

CIVIL, ARCHITECTURAL, AND ENVIRONMENTAL ENGINEERING

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Chair

Brent Stephens

Faculty with Research Interests

For more information regarding faculty visit the Department of Civil, Architectural, and Environmental Engineering website.

The Department of Civil, Architectural, and Environmental Engineering offers graduate programs focused on infrastructure and infrastructure systems, with strengths in structural engineering, transportation engineering, environmental engineering, public works, construction engineering and management, architectural engineering, energy systems engineering, engineering management, and urban systems engineering. The CAEE department maintains close relationships with business, industry, and government organizations and leaders. Our central location in Chicago provides our students with access to an extraordinary range of opportunities, including exploring one of the world's great cities and the historical and cultural heart of America's architecture, engineering, and construction (AEC) industry. Our faculty members include a combination of research- and teaching-focused professors and adjunct professors with years of industry experience.

Research Facilities

Research facilities include laboratories devoted to concrete structures, metal structures, building materials, building energy and environmental systems, indoor and outdoor air quality monitoring, transportation engineering, construction engineering and management, and environmental and water resources engineering.

In addition, faculty and graduate students have access to regional facilities such as the Argonne National Laboratory. Also, the department has a computer-aided engineering and design lab equipped with state-of-the-art hardware and software.

Research Areas

The main research areas in the department are architectural engineering, construction engineering and management, environmental engineering, transportation engineering and public works, and structural engineering.

In architectural engineering, faculty conduct research in the built environment, airflow and thermal modeling, indoor air quality, energy and sustainability, and thermal comfort.

Construction engineering and management research involves construction productivity, scheduling and progress control, dispute resolution, construction company organization, sectorial studies, and project management.

Environmental engineering research areas include air resources and water treatment, wastewater treatment, and water resources engineering.

Research in the public works specialty area includes public policy evaluation, management of engineering operations, maintenance, and rehabilitation and construction of civil infrastructures such as roads, bridges, and traffic safety hardware.

Structural engineering research concentrates on structural dynamics and earthquake resistant design, structural health monitoring, computational mechanics, and bridge engineering.

Transportation engineering research areas include multimodal transportation infrastructure and dynamic traffic network mobility, safety, security and emergency management, transportation asset management, and network economics.

Admission Requirements

Minimum Cumulative Undergraduate GPA

3.0/4.0

Minimum GRE Scores

- Master's/Master of Science: 292 (quantitative + verbal), 2.5 (analytical writing)
- Ph.D.: 292 (quantitative + verbal), 2.5 (analytical writing)

Minimum TOEFL Scores

80/213 (internet-based/paper-based test scores)

Note: the GRE requirement is waived for master of engineering degree applicants who hold a bachelor of science in a related field from an ABET-accredited university in the U.S. with a minimum GPA of 3.0/4.0.

Meeting the minimum GPA and test score requirements does not guarantee admission. Test scores and GPA are just two of many factors considered.

Each full-time graduate student is assigned a faculty adviser at the time of initial registration. Part-time or non-degree students who have not been assigned an adviser and who intend to pursue a degree should contact the department for counseling before registering for courses.

Degree Programs

- Master of Engineering Management, Project Management Track
- Master of Engineering in Architectural Engineering
- Master of Engineering in Construction Engineering and Management
- Master of Engineering in Energy Systems, Energy Conservation and Buildings Track
- Master of Engineering in Environmental Engineering
- Master of Engineering in Structural Engineering
- Master of Engineering in Transportation Engineering
- Master of Engineering in Urban Systems Engineering
- Master of Public Works
- Master of Science in Architectural Engineering
- Master of Science in Civil Engineering with specialization in:
 - Construction Engineering and Management
 - Structural Engineering
 - Transportation Engineering
- Master of Science in Environmental Engineering
- Doctor of Philosophy in Architectural Engineering
- Doctor of Philosophy in Civil Engineering
- Doctor of Philosophy in Environmental Engineering

Certificate Program in Architectural Engineering

- Architectural Engineering
- Building Commissioning
- Building Energy Modeling

Certificate Programs in Civil Engineering

- Construction Management
- Earthquake and Wind Engineering Design
- Environmental Engineering
- Infrastructure Engineering and Management
- Transportation Systems Planning

Course Descriptions

CAE 502

Acoustics and Lighting

General introduction to the aural and visual environment. Subjective and objective scales of measurement. Laws of psychophysics. Introduction to vibration. The hearing mechanism. Transfer of sound. Passive control of noise in buildings, transmission loss. Absorption and reverberation time. Active control of the aural environment. Visual perception. Photometry, brightness, luminance and illumination. Natural lighting of buildings. Artificial lighting.

Lecture: 3 Lab: 0 Credits: 3

CAE 503

Advanced Structural Analysis

Introduction to the mechanics of solids. Energy methods and the calculus of variations. Ritz/Galerkin approximation methods. Introductory discussions on elastic stability and plate analyses.

Prerequisite(s): CAE 411 with min. grade of C or MMAE 501* with min. grade of C or CAE 514* with min. grade of C or Graduate standing, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

CAE 504

Seismic Retrofit and Earthquake Hazard Reduction

Selection of site-dependent earthquake for retrofit. Strength and ductility of aging structures. Cyclic behavior and modeling of structures under seismic loading. Performance-based retrofit criteria. Evaluating earthquake vulnerability of existing buildings and bridges. Upgrading lateral load-carrying systems. Conceptual basis for seismic isolation and energy-absorbing techniques and their applications in earthquake hazard reduction in existing bridges and buildings. Selection of retrofit methods. Case studies of seismic retrofit of typical buildings, bridges, and industrial facilities using strength upgrading, energy dissipation devices, and base isolation.

Prerequisite(s): CAE 529 with min. grade of C

Lecture: 4 Lab: 0 Credits: 4

CAE 505

Applications of Computational Fluid Dynamics in Engineering

The course introduces concepts of computational fluid dynamics (CFD) and focuses on engineering applications of CFD. Students will learn how to use CFD tools to model internal and external flows in a wide range of architectural, chemical, civil, and mechanical engineering applications. Projects offer students flexibility in selecting their applications. Example semester long projects include design of room air distribution systems, indoor and outdoor air quality, natural ventilation, heat transfer coefficient calculations, pipe flow, rotating reference frame, and more.

Lecture: 3 Lab: 0 Credits: 3

CAE 506

Building Envelope Rehabilitation

Repair and rehabilitation of existing building exterior envelopes. The course will include problem identification, investigative techniques, repair methods, preparation of remedial design documents and general management of rehabilitation projects. Types of constructions include buildings, exterior walls, facades, cladding, roofing, plazas, porches, fire escapes, and others.

Lecture: 3 Lab: 0 Credits: 3

CAE 508

Advanced Bridge Engineering

Specifications for bridge design and evaluation. Advanced bridge design and evaluation topics such as design load envelope, seismic load design, bridge condition rating, bridge load rating, and steel bridge fatigue evaluation. Bridge management systems. Life cycle analyses. Use of high performance materials in bridge engineering.

Prerequisite(s): CAE 408 with min. grade of C or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

CAE 510

Dynamics of Fire

Introduction to fire, physics and chemistry, and mass and heat transfer principles, fire fluid mechanic fundamentals, fundamentals and requirements of the burning of materials (gases, liquids, & solids), fire phenomena in enclosures such as pre-flashover and post-flashover.

Lecture: 3 Lab: 0 Credits: 3

CAE 511

Fire Protection of Buildings

Fundamentals of building design for fire and life safety. Emphasis on a systematic design approach. Basic considerations of building codes, fire loading, fire resistance, exit design, protective systems & other fire protection systems. For architects, and engineers not majoring in fire protection and safety engineering.

Lecture: 3 Lab: 0 Credits: 3

CAE 513

Building Science

Study of the physical interactions between buildings, people, and climate (i.e., temperature, humidity, wind, sun, rain, snow, etc.).

Topics include: heat transfer, psychrometrics, thermal comfort, indoor air quality, ventilation, infiltration, solar insolation, heating and cooling load calculations, building energy efficiency, and building codes.

Lecture: 3 Lab: 0 Credits: 3

CAE 514

Mathematical Methods for Structural Engineering

Matrices, linear spaces and transformations, eigenvalue problems, and their application to civil engineering. First-order differential equations for structural dynamics. Calculus of variations and variational principles for dynamics and statics. Rayleigh-Ritz method, finite element approximations, Newmark-Beta method, Green's Function, and Duhamel Integral and their application to civil engineering.

Lecture: 3 Lab: 0 Credits: 3

CAE 515**Building Information Modeling Applications for Building Performance**

Building Information Modeling (BIM) is at the core of building performance optimization and sustainability, making it possible to model performance while tracking construction of the building in sequence. This course builds essential knowledge of building performance optimization using BIM processes and provides the necessary background and skills to use BIM with building energy simulation software tools. Autodesk Revit with Insight will be used as the primary design authoring, manipulation, and analysis tool. Secondary Autodesk BIM tools such as Formit for building massing and orientation; recap for existing conditions capturing; Navisworks for interference checking and design collaboration; revit Live for Virtual Reality visualizations and presentations; and BIM 360 Ops for facility management and operation will also be used in class. Proven methods for using BIM to address essential building performance and sustainability issues will be presented using real-world examples, placing particular emphasis on using BIM for analysis of design alternatives for the life cycle of a building. Complete with coverage of sustainability, integrated design, and lean construction requirements, this is a valuable course for architects, architectural engineers, MEP engineers, facility managers, and other construction professionals involved in building performance modeling and optimization.

Lecture: 3 Lab: 0 Credits: 3

CAE 517**HVAC Systems Design**

Study of the fundamental principles and engineering procedures for the design of heating, ventilating, and air conditioning systems; HVAC system characteristics; system and equipment selection; duct design and layout. Attention is given to energy conservation techniques and computer applications.

Prerequisite(s): CAE 331 or CAE 513

Lecture: 3 Lab: 0 Credits: 3

CAE 518**Advanced Reinforced Concrete**

Advanced topics in behavior and mechanics of reinforced concrete members: ultimate flexural strength, development of reinforcement, moment-curvature analysis, non-linear deflections, two-way slabs, deep beams, torsion, columns with biaxial bending, slender columns, and numerical methods. Strong emphasis is placed on the underlying structural behavior and its influence on building codes and design standards.

Prerequisite(s): CAE 432* with min. grade of C or Graduate standing, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

CAE 519**Structural Forensic Engineering**

Introduction to structural forensic engineering as relates to civil and architectural engineering. Application of engineering principles to failure investigations including understanding the causes of failures, and safety issues at collapsed sites. Field investigations and data gathering including the use of sensor technology, sampling, and structural monitoring. Understanding the effects of the environment on the properties of common structural materials. Evaluation of distress conditions such as vibrations, cracks, metal fatigue, excessive deformation resulting from creep and inelasticity, thermal effects, fire damage, effects of extreme loading conditions, and localized failures. Preparation of forensic reports, presenting results of evaluations of failed structural systems and structural distress conditions, insurance/legal issues, responsibility of engineer and ethics issues. Review of case studies.

Lecture: 3 Lab: 0 Credits: 3

CAE 520**Buckling of Structures**

Review of simple column buckling for various conditions. Basic considerations of stable and unstable equilibrium. Determination of buckling loads of columns with variable cross-section. Analysis of elastic stability of framed structures. Approximate solutions of more complicated problems by various numerical and energy methods. Analysis of lateral and torsional stability of beams and beam-columns. Stability in the inelastic range of columns. Buckling of plates and cylindrical shells.

Prerequisite(s): CAE 431 with min. grade of C and CAE 411 with min. grade of C

Lecture: 4 Lab: 0 Credits: 4

CAE 522**Structural Model Analysis**

Theory of measurements, statistics, similitude, and model laws and the usefulness of structural models. Displacement and strain measurement techniques. Theory and practice of indirect model analysis. Theory and practice of direct model techniques including photo elasticity and Moire methods.

Prerequisite(s): CAE 503 with min. grade of C

Lecture: 2 Lab: 2 Credits: 4

CAE 523**Statistical Analysis of Engineering Data**

Descriptive statistics and graphs, probability distribution, random sampling, independence, significance tests, design of experiments, regression, time series analysis, statistical process control, and introduction to multivariate analysis.

Lecture: 3 Lab: 0 Credits: 3

CAE 524**Building Enclosure Design**

Design of building exteriors, including the control of heat flow, air and moisture penetration, building movements, and deterioration. Study of the principle of rain screen walls and of energy conserving designs. Analytical techniques and building codes are discussed through case studies and design projects.

Prerequisite(s): CAE 513 with min. grade of C

Lecture: 3 Lab: 0 Credits: 3

CAE 525**Advanced Steel Structures**

Torsion and web openings. Behavior and design of rigid and semi rigid beam-to-column connections and base plates. Inelastic behavior of steel and composite members and systems under severe cyclic loading. Design of steel-concrete composite and hybrid systems. P-delta effect and design considerations for system stability. Design of special and ordinary moment-resisting frames. Design of concentrically and eccentrically braced frames. Design of bracing for stability. Plate girders. Fatigue and fracture.

Prerequisite(s): CAE 431* with min. grade of C or Graduate standing, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

CAE 526**Energy Conservation in Buildings**

Introduction to both theory and hands-on applications in building energy conservation and energy efficiency in buildings new and old. Analyzing energy consumption patterns in buildings. Understanding building rating systems and measures to design and operate energy efficient buildings. Use of building energy simulation tools to predict energy consumption of building energy end-uses. Calibration of building energy models. Energy retrofit strategies and parametric design. Visualize and analyze building performance data.

Prerequisite(s): CAE 331 or CAE 513

Lecture: 3 Lab: 0 Credits: 3

CAE 529**Dynamics of Structures**

Fundamentals of free, forced, and transient undamped and viscously damped vibration of single and multi-degree of freedom structures. Time, frequency, and approximate methods of analysis. Application of numerical methods in time and frequency domain. Response spectra, modes, coupling and modal space. Response history and response spectrum analyses and an introduction to earthquake engineering.

Prerequisite(s): CAE 411 with min. grade of C or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

CAE 530**Finite Element Method of Analysis**

Advanced and special topics in finite element analysis such as finite element-boundary element method, plates, and shell analysis using finite elements.

Prerequisite(s): CAE 411 with min. grade of C or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

CAE 532**Analysis of Plates and Shells**

Exact and approximate stress analysis of elastic, isotropic plates of various shapes acted upon by forces in their plane, as well as transverse forces. Stability of plates with various edge conditions, orthotropic plates, elastically supported plates and simple cylinders. Approximate methods such as finite differences, finite elements and the methods of Ritz and Galerkin.

Prerequisite(s): CAE 503 with min. grade of C

Lecture: 4 Lab: 0 Credits: 4

CAE 533**Theory and Analysis of Thin Shells**

Differential geometry of surfaces. Elastic theory of general shells with nonorthogonal curvilinear coordinates. Specialization to cylindrical shells, shells of revolution and translational shells. Exact and approximate solutions applied to the bending membrane theories of thin shells. Approximate methods including finite differences, finite elements and methods associated with Ritz, Galerkin, Puchler and Gaeckler.

Prerequisite(s): CAE 503 with min. grade of C

Lecture: 3 Lab: 0 Credits: 3

CAE 534**Computational Techniques in Finite Element Analysis**

Survey of numerical methods as applied to FEM software. Database management, equation solvers, eigen value routines and schemes for direct integration (both implicit/explicit), all as employed in the development of a finite element program. Topics covered also include band and front minimizers, static and dynamic substructuring via super elements and sensitivity studies. Same as MAE 538.

Prerequisite(s): CAE 530* with min. grade of C or Graduate standing, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

CAE 535**Nonlinear Finite Element Analysis**

FEM as applied to nonlinear problems. Contact problems, the mechanics of large deformation, full and updated Lagrange formulations, review of plasticity, solution algorithms, Eulerian approaches, application to FEM to limit analysis. Same as MAE 539.

Prerequisite(s): CAE 442 with min. grade of C or MMAE 501 with min. grade of C or CAE 514 with min. grade of C

Lecture: 3 Lab: 0 Credits: 3

CAE 537**Homeland Security Concerns in Building Designs**

Review of blast effects produced by solid phase weapons and their effects on structures and people. Estimation of the risk of a terrorist attack and the corresponding threat. Review of simplified methods for the analysis and design of structures to meet homeland security concerns and procedures to minimize casualties. Analysis of post event fires and how to prevent them. Review of security measures to minimize the effects of blast on buildings and people.

Lecture: 3 Lab: 0 Credits: 3

CAE 538**Control of Building Environmental Systems**

Introduction to automatic control systems. Control issues related to energy conservation, indoor air quality and thermal comfort in buildings. Classification of HVAC control systems. Control systems hardware: selection & sizing of sensors, actuators & controllers. Practical HVAC control systems; elementary local loop and complete control systems. Case studies. Computer applications.

Prerequisite(s): CAE 331 or CAE 513 with min. grade of C or MMAE 322

Lecture: 3 Lab: 0 Credits: 3

CAE 539**Introduction to Geographic Information Systems**

Geographic information system (GIS) technology allows users to combine tabular information with maps, creating powerful spatial databases which display and query information in new ways. This course will teach general GIS and GPS skills and concepts, useful to students and practitioners in a variety of disciplines. Students will complete a final GIS project relevant to their field of study. This hands-on class will use ESRI's ArcView and Spatial Analyst products, as well as Trimble GeoExplorer GPS units.

Lecture: 3 Lab: 0 Credits: 3

CAE 540**Asphalt and Concrete Mix Design**

Types of asphalt and physical properties of asphalt. Types of mixes: dense graded, open graded, base courses, and maintenance mixes. Types of pavement structures and hot mix asphalt placement. Aggregate physical properties, tests, and blending. Maintenance and rehabilitation materials. Mixture design procedures, including Marshall and Hveem procedures, and weight-volume relationships. Evaluation of mixture properties, engineering property's importance to performance, resilient modulus, fatigue, and creep testing, and thermal cracking properties. Laboratory included.

Lecture: 2 Lab: 3 Credits: 3

CAE 541**Pavement Evaluation and Management**

Pavement management systems (PMS) concepts, network definition, condition survey, pavement condition index (PCI), non-destructive deflection testing (NDT), measurement of roughness and skid resistance, micropaver PMS, PMS implementation, project and network-level management, maintenance alternatives, development of annual and long-range work plans.

Lecture: 3 Lab: 0 Credits: 3

CAE 543**Demand Models for Urban Transportation**

Fundamental theory of supply and demand, transportation economics, network equilibrium, land use and transportation equilibrium. Demand models: trip generation, geographical distribution, mode split, route assignment, the direct-demand model and disaggregate-behavioral-demand models. Special properties of models. Relationships among models.

Lecture: 3 Lab: 0 Credits: 3

CAE 544**Urban Transportation Planning**

Exploration of the goals of urban transportation. Program planning in relating transportation technology to social, economic, and environmental systems. Systems analysis in forecasting urban land use and travel demand and evaluating alternatives in transportation planning to reach a balance between demand and supply.

Lecture: 4 Lab: 0 Credits: 4

CAE 545**Traffic Operations and Flow Theory**

Studies of space and time distribution of speed and other traffic characteristics in the transportation network. Macro, micro, and mesoscopic traffic flow theories. Simulation in traffic networks. Application of flow theories to traffic control and operations.

Lecture: 3 Lab: 0 Credits: 3

CAE 546**Public Transportation Systems**

Operational and economic characteristics of urban systems. Transit planning process: demand for transit, transit routing, transit scheduling, network design. Improvements of existing systems and exploration of new technologies.

Lecture: 3 Lab: 0 Credits: 3

CAE 547**Advanced Traffic Engineering**

Data collection, statistical analysis, and interpretation of traffic information. Advanced traffic engineering topics such as signaling, street-and-highway capacity analysis, and highway safety research.

Lecture: 3 Lab: 0 Credits: 3

CAE 548**Transportation Systems Management**

Transportation as a system. Problems of traffic congestion, land use/transportation intersection; intersection control; freeway and arterial incident management; safety considerations; evaluation of strategies; case studies.

Lecture: 3 Lab: 0 Credits: 3

CAE 549**Transportation Economics, Development and Policy**

Application of managerial, micro- and macroeconomic concepts to transportation systems. Investment and impact analysis. Transport policy as it relates to social, economic and environmental issues. Legislative actions affecting transport issues.

Lecture: 3 Lab: 0 Credits: 3

CAE 550**Applied Building Energy Modeling**

This course introduces students to building energy modeling software and techniques that are widely used in industry applications. The course is practice-oriented and builds upon building energy modeling methods as they are practiced in engineering offices (using IES software). The course centers on the two most common types of energy models in practice: (1) models for LEED and code compliance, and (2) parametric models for evaluating energy conservation measures. During the first half of the course, students will learn modeling methods and assumptions to create an energy model of an actual building project for the LEED Energy and Atmosphere credit with all supporting documents required for LEED submission. In the second half of the course, students will learn to analyze energy conservation measures using parametric energy models. The course will also focus on advanced energy modeling topics, such as modeling HVAC systems and controls, passive techniques, composite fenestration, thermal bridges, thermal mass, and others. At the end of the course, students will have two complete energy models that they can use in their portfolio.

Prerequisite(s): CAE 331 or CAE 513

Lecture: 3 Lab: 0 Credits: 3

CAE 551**Prestressed Concrete**

Fundamental behavior, mechanics, and design of prestressed concrete members and structures. Service loading, ultimate strength, computation of prestress losses, deformations, and precast concrete components. Exposure to relevant building code provisions, design standards, and industry recommended practice. The opportunity for students to compete in a prestressed concrete beam fabrication and design competition may also be offered.

Prerequisite(s): CAE 432

Lecture: 3 Lab: 0 Credits: 3

CAE 552**Introduction to Sustainable Building Design**

This course introduces students to the fundamentals and practice of sustainable building design and certification. The core of the course is fundamental training in modern passive building, including building science fundamentals, calculations, and design strategies for a conservation first methodology. Students will be prepared to take the written and design portions of the Certified Passive House Consultant (Phius CPHC) examination. Green building certification and rating systems will be explored and their impacts on the design and construction of buildings discussed. Students will engage with the requirements of these standards in depth in preparation for the professional work environment. This course is open to all majors with interest in buildings, their systems, and the sustainability and resilience of the built environment.

Lecture: 3 Lab: 0 Credits: 3

Satisfies: CAE Design Course (D)

CAE 553**Measurement and Instrumentation in Architectural Engineering**

Hands-on experience with energy and indoor environmental quality measurements in buildings including experimental design, data analysis, and experimental statistics. Measurements and techniques covered include: thermal performance (e.g., temperature, humidity, and heat flux); fluid flows and HVAC characteristics (e.g., velocity, pressure, and airflow rates); energy performance (e.g., current, voltage, and power draw); whole building diagnostics (e.g., envelope airtightness, ventilation performance, and duct leakage testing); and indoor air quality (e.g., tracer gas techniques, particle measurements, and gas measurements). Course combines lectures and field measurements in buildings on campus.

Lecture: 3 Lab: 0 Credits: 3

CAE 554**Building Commissioning**

This course introduces students to the fundamentals and practice of building commissioning and prepares students for the Building Commissioning Professional (BCxP) Certification Exam. Building commissioning is an integrated process of quality assurance (QA), quality control (QC), and communications that is utilized to ensure that all of its systems, including mechanical, electrical, lighting, plumbing, fire protection, acoustical, and controls, perform interactively and according to the design intent. Building commissioning also ensures that building operators are prepared to operate and maintain its systems and equipment, which saves time, money, and energy, and improves the sustainability and resilience of buildings. This course is open to all majors with familiarity in buildings and their systems.

Prerequisite(s): CAE 331 or CAE 513

Lecture: 3 Lab: 0 Credits: 3

CAE 555**Transportation Systems Evaluation**

Concepts and principles of transportation economic analysis, transportation costs and benefits, user and nonuser consequences, needs studies, finance and taxation, methods for evaluation of plans and projects, cost-efficiency, cost-effectiveness, environmental impact assessment, and economic development assessment.

Lecture: 3 Lab: 0 Credits: 3

CAE 556**Net Zero Energy Building Design I**

An interdisciplinary project-based course in which students work in teams to design and provide full design documentation for a net zero energy building, meaning that it combines energy efficiency and renewable energy generation to consume only as much energy as can be produced onsite through renewable resources on an annual basis. Teams are expected to effectively and affordably integrate principles of building science, construction engineering and management, economic analysis, and architectural design in an integrated design process. Teams are required to submit full sets of plans, drawings, renderings, construction details, and analyses for energy efficiency, costs, affordability, environmental justice, equity, sustainability, and resiliency. The course aligns with a design competition, typically the Department of Energy's Solar Decathlon Design Challenge. The course prepares the next generation of architects, engineers, and construction managers with skills and expertise to start their careers and generate creative solutions for real-world net zero energy buildings. CAE 556 is the first course in a two-course series.

Lecture: 3 Lab: 0 Credits: 3

CAE 557**Net Zero Energy Building Design II**

An interdisciplinary project-based course in which students work in teams to design and provide full design documentation for a net zero energy building, meaning that it combines energy efficiency and renewable energy generation to consume only as much energy as can be produced onsite through renewable resources on an annual basis. Teams are expected to effectively and affordably integrate principles of building science, construction engineering and management, economic analysis, and architectural design in an integrated design process. Teams are required to submit full sets of plans, drawings, renderings, construction details, and analyses for energy efficiency, costs, affordability, environmental justice, equity, sustainability, and resiliency. The course aligns with a design competition, typically the Department of Energy's Solar Decathlon Design Challenge. The course prepares the next generation of architects, engineers, and construction managers with skills and expertise to start their careers and generate creative solutions for real-world net zero energy buildings. CAE 557 is the second course in a two-course series.

Prerequisite(s): CAE 556 with min. grade of C

Lecture: 3 Lab: 0 Credits: 3

CAE 558**Urban Systems Engineering Design**

CAE 558 is a project-based course where students will explore integrated designs of urban systems. Each project will apply the students' engineering disciplines (such as structures, transportation, building science, construction engineering and management, environmental engineering) in a comprehensive analysis that considers the economic, human, and environmental issues associated with the project.

Lecture: 3 Lab: 0 Credits: 3

CAE 559**Urban Systems Engineering Seminar**

CAE 559 is an active seminar course that emphasizes current topics in urban systems engineering. Invited speakers will include researchers and representatives from current practice such as municipal and regional planners and consultants. Appropriate readings will be assigned in advance of each speaker to guide students in preparation for active discussion with each speaker. Each student will also write a term paper on an urban systems engineering topic of their choice, connecting material from the assigned reading, the speakers, and additional references selected by the student.

Lecture: 3 Lab: 0 Credits: 3

CAE 560**Plastic Methods**

Fundamental concepts of plasticity in the design of steel structures. Principle of plastic hinges. Upper and lower-bound theorems. Alternating plasticity and incremental collapse. Analysis and design of single story and multi-story framed structures.

Prerequisite(s): CAE 431* with min. grade of C and CAE 503* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 4 Lab: 0 Credits: 4

CAE 561**Structural Reliability and Probabilistic Bases of Design**

Fundamentals of probability theory and stochastic processes; statistical analysis of engineering data; probabilistic modeling of structural loads and material properties. Reliability analysis and design of structure, reliability-based design criteria. Evaluation of existing design codes. Safety analysis of structures under fatigue loads. Fault and event tree analysis.

Prerequisite(s): CAE 307 with min. grade of C or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

CAE 562**Engineering Behavior of Soil**

Soil mineralogy and soil fabric, soil-water electrolyte system, dispersive clay, stress and strain analyses, elastic equilibrium in soil masses, plastic equilibrium in soil masses, in situ and laboratory stress paths, shear strength of sands and clays, thermal properties of soils, critical state soil mechanics principles, nonlinear pseudo elastic and elastoplastic constitutive models.

Lecture: 4 Lab: 0 Credits: 4

CAE 563**Advanced Soil Mechanics Laboratory**

Advanced aspects of soil property measurement with application to design and analysis, system characteristics on soil sediment, pinhole test for identifying dispersive clays, consolidation, triaxial compression and triaxial extension with porewater measurement, cyclic triaxial test, permeability with back pressure, determination of critical void ratio.

Prerequisite(s): (CAE 323 with min. grade of C or Graduate standing) and CAE 562* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 1 Lab: 3 Credits: 1

CAE 564**Design of Foundations, Embankments and Earth Structures**

Consolidation phenomena, derivation of bearing capacity equations, beams and slabs on soils, piles and pile groups, compaction, earth pressure theories and pressure in embankment, slope stability analyses, retaining structures, embankment design, soil structure interaction during excavation, design of anchors for landslide stabilization and retaining structures and instrumentation.

Prerequisite(s): (CAE 323 with min. grade of C or Graduate standing) and CAE 457 with min. grade of C

Lecture: 4 Lab: 0 Credits: 4

CAE 565**Rock Mechanics and Tunneling**

Rock classification for engineering purposes, mechanical behavior of rocks, in situ stresses in rock, stresses around underground openings, rock slope engineering, design of underground structures, design of deep support excavation and tunnels, primary and secondary linings of tunnels, mined shafts, instrumentation.

Prerequisite(s): CAE 457 with min. grade of C

Lecture: 4 Lab: 0 Credits: 4

CAE 566**Earthquake Engineering and Soil Dynamics**

Earthquakes and their intensity, influence of group motion, review of I-DOF and M-DOF systems, wave propagation theories, vibration due to blast and shock waves, design earthquake motion, dynamic properties of soils, soil liquefaction, bearing capacity during earthquakes and design of machine foundations, isolation of foundations, pile foundation, and dynamic analysis, earth pressure during earthquakes on retaining structures and embankment.

Prerequisite(s): (CAE 323 with min. grade of C or Graduate standing) and CAE 420 with min. grade of C

Lecture: 4 Lab: 0 Credits: 4

CAE 568**Transportation Asset Management**

Processes and techniques for managing the preservation and expansion of highway transportation facilities such as pavements, bridges, and traffic control and safety hardware; system usage concerning mobility, safety and security, energy consumption, and vehicle emissions; and economic development impacts. Five component management systems are first examined: pavements, bridges, traffic control and safety hardware, roadway maintenance, safety, and congestion. Finally, the methodology for overall transportation asset management is discussed. The primary emphasis is on data collection, database management, performance modeling, needs assessment, project evaluation, project selection, program development strategies, risk and uncertainty modeling, and institutional issues.

Lecture: 3 Lab: 0 Credits: 3

CAE 569**Construction Methods, Cost Estimating, and Project Budgeting**

The role of program management and project budgeting in establishing a construction project, estimating in construction design and contract administration. Types of estimates, unit costs and production rates; job costs. Preparing bid for complete building project using manual methods and the CSI format; checking quantity take-off and cost estimating in selected divisions using a computer software package.

Lecture: 3 Lab: 0 Credits: 3

CAE 570**Legal Issues in Civil Engineering**

This course introduces students to the legal aspects of engineering and construction, contract documents, and contract clauses. Upon completion of this course, students will be able to do the following: (1) identify the elements of contract formation; (2) interpret contract clauses; (3) explain the rights and duties of the parties involved in design and construction; and (4) evaluate changes and their root causes. Students will also be able to objectively identify and analyze legal liabilities and the expected professional standard of architects, engineers, and contractors.

Lecture: 3 Lab: 0 Credits: 3

CAE 571**Lean Construction and Control**

This course introduces students to lean principles and the lean project delivery system (LPDS) applied to the construction industry. Lean construction and lean project delivery embrace concepts and techniques originally conceived in the automobile manufacturing industry and adopted by the construction industry. In the manufacturing sector, lean production has revolutionized product manufacturing, resulting in significant gains in plant productivity, reliability, and reductions in defects. Specific concepts that will be covered in this course include Plan-Do-Check-Act continuous improvement, A3 reporting, value stream mapping, pull systems and pull planning, kanban, 5S, standardization, and the Choosing by Advantages Decisionmaking System.

Lecture: 3 Lab: 0 Credits: 3

CAE 572**Construction Business Operations and Cost Accounting & Control**

Teaches the company basics of preparing Design Proposals and Construction Bids. Explains the dual accounting systems of corporate accounting (GAP) and Earned Value (EV) accounting used in the construction industry. Review of basic accounting principles and techniques—purchasing, accounts payable, invoicing, accounts receivable, general ledger, payrolls and indirect costs. Job costing and budgeting. Recording and reporting procedures in construction projects—invoices, subcontractor applications for payment, labor time cards, unit completion reports, change orders. Cost coding systems for construction activities. Variance reporting procedures. Project closeout.

Lecture: 3 Lab: 0 Credits: 3

CAE 573**Construction Management with Building Information Modeling**

Fundamentals and practical use of information technologies in the construction industry; basic concepts of building information modeling (BIM); review of software and technology available for BIM; practical use of BIM including design and clash detection; impact of BIM on construction management functions; construction scheduling and sequencing using BIM; cost estimating using BIM; facility management with BIM; integrated approach to navigate BIM as a multi-disciplinary design, analysis, construction, and facility management technology; class exercise to create a BIM model and to use it in scheduling, sequencing, cost estimating, management, and simulation of a construction project.

Lecture: 3 Lab: 0 Credits: 3

CAE 574**Economic Decision Analysis in Civil Engineering**

Basic economic concepts including interest calculations, economic comparison of alternatives, replacement decisions, depreciation and depletion, tax considerations, and sensitivity analysis. Evaluation of public projects, the effect of inflation, decision making under risk and/or uncertainty, economic decision models. Case studies from the construction industry.

Lecture: 3 Lab: 0 Credits: 3

CAE 575**Systems Analysis in Civil Engineering**

Management and system concepts, linear programming, graphical methods, Simplex, two-phase Simplex, the transportation problem, the assignment problem, integer programming, and sensitivity analysis. System modeling by activity networks; maximal-low flow, longest-path and shortest-path analyses, flow graphs, decision-tree analysis, stochastic-network modeling, queuing systems, and analysis of inventory systems. Case studies from the construction industry.

Lecture: 3 Lab: 0 Credits: 3

CAE 576**Applications of Unmanned Aerial Vehicles (UAVs or "Drones") for Construction Projects**

This course will introduce knowledge on Unmanned Aerial Systems (UAS) for construction projects. UAS are systems, such as Unmanned Aerial Vehicles (UAVs) that require a level of autonomy with minimal or no intervention from project actors to navigate over job-site environments. Instruction and learning activities incorporate all steps of processing UAV information. Laboratory activities include the design of plans to collect, analyze, and draw conclusions from UAV data and the sharing of experimental results with peers and faculty. Students will have access to a university-provided UAV equipped with advanced software for image processing, high-definition video camera, data communication platforms, and positioning sensors to capture a physical environment and register telemetry data related to their projects.

Lecture: 3 Lab: 0 Credits: 3

CAE 577**Construction Equipment Management**

Factors affecting the selection of construction equipment. Descriptions, operating methods, production rates, unit costs related to excavating equipment. Power shovels, draglines, clam shells, and trenching machines. Engineering fundamentals. Moving construction equipment, including trucks, wagons, scrapers, dozers, soil-stabilization and compaction equipment. Belt conveyors, compaction and drilling equipment, pile driving equipment, pumps and crushers.

Lecture: 3 Lab: 0 Credits: 3

CAE 578**Construction Claims Management**

This course provides a basic explanation of construction contract claims by types such as delays, acceleration, and scope issues, the underlying legal theories of the contract construction and claims, elements required for each claims type defenses to the claim, prophylactic claims measures. The claims process within the contract and extra-contractual basis's for claims are examined. Resolution of claims by ADR techniques and the formal litigation process are explained. AIA, AGC, and federal claims provisions are described. In addition to construction contract claims other types of claims associated with construction projects are covered such as Surety bond claims and various insurance claims (CGL, Builder's Risk, workers comp, etc)

Prerequisite(s): CAE 473 with min. grade of C

Lecture: 3 Lab: 0 Credits: 3

CAE 579**Real Estate Fundamentals for Engineers and Architects**

The objective of this course is to introduce civil engineering students to the real estate process. Students will learn techniques and methodologies for evaluating real estate investment opportunities using engineering economic analysis principles. Students will use Time Value of Money analysis for evaluating real estate transactions, including how to carry out calculations using formulas, financial calculators, and spreadsheets. This course will help civil engineering students learn financial skills that can be applied to professional and personal investment decisions.

Lecture: 3 Lab: 0 Credits: 3

CAE 580**Intelligent Transportation Systems**

The concept of intelligent transportation systems (ITS) involves the use of rapidly emerging information and communication technologies in mitigating congestion and attendant problems. A substantial amount of research and development activities have taken place over the last few decades. This course will provide an introduction to the various aspects of ITS and will focus on ITS planning, technology, big data analysis, and evaluation. In addition, such topics as deployment, financing, and management are also discussed. The course will include guest lectures and possibly field visits.

Lecture: 3 Lab: 0 Credits: 3

CAE 581**Algorithms in Transportation**

Modeling and analysis of transportation network problems through the design, analysis, and implementation of algorithms. Emphasis on the use of quantitative and qualitative methods of operations research to model system performance. Covers fundamental data structures, complexity analysis, memory management, recursive programs, application of graph theory, and network analysis to transportation problems, analytical formulations, and solution algorithms for origin-destination estimation, static and dynamic traffic assignments, and transportation resource allocation.

Lecture: 3 Lab: 0 Credits: 3

CAE 582**Structural Wind and Earthquake Engineering**

Introduction to nature of wind, aerodynamic wind-loading and design. Strong ground motion phenomenon. Investigation of the response of structures to dynamic and pseudo dynamic wind, earthquake, shock waves and other deterministic and probabilistic loadings. Design criteria for buildings and nuclear power stations, special topics in lifeline earthquake engineering.

Prerequisite(s): CAE 529 with min. grade of C or Graduate standing

Lecture: 4 Lab: 0 Credits: 4

CAE 583**Performance-Based Structural and Seismic Design of Buildings and Bridges**

This course covers performance-based structural and seismic design (PBSSD) for buildings and bridges. The course will begin with brief reviewing and critical discussion on conventional code-based seismic design followed by the development of the concept and applicability of this new alternative and advanced PBSSD. Computer methods in linear dynamic, nonlinear static, and dynamic analyses will be surveyed and discussed as primary tools in PBSSD. Ample case studies from real-world projects are carried out throughout the course. These case studies include the PBSSD of special structures, tall buildings, and those that building code-based design is not applicable.

Prerequisite(s): CAE 529 with min. grade of C or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

CAE 584**Stormwater Management**

Basic principles of storm water management; hydrology and hydraulics of excess water; excess water management and design; sewer system design and management, storm water detention systems; flood plain system design; risk based design of drainage systems; practical and case study problems.

Prerequisite(s): CHE 301 or MMAE 313 or CAE 302 or CAE 209

Lecture: 3 Lab: 0 Credits: 3

CAE 586**Seismic Design of Building and Bridge Structures**

The course covers six topics, as listed in the course outline, on seismic design of steel and R/C building structures and bridges. In addition to offer fundamentals and experiences in seismic design through design examples, it is also assumed that structural engineers who are preparing for their Structural Engineer License Exam might find extremely helpful.

Prerequisite(s): (CAE 431 with min. grade of C and CAE 432 with min. grade of C) or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

CAE 587**Commissioning of Construction Projects**

This course provides students with the methods and process of Commissioning, a high-level engineering skill in construction projects of independently verifying that the design and the construction meets the Owner's bargained for quality. It enumerates tracking the processes of equipment approval, installation, individual equipment testing and manufacturer training, programming of digital controls, and operational tests in high and low states to verify that end product of the construction project meets the Owner's requirements. The Construction Standard Institute (CSI) of the United States and Canada MasterFormat is used as a guide to specific types of commissioning.

Corequisite(s): CAE 569

Lecture: 3 Lab: 0 Credits: 3

CAE 588**Computing, Informatics, and Advanced Information Technologies in Construction Engineering**

The course covers concepts in computing, processing information and data, representation, and reasoning strategies to be applied in construction engineering tasks during the whole life cycle of a project. The course presents advanced information technologies used to manage project design and construction operations, including application methods and techniques. Topics allow the student to acquire a broad understanding of information, data, and knowledge within any construction process. The instructor will also include research-level topics of discussion concerning the use of state-of-the-art technologies within the civil and construction engineering practice, such as the Internet of Things (IoT), robotics, digital twins, ontologies, and technologies along the virtuality-reality continuum (e.g., augmented reality, mixed reality).

Lecture: 3 Lab: 0 Credits: 3

CAE 589**Groundwater Hydrology and Sampling**

Groundwater geology and flow, response of ideal aquifer to pumping. Chemical properties and principles including source of contamination and estimation of saturated hydraulic conductivity. Principles of exploration and sampling, methods of subsurface explorations, groundwater observation techniques. Instructor permission required.

Lecture: 3 Lab: 0 Credits: 3

CAE 590**Geotechnical Landfill Design and Maintenance**

Regulatory and legal issues, site selection and assessment, geotechnical-subsurface investigation, clay mineralogy and clay-water-electrolyte system, linear and leachate-control-systems design, stability of landfill slopes, cover design, construction and operation, final use and remediation design.

Prerequisite(s): CAE 323 with min. grade of C or Graduate standing

Lecture: 3 Lab: 0 Credits: 3

CAE 591**Research and Thesis for M.S. Degree**

Research and Thesis for M.S. Degree.

Credit: Variable

CAE 594**Research Problems**

Credit: Variable

CAE 595**Current Issues in the Construction Industry**

The task organization and operation of Design and Construction projects is reviewed. Each student selects a major issue/problem they have experienced on their projects as a basis for a podcast interview with the Professor. The other students in the class will provide input by direct participation or by use of the discussion board for that podcast. At the end of the semester each student submits a paper on the strategic directions of the Construction Industry using all the podcasts and their experience as a basis. At least 3 years' experience in the U.S. Canadian design and construction industry where project organizations are task organizations are task organized from many different companies and parties using contracts. The student has worked with the processes of RFP/Bid preparation, monthly Pay Apps, and Change Orders (Mods).

Lecture: 1 Lab: 3 Credits: 3

CAE 597**Special Problems**

Graduate course work in the problem subject matter. Subject matter will vary with the interests and background of students and instructor. Design or research problems may be assigned from the areas of architectural, construction, geotechnical, geoenvironmental, structural, or transportation engineering.

Credit: Variable

CAE 598**Special Topics**

A special topic in civil or architectural engineering at the graduate level.

Credit: Variable

CAE 599**Graduate Workshop**

Graduate workshop.

Lecture: 0 Lab: 0 Credits: 0

CAE 691**Research and Thesis for Ph.D. Degree**

Research and Thesis for Ph.D. degree.

Credit: Variable

CAE 724**Introduction to Acoustics**

This short course provides a brief introduction to the fundamentals of acoustics and the application to product noise prediction and reduction. The first part focuses on fundamentals of acoustics and noise generation. The second part of the course focuses on applied noise control.

Lecture: 2 Lab: 0 Credits: 2

ENGR 502**Medical Device Regulations and Commercialization**

This course helps prepare students for commercializing medical devices within a highly-regulated environment. Concepts include protecting intellectual property, the structure and scope of the Federal Drug Administration (FDA), developing, testing, producing and marketing medical devices under FDA regulations, total product lifecycle, and quality management.

Lecture: 3 Lab: 0 Credits: 3

ENGR 510**Strategic Engineering Management**

This course will review technology-based enterprises and the driving forces that impact corporate strategy. Students will learn how to apply engineering knowledge to determine technology/product direction and make/buy/partnering decisions. Relationships between research and development, operations, finance, marketing, and other functions within engineering-based organizations that drive strategic decisions will be examined. Strategy development and competitive analysis will be included. Case studies from the industry relevant to the student's engineering track will be reviewed.

Lecture: 3 Lab: 0 Credits: 3

ENGR 520**Best Practices in Engineering Project Management**

Many engineering projects suffer due to weak business cases, schedule slippages, and cost overruns. This course presents commonly used tools and techniques and best practices to build an effective business case, develop a realistic schedule and budget, and successfully execute and complete a project. Students are introduced to a generic project management life cycle model, review basic project management principles, tools, and techniques, and learn engineering-tailored best practices used by high performing, project-centric organizations. Students have an opportunity to apply selected tools in the form of short classroom exercises.

Lecture: 3 Lab: 0 Credits: 3

ENGR 521**Risk Management in Engineering Projects**

In project management, a risk is considered an uncertain event that may have a positive or a negative impact on project objectives. Managing identified threats individually through customized strategies is key to project success. Similarly, opportunities must be leveraged for better project outcomes. Implementation of an effective risk management process is imperative for today's complex projects. This course presents a five-step process to manage project threats as well as opportunities. On every project, students will be able to identify and analyze risks and develop response strategies for each identified risk and take proper response action to manage the risks. Industry best practices and quantitative tools and simulations are used to analyze risk.

Lecture: 3 Lab: 0 Credits: 3

ENGR 531**Urban Systems Engineering Design**

ENGR 531 is a project-based course where students will explore integrated designs of urban systems. Each project will apply the students' engineering disciplines (such as structures, transportation, building science, construction engineering and management, environmental engineering) in a comprehensive analysis that considers the economic, human, and environmental issues associated with the project.

Lecture: 3 Lab: 0 Credits: 3

ENGR 532**Urban Systems Engineering Seminar**

ENGR 532 is an active seminar course that emphasizes current topics in urban systems engineering. Invited speakers will include researchers and representatives from current practice, such as municipal and regional planners and consultants. Appropriate readings will be assigned in advance of each speaker to guide students in preparation for active discussion with each speaker. Each student will also write a term paper on an urban systems engineering topic of their choice, connecting material from the assigned reading, the speakers, and additional references selected by the student.

Lecture: 3 Lab: 0 Credits: 3

ENGR 534**Product Design and Innovation**

This course covers all aspects of planning new products or services that are commercially viable and add to a company's suite of offerings. It includes such topics as user research, market analysis, need/problem identification, creative thinking, ideation, concepting, competitive benchmarking, human factors, prototyping, evaluation, and testing. The course includes creative, analytical, and technical skills in a balanced approach using such teaching methods as case studies, individual exercises, and group projects.

Lecture: 3 Lab: 0 Credits: 3

ENGR 539**Robotic Motion Planning**

Configuration space. Path planning techniques including potential field functions, roadmaps, cell decomposition, and sampling-based algorithms. Kalman filtering. Probabilistic localization techniques using Bayesian methods. Trajectory planning.

Lecture: 3 Lab: 0 Credits: 3

ENGR 572**Construction Cost Accounting and Control**

Review of basic accounting principles and techniques – purchasing, accounts payable, invoicing, accounts receivable, general ledger, payrolls, and indirect costs. Job costing and budgeting. Recording and reporting procedures in construction projects – invoices, subcontractor applications for payment, labor time cards, unit completion reports, change orders. Cost coding systems for construction activities. Variance reporting procedures. Project closeout. Class exercise using computer program.

Lecture: 3 Lab: 0 Credits: 3

ENGR 573**Construction Contract Administration**

Characteristics of the construction industry. Project delivery systems. Duties and liabilities of the parties at the pre-contract stage. Bidding. Contract administration including duties and liabilities of the parties regarding payments, retainage, substantial and final completion, scheduling and time extensions, change orders, changed conditions, suspension of work, contract termination, and resolution of disputes. Contract bonds. Managing the construction company. Labor law and labor relations.

Lecture: 3 Lab: 0 Credits: 3

ENGR 574**Economic Decision Analysis in Civil Engineering**

Basic economic concepts including interest calculations, economic comparison of alternatives, replacement decisions, depreciation and depletion, tax considerations, and sensitivity analysis. Evaluation of public projects, the effect of inflation, decision making under risk and/or uncertainty, economic decision models. Case studies from the construction industry.

Lecture: 3 Lab: 0 Credits: 3

ENGR 575**Systems Analysis in Engineering**

Management and system concepts, linear programming, graphical methods, Simplex, two-phase Simplex, the transportation problem, the assignment problem, integer programming, and sensitivity analysis. System modeling by activity networks; maximal-low flow, longest-path and shortest-path analyses, flow graphs, decision-tree analysis, stochastic-network modeling, queuing systems, and analysis of inventory systems. Case studies from the construction industry.

Lecture: 3 Lab: 0 Credits: 3

ENGR 576**Nano Manufacturing**

This course covers the general methods used for micro- and nano-fabrication and assembly, including photolithography techniques, physical and chemical deposition methods, masking, etching, and bulk micromachining as well as self-assembly techniques. It also covers nanotubes, nanowires, nanoparticles, and the devices that use them, including both electronic and mechanical-electronic systems, as well as nano-structural materials and composites. Focus is on commercially available current processes as well as emerging technologies and evolving research areas. Sensing and instrumentation as well as nano-positioning and actuation are covered briefly.

Lecture: 3 Lab: 0 Credits: 3

ENGR 587**Introduction to Digital Manufacturing**

This course is about the digital revolution taking place in the world of manufacturing and how students, workers, managers, and business owners can benefit from the sweeping technological changes taking place. It is about the change from paper-based processes to digital-based processes all through the design/manufacturing/deliver enterprise, and across the global supply chain. It touches on digital design, digital manufacturing engineering, digital production, digital quality assurance, and digital contracting, from large companies to small. There is also a significant focus on cyber security and the new types of threats that manufacturers face in the new digital world. Other topics covered include intelligent machines, connectivity, the digital thread, big data, and the Industrial Internet of Things (IIoT).

Lecture: 3 Lab: 0 Credits: 3

ENGR 588**Additive Manufacturing**

This course examines the fundamentals of a variety of additive manufacturing processes as well as design for additive manufacturing, materials available, and properties and limitations of materials and designs. It also examines the economics of additive manufacturing as compared to traditional subtractive manufacturing and other traditional techniques. Additive techniques discussed include 3D printing, selective laser sintering, stereo lithography, multi-jet modeling, laminated object manufacturing, and others. Advantages and limitations of all current additive technologies are examined as well as criteria for process selection. Processes for metals, polymers, and ceramics are covered. Other topics include software tools and connections between design and production, direct tooling, and direct manufacturing. Current research trends are discussed.

Lecture: 3 Lab: 0 Credits: 3

ENGR 592**Engineering Management Capstone Experience**

Students apply the knowledge they have acquired in the Engineering Management program to a specific problem or case study. Projects will be identified and mentored in conjunction with faculty and industrial partners. A final report or business plan is required that reflects the focus of the capstone project.

Lecture: 3 Lab: 0 Credits: 3

ENGR 595**Product Development for Entrepreneurs**

Elements of product development (mechanical and electrical), manufacturing and production planning, supply chain, marketing, product research, and entrepreneurship concepts are taught in this class. In this course, student teams will be required to create a compelling product that has potential to be sold in today's marketplace. They will be required to create functional prototypes of their product for people to use and critique. If successful, students will be allowed to put their product on Kickstarter.com and take orders for delivery after the class is complete while potentially fostering their own business as a result of this course.

Lecture: 3 Lab: 0 Credits: 3

ENGR 596**Practical Engineering Training**

This course is a mentored, immersive practical engineering training. Students learn under the direction of professional engineers and practicing engineers by working on real engineering projects. The student will perform hands-on engineering, including learning and developing/applying engineering principles and concepts to complete the project assigned to the student. The student will apply engineering ethics and safety during their practical engineering training. Students will communicate the results of their work in written and oral communications. Students will receive assignments of varying complexity consistent with their graduate standing.

Lecture: 0 Lab: 9 Credits: 3

ENGR 598**Graduate Research Immersion: Team Project**

This course provides a faculty-mentored immersive team-based research experience. Research topics are determined by the faculty mentor's area of research. In addition to the mentored research, students participate in seminars, prepare a written report of their research findings, and present their research findings at a poster expo.

Lecture: 3 Lab: 0 Credits: 3

ENGR 599**Graduate Research Immersion: Individual**

This course provides a faculty-mentored immersive research experience. Research topics are determined by the faculty mentor's area of research. In addition to the mentored research, students participate in seminars, prepare a written report of their research findings, and present their research findings at a poster expo.

Lecture: 3 Lab: 0 Credits: 3

ENVE 501**Environmental Chemistry**

Chemical processes in environmental systems with an emphasis on equilibrium conditions in aquatic systems. Processes examined include acid-base, dissolution precipitation, air-water exchange, and oxidation-reduction reactions. Methods presented for describing chemical speciation include analytical and graphical techniques as well as computer models.

Prerequisite(s): ENVE 402 or CAE 402

Lecture: 3 Lab: 0 Credits: 3

ENVE 503**Occupational and Environmental Health and Safety**

This course is intended to introduce students to the basics of occupational and environmental safety and health. Topics include fundamental principles in industrial hygiene and occupational and environmental safety based in the anticipation, recognition, evaluation, and control of chemical, biological, physical, and ergonomic hazards that can be encountered in the workplace and other settings. Applications include indoor air pollution control, natural disaster mitigation, and infectious disease transmission and control.

Lecture: 3 Lab: 0 Credits: 3

ENVE 506**Chemodynamics**

Processes that determine the fate and transport of contaminants in the environment. Upon successful completion of this course, students should be able to formulate creative, comprehensive solutions to transport problems, critically evaluate proposed solutions to transport problems, and acquire and integrate new information to build on these fundamentals.

Prerequisite(s): ENVE 402 or CAE 402

Lecture: 3 Lab: 0 Credits: 3

ENVE 513**Biotechnological Processes in Environmental Engineering**

Fundamentals and applications of biological mixed culture processes for air, water, wastewater, and hazardous waste treatment. Topics include biochemical reactions, stoichiometry, enzyme and microbial kinetics, detoxification of toxic chemicals, and suspended growth and attached growth treatment processes. The processes discussed include activated sludge process and its modifications, biofilm processes including trickling filters and biofilters, nitrogen and phosphorous removal processes, sludge treatment processes including mesophilic and thermophilic systems, and natural systems including wetlands and lagoons.

Lecture: 3 Lab: 0 Credits: 3

ENVE 522**Global Environmental Change and Sustainability Analysis**

This course introduces students to concepts of global biogeochemistry and environmental sustainability, including the practice of life cycle assessment (LCA). The course begins with an overview of the global energy, water, carbon, and nitrogen cycles and their relationships to human activities. The focus then shifts to LCA, which is an analytical approach for quantifying the relationships between economic activities and environmental issues. LCA is often used to develop sustainability metrics to compare alternative approaches to meet economic needs such as transportation, food provision, and building construction. This course is open to all majors with familiarity in basic chemistry, but students will be expected to conduct quantitative analyses and perform basic engineering calculations.

Lecture: 3 Lab: 0 Credits: 3

ENVE 523**Geoenvironmental Engineering**

This course provides students with a comprehensive understanding of global geoenvironmental challenges. Subject matter includes interactions between soils, rocks, groundwater, and contaminants; issues related to hazardous and non-hazardous waste management; contaminated site remediation; and the principles of sustainable development. Essential topics include (1) geoenvironmental problems and the need for geoenvironmental engineering, (2) the fundamental background needed to understand and address geoenvironmental problems, (3) management of wastes through engineered landfills and impoundments, (4) characterizing, assessing, and remediating contaminated sites, (5) beneficial use of waste and recycled materials, and (6) incorporating sustainability in waste management and pollution control. By the end of the course, students will be equipped with the fundamental knowledge and practical skills to address and resolve a range of geoenvironmental issues.

Lecture: 3 Lab: 0 Credits: 3

ENVE 528**Modeling of Environmental Systems**

To introduce students to mathematical modeling as a basic tool for problem solving in engineering and research. Environmental problems will be used as examples to illustrate the procedures of model development, solution techniques, and computer programming. These models will then be used to demonstrate the application of the models including simulation, parameter estimation, and experimental design. The goal is to show that mathematical modeling is not only a useful tool but also an integral part of process engineering.

Lecture: 3 Lab: 0 Credits: 3

ENVE 542**Physicochemical Processes in Environmental Engineering**

Fundamentals and applications of physicochemical processes used in air, water, wastewater, and hazardous waste treatment systems. Topics include reaction kinetics and reactors, particle characterization, coagulation and flocculation, sedimentation, filtration, membrane separation, adsorption, and absorption.

Prerequisite(s): ENVE 404

Lecture: 3 Lab: 0 Credits: 3

ENVE 543**Carbon Capture, Utilization, and Storage**

To address the climate impacts of anthropogenic sources of carbon dioxide (CO₂), it has become increasingly important to focus on solutions for CO₂ removal processes, especially directly from CO₂ emission sources. Carbon capture and sequestration/storage (CCS) is the process of capturing CO₂ formed during power generation and other industrial processes and sequestering it so that it is not emitted into the atmosphere. CCS technologies have significant potential to reduce CO₂ emissions in energy systems. This course will review and explore, in detail, the engineering design principles for solutions of carbon capture at the source or direct air capture (DAC) from the atmosphere, utilization, and storage. Topics include an overview of the importance current and future potential of CCS and other technologies such as direct air capture; power generation fundamentals related to carbon emissions and our reliance on fossil energy; current state of research and development on carbon capture technologies; storage, monitoring, and utilization of CO₂; CO₂ transportation (e.g., pipeline and marine modes); and economics of technologies for removing CO₂ from the atmosphere and additional methods of reducing CO₂ concentrations and other greenhouse gases in the atmosphere.

Lecture: 3 Lab: 0 Credits: 3

ENVE 551**Industrial Waste Treatment**

Industrial waste sources and characteristics, significance of industrial waste as environmental pollutants; applications of standard and special treatment processes including physical, chemical, and biological systems.

Prerequisite(s): ENVE 513* with min. grade of C or ENVE 542* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

ENVE 561

Design of Environmental Engineering Processes

Design of water and wastewater treatment systems. System economics and optimal design principles.

Prerequisite(s): ENVE 513* with min. grade of C or ENVE 542* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

ENVE 570

Air Pollution Meteorology

Physical processes associated with the dispersion of windborne materials from industrial and other sources. Atmospheric motion including turbulence and diffusion, mathematical models, and environmental impact assessment.

Lecture: 3 Lab: 0 Credits: 3

ENVE 576

Indoor Air Pollution

Indoor air pollution sources, indoor pollutant levels, monitoring instruments and designs, and indoor pollution control strategies; source control, control equipment and ventilation; energy conservation and indoor air pollution; exposure studies and population time budgets; effects of indoor air pollution; risk analysis; models for predicting source emission rates and their impact on indoor air environments.

Lecture: 3 Lab: 0 Credits: 3

ENVE 577

Design of Air Pollution Control Devices

Principles and modern practices employed in the design of engineering systems for the removal of pollutants. Design of control devices based on physical and chemical characteristics of polluted gas streams.

Lecture: 3 Lab: 0 Credits: 3

ENVE 578

Physical and Chemical Processes for Industrial Gas Cleaning

Application of physical and chemical processes in the design of air treatment systems; fundamentals of standard and special treatment processes.

Lecture: 3 Lab: 0 Credits: 3

ENVE 580

Hazardous Waste Engineering

Sources and characteristics of hazardous wastes, legal aspects of hazardous waste management, significance of hazardous wastes as air, water, and soil pollutants. Principles and applications of conventional and specialized hazardous waste control technologies.

Prerequisite(s): ENVE 506* with min. grade of C, An asterisk (*) designates a course which may be taken concurrently.

Lecture: 3 Lab: 0 Credits: 3

ENVE 591

Research and Thesis M.S.

Graduate research.

Credit: Variable

ENVE 597

Special Problems

Independent study and project. (Variable credit)

Credit: Variable

ENVE 691

Research and Thesis Ph.D.

Graduate research.

Credit: Variable