College of Engineering & Computational Sciences

Senior Design Trade Fair

MINES™

April 23, 2015

A Special Word of Thanks to Our Judges

It is my pleasure to offer a personal welcome to the judges of the Spring 2015 Colorado School of Mines College of Engineering and Computational Sciences Trade Fair. We appreciate your willingness to take time from your normal activities to evaluate our senior's capstone design projects. The opportunity for our students to get feedback from experienced engineers is invaluable.

Senior design allows our students to demonstrate the engineering knowledge that they have spent four years acquiring. We encourage you to spend time with the design teams and to inquire about their projects and their designs. But also ask about their design process, because in the final analysis, senior design is as much about learning the process of design as it is about creating a design. As these students enter the workforce, it is their ability to use the design thinking methods that they have learned that will serve them most in their careers.

We are proud of our students and their accomplishments and hope you are equally impressed. If you would like to get more involved in our program, we are always in search of more project sponsors. Let us know!

Again, thank you and Happy Judging!

Kevin L. Moore
Dean, College of Engineering
& Computational Sciences

Colorado School of Mines thanks the individuals and families listed below who have provided valuable support to the Senior Design students present today.

Program Partners

J. Don Thorson

Program Supporters

Al Cohen Family

Program Donors

Jamie Eichenberger

Matt & Kim Sands

Robert Amaro

Colorado School of Mines thanks the companies and organizations listed below who have provided valuable support to the Senior Design students present today.

Program Partners

Baker Hughes

Shell Oil Company

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Kiewit

Phillips 66

Woodward Inc.

Program Donors

AISC	Archer Western	Baseline Engineering, Planning and Surveying
Bowman Consulting	CVJ Axles*	Exxon Mobil
EMJ*	Hearly Keeter Trucking	Holcim Inc.
ICAST Engineering	IEEE	KL&A
Pitsco Education	Schlumberger Technology Corporation	Super Vac*
Steel Dynamics	Zimkor*	

*Denotes donation of materials, services, or supplies to the program.

Sponsoring the Program

The Capstone Design Program provides Mines students with multidisciplinary, professional practice experiences as part of their education through projects that matter. The program relies on the generosity of our program sponsors. If you, or your organization, are interested in supporting the program please consider making a financial gift at giving.mines.edu. Your gift is tax deductible and will make a huge impact on our students.

PROGRAM PARTNERS	Donate $25,000 or greater
Your Funds support the needs of many teams. In addition, partners receive:	An invitation to, and recognition at the beginning-of-semester Project Kickoff event. All Sponsor, Supporter, and Donor benefits.

PROGRAM SPONSORS	Donate $10,000 - $24,999
Your funds support the needs of multiple teams. In addition, sponsors receive:	An invitation to, and recognition at the end-of-semester Trade Fair event. All Supporter and Donor benefits.

PROGRAM SUPPORTERS	Donate $5,000 - $9,999
Your funds support the needs of a single team. In addition, supporters receive:	Recognition on the program's website, and on signage in the Capstone Design Lab in the Brown Building Basement All Donor benefits.

PROGRAM DONORS	Donate up to $4,999
Donors receive:	Recognition in the end-of-semester Trade Fair Program and a formal letter of thanks from the Mines Foundation.

Colorado School of Mines thanks the individuals and organizations listed below who have served as clients for the student teams presenting today. Your donation of time, talent, and material support to our students is greatly appreciated.

Boulder Journey School	Sam Hall
Brown and Caldwell	Jamie Eichenberger
Chevron Phillips Chemical	Erik Lord and Will Rommel
City of Golden	Anne Beierle
CSM Center for Space Resources	Angel Abbud Madrid
CSM Metallurgical and Materials Engineering Department	Geoff Brennecka, Ivan Cornejo, and Terry Lowe
Denver Zoological Foundation	Paul Quick
Edward Kraemer Sons, Inc.	Mike McNish
GoFarm	Eileen Regan
Holcim (US) Inc.	Brooke Smartz
Kiewit	Ben Seling, Dave Tedrow, Rob Hoefer, and Victor Mazza
Medtronic	Tom Cilke
Oldcastle Precast	Dan Dodson
POWER Engineers, Inc.	James Trumble
Reactive Adaptations	Jake O'Connor
Shell	Matt Sands
University of Colorado at Denver	Michael Melonis
United States Olympic Committee	Mounir Zok
United States Antarctic Program	Patricia Douglas
Unaffiliated	Paul Brayford
CSM Civil and Environmental Engineering Department	Jeff Holley
CSM Electrical Engineering and Computer Science Department	Randy Haupt
CSM Mechanical Engineering Department	Cameron Turner, Derrick Rodriguez, Greg Bogin, Joel Bach, John Steele, Nils Tilton, Ozkan Celik, and Ray Zhang

Becoming a Client

The Capstone Design program in the College of Engineering and Computation Sciences (CECS) pushes students to go beyond their textbook training and solve real-world design problems. Every semester the college has over 50 student design teams who need great challenges to engage with. What opportunities does your organization have that could be addressed by a student team?

SUGGESTED DONATION	Corporate project sponsors are asked to provide a donation of $8,000 to the CSM Foundation. Up to $2,000 of that donation is made available to the student team for purchasing materials. The additional amount is used to support the program facilities, staff, and overhead. Government agencies, NGO's and startups may request exemption from the suggested donation.
TIME COMMITMENT	The involvement of the project sponsor is a key factor in the success of the project. Great project sponsors will commit one individual for approximately 1 hour per week to support the student team. In addition, any training or on-site resources that you can make available to the students are greatly appreciated.
OTHER	Student access to construction sites, manufacturing partners, or other company resources is always appreciated by the students.

PROFILE OF A GREAT PARTNER

The most successful industry partners share the following traits:

- View sponsoring a project as an outreach activity which helps prepare their junior engineers for management.
- Choose projects from their "nice-to-have" list and avoid having students on their critical path.
- Treat students like an entry-level engineer and plan on providing guidance throughout the process.

GETTING STARTED

Send an email to design@mines.edu to start exploring opportunities with program staff.

General Information Regarding Trade Fair

JUDGE'S AGENDA

Time	Description	Location
7:00 - 7:30	Registration and Breakfast Served	Student Center Main Ballrooms
7:30 – 8:45	Breakfast Program • 492 Essay Winners Announced • 491 Elevator Pitch Presentations	Student Center Main Ballrooms
8:45 – 9:00	Transition to Trade Fair	Lockridge Arena
9:00 – 11:00	Trade Fair	Lockridge Arena

FINDING YOUR WAY AROUND

A floor plan and map of the Trade Fair is available on the back of this program for your convenience.

JUDGES LOUNGE

Snacks and beverages are available for judges in the Judges Lounge. Please feel free to take a break from talking with the teams and grab a beverage or snack in the lounge at any time.

GRADING

We seek to achieve consistency in grading between the teams. With that in mind, the senior design faculty have developed the scoring rubric. Each row includes prompting descriptions that are intended to guide the evaluation process. Each description has an associated point value with it.

To completely grade a team, please select a single number from each row of the grading matrix. Sum the numbers (one from each row) and enter the total team score at the bottom of the ballot. Please return the form to the registration table when it is complete.

Spring 2015 Design Projects

Each year senior students in the civil, electrical, environmental, and mechanical engineering programs in the College of Engineering and Computational Sciences take a two-semester course sequence in engineering design targeted at enhancing their problem-solving skills. Corporations, government agencies and other professional organizations, as well as individual clients, provide projects for the student teams of five to eight students to work on. Students spend the academic year developing solutions for the projects to which they have been assigned, using tools they have learned throughout their careers at Mines.

This semester, we are proud to present the work of our 40 design teams. Their collaborative design work culminates in today's Senior Design Trade Fair. A list of the teams is provided below. In addition, each team has provided a one page synopsis of their design challenge which is included in the following pages.

TABLE OF PROJECTS

Team Number	Team Name	Project
F14-01	Master Mines	2015 ASCE Concrete Canoe Competition
F14-02	That Awkward Moment	2015 ASCE/AISC National Student Steel Bridge Competition
F14-03	Mines Trussworthy Steel	2015 ASCE/AISC National Student Steel Bridge Competition
F14-04	Shell EcoMarathon	2015 Shell Ecomarathon Competition
F14-05	Baja Blasters	2015 SAE Baja Competition
F14-06	Golden Performance Systems	SAE Formula Dry-Sump
F14-07	Formula Win	SAE Formula Dashboard System
F14-08/09	CSM Blasterbotica	2015 NASA Robotic Mining Competition
F14-10	WindMiners	2015 National Wind Competition
F14-11	MINESat	Mines CubeSat Initiative
F14-12	The Power Group	Integrated Protection and Control System
F14-13	Warrior Wear	Energy Absorbing Device for Sportswear to Reduce Trauma
F14-14	Wastewater Wizards	Brown and Caldwell Challenge
F14-15	Mountainside Consulting	Lookout Mountain Lid - Roadway Profiles and Structural Design
F14-16	Creative Drainage Solutions	Lookout Mountain Lid - Water Quality and Drainage
F14-17	Applied Thermal Solutions	Heating System for Metal Nan structuring Machine
F14-18	Bright Futures	STEM Light Lab for Boulder Journey School
F14-19	Superior Surveying	Mines Survey Field Update
F14-20	The A-Team	Mines Survey Field Update
F14-21	One n' Done Anchor	Universal, Precast Anchor Design
F14-22	SODAR	SODAR Phase II

F14-23	Re-Balance	Weight Distribution Training Device and Exercise Games for Stroke Patients
F14-24	Weederbot Team	WeederBot Robotic Control System
F14-25	Turnip the Beet	Food Hub Building System
F14-26	Engineering Collective	CP Chemical Outfall Pond pH Creep Remediation
F14-27	Golden Energy Solutions	GoFarm Food Hub Energy System
F14-28	Dynamic Energy Providers	GoFarm Food Hub Power System
F14-29	Team Dyno	Small Electric Motor Dynamometer
F14-30	Three-Oh Designs	Functional Tracking/Hinge System and Portable Stand
F14-31	Enlightened Robotics	Mobil Indoor Routing
F14-32	Colorado CrankWorks	Reverse Gearing for Hand-cranked Mountain Bike
F14-33	Team Platinum	Multi-mode Furnace Sensor
F14-34	Omeganaut	Vibrations Learning Lab
F14-35	The Jackson VI	Fluids & Controls Learning Lab
F14-36	Smart Drops	Fluids & Controls Learning Lab
F14-37	Continuous Glass Melter	Continuous Glass Research Melter
F14-38	MicroWinder Team	Off-axis Micro Coil Winder
F14-39	Jump Around	Time of Flight Tracking System
F14-40	Peak Performance	Athlete Instrumentation System

ASCE Concrete Canoe

01

Client: David Tedrow
Faculty Advisor: Branden Gonzales
Consultants Ben Seling
Brooke Smartz
Team Name: Master Mines
Team Members: Heather Mergentime, Rachel Steenerson, Laura Brewer, Brett Mahon, Broc Patterson, Dina Vakarchuk, Rachel Nagel

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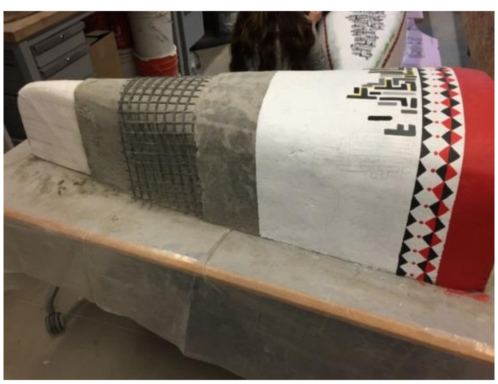
This project involves designing, building, and testing a concrete canoe for the American Society of Civil Engineers Rocky Mountain Regional Concrete Canoe Competition in accordance with the rules and regulations. The canoe is judged on aesthetic appeal, performance in numerous races, a design paper, and an oral presentation. The team was responsible for designing the canoe hull geometry, concrete mix, reinforcement, and formwork as well as incorporating a unique theme.

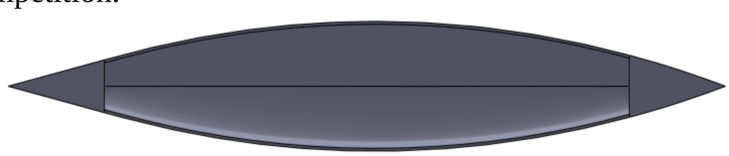
The team started the design process by reverse engineering the hull design from the CSM 2014 canoe. The team utilized a flat bottom design (shown in the F2 below) as opposed to last years' shallow arch. This design improved the stability and maneuverability of the canoe. To minimize the chances of cracking, the team computed the maximum cracking moment and bending moments for four loading scenarios: display, transportation, the two paddler race, and the four paddler race. Since cracking will result in water seeping through the concrete, the team compared the maximum positive and negative bending moments to the maximum cracking moment of the canoe. This confirmed the stresses developed in the canoe would not exceed the rupture strength of the concrete.

This years' concrete canoe is named *Si Mangavang*, after the large plank boat built by the Taoist oarsmen of Orchard Island in 2011. This unique canoe was crafted to honor the tribesmen's rich marine culture, and featured elaborate paintings in red, black, and white (shown in F1 below).

Master Mines constructed the *Si Mangavang* to represent Taoist values of craftsmanship, teamwork, community, and adventurous spirit. Each team member played a vital role in the project, and worked toward continuing the Colorado School of Mines' ASCE tradition of passionate competition.



F1: Cutaway Section Showing Construction Process



F2: Bottom view of hull design

ASCE/AISC Steel Bridge Competition

02

Client(s): Kiewit: Mr. Victor Mazzarella
Faculty Advisor: Dr. Cooper
Consultants Mr. Ben Seling, Dave Genova
Team Name: That Awkward Moment
Team Members: Melody Clay, Peter Eisinger, Ryan Hooper, Nathaniel Ober, Audrianna Ricotta, Spencer Wells

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The ASCE/AISC Student Steel Bridge Competition challenges teams to design and fabricate a bridge that complies with all loading conditions and site conditions. That Awkward Moment used RISA, structural modeling software, to account for design strengths and determine the best initial bridge design. Following the design review in the fall the team optimized the design and incorporated suggested changes. That awkward moment chose to use dovetail connections in order to expedite construction during competition. The bridge had to span a 6’6” gap so one major feature of our design was to make minimal connections over the river.

Once the final design was created the team created cut-sheets in Solidworks, which were comprehensively reviewed by our technical consultant Dave Genova at Zimkor. Fabrication took approximately three months and involved grinding, welding, and cutting steel members. The team created a workout program in order to build team dynamics and prepare members for the athletic challenge of building the bridge within the least time possible. That Awkward moment optimized construction time of the bridge to 13 minutes and 15 seconds by SpringFest, the internal bridge competition at Mines

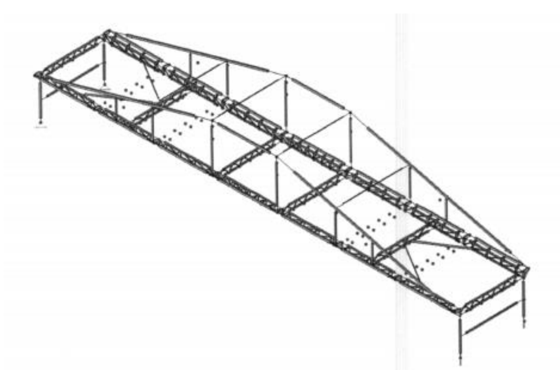

Figure 1 RISA Model

Figure 2: Fabricated Structure

AISC Steel Bridge Competition

03

Client(s): Rob Hoefer
Faculty Advisor: Paul Kaster
Consultants Ben Seling
Team Name: Mines Trussworthy Steel
Team Members: Alexi Scherkenbach, Mark Sundstrom, Max Ransom, Niki Hall, Travis White, Eli Ludtke

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Our project is to design, build, and test a small scale steel bridge that will compete in the AISC - ASCE Student Steel Bridge Competition. The competition mimics bridge building and construction in remote areas. For this reason, the bridge will be made up of multiple members that can be easily transported to the site. The competition tracks the assembly time to represent building the full scale in one dry season. Construction over the river without the ability to touch the river presents another complex challenge. Our design utilizes a curved overhead truss feature to take the load off of the decking members and reduce overall weight. The decking members are tilted inwards while the truss is tilted outwards to increase lateral stiffness. Once assembled, the bridge will span a gap of 18’6” and fit within a 5’ tall by 5’ wide bridge envelope. The bridge can support 2600 pounds of load in the middle while only deflecting 0.6 inches. The bridge itself only weighs 257 pounds and can be constructed in 29 minutes. The competition rules use the bridge weight, deflection, and assembly time to compute a composite score. We spent the first six months of the project designing and modeling the bridge in both RISA 3D and SolidWorks. The next two months were spent fabricating the bridge. The project consists of three competitions. The first is a local CSM competition, regionals, and finally nationals.

Shell Eco-Marathon Competition

Client(s): Matt Sands
Faculty Advisor: Bill Sekulic
Consultants Darek Bruzgo
Team Name: Miner Fuel Consumption
Team Members: Leo Frenkel, Kyle Hilberg, Jenny Lee, Evan Manning, Sara Starks, Jon Tran, Warren Randall, Justin Wahler

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This year Team Miner Fuel Consumption was chosen to represent the Colorado School of Mines in the 2015 Shell Eco-marathon Americas Competition. In this competition teams must design and build a hyper fuel-efficient, one-person vehicle. Overall fuel economy will determine the winner in each vehicle category or class. The specific area of the competition for the team is the diesel fuel category where they have set a goal of reaching over 1000 mpg.

Team Miner Fuel Consumption initially received the car from last year's competition and was asked to troubleshoot and redesign the vehicle to achieve a stable prototype that would complete the race. Some of the problems that the team encountered were to increase stability of the vehicle and reduce weight from the previous year as well as increase overall efficiency. With the help of Dr. Robert Amaro, John Jezek and everyone at the Mines machine shop, proper analysis and design were conducted and the team finalized the vehicle. Some notable features of the car include electronic throttle control, optimized engine mounting systems, and adjustable wheel alignment for optimal handling. The final design now weighs 210 lbs. (a reduction of ~50 lbs.) with a very aerodynamic carbon fiber body, low rolling resistance, proper safety specifications, and tuned engine and gearing components. The team competed in the event from April 9th-12th in Detroit, Michigan and would love to share the results with you and answer any questions when you stop by our booth during Trade Fair.

2015 SAE Mini Baja

05

Client(s): Derrick Rodriguez
Faculty Advisor: Jered Dean
Consultants Frank & Kay Peterson
Team Name: Baja Blasters 2015
Team Members: Aaron Fisk, Zachary Fitzgerald, Matt Heidebrecht, Jacob Hill, Justin Mattice, Matt McDonnell, Kyle Weinmeister

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The 2015 CSM Mini Baja team will represent CSM in the Baja SAE competition in Portland, OR. This competition simulates a real-world engineering project in which teams must design, manufacture, test, market, and race a single-operator, off-road vehicle. Our vehicle must conform to technical specifications put forth by SAE, without compromising driver safety or vehicle performance. In Oregon, the vehicle will be tested in rock crawl, hill climb, and maneuverability events, as well as a four-hour endurance race. Teams are scored on design, cost, and performance.

Our team inherited the 2014 CSM Baja vehicle, but ultimately decided to completely redesign and rebuild a new vehicle. Primary focus was given to lowering the vehicle's weight, minimizing construction costs and complexity, and improving the robustness and performance of the previous teams' designs. All components—with the exception of the stock engine mandated by competition—were re-engineered, using previous teams' experience for guidance, and the most important components were analyzed using FEA or physical testing. We also maintained a top-level assembly containing all vehicle systems in Solidworks in order to verify tool and component clearances.

The final design is significantly smaller and lighter than previous teams' vehicles. It features a continuously variable transmission that transfers power to the locked differential, maximizing power output at the wheels from the small 10 HP engine. The vehicle also incorporates a drop-out engine and tunable suspension components that potential owners could use to customize or easily access vehicle systems for maintenance. Our vehicle will be a strong competitor in all competition categories, and has the potential for a top ten finish.

FSAE Dry Sump Lubrication System

06

Client(s): Dr. Gregory Bogin and FSAE
Faculty Advisor: Dr. Ron Slovikoski
Consultants Engines and Car Racing
Team Name: Golden Performance Systems
Team Members: Sam Compton, Sam Fletcher, Jace Kelly, Preston Kosiara, Geoff Odgers, Ignacio Villen

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Our team goal was to increase the performance of the Formula Society of Automotive Engineers race vehicle by designing a dry sump lubrication system. Dry sump systems differ from traditional wet sump engine lubrication systems in that the primary engine oil reservoir exists in a remote location, rather than at the bottom of the engine block in a deep pan.

The advantage to the dry sump is that the shallower oil pan allows the engine to be placed lower in the vehicle, lowering the overall center of gravity of the vehicle. Vehicles with a lower center of gravity can corner harder and remain more stable during tight maneuvering than vehicles with a higher center of gravity.

Employing a dry sump lubrication system includes several key design challenges. Moving oil to and from the remote oil reservoir requires well matched flowrates between the engine circulating oil pumps within the engine and the scavenge oil pump circulating oil to the reservoir. Moreover, designing a system that can be integrated with an engine originally configured as a wet sump presents an immense logistical challenge. Finally, the dry sump system must be completely reliable; any failure to properly lubricate engine components during operation will result in catastrophic engine failure.

Our final system is the result of approximately 1000 hours of labor. We were responsible for the design, fabrication, and retrofitting of our dry sump lubrication system. Along with the dry sump components, we have prepared extensive documentation of our research and design process.

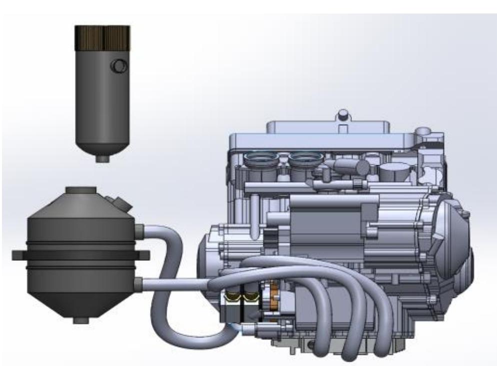

Figure 3: Dry Sump System and Engine

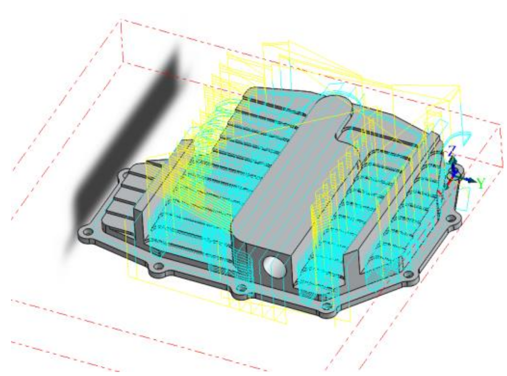

Figure 2: Oil Pan Machine Tool Path

Formula SAE Dashboard

07

Client(s): CSM FSAE Team

Faculty Advisor: Dr. Chuck Reynerson

Consultants Dr. Greg Bogin

Team Name: Formula Win

Team Members: Kendall Samuel, Colin Royston, Grant Spencer
Keith Nygard, Corbin Smith

The Society of Automotive Engineers (SAE) is an international professional society that concerns itself with the development of technical standards for all industries related to transportation. SAE is also known for its collegiate design challenges intended to develop engineering students' competency in their profession by giving them experience designing, manufacturing, and competing with each other. This Senior Design team is working alongside the Colorado School of Mines Formula SAE Team to build an open-wheeled formula-style car. This team is responsible for designing and manufacturing a digital dashboard system to provide the driver with vital information on the car's operating conditions and to aid those team members tasked with calibrating the engine control system. Due to space constraints, the display will be steering-wheel-mounted. The proposed characteristics to display during vehicle operation include engine temperature (coolant and oil), engine speed, vehicle speed, oil pressure warnings, and various other failure indication lights. By analyzing vehicle data, power can safely be increased while also improving reliability and detecting bugs in many of the interconnected systems required to keep and engine and car running properly. The addition of speed monitoring will help decrease lap times and push the vehicle to its limits safely and consistently. RPM monitoring will help avoid engine and transmission damage and keep the driver out of harm's way and protect the time and money invested by the Colorado School of Mines FSAE Team and the various sponsors that provided support along the way.

Figure 4 Professional Formula Wheel

NASA Robotic Mining Competition

08/09

Client(s): Dr. Angel Abbud-Madrid
Faculty Advisor: Dr. Christopher Dreyer
Consultants Dr. Ozkan Celik
Team Name: Blasterbotica
Team Members: Lucas Brockman, Nichole Cusack, Ryan Gerney, Laine Greaves-Smith, William Holleman, Kathryn Kostecka, Michael Kuzminsky, David Long, Ryan Mack, Kaitlyn Martin, Zachary Nahman, Taylor Ray, Eduardo Urquidi, Scott Von Thun

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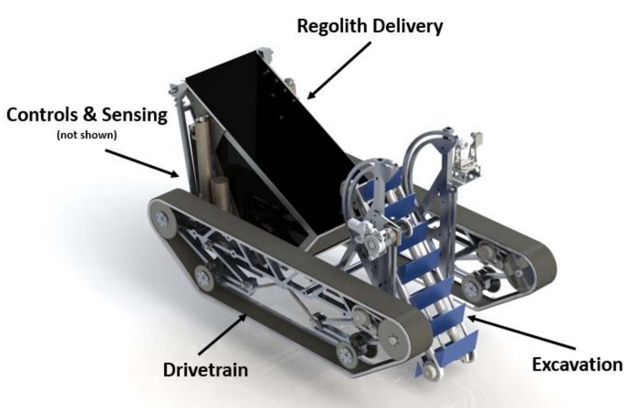
Team Blasterbotica was tasked with designing, testing, and building a rover to participate in the Sixth Annual NASA Robotic Mining Competition. In this competition, university students operate rovers designed to collect, transport, and deliver a minimum of 10 kilograms of simulated regolith within a 10 minute time period while traversing an arena containing several obstacles.

The design project was divided into six subsystems. The Drivetrain subsystem is comprised of a chained-tank treaded system with spring suspension which allows the rover to cross the arena. The Excavation subsystem utilizes a bucket ladder to excavate regolith and transport it to the Regolith Delivery subsystem. The excavator moves along a curvilinear rail system so that the rover complies with the required envelope dimensions at the start of the match, and is able to move to other positions that allow for excavation and regolith delivery. The Regolith Delivery subsystem is a dump truck system operated by linear actuators allowing for storage of regolith while the rover is crossing the arena as well as the exportation of regolith into the designated collection bin. The Sensing subsystem consists of a variety of sensors to determine the position of the rover in the arena. The Controls subsystem takes data from the Sensing subsystem and uses a Graphical User Interface with a controller to allow for tele-operative control of the rover. Prototyping and testing of these subsystems was completed to ensure that each subsystem interfaces properly to produce a functional and competitive rover.



DOE Collegiate Wind Competition

Client(s): Dr. Cameron Turner
Faculty Advisor: Dr. Yitz Finch
Consultants Dr. Kathryn Johnson
Team Name: WindMiners
Team Members: Michael Brocious, Amanda Chaney, Connor Fritcher, Bryce Gorove, Tyrenny Hidy, Victoria Kosinska, Jason Ron, Colin Tombari

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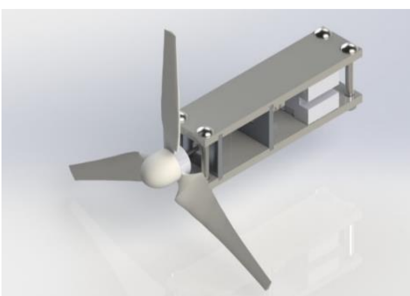
The 2014-2015 DOE Collegiate Wind Competition Team is tasked with designing a small scale wind turbine system for the DOE Collegiate Wind Competition against nine other universities on April 29th – May 2nd, 2015. The completed turbine must fit inside a 45cm x 45cm x 45cm cube, and must be able to withstand continuous wind speeds of a maximum 14 m/s. The turbine must be capable of braking when required, and cannot have any battery system.

There are five tests the team can be scored on, including the power curve performance, cut-in wind speed, control at maximum power, durability, and safety tests. These tests each vary between ten and twenty percent of the team's total wind tunnel score. Testing is 60% of the overall score, and a comprehensive technical design report, due April 13th, is 40% of the team's overall score. Each category is weighed and considered accordingly in the design of this system.



Rotor blades have been designed using a Schmitz optimization method designed to a tip speed ratio of 4, dictating the most effective distribution of chord length and pitch angle for the blades. The blades are to be built using selective laser sintering, which produces a true-to-form part made of light weight, rigid polymer. A 3-bladed rotor was chosen over 5+ blade design due to diminishing returns in power extraction due to Bentz limit. A parametric flow simulation has been conducted to determine the no-rotation, or startup torque produced by the rotor for any given wind speed. A BEM Theory solver was used to predict rotor performance.

Startup torque is a primary concern when selecting a generator. A new motor with lower starting torque is likely to be chosen to replace the current stepper motor to more closely match the rotor torque at low wind speed, in order to achieve a lower cut-in speed and negate the necessity of a gearing system. The motor is wired to also serve as an effective electronic brake.

The nacelle is designed to effectively interface the rotor with the electrical components. The nacelle is designed to include all electrical components while minimizing free space, weight, and minimal bearing spacing to avoid shaft whirl and cantilever bending. The final nacelle will include a thrust bearing and a fin to allow passive reorientation facing the direction of the wind.

Mines CubeSat Initiative

11

Client(s): Dr. Randy Haupt
Faculty Advisor: Dr. Payam Nayeri
Consultants:
Dr. Atef Elsherbeni, Prof. Jered Dean
Team Name: MINESat (Multiple Imaging Nano-Efficient Satellite)
Team Members: Timothy Blondin, Garrett Hoch, Ana Ilic, Michael Kissinger, Joe Lichthardt, Ross Peters

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With the recent growth in aerospace and communication industries, there is a great need for engineers who can design robust satellite systems. The design of CubeSats, small-scale satellites used for data acquisition in low-earth orbit, provides essential experience for students interested in these industries. In August 2014, Colorado School of Mines organized the institution's first CubeSat design team with the intention of submitting a formal design proposal to the NASA CubeSat Launch Initiative by Fall 2017. MINESat (Multiple Imaging Nano-Efficient Satellite) is a nano-satellite used to collect Earth imaging data in multiple electromagnetic spectrums. In the first year, design has been focused on the satellite. In the next two years, design will shift to the ground station, and then to launch and deployment logistics. Throughout the duration of this project, the MINESat team is also actively fundraising in order to fabricate a space-rated final design.

In order to demonstrate a proof of concept for the imaging, communication, and control systems, an Alpha Prototype has been developed over the past few months. The prototype has been designed with commercial parts to remotely capture an image, transmit the data to a ground station model, and display the image once reassembled. At the Senior Design Trade Fair on April 23, the MINESat team will demonstrate its Alpha Prototype to the general public, and will present its results from the first year of satellite development.

Protection & SCADA Integration

12

Client(s): James Trumble at POWER Engineers
Faculty Advisor: Paul Kaster
Consultants Dr. Ravel Ammerman
Team Name: The Power Group
Team Members: Lucas Cook, Kyle Feaster, Sarah Holmes, Derek Russell, Clinton Smith, Bryan Wickstrom, Andrew Wilson

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The purpose of this project was to design and implement the protection and communication systems for a small substation provided by POWER Engineers. The protection system is responsible for detecting and responding to faults and other anomalies in the substation. This involves using protective relays to monitor quantities such as the current in a line, and send commands to open circuit breakers and isolate the problem. The communication, or Supervisory Control And Data Acquisition (SCADA) system is responsible for sending measurements and breaker status data to a control center, as well as providing control of the substation components. These two systems combine to allow operators to open and close breakers, analyze the cause of a fault, and monitor the substation from a remote location.

The protection scheme was developed according to the following five criteria: reliability, selectivity, economics, speed, and simplicity. The protection settings were verified using fault studies performed both by hand and with the help of computer simulations. The settings were also verified to be compliant with the applicable IEEE standards. The SCADA system was developed using a data concentrator to take the data points from the relays and send them to a Human Machine Interface (HMI) that allows the user to monitor the system and send commands. All of the relays and the data concentrator are made by Schweitzer Engineering Laboratories (SEL).

Physical testing and design demonstration was made possible by SEL, who generously donated all of the relays and the data concentrator to the school for this team and future teams to use.

Energy Absorbing Device for Sportswear

13

Client(s): Dr. Terry Lowe and Kady Zinke
Faculty Advisor: Mirna Mattjik
Consultants Dr. Lauren Cooper
Team Name: Warrior Wear
Team Members: Leah Brown, Katie Duvall, Jaime Leon, William McCarthy, William Schvetz, Madeline Woodard

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The energy absorbing device in question is a hybrid pad that includes a shear-thickening fluid and a micro-truss structure and will be used for impact protection. The pad will be secured at the knee of dance pants as shown below in Figure 1. Warrior Wear's focus for this project was the micro-truss structure, which is the primary source of energy absorption and impact force reduction in the pad. Warrior Wear worked alongside a Materials and Metallurgical (MME) senior design team in order to fabricate the micro-truss design alternatives created. An initial proof of concept, shown below in Figure 2, was presented to the team before beginning the project and was used as a foundation for other design alternatives of the micro-truss structure. Warrior Wear was asked to develop a validated design tool in order to explore and optimize alternative designs of the micro-truss structure to maximize impact protection and manufacturability. This tool is an array of designs in SolidWorks that can be manipulated for finite element analysis (FEA) for any future analyses that must be performed. In order to develop this tool, the team tested alternatives with FEA then 3D printed a physical prototype for the MME team to test and compare with the FEA results.

Figure 5: Kadyluxe Dancewear (Provided by Dr. Lowe)

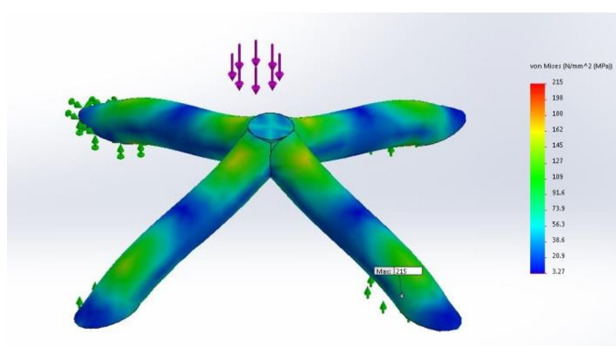


Figure 6: Micro-Truss Initial Proof of Concept Stress Distribution

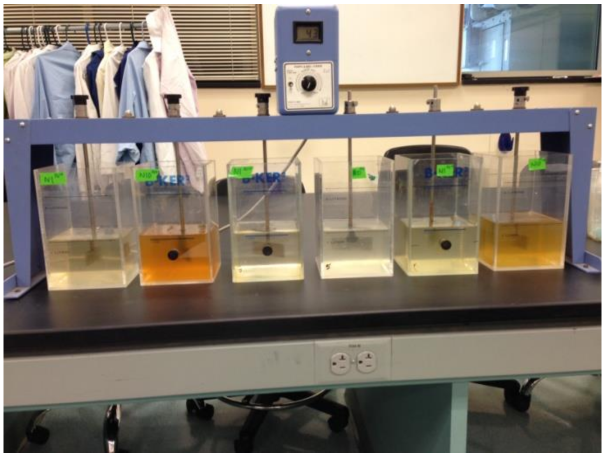
Brown and Caldwell

14

Client(s):	Brown and Caldwell – Jamie Eichenberger
Faculty Advisor:	Lee Landkamer
Consultants	Linda Figueroa
Team Name:	Wastewater Wizards
Team Members:	Evon Harmon, Katie Sexton, Lindsey Freytag, MacKenzie King, Rebecca Erickson, Will Porter

The Wastewater Wizards were challenged by the engineering firm Brown and Caldwell to design a chemical feed system for the Littleton/Englewood Wastewater Treatment Plant (L/E WWTP). The purpose of the chemical feed system is to remove phosphorus to enable the L/E WWTP to meet new nutrient criteria set forth by the Colorado Department of Public Health and Environment. The new nutrient criteria require that phosphorus discharge is limited to less than 1 mg/L by the year 2020. The team's deliverables included selecting the chemical and proper dosage, locating where in the process the chemical should be added, and designing the chemical feed system to a 30% design level.

The team determined that ferric chloride will be used to remove phosphorus though co-precipitation with ferric oxy-hydroxides. Ferric chloride was chosen over sodium aluminate and ferrous chloride after performing jar testing with wastewater from several locations at the plant. The optimum dosage of ferric chloride was also determined by these jar tests. After the analysis of multiple factors at each location, including lifecycle cost and process impacts, the team decided that the chemical will be added immediately following the solids contact tanks, with the resulting precipitated solids removed by the secondary clarifiers. The chemical feed building design includes appropriately sized tanks, pumps, and pipes using materials compatible with the selected chemicals. The feed system was designed to be compatible with the existing structures and buildings, and allows for flexibility to change the precipitation chemical if needed in the future.



Lookout Mountain Lid Structure

15

Client(s): Anne Beierle
Faculty Advisor: Lee Landkamer
Consultants Joe Crocker, Mike McNish
Team Name: Mountainside Consulting
Team Members: Michelle Danaher, Jeri Mero, Krystina Pacheco, David Ploense, Meaghan Schwindt, Adam Vogel, Brad Wood

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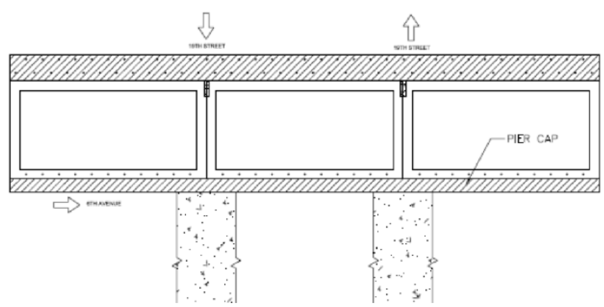
Mountainside Consulting worked with the City of Golden in Colorado to design a bridge structure that allows 19th Street to pass over US 6. This design provides safe access for pedestrians and cyclists, as well as connects the community west of US 6 to downtown Golden. The structure will support both a park and roadway separated by trees and grass covered berms.

The specific live and dead loads that will be applied to the deck of the bridge were calculated for both the park and roadway, with the roadway presenting the largest load at 640 lb/ft^2. In order to minimize the load presented by the park, lightweight manufactured soil that was originally developed for rooftop gardens will be used for the park. An adjacent box-girder design supported mid-span by columns was selected for reasons of constructability and accessibility as the support structure for the bridge. The deck slab, adjacent box girders, pier cap, mid-span support columns and bridge abutments were designed to the proper size and strength based on the maximum roadway load. Both sides of the bridge will use this design because the bridge will be built in two phases; the park side will carry traffic during construction of the roadway side of the bridge. A cost estimate for the lid structure was also completed. Additional calculations have been completed to determine the amount of excavation that will be needed to lower US 6 under 19th Street.



Photo

Cross section of bridge at mid-span; showing bridge deck, box girders, pier cap and support columns

Courtesy of City of Golden

Highway 6 and 19th Street Stormwater Drainage and Treatment System

16

Client(s): Anne Beierle, City of Golden
Faculty Advisor: Lee Landkamer
Consultants Terri Hogue, Mike McNish
Team Name: Creative Drainage Solutions
Team Members: Claire Levinson, Dave Jones, Erik Sheader-Smith, Maria Blakely, Nicole Neals, Susan Paret

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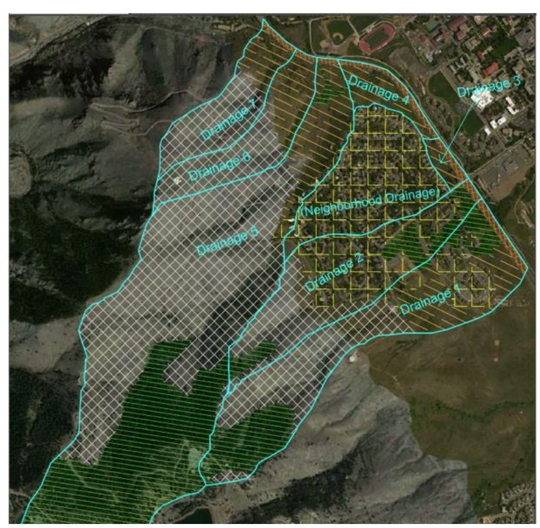
The City of Golden is redesigning the intersection of Highway 6 and 19th Street. The Highway 6 profile will be lowered approximately 25 feet under a new bridge structure for 19th Street. The new bridge structure over Highway 6 will be designed to accommodate both vehicular traffic and a large park area for public use. The lowering of US 6 will necessitate a drainage system to convey stormwater from the newly created low point.

Proposed Highway 6 and 19th Street Intersection Redesign

The scope of the project encompassed calculating runoff into the intersection, designing subsurface piping and surface channels to carry water away from the area, and designing a passive water treatment feature to improve the water quality of the runoff. The team considered public and client input along with regulatory requirements to design a system that would meet the needs of Golden and satisfy the requests of the surrounding community and its residents. Carlson Civil AutoCAD, drainage basin topography and soil types, and National Oceanic and Atmospheric Administration precipitation estimates were used to determine the peak runoff flow rate from the drainage basin during a 100-year flood event. Using this peak runoff value, the Urban Storm Drainage Criteria Manuals, and engineering principles, the pipe size and slope required to convey the water to Clear Creek was determined. In addition, an extended detention treatment system was designed to improve the water quality of the storm water runoff and placed in a suitable location.



Drainage Basin Map

Control System for ECAP-C

17

Client(s): Dr. Terry Lowe
Faculty Advisor: Dr. Yitz Finch
Consultants Dr. John Berger
Team Name: Applied Thermal Solutions
Team Members: Malek Awad, Taylor Bettine, Matthew DeGeorge, James Derrickson, Logan Nissenson, Benson Tan

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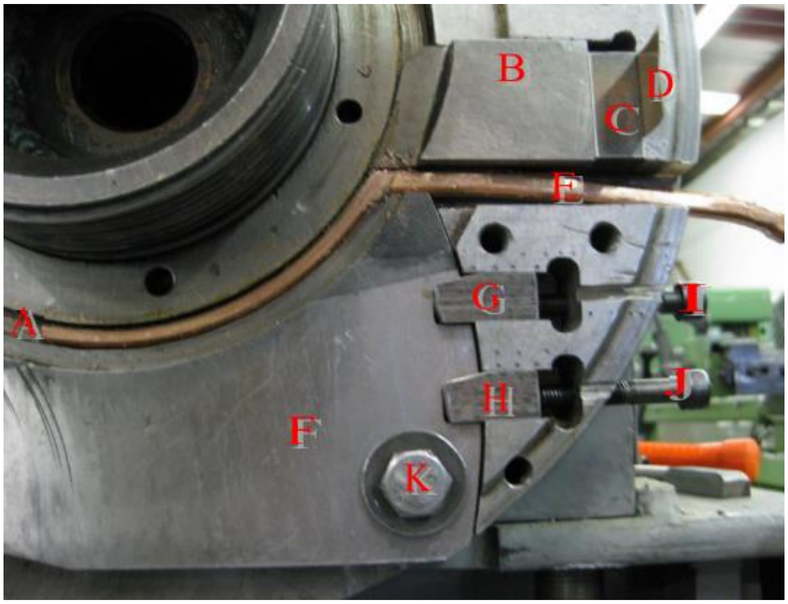


Applied Thermal Solutions has been tasked with the project to improve the ECAP-C machine with a heating and cooling control system. Currently, the ECAP-C machine resides in Hill Hall where it performs an interesting experiment on metal samples. A metal sample passes through the machine and, through friction and pressure, is bent at a severe deformation angle. This bending allows the metal to align its grain structure, causing the metal to become stronger as a result. The piece of metal, called a billet, is preheated before it enters the machine. It loses its heat quickly while moving through the machine because the machine itself is a huge heat sink. While undergoing the shearing process, the billet generates a large amount of heat. Often, this heat is larger than the desired temperature for the shearing process. It is important that the heat at the shearing section be controlled so that the desired metal characteristics develop during the shearing process.

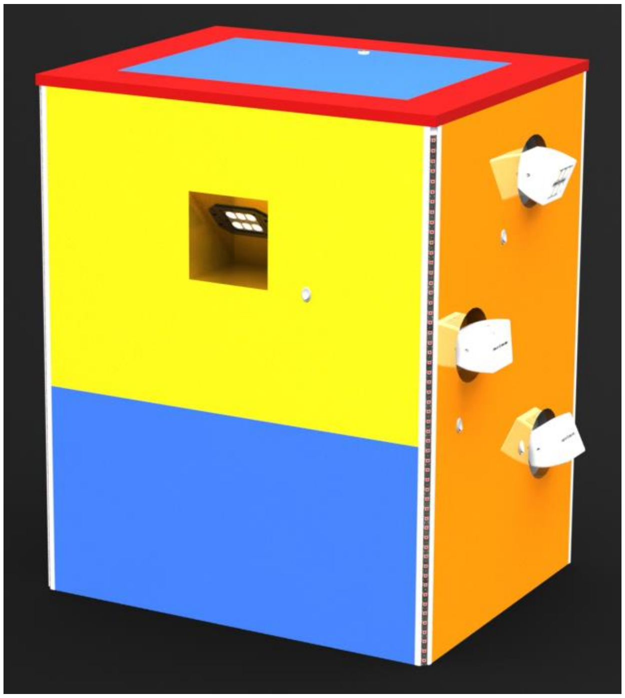
It is the duty of Thermal Heating Solutions to develop a control system that maintains the billet's heat during its path through the machine, keeps the billet at the correct temperature during the shearing process, and cools the billet down as quickly as possible after the process has ended. If done successfully this new process can change the way that metal is produced in the World. The metal coming out of the ECAP-C machine has strength greater than alloys. The finishing of this project can lead to stronger metals worldwide.

“The Illumidor”- An Interactive Light Lab

18

Client(s):	Boulder Journey School – Sam Hall
Faculty Advisor:	Mirna Mattjik
Consultants	Jenifer Blacklock
Team Name:	Bright Futures
Team Members:	Brent Last, Joshua Madole, Tyson Manning, Joshua Martinez, Lauren Revis, Jasmine Sanchez

Boulder Journey School is a private institution located in Boulder, Colorado driven by inspiring children ages six months to six years to explore the world around them. Their facility features many technology-related activities that encourage children to create their own learning experience. The school has requested for Bright Futures to design an open-ended module centered around investigating light and its properties. The design is focused on safety, mobility, student learning and ease of use. Bright Futures has applied their engineering expertise to analyze the safety and functionality of the design. Analysis conducted includes failure modes, user feedback and safety testing. Bright Futures will deliver “The Illumidor,” an interactive box with various light fixtures built for children ages six months to six years; inspiring all ages. In addition to the light box itself, Bright Futures will also deliver a complete drawing package and user manual. The Illumidor features one large LED light panel, moveable LED light pods, fixed lights and color-changing light strips. On/Off buttons and a color-changing wheel add to the interactive element of the light box.



Mines Survey Field Update

19

Client(s): Jeff Holley
Faculty Advisor: Branden Gonzales
Consultants Dre Guerra
Team Name: Superior Surveying
Team Members: Brad Burback, Stephanie Ecker, Kyle Hampton, Taylor Madden, Kate Percival, Samantha Stokes

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The Colorado School of Mines Survey Field, located south of Mines Park, is an important part of Mines and it's engineering history. The site is currently used for Civil Engineering field sessions and surveying courses, but the field was once part of every major's field session, and holds both sentimental and historical value for numerous Mines alumni.

Superior Surveying has completed a detailed proposal for updates to the Mines Survey Field for the client, Jeff Holley. The team performed surveys of the existing site and conducted site and soil analyses in order to develop a grading plan, site plan (Figure 1), drainage plan, and proposed site designs that comply with local, state, and federal regulations.

Proposed improvements to the Mines Survey Field include a new parking lot featuring a permeable pavement system that will enhance the aesthetic appeal of the area, and increases drainage throughout the site. Additionally, updates to the existing building provide a new patio area for congregation, and added ramps and handrails ensure ADA compliance. A new building was also designed, with a proposed location to the north of the existing parking lot, which features a classroom area, atrium, and ADA compliant restrooms. The new classroom space has the potential to accommodate a variety of classes, and is sized to hold to largest expected class in the foreseeable future. The atrium will display historical surveying equipment and highlight the history of the Mines Survey Field. The proposed design is intended to be low-maintenance, cost-effective, and environmentally conscious.

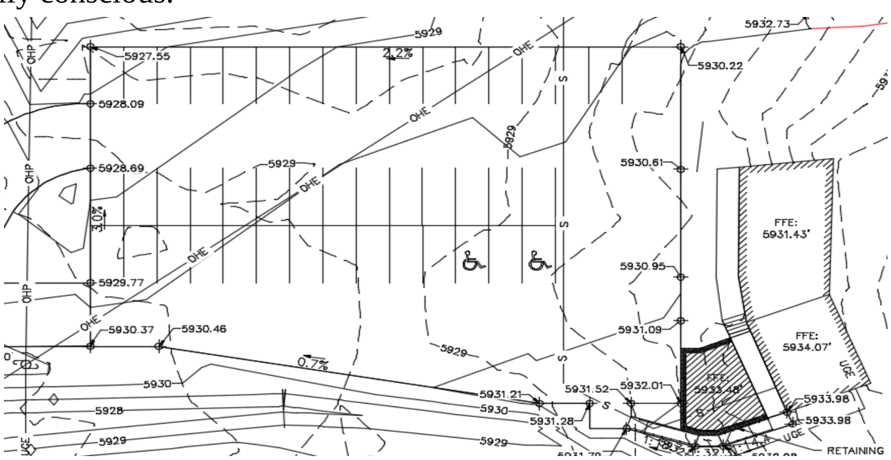

Figure 1: Site Plan For The Southern Part of the Survey Field

20

Mines Survey Field Update

Client(s): Jeffery Holley, CSM Civil Engineering Department
Faculty Advisor: Branden Gonzales
Consultants Andres Guerra, CSM Civil Engineering Department
Team Name: The A-Team
Team Members: Jordan Arndt, Rebecca Boggan, Anna Borchert, Daniel Gibbons, Bethany Klinkerman, Paul McDonald

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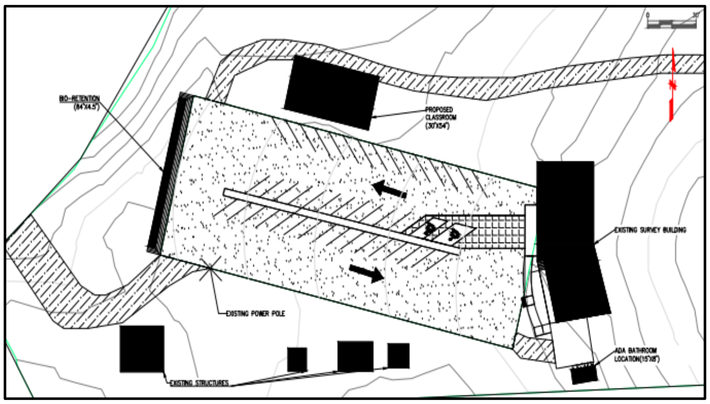
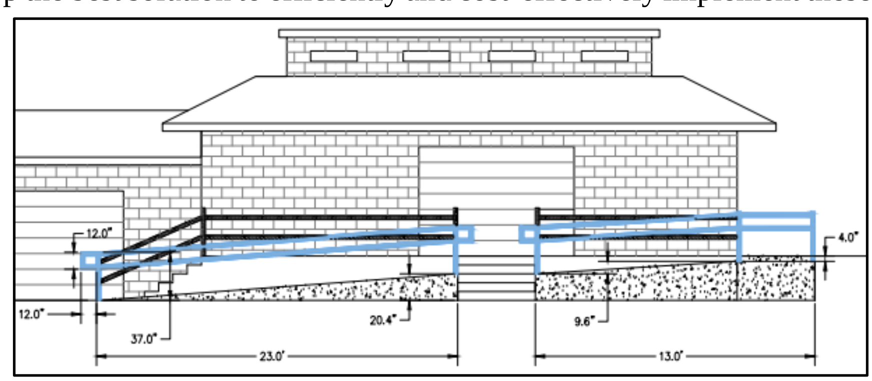


Site Layout for Proposed Update

The Mines Survey Field has served as an integral site and trademark of an engineering education at Colorado School of Mines (CSM) for decades. This world class facility holds significance for a multitude of engineering disciplines at CSM, including those who were required to learn surveying at this field. This in turn has created a unique alumni support network for the area as well as a goal to honor its past in future updates.

The existing Mines Survey Field has remained unchanged since its original construction. Although minor site improvements have been implemented in the past decade (i.e. construction of the shielded picnic tables designed by the EPICS program), the site as a whole is in need of modernization. Among the areas needed to be improved, include: the parking lot surface and grading, additional bathroom units, American Disability Act (ADA) compliance and accessibility.

The Mines Survey Field Update proposed by the A-Team includes: recycled concrete paving surface, concrete wheel stops, poured concrete parking surfaces and ramp for ADA accessibility, and a new structure to provide two (2) new ADA compliant restroom facilities. Through the course of this project the team also has proposed a location for a future classroom and stormwater drainage and treatment through a bioretention system. The A-Team worked alongside the Civil Engineering Department of CSM to develop the best solution to efficiently and cost-effectively implement these improvements. The A-Team welcomes all interested parties to come by our booth and seek further information.



Ramp and Building Profile

One 'n' Done Universal Anchor

21

Client(s): Oldcastle Precast
Faculty Advisor: Branden Gonzales
Consultants: Joe Crocker, Andres Guerra, Jeffrey Holley, Shiling Pei
Team Name: Mines Anchor Design Team (MADT)
Team Members: Eli Betz, Mike Campbell, Justin Downs, Adrian Eccles, Jaime Sandoval, Cassie Vick, Dylan Woldt

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The purpose of the One 'n' Done Universal Anchor is to provide a safe, reliable, and efficient light-pole base that can support up to 90 percent of light-poles commonly available. The light-pole baseplate is a key aspect of the project design providing the light-pole base its universality.

The light-pole base consists of a cylindrical, steel reinforced, precast concrete base with a 2 ft diameter and a height of 8 ft. The base must be designed to withstand a maximum wind load of 115 MPH in the worst-case soil conditions and a light-pole and luminaire combination with an Estimated Project Area (effective area perpendicular to wind flow) of approximately 6 ft^2.

Attached to the base is a unique steel baseplate with an adjustable bolt circle diameter from 7.5 in. to 11 in. This enables the One 'n' Done Universal Anchor to accommodate a large variety of light-pole connections and configurations. MADT's innovative baseplate (shown in Figure 2) features four fastening components called "sliders" which are allowed to slide along the designated slots that are directly anchored to the base reinforcement.

The final design package for the One 'n' Done Universal Anchor includes a calculation package, marketing and design Excel spreadsheet, 3D printed scale model, installation manual, final design drawings, and a bill of materials.

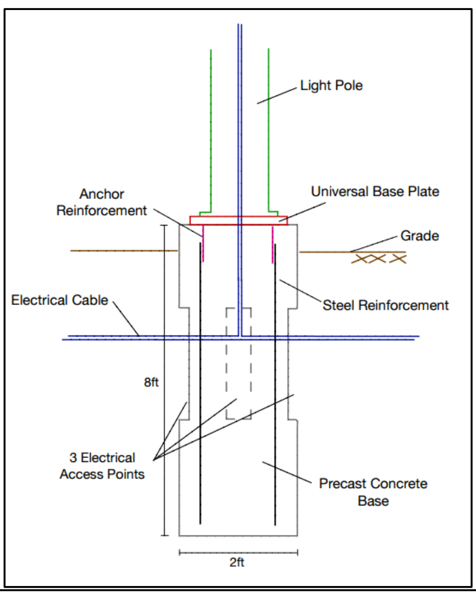

Figure 1: Universal Anchor Overview

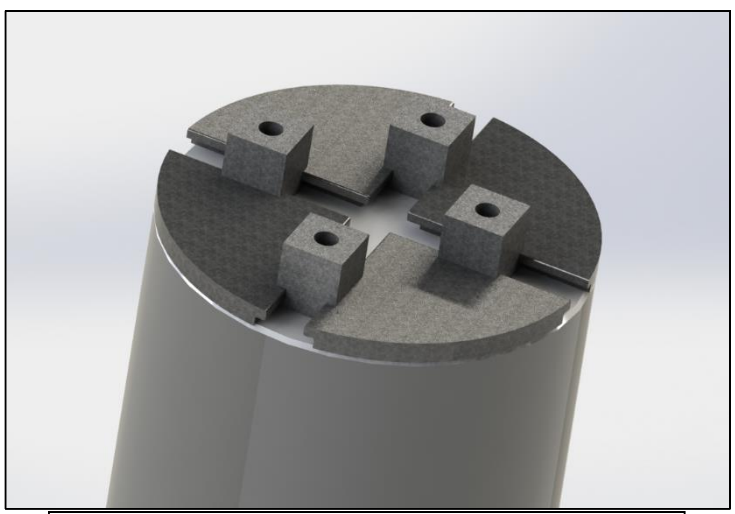

Figure 2: Baseplate SolidWorks Rendering

22

SODAR Phase II

Client(s): Patricia Douglas, Michael Carmody
Faculty Advisor: Dr. Chuck Reynerson
Consultants Dr. Tyrone Vincent
Team Name: Team SODAR
Team Members: Jason Actis, Silviu Boanta, Travis Gorhum, Luke Northey, Matt Rakestraw, Nathan West

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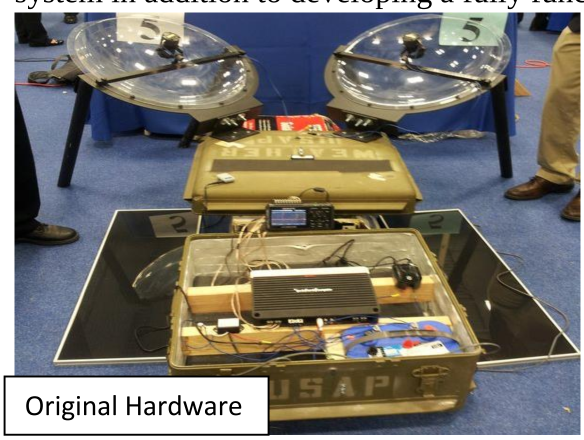
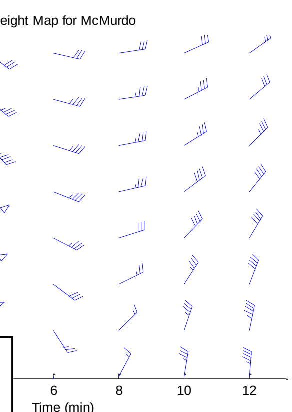
SODAR Phase II is the continuation of an attempt to develop a portable SODAR (**SO**nic **D**etecting **A**nd **R**anging) system for Lockheed Martin and the United States Antarctic Program. The system is needed to characterize wind resources throughout Antarctica with the help of the YETI Robot. SODAR technology analyzes the frequency shifts in transmitted signals in order to map the wind velocity field in a given location. It was intended for the hardware system from SODAR Phase I (shown below, left) to be used in order to transmit a signal and to record data from the reflected signal. The original scope of SODAR Phase II was to develop a complete software package (shown below, right) that processes, analyzes, and presents field data collected from the hardware. However, the scope was ultimately redefined to include: reverse engineering, repairing, testing, redesigning, and modifying the hardware within the constraints of the previously established system in addition to developing a fully functional software package in MATLAB.



Original Hardware



Sample Chart from Software

The team had numerous challenges on the project: researching and developing a technology that had never been made affordable and portable for harsh environments, working with a rare two dish SODAR configuration, implementing microcontroller methods to transmit and record signals within a minimally documented, ineffectively established, and limited system, and redefining project goals and roles in order to ensure that the client's expectations can be met. Ultimately, the project was a test of the team's ability to recover from unexpected shortfalls and to identify the ideal approach in order to right the course of the project. The unique atmospheric conditions of Antarctica create tremendous challenges for effective and accurate wind profiling, but the current hardware and the associated software package will be invaluable to perfecting an affordable and portable SODAR system.

Weight Distribution Training Device and Exercise Games for Stroke Patients

23

Client(s): Dr. Ozkan Celik

Faculty Advisor: Dr. Yitz Finch

Consultants: Dr. Hao Zhang; Dr. Juan Lucena

Team Name: RE-Balance

Team Members: Rey Chavarria, Jeremy Guiley, Chelsea Hudgen, Danielle Honas, Kole Kadavy, Laurie Le

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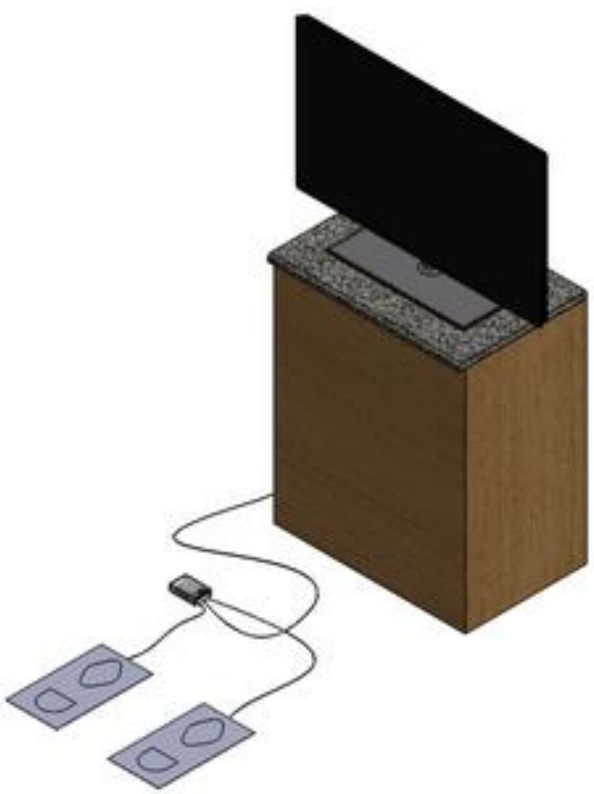

People who suffer from strokes are highly likely to lose their balance as a result of the stroke. The Colorado Neurological Institute (CNI) has tasked our team with designing an updated version of their stroke rehabilitation device. The device needed to be able to display real time data so the patient may observe how much of their weight is on each foot at one time. The system must be readily portable so CNI can rent out the system to patients to provide in home care and enhance their time in rehabilitation. The purpose of the project is to create a functioning prototype of the updated system.

The design approach incorporates elements from the original device including thin foot pads, enjoyable games and an easy to use interface. The device utilizes force sensing resistors (FSR) in the foot pads in order to measure the weight distribution of the patient over both foot pads. This provides ease between each of the users as the weight of the user does not need to be updated in the program before each use. The foot pads created are comprised of sheets of plastic, foam, FSRs and distribution pads. The system also incorporates a portable microcomputer, which stores programmed games that can be selected and played through the use of a keyboard and mouse. The production prototype is currently in progress.

Weederbot VI

24

Client(s): Dr. John Steele
Faculty Advisor: Lieutenant Colonel Paul Kaster
Consultants Dr. Douglas Van Bossuyt
Team Name: Weederbot VI Team
Team Members: Dan Dvorak, Byron Garcia, Tyler Graeve, Brandon Storm and Tyler Tourney

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Figure 1: eXmark Mowing Platform

The objective of the Weederbot VI project was to take an existing eXmark mowing platform that can mow under both the usual manual control as well as autonomous control, and improve upon the mechanical switch between the two. Under the manual control the mower can operate with a user controlling the lever arms that in turn control the hydraulic controls that steer the mower. Under the autonomous mode GPS signals are used to control linear actuators that then signal the hydraulic controls that steer the mower. The previous design of the Weederbot had a transition that was cumbersome and time consuming. The main objective of the Weederbot VI Team was to improve upon this aspect of the design. The team explored many solutions to this problem including hydraulic controls, electrical controls and mechanical control, ultimately seeking a mechanical solution to the problem. The team has chosen to use quick disconnect linkages to replace the current system in place. These linkages were modeled in SolidWorks to run analysis to ensure that they could undergo the stresses and strains associated with the operation of the mower. Along with the linkages, the entire lever arm and connection system to the hydraulic steering controls were also rendered in SolidWorks and tested for failure, safety and fatigue. From these tests the team was able to confidently implement the design that was developed and solve the problem of switching between manual and autonomous operation.

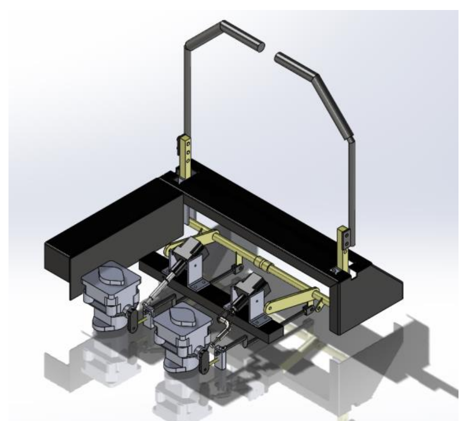

Figure 2: SolidWorks Model of Connections

Figure 3: Quick Disconnect Linkages

GoFarm Food Hub Building

Client(s):	Eileen Regan, Go Farm
Faculty Advisor:	Mirna Mattjik
Consultants	Andres Guerra/Heather Christensen
Team Name:	Turnip the Beet
Team Members:	Taylor Baird, Daniel Broas, Carmella Caltagirone, Cassie Ford, Kevin Trautman, Meghan Way

The GoFarm Food Hub will be located in Golden, CO and will be the main location for local small and mid-sized farmers to store their crops. It will also serve as the main office and pick-up location for the Community-Supported Agriculture program. In cooperation with two other Senior Design Teams, Team Turnip the Beet has been tasked with the structural design and sustainability considerations of the building itself. The final design is based on a warehouse concept, consisting of a layout that includes freezer and refrigeration space, dry storage, an office area, and a loading/unloading dock. The floorplan is unique in the way that it integrates functions that allow it to serve farmers and employees, and creates an interactive and educational customer experience. A combination of structurally insulated panels and glazed glass curtain walls enable the building to meet its desired functions while utilizing passive energy, coming to a total cost of $1.47 million. The materials have been chosen to optimize energy efficiency while also considering LEED certification and user experience.

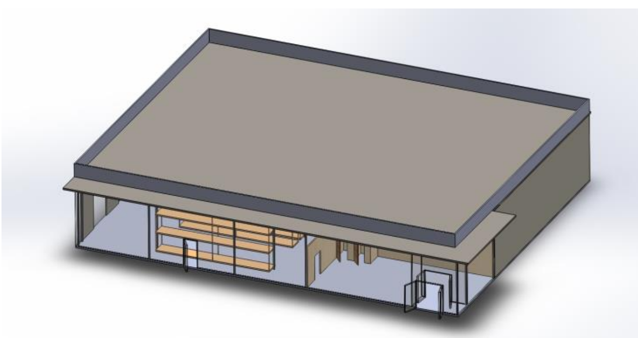

Figure 1. Overall building design SolidWorks rendering. Building dimensions: 112 ft x 90 ft x 26 ft

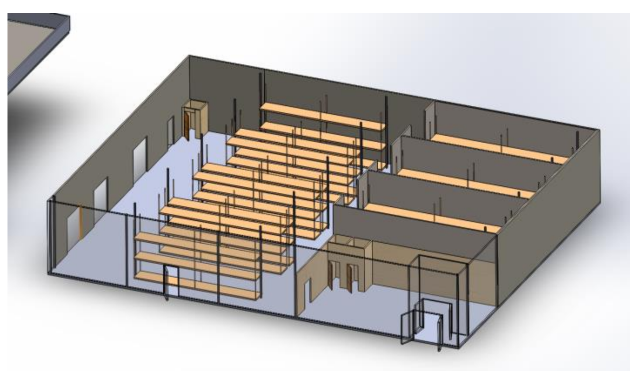

Figure 2. Interior building design SolidWorks rendering. Includes freezer in top right hand corner, fridges below.

Chevron Phillips Chemical Outfall Pond Automated pH Remediation

26

Client(s): Chevron Phillips Chemical, Mr. Erik Lord
Faculty Advisor: Dr. Lee Landkamer
Consultants Mr. Will Rommel
Team Name: Engineering Collective
Team Members: Justin Basel, Natalie Boldt, Courtney Derus, Ashley Engen, Keeley Hernandez, Nichole James, Lukas Newbury

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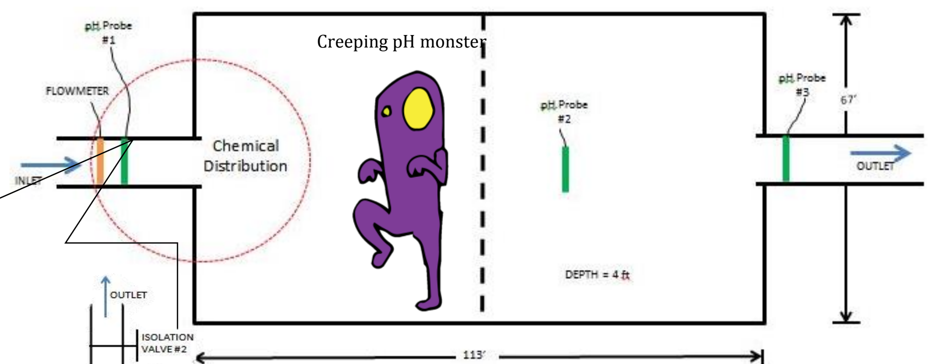
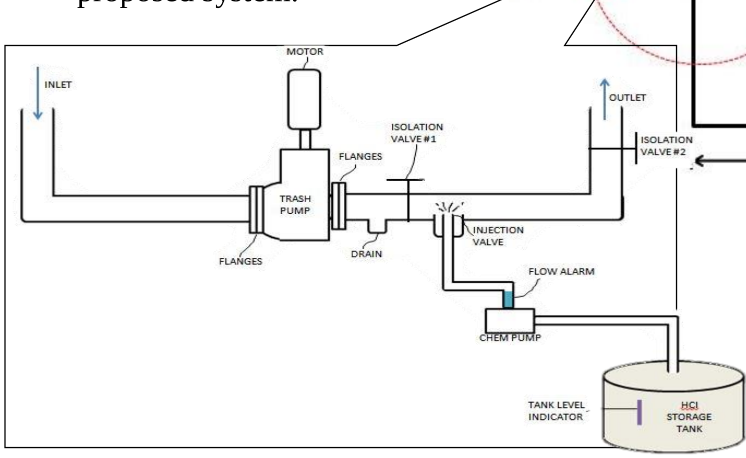
Chevron Phillips Chemical is experiencing pH increases to alkaline levels of treated process water in an outfall pond at their plastics manufacturing facility in Orange, TX. This process is referred to as "pH creep" and is leading to an exceedance of discharge requirements for the pond if left untreated. The manual addition of citric acid is currently employed as an unsatisfactory solution to the problem. Team Engineering Collective was tasked with designing an automated chemical distribution system to remediate the overly alkaline pH levels occurring in the outfall pond.

Engineering Collective approached this interdisciplinary problem by dividing the project into three components: environmental, mechanical and electrical. The purpose was to individually evaluate design components within each of the disciplines. The subsystems were then compiled into a single cohesive design.

The team designed a system that will meet federal and state defined pH discharge standards, regardless of the influent pH and composition. The use of an automated system will monitor the pH of the water at the influent, mid-pond and outfall and dispenses and distribute hydrochloric acid as necessary to address pH increases in the pond. The design was verified with the creation of a small-scale prototype that simulates the proposed system.





Food Hub Energy System Project

27

Client(s): Eileen Regan

Faculty Advisor: Mirna Mattjik

Consultants Dr. Greg Jackson/Dr. Paula Farca

Team Name: Golden Energy Solutions

Team Members: KC Schultz , Mark Weller , Noah Matthews , Kyle Burt, and Carly Conley

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The Food Hub Load Analysis project was a section of an overall food hub design project for GoFarm. GoFarm is a company based in Golden, CO that aims to create a way for local farmers to sell their produce to the community. In order to meet this goal GoFarm showed desire to construct a food hub in Golden. This design project was split into three projects: a building design, a power supply design, and a heat load analysis.

Golden Energy Solutions' (GES) main goals in the Food Hub Energy System Project were to analyze the heats loads, suggest a refrigeration system, and perform a sensitivity analysis the heat loads. The suggested refrigeration system is capable of cooling 6 zones to different temperatures, and regulating the humidity in each of these 6 zones. Considerations which affected the selection of this design included environmental impacts, ASHRAE standards, local energy codes, and stakeholder desires. From this analysis GES chose a geothermal/vapor-compression hybrid energy system.

A geothermal/vapor-compression hybrid energy system utilizes the constant ground temperature as a source of heat rejection from the system. This system has consistently proven to give consumers a 30% reduction in energy bills and lower environmental impacts than a standard vapor-compression system.

GES primarily used Energy Plus, an energy simulation program developed by the Dept. of Energy, to analyze the food hub. The simulations developed by this program provided a general characterization of the thermal loads and demands that will be experienced by the food hub. These loads were used to provide sizing information for the design of the geothermal/vapor-compression system.

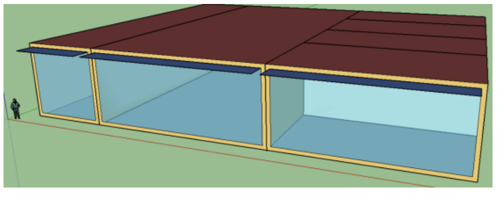

Fig. 1 – Google Sketch-up building model used for EnergyPlus simulations

GoFarm Food Hub Power System

28

Client(s): Eileen Regan
Faculty Advisor: Payam Nayeri
Consultants Greg Jackson, Paula Farca
Team Name: Dynamic Energy Providers
Team Members: Christopher Chartier, Reed Sanchez, Leslie Stockton, David Garcia, Drue Hernblom

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GoFarm Food Hub is a project being developed by Eileen Regan. The food hub will act as a storage and distribution center for local farmers. The goal of GoFarm is to allow local farmers to connect with the local community and to bring local produce to local consumers. Our team, Dynamic Energy Providers, is tasked with designing the power system for the food hub facility. The goal is to focus mainly on a design that allows for consistency and the use of alternative energy sources. Our team's proposed design utilizes many different components to accomplish these goals.

Our design is broken up into three main subsystems that are used to create a comprehensive system that provides the necessary power. The three subsystems are the grid, two natural gas generators and a biodigester. One natural gas generator will power the refrigeration system and one will power the remaining load. An automated transfer switch will synchronize the generators and the grid. The utilization of these components gives a design that produces the desired power, produces consistent power, and utilizes alternative energy sources.

To ensure that our design will meet our desired goals, modeling software called HOMER was used. With the use of HOMER and through various engineering calculations we have verified that our proposed design will create the power needed to run the GoFarm Food Hub, as well as meet the goals of consistency and use of alternative resources.

https://wefuturecycle.files.wordpress.com/2014/12/biodigester.jpg?w=672&h=372&crop=1

http://www.homedepot.com/catalog/productImages/300/57/575a0870-9254-4b76-9dda-5c0df67d227c_300.jpg

Micro-Dynamometer

29

Client(s): Paul Brayford
Faculty Advisor: Bill Sekulic
Team Name: Team Dyno
Team Members: Robert Earl, David Futch, Matt Garvin, John Paul, Everett Chouinard, Michael Rerecich

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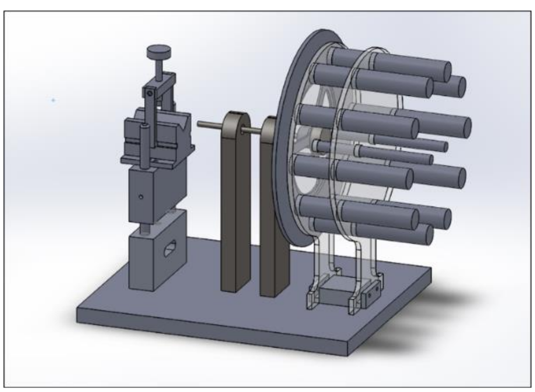
Absent or non-existing data sheets often restrict mechanical system engineers in industry today. Often times, design companies are reluctantly forced to invest large amounts of capital into acquiring these datasheets. In the specific case of DC motors, acquiring motor characterization curves proves to be particularly costly due to the highly technical and specific equipment needed.

Team Dyno's micro-dynamometer provides our client, Paul Brayford, with a cost-effective means of acquiring motor characterization curves. Our design focuses on DC brushed and DC brushless motors. These motors are generally capable of a maximum of 1N*m of torque with sizes ranging from 3mm to 50mm. The motor plots produced contain curves for torque, power, current, and efficiency at varying speeds.

Common DC Motor

The dynamometer design Team Dyno has developed utilizes a V-shaped motor mounting block, a magnetic eddy-current brake, and a LabVIEW data acquisition program in combination to produce motor plots. All of this was done within a $350 budget. Our project deliverables include the physical dynamometer system as well as an operation manual to be presented to the client upon project completion.



Final Micro-dynamometer

Functional Hinge/Tracking System

30

Client(s): Paul Quick, Kristen Beard
Faculty Advisor: Dr. Ron Slovikoski
Consultants Dr. Anthony Petrella
Team Name: Three-Oh Designs
Team Members: Corky Patton, Shana Wolfer, Mark Goldsmith, Austin Roup, Emily Arato, Karson Klein, William Sullivan

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The Denver Zoo's Planning/Capital Projects Department tasked Three-Oh Designs to design an armature system to provide easy movement and positioning of a radiograph machine in the zoo treatment room. In addition, the Zoo tasked the team to design a portable unit for use in the field.

The Zoo's veterinary staff purchased a new radiograph unit to replace the old bulky system. Currently the staff does not have any way to easily maneuver the new radiography unit and must hold it by hand to take the x-rays. The armature and mobile systems are designed to make this process easy, safe, and user-friendly both inside the examination room and out in the field.

The team utilized steel tubing along with locking hinges and dampers to hold the radiography unit and allow for easy movement and positioning on both the indoor and mobile units. The indoor unit mounts directly to the ceiling and rotates 360 degrees. The mobile system utilizes a dolly for easy transportation of the system. The team implemented a quick release system to allow the staff to easily and quickly transfer the radiography unit from the indoor armature to the mobile unit's armature.

The final deliverables consist of a fully functional indoor and mobile unit along with drawing and calculation packages for each.

Mobile Unit

New Radiography Machine

Indoor Unit

Mobile Indoor Routing

31

Client(s): Michael Melonis
Faculty Advisor: Dr. Chuck Reynerson
Consultants Dr. Stephanie Claussen
Team Name: Enlightened Robotics
Team Members: Johnny Nguyen, Steven Mollard, Drew Kerschieter, Zach Stevens, Kyle Wenner, Steven Avetissian

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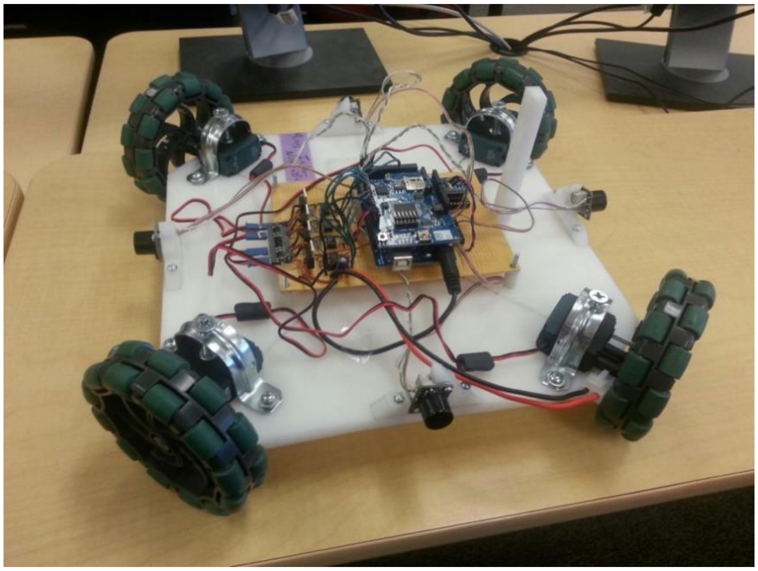

Our task was to create a robot that was capable of navigating between different rooms around a floor of a building given a starting location and had to get within five feet of the specified destination, with the envisioned purpose being to help people with cognitive disabilities who work in a warehouse-type setting. The movement was to be autonomous, and the new locations would be specified by the user. The main deliverables to the client includes a working prototype that can route to at least five different points, with the hardware specifications and software source code for the navigation system Also, a documented list of challenges overcome and any existing known problems are to be provided as well.

We were able to utilize a previous team's robot that chose to implement Wi-Fi triangulation, mainly the hardware pieces like the chassis, wheels, sensors, and Arduino Mega microprocessor. However, after looking into different navigation schemes, we wanted to go a different direction with our robot. The downfalls of both teams before us that used Wi-Fi triangulation and RFID sensors led us to use line following due to its straightforwardness and accuracy. This method utilizes infrared sensors to detect specified colored lines on the ground to navigate. Employing a checkpoint system in addition to the navigation algorithm allows the robot to always know its location while traversing through the grid by calculating the most optimal route. We believe that this solution will satisfy Mr. Melonis' needs effectively and cost efficiently.

Hand Cycle Reverse Gear

Client(s): Jake O'Connor
Faculty Advisor: Ben Teschner
Consultants Jered Dean, Dr. Joel Bach
Team Name: Colorado CrankWorks
Team Members: Jose Arellano, Katie Herrera, Alex Howard, Nic Jimenez, Alex MacKenzie, Tanner McManus

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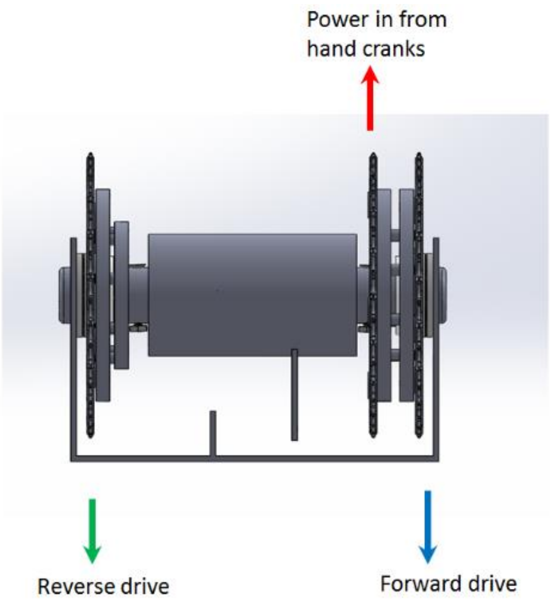
Most cyclists take their legs for granted. Mountain bikers know that if they run into an obstacle on a trail, they can simply back up using their feet and try again. But what happens if you're a cyclist, but do not have the use of your legs? That issue is what the Colorado CrankWorks senior design team is working on. Our goal is to make a hand cycle go in reverse, without depending on the user's legs.

The Colorado CrankWorks team originally started with a fairly simple design: pedal forwards to go forwards, and backwards to reverse. However, by talking with designer of the bike, we discovered that the motion of pedaling backwards would pull someone without the use of their legs out of their seat.

After modifying our thought process, we landed on a design that translates forward chain motion into the reversing of the bicycle. This has been accomplished by modifying the bottom bracket of the bike so that it disengages the forward drive system and activates our designed reverse gear system. This is done with the use of a mobile chain ring that can slide between the forward and reverse drive systems. Our system has been tested under extreme conditions, and by real-world users that can trouble shoot potential hiccups and problems.



Our final design, U-Bracket #1, is prototyped and trail-ready. Along with all of our research of previous designs, failures, and brainstorming will be given to our client so that he can incorporate them into his products, making hand cycling a safer and more enjoyable activity for all.

Multi-Mode Force and Field Assisted Sintering Device

33

Client(s): Dr. Geoff Brennecka
Faculty Advisor: Paul Kaster
Consultants: Dr. Neil Sullivan
Team Name: Team Platinum
Team Members: Anastasia Candelaria, Andrew Raygoza, Braeden Lieberman, Brent Risting, Brett Dyke, Bryce Cullen

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Our project challenge was to design a multi-mode force and field assisted sintering device. This device should not only incorporate an electric field and apply a mechanical force onto a sample of ceramic during the sintering process, but be able to measure the force and electric field as well. All of this must be done at temperatures reaching up to 1400 degrees Celsius, which presents us with the unique challenge of using highly thermal resistant materials. These materials end up being either highly expensive or highly brittle making normal mechanical uses such as being able to use threads/screws and moving parts within the furnace an extreme challenge. Another challenge of this project is that we have to maintain a controlled atmosphere while applying a force from outside the furnace. The furnace is pictured below in Figure 1. The device also has to be small enough to fit inside a 3 inch diameter tube, and accommodate a budget under ten grand. Considering the entire project constraints, our team decided to make a 3D printed prototype of a fully encased design with all the moving mechanical parts outside of the furnace for the final product, with calculations and analysis to back up the hypothetical material and electrical programming: alumina, platinum, aluminum, linear actuator, bellows, seal, force sensors, DS probe, platinum wires, Arduino board, and Labview programming. A Solidworks picture of the multi-mode force and field assisted sintering device is shown in Figure 2.

Figure 1: Sintering Furnace

Figure 2: Multi-Mode Force & Field Assisted Sintering Device

34

Vibrations Learning Lab

Client: Ray Zhang
Faculty Advisor: Jeff Schowalter
Consultants John Steele
Team Name: Omeganauts
Team Members: Ben Dorbin, Rolland Gyorfi, Thomas Hoskins, Shawn Kobylinski, Jayden Kulhawy, Zachary Mott, Devin Thewlis

The Omeganauts designed the Vibrations Learning Lab to demonstrate axial, bending, and torsional modes of vibration. This one of a kind apparatus will provide students studying engineering vibrations with a physical demonstration of vibrational phenomenon to facilitate a deeper understanding of the theories provided in class.

The Vibrations Learning Lab demonstrates all three modes of vibration below, at, or above the natural frequency. For each mode the mass, spring constant, and viscous damping can be adjusted to vary the vibrational response.

Each mode of vibration can be demonstrated as free or forced vibration. A payload car will provide the driving force for base excitation for all three modes. An additional car will glide freely along two parallel rails and will be used to demonstrate axial vibration. Bending vibration is demonstrated using a thin cantilever beam mounted on top of the drive car. Torsional vibration is demonstrated utilizing a beam which rotates about a fulcrum composed of a bundle of flexible nylon rods which twist under load.

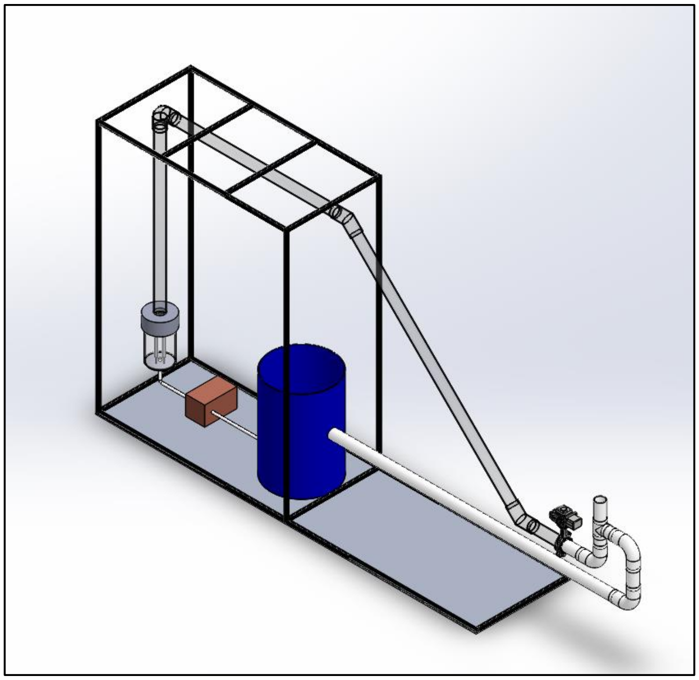
The supporting cart and shelf is made from 80/20 aluminum providing a strong and modular structure. Caster wheels allow the cart to be easily moved between classrooms and retractable feet provide a stable base during operation. A large shelf is available to hold equipment for storage and transportation. Data collected from accelerometers and rotary encoders is displayed on a shelf-mounted monitor in real-time. This data stream can also be displayed on an overhead projector.

Fluids Teaching Laboratory

35

Client: Dr. Nils Tilton
Faculty Advisor: Dr. Greg Jackson
Consultants Dr. Derrick Rodriguez
Team Name: The Jackson VI
Team Members: Lucas Christian, Curt Colburn, Karvel Haug, Albert Nguyen, Daniel Petree, Matt Swanson

The Jackson VI is proud to present the Fluids Teaching Laboratory to be used in conjunction with Colorado School of Mines fluids courses. The client of this project requested the design and build of a laboratory that introduces students to hands on experience with curriculum fundamentals. Further, the client wished for the laboratory to go beyond traditional fundamental experiments and introduce students to real, complex, industry challenges.



Experiment Rig 1

The Jackson VI has successfully designed and constructed a laboratory that effectively meets the client's demands. This rig is a goliath, measuring eight feet tall by twelve feet long and utilizes clear pvc piping so that students can visually observe the phenomena they are experimenting with. The rig has the ability to run single phase (water) as well as two-phase with CO_2 injection. The rig uses LabVIEW, a data acquisition software, to communicate with various pressure transducers, automated valves, and pumps so that students get hands on experience gathering data and controlling a live fluid network.

Along with the rig itself, the Jackson VI has developed a series of experiments to be performed by the students that are focused on the concepts and fundamental learned in their Fluids I & II courses. This laboratory goes beyond the traditional fluid experiments and gets students excited about learning!

Fluids II Lab Development

36

Client(s): Dr. Derrick Rodriguez
Faculty Advisor: Dr. Greg Jackson
Consultants Dr. Nils Tilton
Team Name: Smart Drops
Team Members: Brandi Fruge, Noah Langford, Antonia McMullan, John Nguyen, Kellan Richard, Spencer Tryba

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Smart Drops has been presented with the challenge of creating a fluid flow loop for future undergraduates to expose them to complex flows that often occur in industry. With the final deliverables of a fully built flow loop and an accompanying manual for the use and management of the loop. Smart Drops has chosen the challenge of producing slug flow, essentially bubbles that produce large pressure spikes in many piping systems that use two phase flow. There are larger flow loops that have been able to achieve this, however Smart Drops is required to shrink down the scale to a size that fits into a room. The largest challenge in this project is to be able to shrink the size of the flow loop while maintaining the physics necessary to produce a slug. The solution was to take many of the papers written on the larger flow loops and use the data, primarily the unitless data on superficial velocities to find the proper height needed for the vertical test section to produce a slug with a given diameter. Another focus was placed on visualization to aid in student learning. To overcome this concern, a clear test section with the pipe diameter of 3” was chosen, so that students can clearly see the multiphase flow. Along with the main focus of multiphase flow, the pipe system has been designed for other experiments to ensure a more robust student learning including multiple concepts from the fluid dynamics courses that are offered at Mines.

Assembly of Flow Loop Design

Continuous Tabletop Research Glass Melter

37

Client(s): Dr. Ivan Cornejo
Faculty Advisor: Dr. Yitz Finch
Consultants Dr. Steven DeCaluwe
Dr. Geoff Brennecka
Team Name: F14-37
Team Members: Alexander Cerny, Joelle Marshall, Nathaniel Marshall, Sarah Pekarek, Tyler Johnson, Daniel Devers

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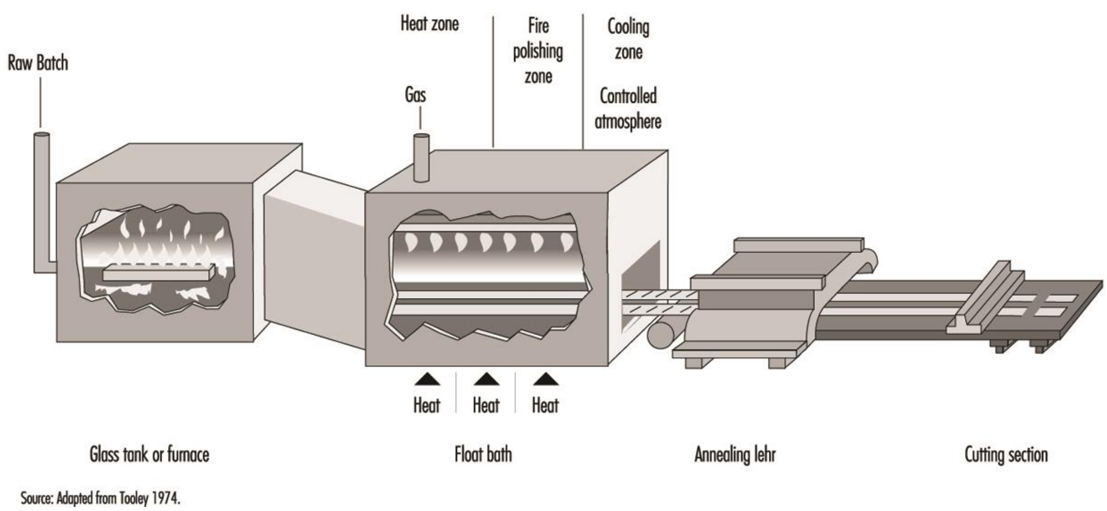
In the materials lab, here at the Colorado School of Mines, numerous professors want to perform research on glass. However, they are limited to only making glass utilizing a batch melting system. This current process does consistently create glass, but the glass created doesn't have the same mechanical properties as glass created by industry melters. Because of this difference, any research done on the glass made at Mines is essentially irrelevant to the real world.

In order to rectify this situation, it is our team's responsibility to design a melter that emulates industry melters. Since industry melters can be up to 1/3 of a football field in size, scaling them down creates some additional complexity in the project.

In order to ensure that our melter design functions like an industry melter, we identified the key metrics to be designed to. Temperatures in the various stages of the melter must match the temperatures maintained throughout industry processes. Additionally, glass moving through our melter should follow the same steps as in industry. The steps of industry glass melting are highlighted by the image below:



Our team has performed several hand calculations and thermal analyses through SolidWorks to demonstrate that our melter design will accurately emulate industry melters and produce glass with similar mechanical properties.

Off-Axis Micro Coil Winder

38

Client(s): Medtronic – Tom Cilke & Greg Smith
Faculty Advisor: Dr. Chuck Reynerson
Consultants Dr. William Hoff
Team Name: Off-Axis Micro Coil Winding Team
Team Members: Devin Jorstad, James Morris, Luke Pepperl,
Kyle Moore, Marvin Ruiz-Ibarra, & Michael Schuster

The aim of the Off-Axis Micro Coil Winding Project is to design a coil winding machine that wraps three coils of 50AWG wire around a stylet off-axis relative to its central axis. Stylets are surgical tools that are used in medical imaging using electromagnetic (EM) waves in order to pinpoint a location in space. These stylets are used by surgeons to perform less invasive surgeries by allowing them to guide medical instruments through small incisions in the patient's body.

Figure 1: Stylet Coil Winding

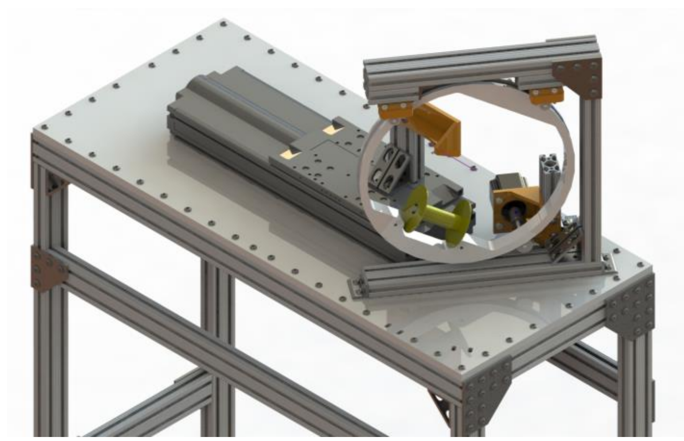


Figure 2: Coil Winder

Medtronic currently has the ability to wind coils that are perpendicular to the stylet which allows for 2D location; however, they want to move to using coils that are wound off-axis. Having three coils that are wound off-axis will enable higher resolution imaging with 3D location.

One of the challenges of this project is to create a method for keeping the coil off-axis from the stylet. This is difficult because under tension the wire will slide to the perpendicular position on the stylet. Another challenge is finding a technique for winding coil that is 50 AWG in size because it is approximately 0.0251mm in diameter, which is thinner than a strand of hair.

Our team has currently developed what is known as a toroidal coil winder. This type of winder uses the rotation of a shuttle to lay the wire onto the stylet. The winder also uses linear actuation to move the stylet to the desired position while the shuttle rotates to wrap the coil around the stylet.

Olympic Trampoline Measurement System

39

Client(s): Dr. Mounir Zok, United States Olympic Committee
Faculty Advisor: Dr. R. D. Slovikoski
Consultants Dr. Joel Bach
Team Name: Jump Around
Team Members: Nathalie Bram, Jed Braun, Andy Miller, Ross Sagehorn, Michael Werner, Colt Wilkins

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The sport of Olympic Trampolining features a number of metrics that can influence an athlete's score. These metrics include the athlete's landing position and the total time of flight (ToF) for the athlete's routine. Accurately measuring these metrics during training will put coaches in a strategic position to provide their athletes with objective feedback based on data, rather than relying exclusively on video and coaches' expertise. With this in mind, the United States Olympic Committee (USOC) has tasked our team with producing a measurement system for the trampoline event. Specifically, Team Jump Around is responsible for delivering a system capable of measuring an athlete's ToF, jump height, and landing position. This system must also record video footage of the jumps and provide the specified information in real-time.

Jump Around's measurement system uses 9 Idec type SA1E-TN2-2M photoelectric sensors (placed below the trampoline bed) to gather data. ToF is measured as the time between sensor trips and will be used to calculate jump height through simple kinematics. The order in which individual sensors are tripped can show if the athlete landed inside the trampoline's deduction box. This information is supplemented by video footage gathered by a Muhi Veho K2 camera, which provides adequate detail for slow-motion video replay. This data is stored in a database, and an easy-to-use GUI will display time of flight and position deduction information in real time along with post-event replay.

Prototype development has included subsystem/full-system tests at actual trampoline training gyms. Results have been compared to those produced by commercially available measurement systems to ensure that our system can provide comparable data in training scenarios.

Athelete Instrumentation Project

40

Client(s): Dr. Mounir Zok, United States Olympic Committee
Faculty Advisor: Dr. R. D. Slovikoski
Consultants: Dr. Joel Bach, Dr. Anne Silverman
Team Name: Peak Performance
Team Members: Chris Hayes, Geoff Sowash, Jessica Lyon, Graeme Smith, Cory Carter, Zane Perez

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The purpose of the Athlete Instrumentation Project is to help the US Olympic Men's Gymnastics Team with their performance on the Pommel Horse event. We are exploring the use of small, wireless, body mounted Inertial Measurement Units (IMUs) to allow the coaches to easily and accurately quantify rhythm and pacing. In this project we built Matlab software that displays, processes and stores IMU data in a simple and useful way.

Traditionally coaches have had no quantitative way to track rhythm in a routine (other than simple video recording). Our system focuses on the circle type movement on the pommel horse and allows easy measurement of average and individual circle times in a routine.
The hardware we are building our software on top of is the APDM Opal IMU system. This hardware and software package is relatively inexpensive and gives accurate triaxial accelerometer, gyroscope and magnetometer measurements at 128 Hz. It also offers simple wireless data collection (in our case with up to 5 IMUs) and 10 hour battery life. To detect when an athlete completes a circle we analyze magnetometer data, which shows clear cyclic variation as the IMU rotates through the Earth's magnetic field.

The final design package consists of a working prototype instrumentation system including our MatLab software, design documentation, code documentation for future development, and system validation tests.

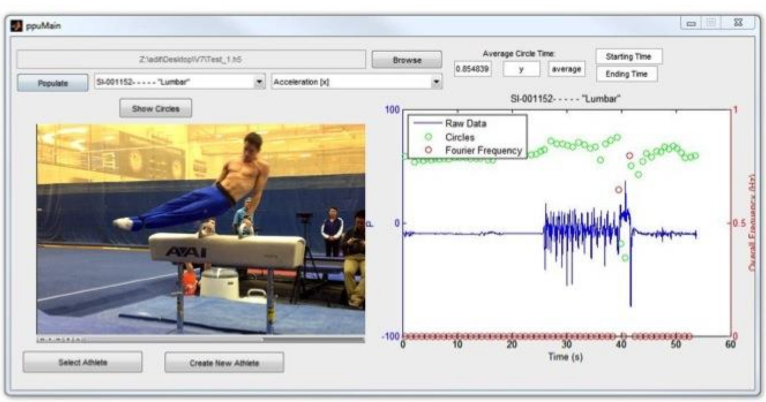

Figure 1: Main user interface window

Figure 2: Typical pommel horse routine

Individual Broader Impacts Essay

This semester all Senior Design students were assigned to write and submit an individual, 1500 word essay about how their engineering choices impact the social, environmental, and/or economic lives of communities and individuals. The topic for this semester's essay is:

As a practicing engineer you must "design within constraints." While most engineers gravitate toward the technical constraints, there are often social, environmental, and/or economic constraints as well. For example, how do you design a wind installation to achieve targeted output, minimize its environmental impact, and maximize social acceptance? Present a discussion, using an example, of engineers designing within a complex mix of technical, social, environmental, and/or economic constraints that is either related to your project or your field of engineering.

The top 13 essays from this semester's group of 250 senior engineering students were chosen by the course faculty and are included in the Program in alphabetical order.

Essay Title	**Author**
Broader Impacts: The Challenge of Engineering in the Modern World	Steven Avetissian
Hoover Dam Bypass	Michael Campbell
Genetic Modification and Your Food	Kathryn Duvall
Engineering Design Constraints: Social, Environmental, and Economic	Lindsey Freytag
Inspiring Change	Katherine Herrera
Gazing Skyward	Brent Last
A New Direction in Restoration	Jessica Lyon
The Helicopter Dilemma: Safety Not Guaranteed	Zachary Mott
Hydraulic Fracturing – An engineering advancement being halted in any way possible	Lauren Revis
An Integration of Many Factors	Kenneth Schultz
Desalination Plants Worth Their Salt?	Katharine Sexton
The Broader Impacts of Electronics Manufacturing	Geoffrey Sowash
Designing the Frederic C. Hamilton Addition to the Denver Art Museum	Kevin Trautman

The top three essays have been judged by a panel of volunteer judges and winners of the best essay contest will be announced along with the Trade Fair results. This year's judges were:

John Agee	Brenda Chergo	Caitlin Ewing
Sarah Gilmore	Hans Hoppe	Jamie Jackson
Steve Kutska	Valeriy Maisotsenko	Lily Nguyen
Art Pansze	Anthony Petrella	Eric Phannenstiel
Charles Speltz	Kim Vo	Ken Witherell

We thank you very much for your time and effort involved in choosing the top essays!

Broader Impacts: The Challenge of Engineering in the Modern World

Steven Avetissian

Any young engineer must learn the difference between practical and theoretical design work. That is, engineers must learn what it means to design a product within the various economic, social, and environmental constraints that exist in the real world. Engineers still in school often neglect these important factors and focus solely on the technical constraints of a project. This can lead to misinformed designs that will not operate successfully under real world conditions, or worse yet will never be fully developed due to consumer backlash. The challenge of balancing technical constraints against the various other economic, social, and environmental constraints is one that all engineers must be prepared to face. How well the challenge is met can often determine the success or failure of a product.

In any type of design work, the very first question any engineer must ask themselves is "what problem am I attempting to solve?" The design process must always begin with an accurate description of the problem. This ensures that the engineer does not neglect important details nor include extraneous information. The definition of the problem must be accurate and concise while leaving enough room for the exploration of multiple solutions. This stage of the design phase is critical because it is the foundation for all other aspects of design. Without a proper problem definition, it is impossible to continue through the design process.

Once the problem has been properly defined however, the engineer may move on to identifying all known information about the problem. It is in this phase that the engineer must begin considering constraints outside the technical realm. All available information about the problem must be taken into consideration. In the context of economic constraints, the engineer must consider first whether or not the problem can be successfully solved with the allocated budget. Money is one of the most important factors in the design process and engineers should always design with economic constrains in mind. In this early stage of the design process it is important for the engineer to make estimates about the total cost of the project. The engineer must not only consider actual dollar values but also factor in cost in terms of man hours to completion and other valuable company resources. The next bit of information an engineer must consider, in regards to the problem, is any available information regarding the environmental impact. In this stage it is most valuable to conduct extensive research on the problem. This research can also help shed light on the social constraints of the design process. When brainstorming possible solutions to a problem, the engineer must keep in mind how the design will affect (if at all) the local (or perhaps global) ecosystem. Questions should be asked regarding the plant and animal life in the area, the type of waste produced by the construction and operation of the product, the impact on the various natural resources of an area, etc. All of these questions must be answered, at least in part, before the company can decide to spend more money on the design and development of the product. Similar questions must be asked about social constraints as well. The engineer must conduct research to determine if there is demand for such a product, how the public will react to such a product, does it have any unintended health effects, etc. The answers to these questions are just as important to the success of the design project as the environmental constraints. Economic, environmental, and social constraints go hand-in-hand. Often time's one constraining factor drives the other constraints. If more money can be allocated to the project then it is easier to include more social and environmental constraints to the process. If environmental or social constraints are paramount, more money may be allocated to meet those constraints. Conversely, if environmental and social constraints are not as important, less money may be allocated to the project. This early phase in the design process is crucial. Any information neglected here may cause problems for the design team later in the future.

The next phase in the design process is to make all the necessary assumptions and justify them. Here again, many of the same constraints that needed to be considered in the information gathering phase must be considered in this phase. Making the appropriate assumptions about the project is vital for designing a viable technical solution to the problem. But these assumptions must include assumptions about the economic, environmental, and social impact of the product as well. For example, if the product is going to generate some type of waste, assumptions need to be made about the quantity of waste produced, the usefulness of such waste, and what is to be done with said waste. Additionally, one must make assumptions about the social impact of a product. Engineers should make assumptions regarding the effect of the product on local populations. These assumptions can include things like increasing the available jobs in an area, bringing increased revenue to an area, etc. Making the proper assumptions about the design in question is remarkably important for determining the success of any design project. Companies have often been vilified for making incorrect assumptions about a product. Of course the validity of any assumption should be verified and this is often where the information gathering phase (the phase prior to the assumption phase) is most valuable. In the next phase of the design process, all the constraints of the project must be accounted for in order to avoid failure.

The next phase of the design process is the phase that most engineers are familiar with. The actual design and test phase. This phase of the process is almost wholly determined by the information collected in the previous three stages. The design must solve the problem attempting to be solved. The success of this is determined by how thorough the information gathering was and how accurate the assumptions were. Often times this is the most time consuming and expensive phase of the design process because it is here that the unexpected must be accounted for. For example, if the one of the assumptions made was that the product would produce a certain kind of waste and the product actually produces a different kind of waste, money must be invested to reevaluate and modify the original assumptions. Of course, the obvious technical constraints are considered heavily in this phase as well. Technical constraints often force engineers to reconsider aspects of the design. This can lead back to square one as a whole new problem might need to be defined and solved before progress can be made on the one already started. This phase of the design process has obvious technical and economic constraints but the engineer must not overlook the environmental and social impacts of the design and test phase as well.

It is in the final phase of the design process that a complete picture of the product is formed. During the implementation phase of the design process, the product must solve the problem it was originally intended to solve while still operating within the various economic, environmental, and social constraints that were originally placed on it. Is the product sustainable within these constraints? It means very little to successfully install a new wind turbine if the wind turbine is not going to produce enough energy to pay off the investment of installing it, or if the environmental impacts force further investment of resources, or if the surrounding population hates it demands its removal. This is why the information and assumption making phases are so crucial and why it is especially important to consider all of the constraints during these phases. The long term success of the project quite literally depends on the engineer’s ability to design within all of the present constraints.

The design process is not an easy process. It is costly in both time and resources. When an engineer begins the design process, there is no guarantee of success. However, by ensuring that the engineer has a good understanding of the various constraints of the project and keeps those constraints in mind throughout the design process, the chances of success can be increased exponentially. It is always important to consider the economic, environmental, and social impacts of a design throughout the design procedure. This is something very hard to teach in an academic setting and is something that must be learned in a practical work environment. This is one of the first and most valuable lessons all young engineers entering the work force must learn. Once the lesson is learned, the possibilities are boundless.

Hoover Dam Bypass

Michael Campbell

Engineers tend to different perspectives of the world than most people. Engineers tend to look a structure, a road, a machine, and think about how it works, and why it works. They then use math and science to prove the how and the why. A progressive idea is created and the engineers are the force that makes it a reality. At first glance, the work of engineering is considered to be very science and math intensive regarding the safety and workability of a design. The public and even most engineers view themselves to be masters of in technical analysis for their field of practice. Therefore, engineers tend to gravitate towards the technical aspects and disregard the social and environmental aspects that affect a project. From a fourth year college student in civil engineering, many technical aspects are involved in order to design and build dams, roadways, and bridges. For the bridge alone, engineers must take into account, the physical design of the bridge, the material that the bridge is made of, the connections, the anchoring to the ground, and the many different loading situations. There is a great amount of technical work that goes into designing anything in the civil application. But the following example of the Hoover Dam Bypass displays how civil engineering projects consider social and environmental aspects.

The Hoover Dam was built in the 1930's and is still one of the greatest civil engineering projects today. Over the years, the Hoover Dam became a hot spot for visitors to stand on top of its greatness viewing the canyon and Lake Mead. U.S. Route 93, the highway that passes through the dam and a major connector between Nevada, Arizona, and Utah, is a four-lane highway that reduces to a two-lane highway to get up and over the dam. Because of the major traffic rolling through this area due to tourism and general thru traffic, the canyon became a huge bottleneck for travelers and mostly truckers. Since 1964 there has been more than 500 crashes on the windy canyon road, in which one fifth of them included trucks. The Hoover Dam is a major supplier of hydroelectric power to Southern California, and if there were to be an accident on the dam, millions of human lives would be impacted for the worse. Also, a crash on the dam involving hazardous material could seriously impact the quality of the water flowing in the Colorado River. The Colorado River is also a major water supply for the many surrounding states. Therefore, in the late 1980s and early 1990s, many bypass projects were presented to fix this problem [1].

In order to execute the Hoover Dam Bypass project, the U.S. Bureau of Reclamation working with the Federal Highway Administration (FHWA) must consider the wildlife impact that the construction of the bypass would impose on. Any bypass option seems that it would impact the ecosystem of the surrounding Mojave Desert, including the habitat of the bighorn sheep and the desert tortoise. At this point in the early 1990s, three proposals were made in order to execute the construction of the bypass. There was the "Promontory Point" option, which included constructing a bridge upstream from the dam and imposing little environmental impact. The second option was the "Sugarloaf Mountain" proposal that consisted of constructing a bridge downstream of the dam, and imposed the least amount of environmental impact. The third option was the "Gold Strike Canyon" proposal which also consisted of building a bridge further downstream of the dam, and affected the environment the most out of the three options. The "Gold Strike Canyon" project would significantly increase the noise and take away more area from the wildlife than the other two projects. It turns out, that none of these options were executed at this time due to the lack of funding for environmental studies. Therefore, the project was put on hold [1].

In the late 1990s, the congestion crossing the dam became too much for travelers and something needed to be done. Two more proposals were created for the Hoover Dam Bypass and both these proposals were rejected due to environmental or social impacts. One of the proposals consisted of adding 36 kilometer of new high highway that would relieve trucks from flowing through a town in Boulder City, Nevada but would prove to be more expensive and damaging to the environment near the Lake Mead National Recreation Area. Therefore, this idea was thrown out. The other proposal consisted of mostly using existing roads, but adding a 37 kilometer detour around the dam through steeps grades. The social effects of this proposal were its downfall [1].

After about of decade of decision making, trying to comply with the environmental and social aspects of building the Hoover Dam Bypass, a proposal was selected in 1998. The FHWA ended up selecting the "Sugarloaf Mountain" proposal, which consists of 5.3 kilometer of new highway, and 580 meter cable-stayed or steel truss bridge located 460 meters downstream of the Hoover Dam. This option received the most support from the public and from local, state, federal agencies. This selection also had the least impact on the environment in regards to the habitat of the bighorn sheep and the desert tortoise because of its lack of impact on Lake Mead and the drinking water supply for the surrounding states. Before completing the project, the FWHA will have to devise a mitigation plan that minimizes the effect on habitat used for migration or mating, replace lost habitat, include erosion control and storm water runoff plans to comply with the environmental impacts of the bypass. The technical aspects of the “Sugarloaf Mountain” project presumed to be the safest of any of the other proposals because of the lower grades and eliminating curves at the ends of the bridge. Construction started in 2002 and the bypass finally opened in 2010 [1].

The technical aspects in respect to the Hoover Dam Bypass were the least of the worries in the decision process of execution. The social and mainly environmental effects were the governing factors for completion of this project. Even though engineers tend focus more on technical aspects of a project, the social and environmental impacts are just as important. It is crucial that engineers step back from the calculations and take in the bigger picture of a situation. Without environmental and social constraints, Mother Nature itself might as well be a thing of the past considering the direction society is heading towards. Technology is a major part of developing the human race, but the human race is part of nature and must comply with preserving the environment that humans live in.

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Genetic Modification and Your Food

Kathryn Duvall

As engineers, it is our duty to examine the long-term and widespread effects of any project we are a part of. This includes, but is not limited to social, technological and environmental impacts. No such project has a greater influence on these areas than genetically modified organisms (GMO) in food products. There are few technological and scientific advances that have made such a stir as the GMO industry. This essay will delve into the details of the social, economic and environmental effects of this biotechnology. Before getting into these details, it is important to understand what GMOs are and why they exist.

For as long as there have been humans on Earth, starvation has also existed. The shift from a hunter-gatherer to an agricultural species was a great help in making sure that more people got food. But where there are farms, there are pests, plagues and draughts to threaten the vitality of these crops. Beginning around the turn of the 20th century [1], farmers began heavily relying on chemical pesticides, mainly DDT, to protect crops from detrimental insect damage. Then in 1962, Rachel Carson published “Silent Spring,” displaying for the public the dangers of these chemicals when consumed by humans. In order to economically grow mass amounts of food, something else had to be done. So, in 1980, the first patent for a genetically modified organism was issued, and in 1982, the FDA cleared the first GMO [2].

With genetic modification, crops are now inherently resistant to insects. Another benefit is that these foods now have a longer shelf life, as they are being modified to ripen and decay at a lesser rate than their non-modified predecessors.

With this base knowledge into the history and purpose of GMOs, the large-scale impacts must be examined. The first major area that is influenced is society. Here in the United States, there is a lot of debate about everything we put into our bodies. Should it be organic? Should we be eating gluten? What are the risks of vaccines? GMOs are no different. There are those who argue that these modifications are unnatural and therefore unsafe for human consumption, however all GMOs on the market today have been approved by both the FDA and the EPA, which have stringent safety standards. Most standards set by the EPA are in fact much more strict than is required, to stay on the safe side.

With a longer period of freshness and resistance to insects, foods grown in certain areas of the globe are more easily distributed over longer distances. This is a vital step forward in a world where so many people go hungry and die of starvation. If producing areas are able to get food to far reaches, more people will have access to it. These new crops are also easier to grow. A farmer who cannot afford to protect his crops with pesticides can now use these GMOs in order to have a higher yield from each harvest. This is vital for those in developing countries. Genetic modification of food products can also make these foods more nutrient-rich. In countries where food is scarce, getting the largest possible nutritional value out of food is of the utmost importance. GMO crops are allowing for crops that yield more food, which in and of itself has a higher nutritional yield. Without using harsh chemicals that are damaging to the environment, GMO crops are an incredibly sustainable way to farm.

A negative social effect can also be found for farmers who do not wish to use GMO products. There have been many lawsuits by biotech companies, most famously Monsanto, against farmers whose crops have cross-pollinated with biotech crops. Because the modified DNA is a patented product, their use is restricted to those who have paid for it. Plants are naturally designed to propagate largely on their own, so wind, insects and birds can contaminate a non-GMO crop with a neighbor's patented crop. Fortunately, corn cannot reproduce without human intervention, so the most important grain in America is unaffected. Many argue that this is hurting the American farmer and therefore the American economy.

The economic impacts of GMO foods cannot be ignored. In the US and abroad, these biotech products are causing quite a stir, as mentioned in the previous paragraph. Since the EPA has a requirement for ethanol in gasoline, the corn industry is absolutely critical. According to a study completed by Iowa State University, if it weren't for biotechnology, global prices for corn would be 6% higher than what they are today [3]. People who oppose GMOs have implied that since these crops are patented, that the seeds have a higher cost than the non-biotech versions. This may be true up front, but clearly studies have shown that the cost for maintenance, combined with the higher yield per harvest actually causes a net savings. The case for corn is that we use it so much in our everyday lives that these savings are not only on the price per bushel. There are a wide variety of corn products, from other foods to biodegradable flatware, and it is absolutely indispensable to the economy of the US. Making these products more accessible, both domestic and abroad, helps keep America afloat.

As mentioned in the discussion of social impacts, farmers all over the world are finding economic benefits from GMOs. A smaller patch of farmland may still produce a large quantity.

Since the same plot cannot be reused every year due to soil nutrient depletion, even using a portion of land may return more than non-GMOs would, using the entire area. Having a longer period of freshness also means that a season's growth will last. These growers do not need to use a pesticide, which, in turn, saves money with every harvest.

Farmers are not the only people to experience the benefit of not using pesticides. The environmental impact of GMOs cannot be ignored. As previously mentioned, the primary way to protect crops from insects without GMOs is pesticides. The pesticide most commonly used is DDT. DDT has been shown to have a wide variety of negative effects. It is toxic when consumed and, starting with insects and plants, this toxicity makes its way up the food chain. The saying, "you are what you eat," includes these harsh chemicals. By taking these chemicals out of the ecosystem, any unintended targets can now thrive. A study has shown that the decline in the use of pesticides has led to an increased population of the natural predators, like spiders and ladybirds, of the herbivorous insects that wreak havoc on crops. If the natural predators are more prevalent, it reduces the population of these insects [4]. This strengthens local ecology in another way as well. Every predator is prey to other animals, and the increased population of prey sustains predators.

As GMOs gain momentum, there is also the chance of creating plants that can grow in environments that are not conventional farmland. For instance, geneticists are working on plants that can grow in the San Joaquin Valley, which has notoriously high salinity [5]. This and other previously uninhabitable areas may, in the future, be used for various crops. More plants will have positive effects on the environment, because they consume CO_2 and produce oxygen. This will also help offset the rapidly growing world population.

The use of biotech crops helps to reduce land area required for the same yield as traditional seed. This helps to reduce CO_2 emissions. The low maintenance quality of GMOs produces the same result. Farmers do not need to use heavy equipment to treat the fields as often or as intensively. With traditional crops, farmers must till the soil to keep the nutrients fresh. This releases CO_2, which is generally trapped within the soil and used to help the plants grow. Studies have show that in 2009, biotechnology helped reduce emissions by 39 billion pounds [3].

The purpose of GMOs is to create very broad impacts, but the extent may not have been fully anticipated. Although engineering projects and products are primarily developed in order to benefit the world, every point has a counterpoint. There are many, especially in the scientific community, which hail the benefits of GMOs. The ability to artificially alter the DNA of a living thing opens the door to endless possibilities for genetic engineering, which is a very exciting step forward. Supporters say that this is science speeding up the process of natural selection, while opponents argue that this is tempting fate.

Whatever your view of GMOs, it is undeniable that they have made their mark on the course of global history. With any great technological advance, there are many costs that come with each benefit. It is the job of responsible engineers to weigh these and make a decision that will hopefully impact the world in a positive way.

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Engineering Design Constraints: Social, Environmental, and Economic

Lindsey Freytag

For any design challenge, there will be constraints that will guide the design process. These constraints can fall under four categories: technical, social, environmental, and economic. Typically, technical constraints are the most significant priority for engineers to design according too. However, the last three are equally as important, especially in the field of environmental engineering.

As an environmental engineer, everything I design, analyze, or evaluate always gravitates toward the environment. Everything I do is geared towards protecting or restoring the environment; this will be a constraint on anything I do with my career, whether that be treating wastewater for safe release into the environment or remediation of contaminated sites to restore the environment to it's original, healthy condition or investigating permit and compliance issues in industry. So the design and consideration of environmental constraints is nothing new or groundbreaking to me. Additionally, economic constraints are very well ingrained into every engineer's mind that it's not really worth being the focus of this essay. Cost is typically the bottom line. An example: if a new regulation is being imposed on a wastewater treatment facility that restricts the phosphorous levels in the effluent from the plant, there is a certain point where is it more cost-effective to violate that permit and pay the fine than it would be to input a new system for more efficient phosphorous removal. For this example, the economic constraint is that the new phosphorous removal system must be cheaper than the cost of violating the permit. This is why cost analyses are always ingrained into every design project we have at this school.

So the point here is that most engineers are aware of environmental or economic design constraints. What is often forgotten, however, are the social constraints of design. There are many, many examples of situations where engineers design something without considering how it's intended use will impact the people it is being designed for.

One example of this came as part of a TED talk by Liz Ogbu called "Why I'm an architect that designs for social impact, not buildings". In many southern, poverty-ridden areas, a common obstacle for many people is cooking. The typical method involved using a three stone fire to prop up a metal cooking pot over the wood fire. Several problems arise from this method; smoke inhalation by the user, fuel usage and resulting deforestation, and air pollution. In response to this, a global initiative has already taken action and designed a solution. This solution is a cook stove that is fueled by coal. Liz was working on a design project for these regions when she came across the astounding fact that even though many people own these “cook stoves”, they rarely use them enough to actually reap the benefits from them. Her next step was to investigate why, and what she found was that the women who used them often complained that they were more of a hassle to use than the original method, especially if they needed to cook large quantities. Additionally, the cost of fuel (charcoal) for a month was more expensive than a year’s worth of wood for fuel. This is one example where an engineering solution was designed without the social impacts in mind.

The solution fit all of the technical design constraints: it efficiently and safely allowed it’s users to cook a meal. It fulfilled all of the environmental constraints: it utilized a fuel that would slow the rate of deforestation, reduce air pollution, and reduce negative health impacts of smoke inhalation. It fulfilled the economic constraints: it was affordable enough that most people in these areas could attain one. It did not, however, fulfill the social constraints. Because of the lives these people lead, they could not afford the increased fuel usage. So what good did this solution really do for the people it was intended for?

Examples like this occur frequently and globally. There needs to be a bigger initiative to include social aspects and impacts as constraints for engineering projects. This could be a potential challenge however. It requires much deeper insight into the intended user audience. This can often be hard for engineers who are designing for different classes, social groups, or cultures. Another good example of this comes from the movie “Urbanization”, which discusses a subsidized low income housing project in Lo Barnechea. The engineers and decision makers had a certain budget to provide the most essential necessities of a house and there was not enough for both a bath tub and a hot water heater. So the decision makers (the engineers and politicians) were given the choice, and most would instinctively have chosen a hot water heater to supply shower water. But potential residents always preferred the bathtub. This is because they came from a life where a shower meant a bucket of cold water and a hot water heater would meant a gas bill that they couldn’t afford. This is just another situation where engineers and the people in charge of these decisions did not have all of the information in front of them to make the best educated decisions based on the social constraints.

I have taken one class here at CSM that really digs deep into this issue, Sustainable Engineering Design. A lot of the discussion in this class involved social impacts and what role designing for sustainability played. A large focus was put on Social Life Cycle Assessment (SLCA) and using this type of analysis to evaluate the social impacts of a product throughout its entire life cycle, or from “cradle to grave”. This type of analysis can identify social “hotspots” in a product lifecycle; these hotspots are places that have significant social impacts. SLCAs can identify positive impacts as well. SLCAs can include factors such as human rights, working conditions, health and safety, cultural heritage, governance and socioeconomic repercussion [3]. This type of analysis could be incorporated into design projects here at CSM in order to help teach social responsibility and designing for social constraints. As trouble spots are identified, the process or product can be modified for improvement. This makes it an iterative process and an effective process for analyzing social impacts.

Social, environmental, and economic constraints are often extremely interconnected, especially in the field of environmental engineering. As with the example stated earlier, sometimes economic constraints take priority over environmental or social constraints when protecting the environment becomes too costly to be economical. There is currently a growing problem involving the regulation of environmental levels of the active ingredient in common birth control pills. This is an extremely important example of how the social, environmental, and economic constraints are all so interconnected. Ethinyl Estradiol (EE2) is an active ingredient in many common forms of birth control; as such, it is excreted from the female body into wastewater effluents which are then released into the environment [4]. This chemical is highly damaging to wildlife and effluent levels in wastewater are not yet regulated or controlled. This chemical is causing serious damage to the reproductive abilities of aquatic wildlife. Yet a main concern lies in how to regulate this chemical in wastewater and who should bear the cost, the public or the pharmaceutical companies that produce it? As it is, the problem is exacerbating as the debate drags on about how to proceed because it would be very costly to treat and regulate wastewaters for this contaminant. This dilemma has an important social aspect as well, another potential solution would be to vary forms of birth control to avoid EE2, but what impacts would that have on females? Would there be unforeseen consequences such as rising costs of birth control and a consequential rise in unplanned pregnancies? What kind of implications would this have for poverty-stricken females who might have no alternatives? These are all important constraints that need to be considered in complex environmental problems such as these.

In many engineering projects the social, environmental, and economic constraints are often considered with less importance. As explored in this essay, this can be potentially detrimental, as in the case of EE2, or it can even negate the effectiveness of the engineered solutions, as in the case of the cooking stove. Because many engineers are taught solely to focus on technical constraints, this is where the problem arises. Not enough emphasis is placed on the considerations of social, environmental, and economic constraints, even though these are all very vital considerations in any design undertaking. The fact remains that social considerations still remain the most ignored, and an important tool for correcting this situation could be the use of SLCAs. All of the above examples are just a few of many about the challenge that any engineer faces in designing to satisfy the complex combination of technical, social, environmental, and economic constraints that are faced in our increasingly complex world.

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Inspiring Change

Katherine Herrera

Give me a truss. I can analyze it in more detail than you probably want. In less than 60 minutes, I can throw down a piece of E2 paper with so many numbers and equations you'll know more about that truss than you may have thought possible. I am a Colorado School of Mines Civil Engineer; physics, thermodynamics, statics, and mathematical representations of physical problems are my bread and butter. Give me a set of numerical constraints, and I can deliver a numerically sound, efficiently engineered solution.

But what if the constraints aren't numerical?

What if failure is not defined by the deflection of steel, or the cracking of concrete? What if something was a true feat of engineering; a cost-effective, entirely safe, durable bridge connecting one rural village to another? This bridge could connect communities, allow the children from one to go the school in the other, allow for more collaboration, cooperation, and exchange of information between the two cities. A beautiful feat of engineering that *also* brings sustainable development, economic growth, and access to more opportunities to a developing nation?

However, what if these two villages lived across a canyon from each other because they were at war in years past? What if conflict had inflicted wounds that time was just beginning to heal? What if this bridge was going to re-open those wounds, and spark a dispute that may last many years into the future? Just because this bridge is a beautiful testament to engineering does not mean that it will benefit the community.

The problem statements that are presented in classes are clearly defined. There are specific constraints. The beam is fixed, or cantilevered, or pinned to some non-descript section of a building. What the beam will be holding and who the structure belongs to is not considered, but it should be.

Can I be an engineer that affects change, not only in the technological realm, but in the social or environmental or economic realms as well? Can really I come from a world of analysis, calculations, and math to enter a world of emotion, politics, and drastically varying cultures and ideals?

Why not?

The seven wonders of the ancient world are all feats of engineering: the Hanging Gardens of Babylon, the Great Pyramid of Egypt, the Statue of Zeus of Olympic, the Temple of Artemis at Ephesus, the Mausoleum at Halicarnassus, the Colossus of Rhodes, the Lighthouse of Alexandria [1]. Whether an enormous statue, pyramid, or building, the seven wonders were not famous because of their function; they transcended history because they inspired *wonder*. They captured the spirit of what was important during that time, such as the Greek gods, or the tombs of ancient rulers. These engineers did not just build a functional lighthouse or statue, they took into account the desires and priorities of the culture around them. They broadened their scope, designed beyond the technical constraints.

My goal is not to build a monument for the glory of our current world leaders. The world we live in does not appreciate gaudy symbols of power, and I have no interest in creating them. However, like the designers of the ancient wonders, I don't want to design for the sake of math and the pursuit of knowledge. Instead, I want my engineering stamp on plans that enhance the communities they're designed for. Rebar and concrete suppliers should not be the only ones who prosper from a bridge design. I want to frame the problem differently: non-numerical constraints and non-technical results.

Small rural villages, however, are not the only places where non-technical concerns arise. Take, for example, the 19th Street over 6th Avenue lid. This intersection was identified as an area with high rates of pedestrian travel, accidents, and traffic congestion. What is the obvious engineering solution? Build a bridge. This would keep traffic flowing across 19th, eliminate a stoplight, and provide a safe path for pedestrians and cyclists to cross the highway. A bridge is simple, straightforward, and elegant; any engineer would consider this problem solved. But is this truly a good solution?

The City of Golden asked the residents of Golden this exact question with staggering results. In three public meetings to discuss this project, the residents of Golden, particularly those on the West side of 6th Avenue expressed support for the project, but not necessarily for the bridge. Members of the community expressed many concerns and desires, but that one sticks out the most: the worry this bridge would end up isolating this smaller western neighborhood from the rest of Golden [2].

The realization that a bridge, of all things, would lead to potential division, led the City of Golden back to the drawing board, this time looking to form a bridge between people, not places.

The result was the Lookout Mountain Lid. The new goal behind the bridge was to prevent people driving, walking, or biking over 6th Avenue from noticing that they are moving over a highway. With this new focus, the City of Golden once again opened up the floor to residents of Golden who had an opinion about the lid, and got feedback that helped them pinpoint a design. Members of the community expressed a desire for a dog park, and spoke out against sound walls and giant statues that would block or disrupt the views [2].

The community feedback helped contribute to the final design, which drastically changed from the initial plans. A simple bridge would have been more cost effective, and may have met the basic safety and traffic flow concerns, but it also would have caused damage to the community. Digging deeper and actively listening to the community allowed Golden to contract Kraemer North America to move forward with a sustainable design that will not only improve safety, but also give the city a better community.

I want to be the engineer that asks those questions; that discovers that not all villages get along, and a park is often worth the investment. Looking beyond the soil samples and survey points can provide a whole different perspective on the scope of the problem. I want to be the engineer that finds the sustainable, effective, win-win solution to a given problem, not just the most technically proficient. I want the plans I stamp to meet the real needs of a community, not just the needs that I see first.

I want to have an impact on more than just E2 paper.

It's why I chose to sign on with Kraemer. I didn't just want any job when I graduated; I want to make an impact on the communities I work in. When I step onto a construction site, I want to make sure that the pier columns I'm inspecting will support a structure that the community wants. At the intersection of 6th and I-25, Kraemer is demolishing and rebuilding thirteen brides and widening 6th Avenue to improve the traffic flow. I learned that they were also renovating three parks, and connecting them with a pedestrian bridge. People driving through the worksite may not even notice the smaller bridges, but the community members do. This neighborhood is the poorest area in Denver, and many people walk or bike to work, not able to afford a car. This meant that safe parks located near these neighborhoods much more significant and valuable to the community. The pedestrian bridge that crosses 6th Avenue allows community members to avoid major streets and sub-par bike lanes. I want to work for a company that notices this, that does not cut corners or ignore the concerns of the neighborhood.

I want to see the non-technical issues while solving technical problems. I want to have time to stop and listen to community members, even while I'm measuring concrete forms I want to work for a company that invests in the community; that sees the value in gathering non-technical input. The parks, bridges, roads, lids, and infrastructure I build should bring sustainable development, economic growth, and access to more opportunities to the communities I am working in. The things I impact in life should not be limited to engineers and the technically minded world.

I want to design the Lighthouse of Alexandria. Not literally, of course. I mean that I want to be an engineer that builds for change, to spark inspiration. The plans I stamp should be more than just incredible structural analysis. I want them to bring healthcare, education, fulfillment, convenience, and justice sustainably to people anywhere and everywhere. As a graduate from the Colorado School of Mines, I want to change the world, not necessarily dramatically, or with a statue of a Greek goddess, but I want to inspire the world to change, and to change for the better.

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Gazing Skyward

Brent Last

"Any idiot can build a bridge that stands, but it takes an engineer to build a bridge that barely stands." ~ Unknown

Engineers are trained to be problem solvers. If engineers weren't continually faced with complex, diverse, and ever-evolving design criteria there would be no need for engineers. The quote above is a testament to the complexity of the profession in that it illustrates the need for engineers in light of real-world demands, such as the technical, social, environmental, and economic forces that drive each and every design.

As a child, I always had a fascination with aviation. Who wouldn't? The freedom to go wherever you want. The ability to see so many new places. Just the plain fact that you can soar thousands of feet above the earth. The proposition of flight overwhelmed me – and it does to this very day. This past summer I had the amazing opportunity to be an intern for one of the leaders in the modern aviation industry: Cessna Aircraft Company. While there I got an incredible inside look not only at the technical side of designing an aircraft, but at what truly makes modern planes what they are. We are talking about flight here, so it's obvious that there are a lot of technical considerations… but there is so much more to it than that!

In the world of private aviation, each design starts with the customer in mind. The people who purchase jets from brands like Cessna generally have very specific requirements and desires, and accurately meeting these desires is what ultimately sells products. Designing a plane to be flown by some of the wealthiest people on the planet cannot simply be achieved based on our own understanding of what a plane is or what it has to do. A design like this involves an intricate knowledge of a lifestyle from which 99% of the global population is very far removed. In 2014, Oxfam International reported that the wealthiest one percent of people in the world have wealth equivalent to 65 times that of the bottom half of the global population [1]. Along with large corporations, these are the people who are buying their own jets. What this means for engineers is that we need to think outside the box. While there are things that engineers could probably agree on with the very important people (VIPs) of the world – comfortable seats and ample leg room, for instance – the quality of the design ends up coming down to the details. What is it that makes a VIP love a design? Is the design simply functional or is it elegant? Does it have some flare? Does it *look* as quality as it functions? Does it *function* as well as it looks? There is so much to consider that goes far beyond the numbers and equations that we learn in engineering school.

The social aspect of the design doesn't stop there; it isn't about one customer or even a single demographic; these planes are flown all over the globe by a wide variety of clients. The experience and knowledge of a single engineer simply cannot account for all of the cultural concerns that need to be met. Just creating a design that functions well does not mean people are going to buy it. For instance, in many countries (and the United States as well) it is not uncommon for people to fly with a personal staff. In flight this staff could perform any number of tasks from preparing meals to watching the children. This seems pretty straightforward, except for the fact that also in many countries it is often unusual for the staff to sit with or interact with the other passengers in any sort of social manner. A lot of people familiar with commercial travel may be lead to think that there wouldn't be a problem with this; the staff could merely move to another part of the plane. However, when considering a 9-passenger airplane, simply disappearing isn't an option. The engineers tasked with overcoming this hurdle and others like it have a unique responsibility in that they need to create a separation of space while utilizing every last bit of it that is available. This is something that the technical specifications in themselves cannot account for.

So with specific clients, a fully customized plane sounds like the way to go. Each end-user can have a plane that exactly meets their own specifications and requirements. Sounds perfect, right? But like in every industry, an effort is made early on in the design to minimize capital costs. In aviation, this means integrating as much reusable infrastructure into the base design as possible without adding too much extra weight. Once this is in place, a couch can be moved here or a table can be moved there with relative ease, yet with a limited number of overall options. If a completely custom plane were to be made each time, substantial costs would be associated. A popular trend in the modern aviation industry is "fractional ownership." This is a system similar to that of a time share in which clients basically buy a portion of a plane and can use it for a fraction of the time. This reduces each party's overhead while maximizing the benefits. This may seem like a pretty trivial fact in that it is just a different customer purchasing the plane; however, is a very important consideration when it comes to design. Now a plane not only has to be tailored to a single client, but to two, three, four, or more clients all using the same aircraft and, aside from transportation, all expecting something different out of it. This is where it becomes clear that it is not simply about the technical specifications, but rather about the broader social implications involved.

To this point, the social implications of a design have been the main focus, but perhaps just as important are the economic considerations that go into every design, not only in the world of flight, but in so many other industries as well. Each design decision that is made to meet a technical specification most certainly has broader economic impacts. Every company knows that a product, no matter how good, is worthless if it can't be sold. In engineering school, we learn that some materials are better than others depending on the application. More machining makes a part cost more. A factor of safety is your friend since all calculations have inherent assumptions associated with them. A lot of times, though, the economics associated with these decisions are neglected. This is easy to do when everything is theoretical. Making parts out of titanium makes them very strong while remaining light-weight; this is an incredibly desirable characteristic in the aviation industry, but it is important to consider that an all-titanium airplane would cost an astronomical amount. Starting a part from a solid block of aluminum means that there will be no joints and could give some desirable material characteristics, yet that part could take days to machine, driving the cost skyward. Similarly, a factor of safety of 5 would be great because there is very little risk of a part breaking, yet the costs in extra material and weight make this very unreasonable in aviation. In fact, the Federal Aviation Administration (FAA) only requires factors of safety in the range of 1.5-3.0 for most components even on commercial space vehicles [2]. The economic implications of a design take the technical specifications one step further in not only finding the best design, but the best design that remains practical.

It's true; engineers are trained to be problem solvers. Even as students, all too often we find ourselves dwelling on the numbers, the equations, and the theories. We can't seem to stop thinking about the technical constraints that define the problems we see and this frequently clouds our vision about what can tend to be even more important. Sure, the technical constraints are the basis of every design, but without considering all of the other things that go into a design – the economic, social, and environmental factors – a product is meaningless. If a product is too harmful, too expensive, or just plain unacceptable then the fact that it meets the technical specifications generally doesn't mean a whole lot. Understanding culture and economics are two very important things when it comes to engineering problem solving not only in the aviation industry, but in every industry. And let's not forget that it doesn't necessarily take an engineer to build a bridge, but building a bridge that just barely meets all sorts of complex requirements (and yet continues to does its job well) is truly an accomplishment. This is the sort of thing that engineers are bread for!

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A New Direction in Restoration

Jessica Lyon

There are more than 1.2 million limb amputees in the United States. Of these nearly 20% are transfemoral amputees [3]. By the numbers, each year in this country alone, 30,000 people will lose their leg above the knee. Each of them will suddenly find themselves robbed of 29.5 bones: 5 metatarsals, 14 phalanges, 3 cuneiforms, 1 talus, 1 calcaneus, 1 cuboid, 1 navicular, 1 tibia, 1 fibula, 1 patella, and a large portion of the femur. To add to their bereavement, they will also be down two major joints; the ankle and the knee, which together with numerous muscles account for around 80% of the propulsion power of their leg.

Transfemoral amputation is often referred to as "above knee", or simply AK, and is any amputation between the hip and knee joints that involves completely bisecting the femur. Limb amputations may be vascular or traumatic in nature, and are generally seen more frequently in men than in women. Transfemoral amputees face many challenges including an increase in energy required to complete daily activities, difficulty balancing over rough or unfamiliar terrain, decreased stability associated with the loss of musculature and reflex, trouble in transitioning between a seated and a standing position owing to lack of active joints, physical discomfort due to prosthetic fit and impingement upon soft tissues, emotional discomfort stemming from poor body image and the necessity of wearing a noticeable prosthetic, and social obstacles associated with being treated as disabled.

Dealing with limb loss is a biphasic issue. Any solution designed for amputees must address both their physical and psychological needs. First and foremost, unless the amputee wants only to heal from the treatment and abstain from the use of a prosthetic, the design must emulate, to the best of the engineer's ability, the leg that was lost. Typically, in creating a prosthetic limb there are three ranked priorities: comfort, function, and aesthetic. In the widely frequented realm of socket-based prosthetics, the root of all discomfort is founded in poor fit and soft tissue distress. The socket of such a prosthetic is passively affixed; the tight fit against the skin is all that holds the prosthetic on. This tight fit prohibits any volumetric changes in the residual limb, such as those that would result from an active day standing and moving around. It also induces shear loads upon the skin resultant of said skin bearing the full brunt of all forces acting upon the prosthetic leg where in a natural leg it is the skeletal structure that takes on these forces. Both the inhibition of volume change and the unnatural shearing forces can result in a great deal of pain in the soft tissues of the residual limb. Because the use of a socket-based prosthetic directly violates the first priority, such a design is precluded from consideration, though it is by a wide margin the most common design put to use in the United States.

There is a second design that is quickly gaining traction in the biomedical engineering world. It is rapidly becoming more and more popular throughout Europe and in some South American countries. It is referred to as Osseointegration. Finally, there is an alternative to traditional prosthetics for limb amputees. It was developed by Professor P.I. Branemark as an adaptation to a treatment of the same name commonly used in dentistry [4]. Osseointegration is most popular for trans-femoral amputees. It is an especially good alternative for those patients whose residual limb is not long enough or not suitable for a more traditional, socket-based prosthetic. This prosthetic design is unsuitable for someone who has not reached skeletal maturity as it is mechanically based in the skeleton. Prosthetics attached via Osseointegration allow the user to wear normal clothes; they're prosthetic leg does not necessitate separate clothing allowances from their intact leg. This allows amputees to function in society without having to display their amputee status if they do not wish to.

Transfemoral Osseointegration is a two part procedure for the installation of a three component implant system. During the first stage of the procedure, the end of the residual limb is opened and a titanium bolt is inserted into the intramedullary canal of what is left of the femur. The limb is then sealed and allowed to heal for a mandatory six month period of time. During this healing process, the residual bone is allowed to grow into parts of the titanium bolt, effectively fusing the metal component to the skeleton. At the end of the six months, the second stage initiates. The limb is reopened such that an abutment penetrates the soft tissue and is affixed to the distal portion of the titanium bolt. This abutment is not fully contained within the soft tissues; it projects from the skin of the leg [2]. Following such a major soft-tissue surgery, the amputee must take care that no infection is caused and must undergo a rigorous and long period of rehabilitation that involves strength training and attaching a full prosthetic leg to the abutment.

Following this rehabilitation period, persons utilizing osseointegrated prosthetics have the potential to experience two-fold functionality benefits over socket-based prosthetics users. First, osseointegration patients remarked upon proprioception of their foot and leg. Whereas a socket can provide no sensory feedback, because the titanium bolt is effectively fused with the residual femur, the osseointegrated prosthetic leg is capable of relaying orientation information directly to the brain. Patients also reported feedback of their surroundings, including the terrain on which they stood and contact with any objects thanks to sensations traveling from the prosthetic into the bone.

Second, from a “self-selected walking velocity” study conducted with amputees using traditional prosthetics, it has been determined that in the case of lower limb amputations, more energy is required to achieve the same walking speed; the velocity of transfemoral amputees was 63% that of non-amputees [4]. Additionally, the stride length for transfemoral amputees is shorter than that for non-amputees, necessitating more steps to cover the same amount of distance. In a study of oxygen consumed per meter traveled, it was found that transfemoral amputees consumed more than twice the amount of oxygen of non-amputees in covering the same distance. This demonstrates the increased energy requirements of a non-traditional gait cycle induced by the amputation. Patients of osseointegration have consistently reported increased energy levels. This is likely a product of force transduction through the more natural skeletal path as opposed to through the skin, resulting in more efficient energy usage.

Further consideration must be given to daily tasks that require propulsion. During the simple process of going up stairs, most transfemoral amputees utilizing prosthetics employ a different method than non-amputees. Rather than ascending each foot to a higher step, they step with their good leg up a level and then draw their prosthetic leg up to that same level. This is because most common prosthetics are not equipped to provide significant propulsion power. Many osseointegrated prostheses may be paired with microprocessor controlled powered knees such as the Genium intuitive knee or the C-leg, both developed by Ottobock. These restore some of the missing propulsion, and can facilitate a much more active lifestyle than that granted by a passive leg. Even without these more sophisticated knees; osseointegrated prosthetics users have reported ease of activities such as walking distances and cycling.

Finally, self-consciousness and body image issues are major factors in dealing with the loss of a limb, especially in social situations. Many amputees report apprehension over interpersonal interactions such as fear that a prosthetic will noticeably creak with each step and aggravate nearby people or that the prosthetic will break or fall apart in public. These anxieties are constant inhibitors to a normal lifestyle. Additionally, amputees are also concerned with public viewpoints on the magnitude of handicap resulting from an amputation. When rating a series of disabilities according to severity, and taking into consideration going blind, losing a leg, losing a dominant arm, going deaf, facial disfigurement, and paralysis, non-amputees ranked losing a leg as second only to going blind [1]. Psychological inhibitions and poor public opinion has resulted in many amputees restricting themselves and their lifestyle in order to mitigate the risk of public embarrassment. However, due to the smooth functionality of osseointegrated prosthetics and their incredibly sleek design, users reported that they “no longer felt disabled and were able to participate with full daily living” [4].

Osseointegration is not without its risks. The abutment fixture is known to experience mechanical failure in reaching its ultimate or fatigue strength when not used within the realm of normal daily activities. Abnormal activities include lifting heavy weights, repetitive lifting of weights, swimming in a public pool, running, and jumping. The site on the residual limb where the abutment penetrates the soft tissues must be regularly cleaned and cared for to avoid risk of serious infection. These risks are certainly avoidable, and the benefits of the osseointegration technique to allow for transfemoral prosthesis are profuse. It is a solution for amputees based upon a complex and ongoing global effort. Developments in osseointegrated prosthetics arise every day, and every day we get a little bit closer to a leg that can fully restore functionality to those that have had it taken from them.

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The Helicopter Dilemma: Safety Not Guaranteed

Zachary Mott

The three young travelers drove all day and into the night. They still had fifty miles until they reached Reno, Nevada. She was fast asleep in the back seat when the car began to tumble chaotically. The sound of metal crunching all around her was deafening. Broken glass and dirt filled the air. The violent motion of the crash was over in a few seconds and then it was quiet. The car came to rest on its wheels in the wide median along a lonely stretch of Interstate-80. She was alone in the vehicle. The intensity of the crash had ejected both the driver and front seat passenger. The front of the car was mangled. She climbed out of the back hatch which had come open while the car rolled. Contents from the car were scattered all over the highway and the median. It was very dark which made it obvious when another vehicle finally appeared on the horizon. She stood in the middle of the road frantically waving her arms above her head to flag down the vehicle. Luckily, it was a truck driver who had a CB radio and was able to call for help. It seemed like it took an eternity for the two ambulances to make their way out to the middle of the desert. The passenger died before the ambulances arrived and the medics did not think the driver could survive an hour-long drive to the nearest trauma hospital. They called for emergency helicopter evacuation. My mom watched as the helicopter crew loaded my dad and flew off into the dark night. I was born two years after that traumatic vehicle accident.

Helicopters began to have an impact on my life even before I was born and continue to influence me to this day. Before attending Colorado School of Mines I flew helicopters professionally for 10 years. The helicopter is a uniquely capable tool for search and rescue. It can quickly respond to a ship stranded in the path of a tropical storm, a hiker injured on top of a mountain, or a critically injured motorist on a lonely stretch of highway. The longer I am around helicopters the more I grow to appreciate them as marvels of engineering. Helicopters are my inspiration for becoming a mechanical engineer.

There are many interesting technical challenges to overcome when designing a helicopter. Most of the design constraints are in direct competition. The materials must be strong yet light weight; the power-plant must be powerful yet minimize fuel burn rate. For each of these competing design parameters a trade-off must be made. During my education at Colorado School of Mines I have gained the tools to evaluate the consequences of these design trade-offs. There are also social and economic constraints. The helicopter must be safe yet affordable to buy and operate. This trade-off presents engineers with a dilemma: how safe is safe enough? At first glance, evaluating the consequences of social and economic trade-offs does not appear to fall within the purview of the engineering profession, but the ethics section in the *Fundamentals of Engineering Supplied Reference Handbook* describes engineering like this:

> "Engineering is considered to be a 'profession' rather than an 'occupation' because of several important characteristics shared with other recognized learned professions, law, medicine, and theology: special knowledge, special privileges, and special responsibilities."

Because of the special responsibilities inherent in the profession of engineering, engineers subscribe to a code of ethics. Engineers agree to safeguard the life, health, property, and welfare of the public. [1] How does an engineer interpret this ethical mandate when designing helicopters? As an engineer, what is the right balance between making something economically viable and making something safe? No engineer wants to see his design kill someone, but can we afford not to build helicopters and train helicopter pilots? How safe is safe enough?

The Robinson Helicopter Company is an interesting case of how one helicopter designer chose to balance multi-facetted design constraints. Frank Robinson founded the California-based helicopter company in 1973 with the goal of producing a helicopter that outperformed the competition at a lower purchase and operating cost. [2] He first succeeded with the R-22. Frank Robinson's biography featured on robinsonhelicopter.com boasts: "The first R22 was delivered in late 1979 and soon became the world's top selling civil helicopter. The R22 holds the most world records in its weight class including speed and altitude." How did the Robinson Helicopter Company design a helicopter that outperformed the competition and was lower cost? Frank Robinson's success can be credited to innovative design, but this design came with a cost. Frank Robinson made a design trade-off. He made an affordable helicopter, but the helicopter is less forgiving. Under normal operating conditions the R-22 is as safe as any helicopter in the sky, but when a temporary interruption in power from the motor occurs the rotor speed can slow to the point that the helicopter stops flying. Most helicopters have heavier rotor systems. A temporary interruption in power from the motor has little effect on the rotor speed because the inertia in the heavier main rotor keeps it spinning. The R-22 has such a light rotor system that even a very brief interruption in power can cause the blades to slow excessively - enough that the helicopter stops flying. In response to a series of accidents caused by the low-inertia rotor system design, the company created the Robinson Pilot Safety Course to educate pilots about the risks specific to their design. Eventually the Federal Aviation Administration wrote special regulations requiring special training to fly the R-22 [3], but Robinson Helicopter Company had already been training pilots for over a decade.

How are we to interpret Frank Robinson's design choices through the lens of engineering ethics? Does the Robinson Helicopter Company meet their obligation to the public? I believe Robinson brings a value to the public along with an honest evaluation of risk. The company recognized the trade-off in safety and proactively addressed safety through training courses long before any federal regulations were adopted.

Helicopters have the potential to impact the world in many positive ways, but one major obstacle is the high operating costs. Another obstacle is the high cost to learn to fly a helicopter. Frank Robinson's Helicopters meet an extremely difficult engineering challenge while addressing some of the principal obstacles to helicopter flight, and he does so with calculated trade-offs. For this reason, Robinson Helicopter Company remains the world's leading manufacturer of civil helicopters. [2]

If the constraint for designing a helicopter were that it cannot be dangerous or that it can never injure or kill someone then no helicopter would ever be built. Is the code of ethics realistic then? Does it give engineers an impossible mandate? I believe the code of ethics allows engineers to act morally while balancing the requirements of reality because safeguarding the life, health, property, and welfare of the public is not the same as guaranteeing safety. We, who are engaged in the profession of engineering, must continue to learn and improve while holding public safety paramount. We must tirelessly pursue a safer world. This includes engineers who design helicopters, but helicopters are difficult to design, difficult to build, difficult to fly, and will continue to be risky.

As engineers we are guided by a code of ethics and are equipped with special knowledge, but we are always limited. No design can perfectly balance the spider-web of complex technical, social, and economic constraints, but we must do our best with what we know. The first and foremost responsibility of an engineer is the public welfare, [1] but we do not serve society well by refusing to act because of the fear of the unknown or the unknowable. Engineers who design helicopters can sleep well at night; not in spite of the risks in aviation but because they are willing to face the risks. Helicopters will continue to be a part of our world. They will continue to save lives and they will continue to be dangerous.

The deeper my understanding of engineering becomes the more my sense of wonder and amazement at the helicopter increases. Helicopters appear to operate at the outer edge of what the physical universe will allow. The helicopter is a beautifully complex engineering achievement that allows us to fulfill our dream of flying. They are truly amazing machines. They also can be very dangerous machines. During a decade of flying I have lost over a dozen friends in fatal helicopter crashes. I still believe that aviation is a noble pursuit despite the dangers that persist. Simply said, I believe helicopters and their pilots make the world a better and safer place. When I am tempted to think that helicopters are too dangerous, I remember that in the middle of the night, in the middle of a divided highway, in the middle of a dark desert, a helicopter and her brave crew saved my dad's life and allowed me to live mine.

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Hydraulic Fracturing – An engineering advancement being halted in any way possible

Lauren Revis

Hydraulic fracturing also known as fracking is one of today's most controversial engineering techniques and is currently being performed in Colorado's own backyard. Fracking is a stimulation technique used in both abandoned and newly completed wells in order to help improve overall hydrocarbon production. Low production rates can be caused by multiple abnormalities including low rock permeability, low reservoir pressure, high bottom hole pressure, high fluid viscosity, and high skin just to name a few [1]. In order to frack, pressurized fluid made up of water and chemical additives is injected into a geological formation above the rock strength creating fractures. Once the formation fractures, fluid and proppant (such as sand or ceramic beads) fill the voids to keep them open once the pumping pressure is released, allowing hydrocarbons to flow out of once restricted pores [2]. Although hydraulic fracturing has occurred for over sixty years, this technique is being constrained on all aspects of design and application. Hydraulic fracturing is an engineering advancement that has only made the industry and society better; however, the public and industry regulations are trying to make it as difficult as possible to complete. Currently, hydraulic fracturing has multiple constraints including technical design struggles, environmental impact and regulations, and social acceptance yet even with all of these constraints fracking continues to prosper economically.

One of the biggest constraints engineers endure during a frack job design is the originality of each well. Every frack job requires the engineer to design the stimulation based on the rock formations involved, problems associated with low production, and other specific industry regulations. Even though this stimulation technique has been used for decades, some of the engineering design must be approximated from correlations. In order to produce effective fracture stimulation the engineer must determine the reservoir properties and fracture characteristics to achieve optimum reservoir deliverability, formation rock in-situ stress distribution and mechanical properties, fracturing fluid characteristics, and equipment production abilities [3]. Although most of these calculations can be completed off of obtained data from known rock formations or logs, some calculations must be estimated by the engineer. These estimations include the fracture geometry, orientation, and azimuth angle [1]. Unlike most engineered projects, hydraulic fracturing engineers are not guaranteed expected results. These engineers are working with unpredictable mediums and do not always get the fracture to project how they would like it to.

Hydraulic fracturing engineers must be able to rework their designs immediately when their stimulation designs do not go as planned. Although, fracking is a long improved stimulation technique there is no cookie cutter approach causing there to be more engineering required for each job than most people would expect.

Along with technical constraints engineers have to take environmental constraints into consideration with each frack job design. Service companies that provide hydraulic fracturing are controlled by both government and state regulations. One of the major organizations responsible for the safety of hydraulic fracturing and groundwater is the Interstate Oil and Gas Compact Commission (IOGCC). This commission is a multi-state government agency that oversees the conservation and efficient recovery of American oil and gas while protecting health, safety, and the environment [4]. The industry works with different organizations and local governments to make sure each well is completed properly and within specific standards to insure the environment and society's safety. Roughly 90% of all wells in the United States have undergone some type of stimulation technique to increase production and there have not been any confirmed cases of contamination of underground sources of drinking water [4]. In many cases the environmental problems which make it to the public are ones which had a disastrous failure giving the wrong idea to the public. Along with state regulations, Congress has made other organizations responsible for proper hydraulic fracturing techniques. These organizations include the Ground Water Production Council (GWPC), the Environmental Protection Agency (EPA), and even the Safe Drinking Water Act (SDWA) [4]. On top of strict government regulations the industry uses well completion techniques in order to protect the environment. Well construction requirements are used to protect ground water sources in multiple locations. Water and production zones are protected with steel pipe (known as surface and production casing) and are cemented into place for the explicit purpose of protecting ground water [4]. Frack jobs are completed with the health and safety of the environment along with society as a top priority. On top of all of the technical constraints an engineer must abide to when designing a hydraulic fracture job, they must also follow strict environmental regulations.

Possibly one of the biggest constraints hydraulic fracturing is restrained by is society and their lack of knowledge on the subject. A lot of the concerns seen by society are already issues which are regulated by state and government restrictions. In a small study done on hydraulic fracturing the top three concerns of society included spills and leaks of frack fluid, wastewater management, and water withdrawals [5]. These concerns are already regulated by governments as discussed in the previous paragraph. On top of the regulations already discussed other factors are considered for the safety of the environment and society's drinking water. A typical frack job is completed well below the fresh water aquifers used for public drinking water. Residential wells are usually drilled to a depth of 200 feet but can be as deep as 500 feet where a typical perforation and frack job occurs at a minimum of 4,500 feet [6]. The only way frack fluid could contaminate the water table would be due to a failure in a well completion or if the water traveled through thousands of feet of impermeable rock. Even if frack fluid was to reach a water table most of the components can be found in the common household. A typical frack fluid is 90% water, 9% proppant (either sand or ceramic), and 1% or less other additives including acid, corrosion inhibitor, friction reducer, gelling agents, and scale inhibitors [5]. Today, service companies are required to disclose what components are in frack fluid making societal concerns of unhealthy components nonexistent. The overall concerns of society seem to be associated with uneducated individuals focusing on rare mishaps rather than focusing on hydraulic fracturing facts. The majority of society's concerns with hydraulic fracturing are already relieved by the regulations and actions in place leaving societal constraints unnecessary.

Although hydraulic fracturing has so many negative connotations, the stimulation technique has multiple economic benefits. The overall cost of a hydraulic fracturing job depends on each independent completion. Usually, the cost of a fracture job is dependent on the fracture size; smaller in length yet wide fractures result in higher revenues and lower investment costs [3]. In industry, hydraulic fracture stimulation is only pursued and completed if the technique will be economical for all parties involved. Even though the industry sees restrictions on hydraulic fracturing and in some instances the technique is not economical, overall fracking has helped the United States significantly. In 2012 the industry supported 2.1 million jobs across the country and is predicted to support as many as 3.9 million by 2025 [7]. With an increase in revenue, jobs, and hydrocarbons the country can also expect to see a raise in the amount of manufacturing in the country. A lot of people do not realize that hydrocarbons and petroleum products are used in a lot more components than just vehicles. Typically, 96% of all products society uses on a daily basis contain components made with natural gas or other hydrocarbons [7]. As fracking becomes more common in Colorado it is important to note its local impact. The oil and gas industry impacts Colorado's local governments, school districts, and other special interests. In 2012 alone the oil and gas industry supported 111,500 jobs in Colorado and contributed a total of $29.6 billion to the state's economy [7]. Although many believe hydraulic fracturing is not beneficial or negatively impacts the environment and society, economically the technique is constructive not only for Colorado but also the entire country. Throughout the years thanks to the increase in production and economic growth from hydraulic fracturing the United States has reduced its dependence on imported oil and gas.

Overall, hydraulic fracturing is one of the most beneficial engineering techniques in today's society however it is also one of the most constrained. Hydraulic fracturing engineers must design stimulations to the best of their ability with no guarantee of expected results. Engineers designing hydraulic fracture systems must deal with strict environmental restrictions placed on them by industry and government standards. Along with technical and environmental constraints, hydraulic fracturing is also restrained by society being uneducated on the true facts of the matter. Under such constraints hydraulic fracturing continues to grow economically, proving the risk is worth the end reward. Even though hydraulic fracturing is a very controversial topic in today's world, it is a great engineering advancement which has ultimately helped society and the United States including our own beloved Colorado.

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An Integration of Many Factors

Kenneth Schultz

Introduction

Along the Dnieper River, the generators within the dam of the Kiev Reservoir provide 420 MW of hydroelectric power to the Ukrainian people. At first glance, this reservoir seems no different from the many others like it along the river. However, were something to happen to the water in this reservoir - a sudden dam failure due to natural disaster, or steady lowering of water levels for one reason or another - a threat would be released upon the population of Eastern Europe that is posed by no other water body in the world [1]. What sets this reservoir apart is that, lying within the silt layers at the bottom, are highly radioactive particles that were washed into the waters following the Chernobyl nuclear disaster in 1986. The Kiev Reservoir, along with other fallout from the Chernobyl nuclear disaster, exemplifies the enduring effects that a release of radioactivity from a nuclear power plant can have on humans. As such, the design of nuclear power plants must incorporate much more than just technical considerations. Health, safety, and environmental concerns provide a broad backdrop against which a nuclear engineer must balance numerous other design considerations.

Social Constraints

In addition to Chernobyl, there are two other major nuclear disasters that have occurred - the reactor meltdown at Fukushima Daiichi in 2011, and the partial meltdown at the Three Mile Island power plant in 1979. While no known long term health effects resulted from the Three Mile Island incident, a serious negative backlash occurred against the perception of nuclear power within the public. The Chernobyl incident resulted in the deaths of several plant workers and emergency responders, as well as long term health impacts on the surrounding population. The impact of the Fukushima disaster on the people of Japan is still being determined, and while its health impacts are expected to be minimal, the enhanced coverage of the modern day media no doubt reopened the social wound that nuclear power has never recovered from.

These events highlight the gravity of the impact a nuclear event can have on society. Due to the silent, invisible, and odorless threat posed by radiation, exposure typically occurs without the knowledge of the victim. The results of radiation poisoning can be quickly fatal, but often times result in injuries that cause permanent, visible deformities, or diseases such as cancer that kill over weeks and months. Combine these impacts with the fact that much of the world has still not forgotten the horrible results of the use of nuclear weapons on Japan in WWII, and nuclear technology has a slew of social obstacles that it must overcome. When designing nuclear power plants, the engineer should always consider these obstacles, and how their design may work to overcome them. A quick look at two different reactor designs can illustrate this point.

The reactor designs at Fukushima were developed in the 1960's, when safety considerations were not what they currently are. Following the Fukushima incident, it was discovered that concerns about the threat of reactor flooding had been brought up in the past, but were disregarded as unlikely to occur [2]. Were these concerns to be taken more seriously by the engineers in charge, the incident may have been avoided. Conversely, Westinghouse's new AP1000 reactor incorporates "passive" safety features into its design. This means that, in the event a reactor loses external cooling power, it can remain in a safe shutdown condition for up to 72 hours before external intervention is required. Compare this to the 2 hour "walkaway" time that the Fukushima reactors had, and it is apparent that reactor safety design has come a long way in the past few decades.

Environmental Constraints

The Kiev Reservoir provides a fundamental example of the impacts a nuclear disaster can have on the environment. Due to the long half-life of radioactive materials (uranium-235 has a half-life of about 700 million years), any threat that is released into the environment will remain a threat for a very long time. This radioactive material can have detrimental impacts on all living organisms that may be exposed to it. Furthermore, when confronted with the task of disposing of radioactive waste, all options must incorporate some method of dealing with radioactive materials, as there is currently no way to remove the radioactivity.

These environmental factors must play into several decisions that will impact the design of a nuclear power plant's safety systems. Arguably, one of the primary factors is the location of a nuclear power plant. In order to ensure proper cooling of a plant's reactor, it must have an abundant supply of coolant, which is typically supplied by a large body of water such as the ocean, a lake, or a reservoir. However, waste heat generated by the discharge of these coolant waters back into the water body can have adverse effects on the marine and plant life around these areas. Additionally, considerations about emergency response plans in the case of a release will have a significant impact on the location of a plant. If built in a high population density area, the potential impacts of a release can be significantly more detrimental.

Further environmental constraints to consider are radioactive disposal methods and capabilities. While countries such as France have developed ways of recycling and reusing spent fuel, there ultimately comes a point where all that is left is radioactive byproducts, and this waste must be dealt with. Currently in the U.S., much of the spent nuclear fuel remains on site in casks, awaiting a storage and disposal solution. Certain efforts to create central storage facilities have had limited success, and proposed long-term solutions typically involve deep burial within the ground, which poses a substantial environmental risk.

Economic Constraints

By far, some of the largest constraints encountered when designing a nuclear plant involve economic factors. In the early 1970's, during the heyday of nuclear power plant construction in the U.S., the average cost of building a power plant was around $200-$300 per kW of capacity [3]. Current construction costs are estimated at around $13,000/kW, roughly a 51 fold increase [4]. Over time, these increasing construction costs have forced utilities to scale up their designs in order to make them economically feasible. This means larger and more complex systems, with more potential for error. Additionally, the initial life span for a nuclear reactor was intended to be around 40 years. With a majority of those plants built during the late 1960's and 1970's, many plants in current operation are nearing their intended life span [5]. As such, the various inspections, permits, and upgrades that will be required to keep them operational will require significant investment.

Because of this significant investment, some governments are stepping in to try and help utilities bear the financial risk associated with investing in such a project. The U.S. government is currently involved in insuring the four plants currently under construction in the U.S. China's government is heavily pushing forward with construction of several nuclear power plants in order to meet their ever-growing energy needs. In addition to government-backed assistance, technological solutions are helping to reduce the economic constraints of nuclear reactors. A trend that is gaining increasing traction around reactor design is a concept known as small modular reactors (SMR). The SMR concept improves the economics of a reactor project by tackling the challenges of scale and complexity in nuclear reactor design. Compared to a traditional reactor design of 1000+ megawatts capacity, the SMR designs are typically 300 MW or less, and some are as small as 50 MW. Additionally, while traditional power plants were built on site, the modular design of an SMR allows it to be built off-site in an assembly-line environment, trucked or shipped in pieces, and assembled on site. These capabilities have enormous financial benefits in the areas of manufacturing costs, design complexity, and construction time.

Conclusion

The U.S. Navy has one of the largest nuclear programs in the world, and its operational safety record is immaculate by industry standards. Following the Three Mile Island incident in 1979, Admiral Hyman Rickover, known as the "father" of the nuclear navy and responsible for its first 30 years of existence, was asked to testify before Congress about how the navy had achieved such a pristine record. During his testimony, he responded:

> "I am always chagrined at the tendency of people to expect that I have a simple, easy gimmick that makes my program function. Any successful program functions as an integrated whole of many factors. Trying to select one aspect as the key one will not work. Each element depends on all the others."

Rickover's brilliance as an engineer and project manager stemmed largely from the obsessive attention to detail that he placed on every aspect of nuclear reactor design. He understood very well not only the technical and economic challenges that were involved in making a reactor work, but also the social and environmental challenges that would arise if they did not. In describing his fundamental rule to reactor design, he said "I have a son. I love my son. I want everything that I do to be so safe that I would be happy to have my son operating it." This level of design integrity and scrutiny should be a requirement of anyone who is working on a nuclear reactor.

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Desalination Plants Worth Their Salt?

Katharine Sexton

Engineering anything necessitates engineers to enhance the public welfare by working within a set of specific problems or challenges to produce a usable solution. The challenge of producing enough safe drinking water to satisfy the needs of a steadily increasing population is arguably one of the most important engineering challenges of our time. One option for handling this problem is desalination which is already a major source of water for “Australia, Chile, Israel, Saudi Arabia, and other drought-prone coastal regions” [1]. Desalination is one of several methods which may become a necessity as the United States’ population is projected to increase almost 20% in the next 25 years [2]. Draughts have forced some states, like California, to begin investing in desalination plants even now. Potential impacts of climate change may also increase water demand in the future, intensifying an already daunting issue. Although the idea of harvesting potable water from a source as seemingly infinite as the ocean is promising, desalination is one of the most expensive water treatment technologies. The large amount of energy required for the process and the impacts a plant has on the surrounding environment are also issues which must not be overlooked.

Economically speaking, the country will be hard-pressed to fund the building and operation of desalination plants in coming years. The national debt is a big problem, infrastructure is failing all around the country, and many other issues require the government’s prompt attention and financial support. The Bureau of Reclamation is currently partnered with Sandia National Laboratories in order to develop a desalination research plan and the USGS and EPA are also evaluating the feasibility of desalination as a major water source for the country in the future [3]. Although a lot of progress has been made in the last decade in developing less expensive desalination technology, a relatively small desalination plant, like the one being built in Carlsbad, California costs one billion dollars to build, and will only provide enough water to meet 7% of San Diego County’s potable water needs alone [1].“Currently, desalination projects are funded on a case-by-case basis where 10-40 percent of the actual capital cost to build new desalination plants comes from some kind of government subsidy” [3]. Privatizing the desalination industry may be one option moving forward but would not be without many of its own issues.

One of the problems with desalination technology currently is that producing plant equipment is not particularly lucrative. “Companies that make desalination equipment see incredibly small profit margins, single digit in most cases, with a lot of competition" [3]. Many desalination companies have already gone out of business [3]. The market economy is set up to encourage technological advances, but when it comes to desalination, the incentive to create more efficient technology isn't high because funding is almost non-existent. The cost of membrane desalination is dependent on the salinity of the source water, but it is within the "range of $2-3 per thousand gallons" [3]. For a 50 MGD desalination plant, like Carlsbad's, this would be $100,000-$150,000 per day. Most of this cost is due to the large amount of energy needed for the membrane process.

Due to the high pressures needed to push high-salinity water through membranes, half the cost of operating a membrane plant is energy cost [4]. That being said, the energy consumption does vary according to desalination process in use for example thermal or membrane, and also according to water source and quality [5]. Energy use will change based on the water being treated and will also vary with elements of design such as system design, plant capacity, and utilization of energy recovery devices [5]. There is a large range of reported energy consumption for various types of desalination. The lowest reported consumption is about 1kWh/m3 for brackish water with energy recovery technology and higher consumptions are around 4 kWh/m3 for multi-stage flash distillation [5]. The competent engineer must work with all of the available design options, including energy recovery devices, to minimize energy use and cost. Decreasing the energy demand of membrane processes is a crucial element of making seawater a viable water source for the future [4].

One solution to this problem is cogeneration: the integration of desalination plants with power plants. In this scenario one energy source provides for multiple needs. This solution works particularly well for thermal desalination because after steam is pumped through turbines to generate power, it comes out of the power plant at low pressure which is compatible with the requirements of thermal desalination [5]. There is also research being done to determine the possibility of implementing cogeneration in RO desalination process which could potentially be a big energy saver [5]. Alternative energy sources, which are constantly progressing in efficiency and affordability, would also be a sustainable solution for powering desalination in the future.

The high price of producing desalinated water could lead to widespread dissatisfaction by those residents that have to pay for it; however, water as a product has an extremely inelastic demand. Although conservation efforts can mitigate costs, when desalination and other water sources become a necessity, citizens will have no choice but to pay for them. American citizens may also be wary of increased energy use in the midst of climate change and some activist groups may disagree with taking seawater for human consumption due to the negative impacts that it will have on ocean ecosystems.

One of these negative impacts is impingement and entrainment of marine life. Ocean water is not just water; it is the habitat of phytoplankton, fishes, invertebrates, plants, and more. Impingement is the trapping of fish or other animals on the intake screen which can cause their injury or death [6]. Entrainment happens when small animals, like plankton and fish eggs, pass through the intake screen and are killed during the desalination process [6]. Chemicals, pumps, and predation by filter feeders are the primary causes of these deaths [6]. Animal rights activists as well as the public will take issue with this impact as the technology becomes more widespread.

It is currently unclear how damaging impacts of impingement and entrainment from desalination plants are on the marine environment. There have been no intensive studies of ecosystems near current seawater intakes and the effects of impingement and entrainment vary based on location, year, season, and other factors [6]. “For a single facility, impingement and entrainment rates may be subject to daily, seasonal, annual, and even decadal variation,” making impact studies more difficult to execute and derive meaningful results from [6]. Due to the large variability associated with these effects, site-specific analyses are needed to approximate the type and extent of damage to surrounding ocean ecosystems.

Another huge environmental impact of desalination which must be analyzed on a site-specific basis is brine disposal. The highly concentrated waste product of desalination can be disposed of using evaporation ponds, deep well injection, land application, solar energy ponds, or sewer system [6]. Seawater brine may also be discharged back into oceans or rivers or injected into a confined aquifer [6]. Each of these methods has advantages and disadvantages and will affect other processes, ecosystems, and economies. When brine is sent back into the ocean, the majority of the waste settles at the bottom of the ocean. This is due to the relatively high density of the salty waste. “There is typically little wave energy on the ocean floor to mix the brine, and as a result, dilution occurs more slowly than at the surface” [6]. This means that at the oceans floor, dissolved oxygen levels may become depleted, greatly affecting marine organisms living in this zone. Waste brine can be diluted or diffused to help mitigate these effects, proving that for problems associated with any solution, there are more solutions to be found.

A final consideration of desalination that engineers around the country must keep in mind is the quality of treated saltwater and health concerns associated with the relatively new water source. Recently, bromate ion was found in desalinated waters [7]. The ion is classified as being possibly carcinogenic to humans [7]. Although humans are exposed to potentially carcinogenic chemicals on a daily basis, in products like pesticides, plastics, and stain resistors, the idea of a carcinogen in our tap water may cause public dissent and possibly lead to health problems. It is important that engineering professionals monitor this situation to make sure that the public welfare is protected above all else.

Although there are many obstacles to successful and efficient desalination in the United States, it is the job of engineers to maneuver problems and design solutions, and the technology may become prevalent in the future. Some point to water recycling as a better option, although public opposition of the process may be prohibitive [1]. As alternative energy and energy recovery technology improves, desalination will become more and more possible.

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The Broader Impacts of Electronics Manufacturing

Geoffrey Sowash

Electronics have become a mainstay in modern day culture but the consequences of our connected world have large scale implications which must be addressed. It is simply the norm that Americans have a cell phone, laptop, printer, microwave oven, and many other devices that depend upon underlying electronics to function. However these devices grow old and sooner or later they will be “thrown away”. In nearly every case this lifespan for these devices will be no longer than 10 years on average [1]. The unfortunate reality however is that although they have been disposed of by their owners, they won’t go away, and their impacts will be felt for far after their usefulness has expired. As the future engineers who may be the designers of those devices, the burden lays upon us as to what their impact will be when they are no longer functional.

Planned obsolescence has become deeply ingrained in in many manufacturing sectors, but few more notable than electronics. In many ways it is difficult to avoid due to consistent progress in the fields of electronic storage, semiconductor density, and other contributing fields. This however has broader repercussions. In 2009 it was estimated that between 20 and 25 million tons of e-waste were produced per year globally [1]. While this only accounts for between one and three percent of total waste production [2], the contaminants present in this e-waste cause a disproportionately large environmental impact. The sum whole of all types contains a laundry list of dangerous, toxic substances such as polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDE), arsenic, barium, beryllium, cadmium, chromium, lead, and mercury [1][2][4] just to name a few. Many of these elements and their compounds constitute pervasive environmental contaminants with links to deleterious health effects and carcinogenic properties.

In light of data that showed significant risks associated with e-waste a system of compliance called the Restriction of Hazardous Substances Directive was initiated in 2003 by the European Union and went into effect in 2006 [5]. While only applying to EU member states it has become the de facto standard for the reduction of toxic substances in electronic goods. This to a large extent is due to import restrictions it imposes into a large market for electronic goods. While this is seen as an improvement the regulations only apply within the European Union and only cover five of the most prevalent toxins Pb, Hg, Cd, Cr 6+, PBB, and PBDE [5]. While several attempts have been made within the United States to pass similar regulation, such as the

Environmental Design of Electrical Equipment Act (H.R. 2420), no large scale initiative has been put in place. While some regulation does exist under the Resource Conservation and Recovery Act (RCRA) regulations still are focused upon the disposal of mercury and specific devices, such as cathode ray tubes (CRTs) and different types of lamps and light bulbs [6]. This has led the Environmental Protection Agency (EPA) to state on their website that "At present, there is no Federal mandate to recycle e-waste. There have been numerous attempts to develop a Federal law. However, to date, there is no consensus on a Federal approach." [7]. While 25 American have passed some form of e-waste legislation their scope and implementation varies considerably [8]

How this effects the design and production of electronic goods therefore obviously depends upon the region in which the design and production occurs as well as the intended market for those goods. It also raises several ethical, as well as financial dilemmas especially for engineers who work for manufacturers that primarily cater to the domestic market. Should companies who will not directly fall under these regulatory guidelines voluntarily comply either due to environmental concerns or the ability to easily expand their market area at a later date? Is this a large enough ethical and environmental concern that engineers should be tasked with its implementation even if it may not yield direct financial benefit? In order to fully evaluate these question an in depth analysis of the impacts of such compliance must be evaluated.

The first and foremost concern for companies in such a position is cost. The financial requirements and the bureaucratic overhead associated with adoption can pose a significant expenditure and could potentially put adopting companies at a competitive disadvantage. The original adoption of these standards constitutes the largest outlay and therefore constitutes a large barrier to entry. During this original stage of implementation the costs to businesses in the EU was estimated to be 1.9% of annual revenues or €3,185 per employee per year [9]. This is was further compounded for small and medium enterprises who saw costs of 5.2% of annual revenues [9]. In contrast, costs dropped to 0.4% of annual revenues on average [9] once the system was implemented. Many of these increased costs are related to redesigning previous equipment in order to utilize ROHS compliant components. Ongoing increased costs can be due to the replacement of relatively less expensive lead based solder with the leading alternative tin-silver-copper (SnAgCu or SAC) and the increased expense of purchasing components from manufacturers who they themselves must undergo ROHS compliance testing. These financial considerations could be justified by engineers in order to comply with anticipated future regulation or to prepare their companies for international expansion. Never the less such a voluntary expense could be considered frivolous if the company initiating the adoption does not see any financial benefit.

The second concern is the utility of components which are developed using less toxic alternative materials. It's important to understand that the engineers who originally designed these devices were not careless or inept. They design them to use the most effective materials available to them and without our current knowledge of the scope of this issue it is easy to understand why. They were designing for effectiveness of the components and lowest overall cost, not for environmental issues caused by their wide scale adoption. This if anything increases the difficulty of finding acceptable alternatives. In nearly every case the toxic substances were used because they were quite effective and therefore any alterations made to avoid their use must utilize materials that in many cases have inferior engineering and financial characteristics. It must be understood that this is part of the overall design process. Choices must be made as to what takes priority when creating a new design. If environmental concerns are to take the forefront then other criteria will be de-prioritized generally leading to compromises. One example of this is the lead free solder mentioned previously (SnAgCu). When comparing the SnAgCu (96.3%, 3%, 0.7%) to the previous leaded solder SnPb (62%, 37%) using material costs derived from metal prices (2001), the lead free alternative costs 110% more [11]. This combined with an increased melting temperature, from 187 to 217 [11], inferior wetting properties [12], predisposition towards internal voids [12], and less shock resistance [12] shows the engineering compromises that had to be made in order to focus on the environmental impact.

While the previous concerns focus upon the manufacturer's impetus for adopting less toxic materials and components, the final facet of this topic is global in nature. The current system of e-waste recycling is dramatically flawed. Approximately 80% of "recycled" e-waste is shipped to third world countries [2], with between 70% [1] and 72% [13] being shipped to China. The lower standards for environmental and worker safety regulations in these countries causes increased concerns for health, safety, and ecological impacts. Although the China is starting to close the gap, the western world still produces a vast majority of the e-waste [1] [2] [13], especially if judged on a per-capita basis. What this leads to is a system where the rich countries are shipping their unwanted toxic waste to countries where a lower per capita GDP and standard of living yields people willing to endure the potential safety and environmental contamination concerns. This influx of e-waste has led to regions of China that have become synonymous with e-waste landfills like the city of Guiyu. In Guiyu laborers, many of which are poor migrant workers dig through the trash in order to reclaim any precious materials present [14]. This has led to an extremely dangerous situation where a densely populated of 150,000 is in close proximity to toxic chemicals many of which have been shown to leach into ground water [1] and are known to be carcinogenic and increase chances of birth defects [1]. A situation which has led the United Nations to state that there is “environmental calamity in the Guiyu area” [15]. Overall this just adds another layer to an already difficult and complex topic.

As a sum whole, this topic shows the wider implications of engineering decisions. It’s simple, you can’t have everything. Choices must be made as to what is the primary concern when designing any system. In this case, and in fact many cases, this tug-of-war occurs between the dominant factors of cost and negative impacts. It’s not a simple decision by any regard and there lies unfortunate compromises that must be made regardless of which course is chosen. The course must be chosen soon however as the march of globalization proceeds third world countries such as China will become large producers of e-waste themselves within the next ten years [1]. Our decisions therefore as engineers, both domestically and abroad, will have overarching, global impacts.

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Designing the Frederic C. Hamilton Addition to the Denver Art Museum

Kevin Trautman

Most structures are built for a set function and the aesthetic design works around the constraints of this function, but when engineers were tasked with building the new wing of the Denver Art Museum, aesthetic design was the primary function of the structure. This drove a process to create a unique structure to house 140,000 additional square feet of display space for thousands of pieces of art, one goal of which was to insure that the building itself would be as unique and thought provoking as the art it would contain [1]. This project presented many major technical, social, and economic pressures due largely to the fact that this wing of the museum had to essentially be a piece of art itself. This resulted in a complex structure that required technically creativity on the part of the engineers, the constant presence of the public eye on a high profile project directly affecting the reputation of the famous Denver Art Museum, and the significant cost of designing such an irregular building. Faced with such a challenge, the engineers working on the Frederic C. Hamilton addition managed to deliver a stunning feat of structural engineering on time and inside the parameters of the budget with resourcefulness and the ability to adapt to the required circumstances.

Renowned architect Daniel Libeskind was selected in 2006 to design the Frederic C. Hamilton addition to the Denver Art Museum [2]. Libeskind came up with an angular building with a dramatic angular protrusion jutting into the Denver skyline. Inspired by the peaks of the Rocky Mountains and geometric rock formations in the foothills, this unorthodox structure involved a complex web of structural steel with no members at ninety degrees [1]. Obviously, such a proposal is not an everyday task for Structural Engineers, who were now charged with the duty of turning Libeskind's creative vision into a fully functioning reality. This required engineers to take a piece of visual art and turn it into a museum capable of handling large foot-traffic. These engineers had to rely heavily on virtual modeling and advanced software to design members and connections in the vast steel frame. This involved the use of BIM models to create hundreds of models and thousands of drawings of the structure. These were in the form of plan drawings, gallery walk-throughs, construction drawings, electrical systems, plumbing, and HVAC diagrams. When forced to utilize the ability of computers to easily analyze and communicate complex geometry, engineers were surprised to find that this augmented processes heavily increased collaboration with the construction team during the design process [1]. This communication network included steel detailers, erectors, subcontractors, and stakeholders. The highly detailed modeling of connections ensured that everything lined up and fit-up problems were greatly reduced as a result. This was critical in a project that involved 16,500 pieces of steel in its elaborate frame [1]. This extensive virtually modeling also enabled the assessment of system interfaces between materials which reduced on-site conflict during construction [1]. This saved valuable time and money during the construction of the structure. In addition, the heavily reliance of computer modeling required highly precise and currently updated surveying data to ensure everything was lining up in three dimensions. This allowed for early fitting of sleeves and dramatically reduced the need for on-site concrete core drilling and field steel sleeve installation [1]. All in all, the technical concerns of this project forced engineers to use all the tools at their disposal and actually benefited the cost and timely construction of the project by resulting in a much more thorough knowledge of the proposed structure and a reliance on clear and constant communication with the construction team.

Due to the overwhelming influence of aesthetic design on the Frederic C. Hamilton addition, the project was met with public scrutiny. As with any art, the nature of its audience is subjective and based largely on personal taste. This means that any construction project that is largely concerned with architecture stands a good chance of being met by public scorn from one party or another. The Frederic C. Hamilton addition was no exception to this. Initial criticism was focused on the outsourcing of the design to Libeskind, a Polish born architect. Libeskind, while famous for many bold works, has been criticized for ignoring context and relying on a "limited architectural vocabulary" [3]. While the words of critics rarely influence artists, it does put engineers under an interesting pressure to have their product denounced and criticized during the engineering process. Ultimately, this project required an advanced professionalism and personal confidence of its engineering team. It is also interesting to look at how important the relationships between structural engineers and architects end up being. Despite the fact that the engineers didn't design the aesthetic aspects of the addition, they still end up being accountable, at least in the eyes of the public. And while visionary architects like Libeskind are experienced in dealing with criticism, not all engineers are well-versed in such things. The social interest in a project of this kind ends up resulting in creating a different atmosphere for an engineering team to work in. In the end, the public opinion of the structure was mixed. While largely regarded as a tasteful addition to the Denver skyline, the Frederic C. Hamilton addition has also been referred to as "distant, illogical, and inconvenient” [2]. Needless to say, the people who aren’t pleased scoff at what was delivered for the 110 million dollar price-tag.

This is a good bearing of the the economic challenges the engineers also faced. There was no illusion that the Frederic C. Hamilton addition would be an expensive building. Structures designed with a heavy focus on modern architecture, especially when designed by famous architects, are never cheap. But despite the expectedly large budget, engineers were still accountable for reducing cost when possible and safe. To a large extent, the extensive digital modeling of the building helped the engineers reduce the cost. This was largely in part to the aforementioned ability of the engineers to foresee construction issues and solve them before they became a problem [1]. This significantly reduced the construction costs of the building and also helped it meet its deadline (an important way to avoid un-necessary negative attention). But, with a project that is certain to attract some degree of criticism, any budget will be deemed excessive by some. This is also unfortunate for the engineering team, because even though they did take steps to reduce the cost of the project, there will always be some condemnation of the building as wasteful: another hazard of working on such an architecturally centered project.

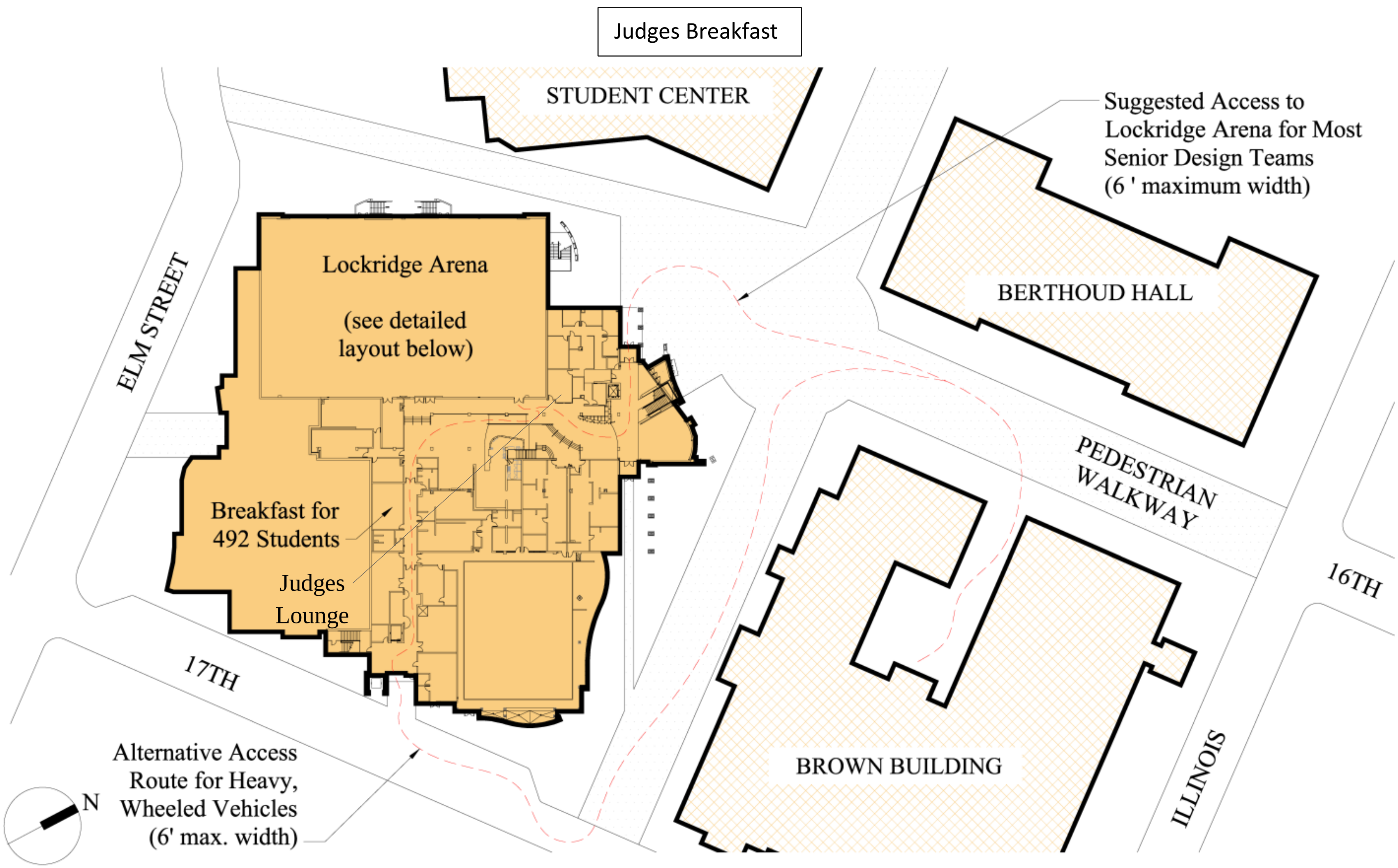
The engineering team working on the Frederic C. Hamilton building faced a challenging environment in which to design a building. They were tasked with bringing life to a highly conceptual vision from visionary architect Daniel Libeskind. This required an advanced utilization of modeling and other computer based analysis to design a complicated and intricate steel frame and to interface it with the other building materials and systems of the structure. While handling this technical challenge, engineers were also under a social pressure from advanced public awareness due to the high-profile nature of the project and its focus as an art piece. The engineers were also responsible for maintaining a reasonable budget on a project that could have easily turned into a money pit. Balancing all of this was a challenge, but the engineering team delivered an impressive and bold piece of architecture on time and with a reasonable cost. This is just one example of a project where engineers have juggled many facets of technical difficult, social pressure, and economic constraints, but it is revealing how even something as seemingly innocuous as designing an addition to a museum can present such an atypical environment filled with its own unique challenges and opportunities.

References:

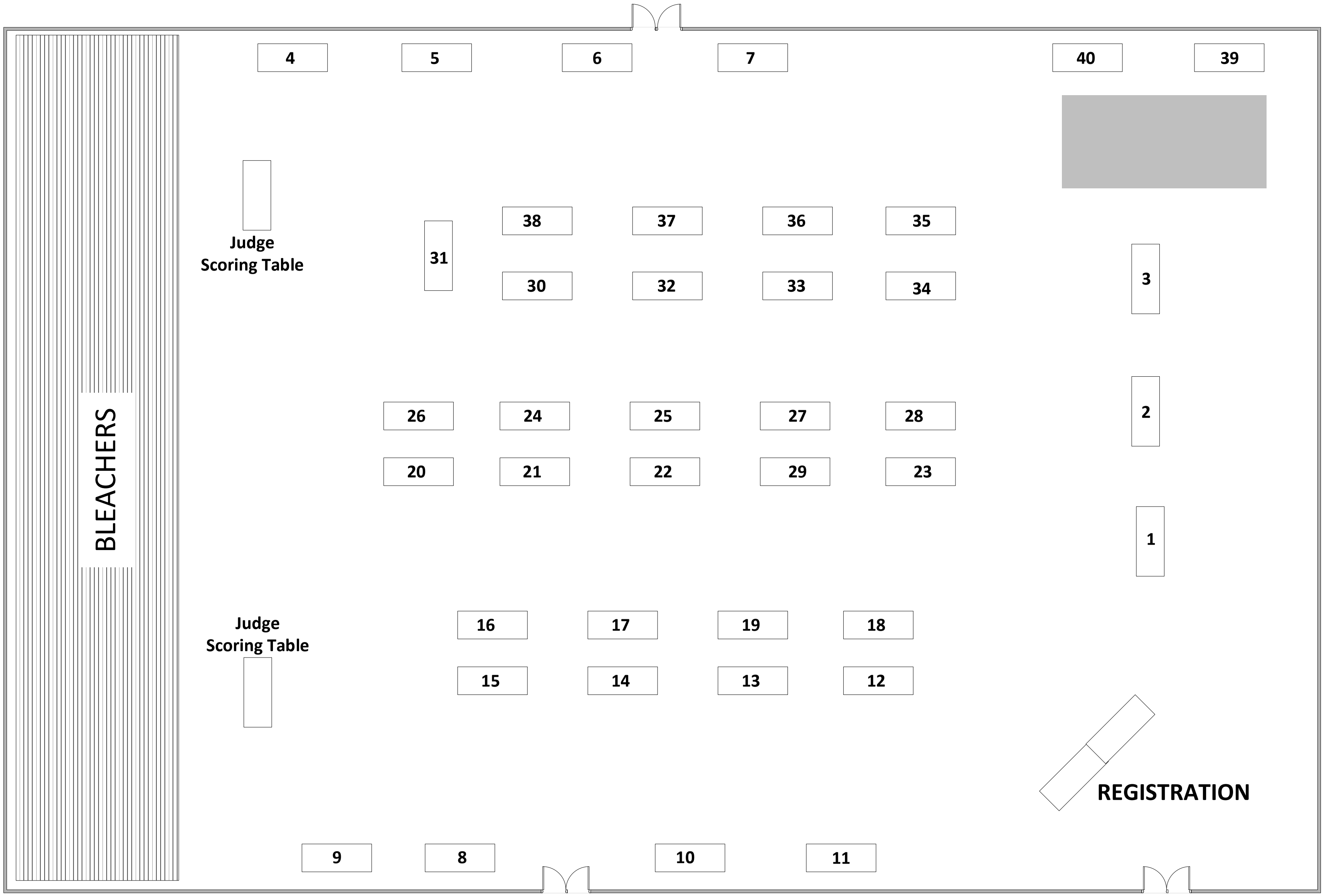
[1] http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab081539.pdf

[2] http://blogs.denverpost.com/artmosphere/2013/04/25/denver-art-museum-unveils-completed-design-for-a-new-11-5-million-administrative-building/9415/

[3] http://denverartmuseum.org/about/the-buildings



LOCATION PLAN - CECS SENIOR DESIGN TRADE FAIR



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