DAC systems. The modeling framework can be extended to compare different sorbent materials, regeneration strategies, or operational scenarios, ultimately supporting efforts to optimize DAC for sustainable large-scale deployment.

ELASTIC ANALYSES OF LUNAR LAVA TUBES

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The presence of lava tubes under the surface of the Moon has been hypothesized for over half a century. Only recently, technological advances and recent discoveries have provided strong support for their existence. These are natural volcanic formations that exist on Earth, and likely under the surface of the Moon and Mars. These underground structures could be the answer to advancements in space exploration, as they offer a safer response against lunar hazards, such as meteoroid impact, moonquakes and radiation, than aboveground structures.

The goal of the study is to investigate the seismic performance of lunar lava tubes when subjected to seismic waves, and give insight into the performance of the tubes. This is done numerically, using the Finite Element software PLAXIS 2D. The analyses assume a homogenous, isotropic, and elastic basalt, with the direction of the seismic motion perpendicular to the tunnel axis. Based on observations of the shape of lava tubes on Earth, the cross section of the opening is chosen as semi-elliptical, with a ratio of 1:3 between the vertical and horizontal axes of the ellipse, and a horizontal bottom surface. Similarly, given the type of rock forming the tunnels (basalt) and its geomechanical characteristics, a GSI (Geological Strength Index) of 70 is adopted. Three different cross-section diameters are explored, each based on past findings: 30m, 300m, and 1,000m. The first value is representative of typical sizes of lava tubes found on Earth, and the other two are consistent with data analysis from the Gravity Recovery and Interior Laboratory (GRAIL).

The results show that, as expected, the larger the diameter of the lava tube, the larger the seismic demand. It was found that overburden depth is a critical parameter, with shallow tunnels presenting higher seismic load. Interestingly, the largest demand on the perimeter of the tube changes with overburden depth. It moves away from the crown, towards the smaller tangential angles, as the overburden increases. The paper maps the combinations of size and depth of lunar lava tubes that, for a given moonquake, induce a higher probability of failure or, at least, of significant damage to the tube.

LLM-GUIDED ROBOTIC TASK PLANNING WITH PERSISTENT SCENE GRAPHS AND MODULAR BEHAVIOR COORDINATION

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Enabling robots to understand and execute complex, natural language instructions in unstructured environments remains a fundamental challenge in robotics. Traditional approaches rely on hand-crafted state machines or symbolic planners that are brittle, labor-intensive, and difficult to scale across diverse tasks and domains. This work presents an integrated system that leverages large language models (LLMs) for hierarchical task planning, grounded in a persistent 3D scene graph that maintains object identities, semantic labels, and six-degree-of-freedom poses throughout task execution.

Our system addresses the gap between LLM semantic reasoning capabilities and the physical grounding required for robot control by combining three core components within a ROS2-based framework: (1) a perception module that constructs dynamic scene graphs from RGB-D data using YOLOv8 for detection and FoundationPose for zero-shot 6D pose estimation, (2) an LLM-based planner (Llama 3.2 70B) that generates structured JSON outputs encoding symbolic subgoals and spatial constraints, and (3) a behavior coordination module that translates high-level plans into parameterized robot primitives with real-time failure detection and recovery mechanisms.

We conducted extensive evaluations across both simulation and real-world deployments on the SquadBot platform. Our system successfully executed complex manipulation and navigation tasks specified in natural language, achieving robust performance through spatial reasoning algorithms that resolve object instances based on metric relationships and dynamic stance-point computation. The architecture supports two-tiered failure recovery: immediate retry mechanisms for transient failures and memory-based adaptation that stores successful alternatives for recurring failure conditions, eliminating repeated user intervention.

The implications of this work extend beyond individual task completion to enabling truly adaptive robotic systems. By maintaining persistent environmental memory and leveraging structured LLM outputs rather than end-to-end policies, our approach provides interpretability, modularity, and rapid deployment capabilities without task-specific retraining. This framework establishes a foundation for intuitive human-robot interaction and scalable autonomous behavior in dynamic, real-world environments, paving the way toward more intelligent and accessible robotic systems capable of long-horizon reasoning and continual adaptation.

ENHANCING GENERAL AVIATION SAFETY BY ASSISTING PILOTS WITH BETTER WEATHER-RELATED DECISION-MAKING

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Many weather-related general aviation (GA) accidents occur when pilots inadvertently fly into adverse weather conditions. This happens when GA pilots fail to ascertain the correct weather conditions at a given location and end up flying from visual flight rule (VFR) conditions into instrument flight rule (IFR) conditions. Previous FAA research indicates that when presented with static display images of weather information sources for specific locations, pilots were unable to accurately distinguish and identify the correct flight rule conditions at these locations. Furthermore, despite inaccurate estimations, they reported a high level of confidence. This dissonance between their estimations and confidence is dangerous as it affects their ability to accurately discern risk. This can lead to flight in hazardous weather conditions, further contributing to the high GA accident rate. The FAA's Partnership for Enhancing General Aviation Safety, Accessibility, and Sustainability (PEGASAS) Project 36, led by the author's research group at Purdue, aims to address this issue through a human factors-based analysis of pilot decision-making in adverse weather conditions. A total of 72 experienced pilots from different age groups with varying flight hours and ratings participated in a part-task study at the FAA technical center in Atlantic City. They were presented with detailed static display images of three distinct aviation regions with varying map layers and increasing resolutions. The pilots interacted with these images and filled out a survey to estimate the flight rules conditions at these locations and indicated their associated confidence levels for their estimations. The preliminary results from this survey confirmed the findings from previous research that despite varying map levels and increasing levels of resolution, pilots still struggle with accurately estimating the correct flight rule conditions, and yet still report high confidence levels. Further data analysis is being conducted to look for the specific underlying reasons behind this phenomenon. By understanding what is causing the pilots to mischaracterize weather risks, it is possible to better support them in their weather-related decision-making processes. If GA pilots can be assisted and trained to make better weather-related decisions, it has the potential to reduce the number of GA weather accidents.

A DEEP LEARNING FRAMEWORK FOR FASHION COMPATIBILITY RECOMMENDATIONS: CAPTURING THE DESIGNERS' PERSPECTIVES

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This research addresses the most fundamental problem faced by the consumers of the global fashion industry, that is currently valued at $1.84 trillion; the problem of Fashion Compatibility. Fashion compatibility can be defined as understanding how harmonious garments are with one another with respect to style, color, texture, and other visual features. In the current state-of-the-art systems in research laboratories, features are extracted from images of the garments with the same importance given to all these attributes. However, in industrial SOTA, all current systems use GPTs for compatibility recommendations, and do not recognize the importance of non-visual features that can influence the assessment of compatibility. To cite just one example of nonvisual features, a fur-lined coat may appear to be compatible with a pair of pants on the basis of visual features such as color and texture, but it would not be an appropriate recommendation for someone living in an equatorial country. We are proposing a framework that seeks to mimic how personal fashion stylists and designers approach the problem of judging compatibility. The proposed system is agent-based, in which each agent is an expert along one compatibility dimension. For example, our framework has an expert on color theory, another expert knowledgeable about material attributes, another expert about textures, and so on. To account for situational factors such as regional style, seasonality, or occasion, the garment query is first processed through a Fashion Context Determination Network (FCDN), which produces a context embedding that informs all expert modules. Cross-compatibility between the expert dimensions is then modeled using a transformer-based cross-attention mechanism, allowing the system to generate recommendations that are both context-aware and interpretable.

SIMULATED MICROGRAVITY GERMINATION USING A PORTABLE ROTATIONAL POSITIONING MACHINE

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Sustainability: Future long-duration space missions depend on bioregenerative life support systems (BLSS) that can recycle air, water, and food through biological processes. To sustain life beyond Earth, understanding how plants respond to microgravity is crucial for developing closed-loop habitats that support human survival on Mars and beyond. This project presents the development of a low-cost, portable rotational positioning machine (RPM) that simulates microgravity on Earth to study plant germination dynamics in analog conditions.

The RPM operates using dual-axis continuous rotation to average out the gravity vector over time, creating an environment of "effective zero-g". A microcontroller-integrated inertial measurement unit (IMU) continuously records acceleration in three axes to validate the simulated microgravity at the device's center. The experiment exposes seeds to this condition for 1 week, modeling their growth "en route to Mars", followed by transplantation into the Mars Desert Research Station (MDRS) Green Hab to replicate the idea of surface cultivation under Martian gravity. Growth metrics such as germination rate, root length, and leaf development will be compared against Earth-gravity germinated plant to assess physiological and developmental differences.

This analog study demonstrates how microgravity exposure may influence early plant adaptation and resilience when transitioning to gravitational environments. The experiment also serves as a proof-of-concept for low-cost ground analogs that bridge space biology and sustainable agriculture research. By combining mechanical design, embedded sensing, and biological analysis, this project advances the understanding of plant behavior in altered gravity fields, offering criticial insights for designing regenerative life support systems and advancing humanity's sustainable presence beyond Earth.

ANALYSIS OF TENNIS STRING STRUCTURE AND PROPERTIES

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Tennis racket performance is determined by two key components - the frame, and the strings. Top level tennis racket frames are sold unstrung, leaving the selection of string type to the player. With hundreds of rackets and strings on the market, there are seemingly endless combinations for players to consider. Commonly reported string properties include brand, material, and gauge; but players must also consider durability, power, price, comfort, and spin.

In previous studies, structural differences in strings were observed using optical microscopy. Tensile testing has been conducted to calculate the dynamic stiffness (~ unloading modulus) of different string materials. Despite this analysis, limited connections have been made between these observations. To provide more insight into string performance this investigation builds upon previous techniques and incorporates connections across results.

Twenty strings were analyzed using the test procedures described. When available, two strings, each from different brands, were selected for each material category and were purchased in two gauges, 16 and 17 respectively. The material categories evaluated include - multifilament, aramid fiber, polyester, synthetic gut, natural gut, and polyester. All samples were taken from a new spool of string at even increments to account for variability within the spool.

To observe structural differences between strings epoxy-mounted microscopy samples were prepared. The cross section of each string was captured on an optical microscope. The micrographs were then analyzed in imageJ to quantify the number and diameter of constituent fibers.

Two mechanical tests were carried out - dynamic stiffness and tensile failure. In the dynamic stiffness test each string was loaded to 280N, held for 100 seconds, loaded to 380N, held for 10 seconds, and unloaded. This sequence approximates what a string would experience during mounting into the frame and play. From these results, the dynamic stiffness or unloading modulus was calculated. In the tensile failure test strings were loaded at a constant rate of 50mm/min until failure. Each of these tests was conducted on five samples.

Initial results highlight significant variability across tennis strings within the same material category. A string morphology with unevenly distributed constituent fibers was found. This combination of test techniques enables analysis of links between string construction and string properties.

ADVANCING PRECISION TIMING: A LOW-POWER, HIGH-LINEARITY DIGITAL-TO-TIME CONVERTER FOR NEXT-GENERATION MIXED-SIGNAL SYSTEMS

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Achieving both high linearity and a wide delay range in digital-to-time converters (DTCs) remains a key challenge in precision timing circuits due to slope distortion and charge redistribution effects. These limitations often restrict the performance of systems such as phase-locked loops (PLLs) and time-based analog-to-digital converters. This research introduces a highly linear, constant-slope DTC architecture that expands the achievable delay range while maintaining fine resolution and ultra-low power consumption - addressing long-standing trade-offs in time-domain design.

The proposed DTC employs a three-capacitor-bank charge-redistribution scheme that includes coarse, voltage-boosting, and fine-tuning banks. This architecture enables efficient charge sharing, raising the initial voltage of the coarse bank to achieve a 4 ns programmable delay range while maintaining a constant discharge slope across digital codes. Linearity is further preserved through a scalable current-source array that maintains a fixed current-to-capacitance (I/C) ratio. To reduce power usage, a native-transistor-based biasing network ensures stable operation at the pico-watt level.

Fabricated in TSMC 180 nm CMOS technology, the prototype achieves 488 femtosecond resolution with 13-bit digital control, a maximum integral nonlinearity (INL) of only 1.5 LSB, and 0.5 mW total power consumption at 25 MHz. These results demonstrate significant improvements over conventional architectures in both linearity and energy efficiency.

Beyond its technical merits, this work contributes to the advancement of energy-efficient, high-precision timing solutions critical for modern communication, sensing, and computing systems. By combining circuit-level innovation with practical manufacturability, this research moves a step closer to realizing scalable, low-jitter time-domain circuits for future integrated systems.

NON-INVASIVE ULTRASONIC TECHNIQUE FOR DETECTION OF LIQUID-VAPOR INTERFACE IN HEAT PIPES

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Heat pipes are passive thermal management devices that transport heat efficiently through the phase change of an internal working fluid. Their operation relies on capillary pumping within a porous wick structure that circulates liquid between the evaporator and condenser. The upper operating limit of these devices is defined by the capillary limit - the maximum heat input at which capillary pressure can overcome pressure drops in the wick and vapor core. Operating beyond this limit depletes liquid at the evaporator, leading to dryout and reduced heat transport capability. Modern electronics, however, experience transient power bursts that frequently exceed this limit, creating challenges for maintaining thin, high-performance thermal solutions. While their transient behavior is governed by complex phase-change dynamics and fluid redistribution, the liquid-vapor interface that dictates these mechanisms has never been directly visualized. Characterizing these dynamics is vital for next-generation cooling technologies, where overdesigning for peak loads is neither practical nor efficient. To address this gap, this work develops non-invasive ultrasonic and X-ray diagnostics to enable in situ visualization of interface motion and improve understanding of two-phase transport in heat pipes under transient operation.

This presentation reports on the development and application of a non-invasive ultrasonic imaging technique for visualizing liquid-vapor interfaces in heat pipes. The method was first demonstrated using optically transparent cuvettes to validate ultrasonic detection of static interfaces under controlled conditions. Exploiting the strong acoustic impedance contrast between liquid and vapor, the approach achieved high-resolution reconstructions of meniscus profiles validated against optical imaging. It was then applied to a sealed, non-operating heat pipe - achieving the first-ever ultrasonic visualization of internal wick menisci and vapor distribution within a heat pipe. Building on this foundation, a transient imaging framework was developed to capture dynamic interface motion, first in a cuvette and later in an operating heat pipe under controlled loads. Preliminary results from complementary X-ray microscopy will also be presented. Together, these diagnostics establish a foundation for in situ characterization of two-phase interface dynamics, providing a tool for understanding dryout, rewetting, and transient heat pipe behavior.

INVESTIGATING FUNCTIONAL METAMATERIALS WITH EMBEDDED SENSING FOR THERMAL MANAGEMENT

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In the field of thermal management solutions, pumped two-phase cooling can significantly improve heat dissipation capabilities, but can also cause maldistribution problems and yield to fluid flow instabilities. In-situ and real-time flow monitoring and detection of these anomalies is challenging and not feasible with traditional sensing methods, leading to a lack of knowledge of the true behavior of these occurrences. To this end, functional metamaterials can be employed to react to different thermal and mechanical stimuli to provide signals to enable control capabilities. Metamaterials can be made of a variety of materials and configurations, and these structures can react to external stimuli and record the information based on interactions. When connected in a network, these metamaterials act as a health monitoring system that is low-cost and low-power.

Our research is exploring the design space and functionalities of memory-enabled metamaterials. Specifically, this presentation will focus on the material characterization and fabrication of multi-material polymer composites along with a validation experiment of displacement with varying temperature for a finite element analysis model capturing the shape morphing characteristics of samples. These structures (made with various materials and printing techniques) are compared, and this knowledge is used to design geometries that can be deployed within an internal flow setup. The goal is to ultimately create a system of bistable passively actuating sensors that can respond to temperature and pressure inputs and create a more robust and resilient thermal management system.

GAME THEORETIC COURSE POLICY DESIGN FOR FAIR GRADING IN TEAM-BASED COLLABORATIVE ASSIGNMENTS

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Team-based projects are widely adopted because collaborative learning improves teamwork and professional skills while enhancing student engagement and academic achievement. However, free-riding, uneven effort distribution and misreporting remain endemic in group assignments, undermining fairness in grading and learning outcomes. Traditional peer-evaluation and calibration meetings are vulnerable to bias and strategic misreporting. Game theory offers a more rigorous approach to align grading incentives with equitable contributions and truthful reporting. Recent game-theoretic peer assessment models provide strong theoretical guarantees but lack large-scale classroom validation. In this study, we introduce a novel contribution reporting mechanism and grading policy that encourages equal contribution by all team members as a Nash equilibrium under full rationality. We implement this reporting mechanism and grading policy in a junior-level computing class for engineering undergraduate students with a class size of 185 students split into 37 teams. Using performance records, survey data and group peer contribution reports from a semester-long course, we ask three research questions: (R1) Does the game-theoretic grading policy lead to an equilibrium of equitable contributions? (R2) Which student-level factors (engagement, motivation, self-expectation, expertise) correlate with reported contributions? (R3) Do teams that claim equal contributions exhibit greater homogeneity in the correlated student-level factors, thereby indicating truthful reporting? Two new metrics measuring team consistency and effective effort exhibited by each student are proposed to infer truthfulness of effort reporting. Results show that 69% of teams reported equal contributions across all team-based assignments throughout the semester. Equitable reporting was strongly positively correlated with individual expertise and weakly positively correlated with self-perception. Teams declaring equal effort were highly homogeneous on correlated individual factors like individual expertise and also had higher mean calculated effective effort, indicating a higher confidence in their reportings. These results provide empirical support that our proposed reporting mechanism and grading policy encourage equal contributions and truthful reporting.Our findings demonstrate that strategically designed grading rules can mitigate free-riding and empower fair merit-based assessment without imposing monitoring.

SIRT1 PROTEIN REGULATION IN A 3D CHONDROCYTE INJURY MODEL

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Post-traumatic osteoarthritis (PTOA) is a progressive joint disease that develops following traumatic joint injury. After cartilage impact, a molecular cascade is triggered in chondrocytes and ultimately leads to cartilage degeneration and OA. While some molecular changes after chondrocyte injury have been identified, a deeper understanding of the signaling response is essential for identifying potential therapeutic targets. Sirtuin 1 (SIRT1), a NAD^+-dependent deacetylase, plays a key role in cartilage maintenance and chondrocyte health. We previously reported that SIRT1 enzymatic activity is suppressed in bovine osteochondral explants after a mechanical impact, and that SIRT1 plays a regulatory role in the chondrocyte injury response.

In the current study, SIRT1 regulation was determined at the protein level in response to injury using a 3D in vitro chondrocyte-loaded hydrogel model. Primary bovine chondrocytes were embedded in 4% agarose and were subjected to a single parabolic compressive load, reaching 65% strain with the maximum acceleration capacity of the motion controller system. Chondrocyte injury was confirmed via measurement of nitric oxide in the media and mitochondrial activity in gels. Cell viability was assessed with Live/Dead staining. Protein was extracted from gels at 5 minutes and 24 hours post-injury for Western blot analysis.

Consistent with our prior findings, SIRT1 activity was suppressed within 5 minutes of the sublethal mechanical load and remained low at 24 hours. NO levels were elevated in the media from the loaded gels. Preliminary data indicated a decrease in SIRT1 protein 24 hours after mechanical load. Furthermore, pretreatment with the proteasome inhibitor MG-132 prevented SIRT1 protein loss at 24 hours, but not at 5 minutes, suggesting that delayed SIRT1 degradation is proteasome-dependent, while early loss is not. Our data show that SIRT1 regulation changes over the 24 hours following injury, suggesting that different treatment strategies may be needed for early versus delayed intervention.

INFLUENCE OF LIMESTONE CONTENT IN CEMENT ON CONCRETE WITH NONTRADITIONAL AND NATURAL POZZOLANS

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Concrete, made from cement, water, and aggregates, is the most widely used construction material in the world. However, cement production accounts for about 8% of global CO_2 emissions. To reduce these emissions and improve concrete durability, producers often replace part of the cement with supplementary cementitious materials (SCMs) such as fly ash or slag cement. Nevertheless, the availability of traditional SCMs continues to decline, therefore nontraditional and natural pozzolans (NNPs), many of which are underutilized, are emerging as a viable alternative. At the same time, the cement industry has phased out the production of Type I cement, which contained less than 5% limestone, and has transitioned to producing Type IL cement, which includes 5-15% finely ground limestone as a partial replacement for clinker.

This research aims to improve understanding of how limestone in preblended cements interacts with nontraditional and natural pozzolans (NNPs). To study the effects of these materials on strength and durability of mortar mixtures, test specimens were prepared using three commercially available Type IL cements with different limestone contents and three NNPs: volcanic ash, calcined clay, and ground bottom ash. The specimens were tested for compressive and flexural strength, and drying shrinkage.

Preliminary results indicate that mixtures containing Type IL cements and NNPs can achieve strengths comparable to or greater than those of the baseline mixture. The data also suggest that cement fineness affects early-age strength, while drying shrinkage depends more on specific mixture composition, with certain NNP-Type IL combinations showing potential for reducing cracking risk. Once fully developed, these findings could provide practical guidance for using of these materials in transportation and infrastructure projects. They also indicate that appropriate pairing of Type IL cements with locally available NNPs can reduce carbon footprint of the mixtures while maintaining or improving performance.