Embedding Standards in Engineering and Related Academic Programs: A Case Study of Senior Design and Capstone Projects

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1. Abstract

In a multidisciplinary Industrial and Engineering Technology (IET) Department with multiple subprograms including Engineering Technology (ET), Industrial Technology (IT), and Occupational Safety, Health and Environment (OSHE) programs, it is not possible to cover the detailed theory and applications of all high-level classes as in a dedicated single discipline engineering technology program. To overcome this problem, faculty utilize senior design courses and research project (capstone) courses to provide students with the necessary knowledge and skills to prepare them for the real world. In this paper, authors present an overview of the classes that theoretically introduce students to American Society for Testing and Materials (ASTM), American National Standards Institutes (ANSI), the ventilation guidelines of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and other standards, codes and rules frequently used in the industry. We present five case studies involving students in material science, including property testing and 3D-printed materials, occupational hazard control strategies for indoor air quality improvement. Each case study is based on an experimental setup. A summary of results and the industrial codes used in each case is presented.

2. Background

2.1. The Department

In a multidisciplinary industrial and engineering technology department, such as the one in Southeastern Louisiana University, that houses three different programs, namely, Industrial Technology (IT), Engineering Technology (ET), and Occupational Safety, Health, and Environment (OSHE), it is not always possible to integrate enough industrial standards with the theory introduced in the curriculum. This is true because the number of common courses shared among different concentrations does not allow an in-depth examination of many of the topics. The IT program offers 4 bachelor of science degrees in 4 concentrations and 4 associate degrees, the ET program offers 5 bachelor of science degrees in 5 concentrations, and the OSHE program offers 1 bachelor of science and 1 associate degrees. The ET and OSHE programs are accredited by the ABET and the IT program is accredited by the Association of Technology, Management, and Applied Engineering (ATMAE). Although all programs meet the accreditation requirements, the limitation of the credit hours for the degrees offered does not allow learning or practicing many of the industrial standards relevant to the curriculum taught in these three academic programs. In addition to ABET and ATMAE requirements, curriculum in each program meets the school requirement, the Louisiana Board of Regent (BoR) for Higher Education requirement, as well as the accreditation requirements of the Southern Association of Colleges and Schools Commission on Colleges.

2.2. The ET Program

As an example, the structure of the ET program, its concentrations, and its relation with other programs and departments, are illustrated in Fig. 1. The five concentrations that are offered are Computer, Construction, Electrical Energy, Mechanical, and Mechatronics. The average annual enrollment in the 13-years old program is about 300 and the average annual number of graduates is about 30. The enrollment and graduation numbers are listed in Table 1 [1].

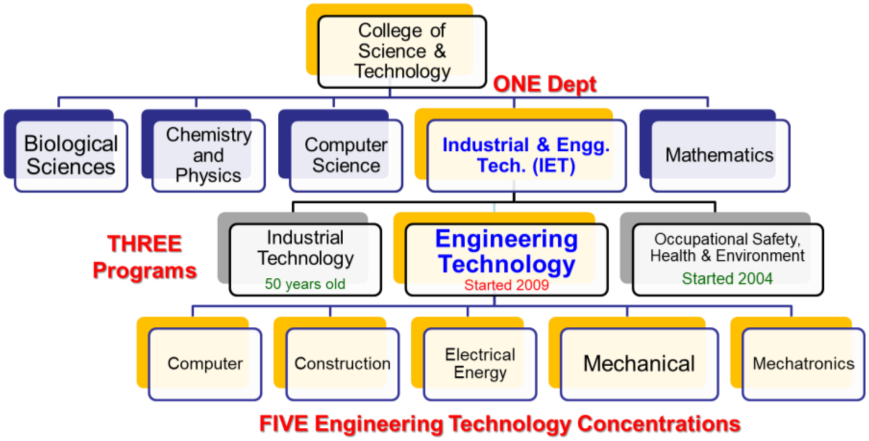
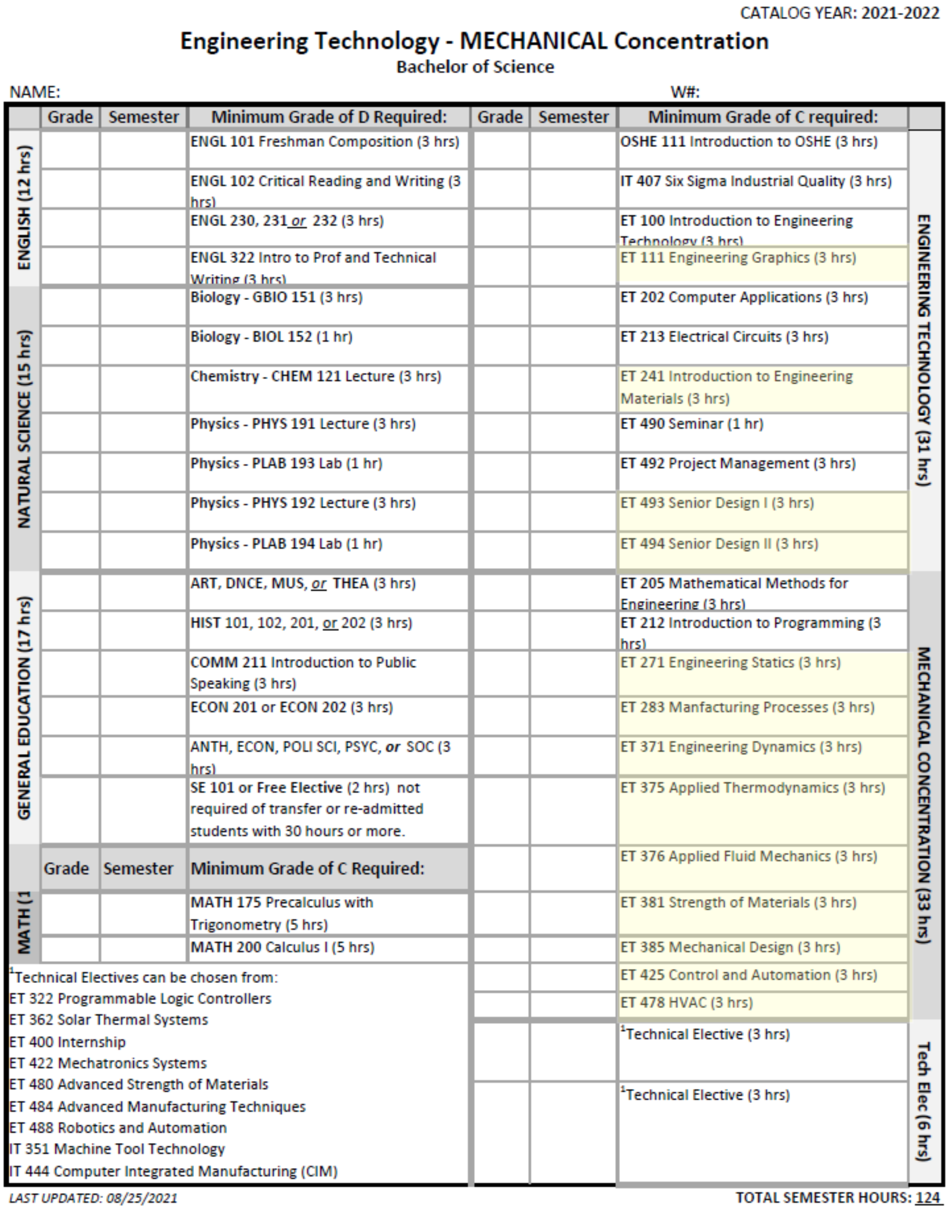


Fig. 1. Engineering Technology Program at Southeastern Louisiana University.

There are only 33 credit hours dedicated for each ET concentration, 31 common ET credit hours shared among the 5 concentrations, in additions to 10 hours of Math, 15 hours of natural science, 17 hours of general education, 12 hours of English, and 6 hours of technical electives, totaling 124 hours for the ET degree. Fig. 2 shows a sample ET curriculum sheet for the mechanical ET concentration. Because of these limitations, many industrial standards are not taught or practiced but rather might be referenced or mentioned with no applications. Also, labs for engineering classes are not offered separately, but rather they are partially embedded with the relevant lectures due to the hour's limitations. There are always tradeoffs between delivering all the theoretical knowledge relevant to the degree offered and equipping the students with all the industrial standards relevant to real-world applications, while meeting the accreditation board requirements. Educators in the engineering and engineering technology fields always utilize innovative ways to overcome this dilemma. In this paper, the authors highlight the use of senior design and capstone projects to introduce and implement a lot of important industrial standards that are mostly not learned or practiced in any other class.

Table 1. Enrollment and graduation data for the ET program.

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Enrolled	139	228	266	296	337	330	317	317	293	296	224	290	275	278
Graduated	0	1	11	11	32	26	27	34	38	26	18	34	28	24



CATALOG YEAR: 2021-2022

Engineering Technology - MECHANICAL Concentration

Bachelor of Science

NAME: W#:

	Grade	Semester	Minimum Grade of D Required:	Grade	Semester	Minimum Grade of C required:	
ENGLISH (12 hrs)			ENGL 101 Freshman Composition (3 hrs)			OSHE 111 Introduction to OSHE (3 hrs)	ENGINEERING TECHNOLOGY (31 hrs)
			ENGL 102 Critical Reading and Writing (3 hrs)			IT 407 Six Sigma Industrial Quality (3 hrs)	
			ENGL 230, 231 *or* 232 (3 hrs)			ET 100 Introduction to Engineering Technology (3 hrs)	
			ENGL 322 Intro to Prof and Technical Writing (3 hrs)			ET 111 Engineering Graphics (3 hrs)	
NATURAL SCIENCE (15 hrs)			Biology - GBIO 151 (3 hrs)			ET 202 Computer Applications (3 hrs)	
			Biology - BIOL 152 (1 hr)			ET 213 Electrical Circuits (3 hrs)	
			Chemistry - CHEM 121 Lecture (3 hrs)			ET 241 Introduction to Engineering Materials (3 hrs)	
			Physics - PHYS 191 Lecture (3 hrs)			ET 490 Seminar (1 hr)	
			Physics - PLAB 193 Lab (1 hr)			ET 492 Project Management (3 hrs)	
			Physics - PHYS 192 Lecture (3 hrs)			ET 493 Senior Design I (3 hrs)	
			Physics - PLAB 194 Lab (1 hr)			ET 494 Senior Design II (3 hrs)	
GENERAL EDUCATION (17 hrs)			ART, DNCE, MUS, *or* THEA (3 hrs)			ET 205 Mathematical Methods for Engineering (3 hrs)	MECHANICAL CONCENTRATION (33 hrs)
			HIST 101, 102, 201, or 202 (3 hrs)			ET 212 Introduction to Programming (3 hrs)	
			COMM 211 Introduction to Public Speaking (3 hrs)			ET 271 Engineering Statics (3 hrs)	
			ECON 201 or ECON 202 (3 hrs)			ET 283 Manfacturing Processes (3 hrs)	
			ANTH, ECON, POLI SCI, PSYC, ***or*** SOC (3 hrs)			ET 371 Engineering Dynamics (3 hrs)	
			SE 101 or Free Elective (2 hrs) not required of transfer or re-admitted students with 30 hours or more.			ET 375 Applied Thermodynamics (3 hrs)	
	Grade	Semester	Minimum Grade of C Required:			ET 376 Applied Fluid Mechanics (3 hrs)	
MATH (1			MATH 175 Precalculus with Trigonometry (5 hrs)			ET 381 Strength of Materials (3 hrs)	
			MATH 200 Calculus I (5 hrs)			ET 385 Mechanical Design (3 hrs)	
[1]Technical Electives can be chosen from: ET 322 Programmable Logic Controllers ET 362 Solar Thermal Systems ET 400 Internship ET 422 Mechatronics Systems ET 480 Advanced Strength of Materials ET 484 Advanced Manufacturing Techniques ET 488 Robotics and Automation IT 351 Machine Tool Technology IT 444 Computer Integrated Manufacturing (CIM)						ET 425 Control and Automation (3 hrs)	
						ET 478 HVAC (3 hrs)	
						[1]Technical Elective (3 hrs)	Tech Elec (6 hrs)
						[1]Technical Elective (3 hrs)	

LAST UPDATED: 08/25/2021

TOTAL SEMESTER HOURS: 124

Fig. 2. Mechanical Engineering Technology curriculum sheet.

2.3. The Senior Design Classes

A closer look at the mechanical ET concentration shows that 46 hours are contributing directly to the concentration as a core or a general ET class. This includes the 2 3-hour senior design classes, a 3-hour project management class, and a 1-hour seminar class. The two technical elective classes may also contribute to the concentration but most probably will be from other concentrations, or even different programs (such as physics, math, or computer science), based on the availability of the classes.

The two senior design classes, as well as research, educational, and hands-on projects embedded in high-level classes, are used to supplement the knowledge and skills of the ET students to equip them with the important skills and prepare them for their career. Among the supplemental knowledge and skills covered in these project-based learning (PBL) experiences are the industrial standards. Utilizing the PBL is proven to help supplement the curricula in the engineering technology program, [2]. At these projects, students not only learn about industrial codes and standards but also, they get to implement them in a real-life application. This has been helping students getting more internships and securing jobs in many industries. It also has been acknowledged by the industrial advisory board of the engineering technology program as one of the important learning outcomes of the program. At the end of these projects, students professionally report their experience and present it before a panel of industrial board members and faculty, at local conferences, professional meetings, and school showcases. This comes in the form of oral presentations, posters, as well as professional conference proceedings [3-9]. This initiative is sponsored mainly through the senior design project funds as well as through grants from agencies such as Louisiana Space Grant Consortium (LaSPACE) and Louisiana BoR.

2.4. Embedding Extra Components into Curriculum

To bridge the gap between the curriculum and new concepts and industrial needs, many researchers tried to embed these topics in their curriculum through different methodologies. Examples of these efforts include embedding sustainability, [10], [11], and ethics [12], in the engineering curriculum as well as embedding the design thinking in a multidisciplinary engineering curriculum, [13]. To help educational institutions bridge this gap, many professional engineering organizations offered grants to help educational institutions integrate industrial standards. A good example is the grants provided by the National Institute of Standard and Technology (NIST) through the Standards Coordination Office's Curricula Development Cooperative Agreement Program. This program aims to enrich college curricula to raise awareness of the role of standards and standardization in science, technology, engineering, math, law, public policy, business, and other related or multi-disciplinary fields, [14]. To increase the awareness of engineering and engineering technology, national organizations, such as Jet Propulsion Laboratory (JPL) of NASA, adopted the inclusion of engineering and engineering technology educations in the early stages of education including K-12, [15], utilizing the Next Generation Science Standards (NGSS) [16]. To further foster engineering education in the early stages of education (K-12), many states and organizations adopted engineering and engineering technology education strategies, [17], [18].

3. Methodology

The majority of industrial standards used in ET and IT senior design projects were related to material testing and characterization. These tests followed the American Society for Testing and Materials (ASTM) standards. Some projects were related to constructions and followed building codes. The industrial standards used in OSHE capstone projects were mainly those relevant to workplace and non-occupational environments. Indoor air quality (IAQ) standards and guidelines for workplace or occupational environments are guided by the American Conference of Governmental Industrial Hygienists' (ACGIHs) threshold limit values (TLVs), the U.S. Occupational Safety and Health Administration (US OSHA) guidelines, the National Institute for Occupational Safety and Health, recommended exposure limits (REL), and the American Industrial Hygiene Association (AIHA's) workplace environmental exposure limits. For buildings in non-work environments, the IAQ guidelines and standards are drawn from the above agencies as well as the World Health Organization (WHO), the U.S. EPA National Ambient Quality Standards (NAAQS) and the American Society of Heating, Refrigeration and Air Engineers (ASHRAE).

3.1. ASTM standards in ET Senior Design Projects

Through the engineering technology senior design projects, many ASTM standards for testing of materials were implemented. In multiple projects, students characterized and evaluated mechanical properties of different 3D printing materials including tensile strength and impact strength. Equipment such as universal testing machines, impact testing machines, extensometers, and 3D printers. Students prepared test specimens using multiple printing configurations and performed tensile and impact tests according to the ASTM standards relevant to these tests. ASTM F2971 (standard for reporting data for test specimens prepared by additive manufacturing) was followed to prepare all the 3D printed test specimens. ASTM D638 (standard test method for tensile properties of plastics) was followed to identify and prepare the specimens based on different 3D printing parameters, including the raster printing orientation, for tensile testing. Using this standard, the number of specimens needed, the tensile test parameters including the strain rate, as well as the type and dimensions of test specimens were determined. ASTM standard A370 and ASTM D6110 were followed to prepare and perform Charpy impact test on 3D printed notched specimens.

3.2. Standards in OSHE Capstone Projects

Poor IAQ is highly correlated to illnesses, lack of comfort and lower productivity. The fundamental importance of ensuring good IAQ in occupational settings, including educational institutions, such as schools and colleges, is widely acknowledged as the cornerstone of improving human health and in the development of effective IAQ improvement programs. Consequently, evaluation of the IAQ in school buildings on the basis of the ventilation requirements, guidelines and standards is an integral component of the OSHE academic program and curriculum. Recognizing that the course is a semester-long that culminates to experiential learning experience students conduct evaluation of classrooms and offices, and various other micro environments and spaces within selected campus buildings. The report presented here is from the IAQ data collected by students from a newly built and commissioned building facility. Students collected data using a template shown Table 2 from the faculty offices, conference facility and the main administrative office of the building. Parameters collected were carbon dioxide (CO_2), relative humidity (RH %), Ttmperature (T °F) and ventilation rates.

Table 2. IAQ data collection forms.

	RM1				**RM2**				**RM3**				
Group 1 Students	CO_2 (ppm)	RH (%)	T (°F)	Q (ft^3min)	CO_2 (ppm)	RH (%)	T (°F)	Q (ft^3min)	CO_2 (ppm)	RH (%)	T (°F)	Q (ft^3min)	**Days**
													1
													2
													3

													4
Group 2 Students													1
													2
													3
													4

The CO_2 concentration levels were compared with the primary and secondary standards of the U.S. NAAQS. Equally, the temperatures and relative humidity were compared with the NAAQS as well as the ACGIH threshold limit values, US OSHA permissible exposure limits and NIOSH recommended exposure limits. Other standards that were used for the preceding parameters were the AIHA's workplace environmental exposure limits and the maximum allowable concentrations of international agencies. The ventilation rates, derived from the income air from the diffusers in each room, were converted by a standard formula to derive the air changes per hour (ACH) and the data compared with the occupancy rates for each office or room, and these were compared with the guidelines of (ASHRAE Standard 62.1-2022: ventilation and acceptable indoor air quality. This case study provides insight into how guidelines and standards can be used to monitor IAQ and provide the basis for IAQ improvement programs. The work presented in this article was conducted by students enrolled in OSHE 341: Industrial Hygiene Field Evaluations. The ventilation data used for this case study is the flow rate, Q in units of ft3/hour, and the ACH, which was computed from a standard formula, and the ACH was then compared with the ASHRAE Standard 62.1-2022.

4. Case Studies

In this section, the authors present samples of the projects they used to introduce and implement the industrial standards discussed above. Summary of each project is presented along with the standard used and project outcomes.

4.1. Sample ET and IT Senior Design Projects

4.1.1. Evaluation of mechanical properties of 3D printed materials. In this project, two grants from the Louisiana Space Grant Consortium (LaSPACE) through the Louisiana Undergraduate Research Assistantship (LURA) program and the senior design program and were utilized and two students were recruited. The work was aligned with NASA Space Technology Mission Directorate and NASA Innovative Advanced Concepts. The project was performed through the 2 senior design classes (ET493 and ET494) for 2 semesters. The main goal was to investigate the mechanical properties of 3D printed products in terms of tensile and impact strength. Two materials, namely polylactic acid or polylactide (PLA) and Tough PLA, were tested and different printing orientations were considered to check their effects on the strength. Student participants working in this project went through the ASTM standards relevant to testing of Additive Manufacturing materials to prepare and code their specimens. This was mainly ASTM F2971 (standard for reporting data for test specimens prepared by additive manufacturing), [19], Fig. 3, and it was used to properly code and name different test specimens.

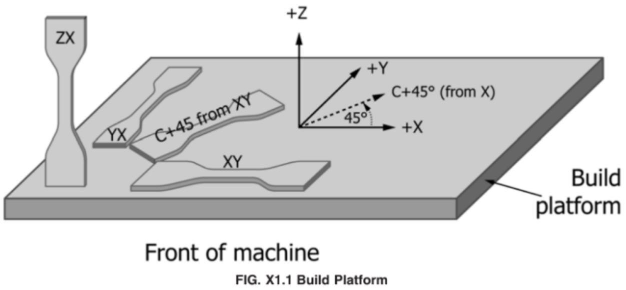


Fig. 3. ASTM F2971 – Specimen orientation designation [19].

They also implemented the ASTM D638 (standard test method for tensile properties of plastics) to determine the proper specimen size for tensile testing, [20], Fig. 4, and followed the recommended number of specimens for each configuration. Tensile tests were done using a vertical testing machine, Fig. 5. ASTM standard A370 was followed to prepare and perform Charpy impact test specimens. Total of 192 tensile specimens and 192 Charpy specimens were printed to cover varieties of percentage infill, printing orientation, and material type configurations. The projects resulted in finding the correlation between strength and percentage infill as well as the effect of printing orientation on the strength. Sample results from the impact test is shown in Fig. 6.

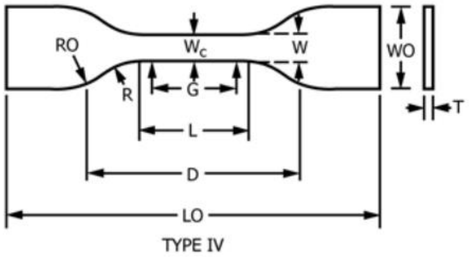


Fig. 4. ASTM D638 Type IV specimen specifications [20].

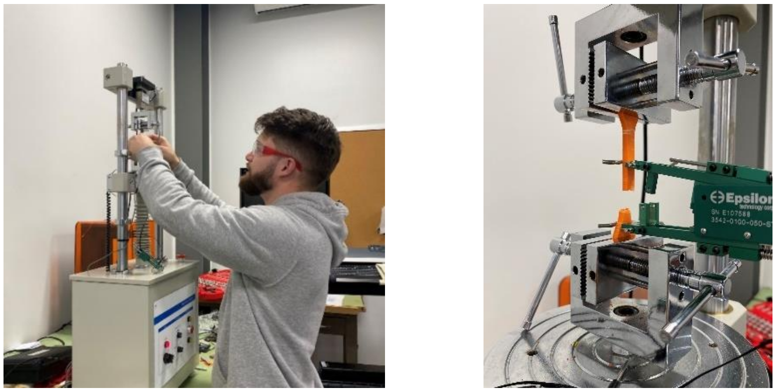


Fig. 5(a). Loading universal testing machine, (b) loaded specimens with extensometer attached after failure.

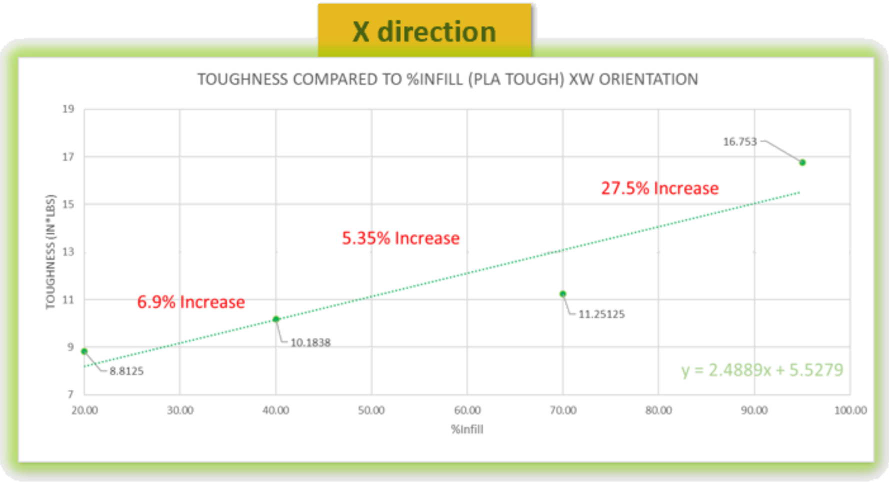


Fig. 6. Sample results for Charpy test.

The knowledge of standards along with finite element analysis allowed one of the students who worked in this project to secure an internship and job in a marine crane fabrication company. The work was presented in the senior design discussion before a panel of faculty and industrial partners and resulted in some publications [21-23].

4.1.2. Recycling and reuse of composite materials for 3D printing. This project was completed by two Senior Design students from the Mechanical Engineering Technology program. The project was funded by the Louisiana Board of Regents Research Competitiveness Program. The project aimed to tackle the challenges related to recycling polymer composites in an environmentally friendly manner. By extensively researching existing studies on polymer composite recycling and additive manufacturing technologies, and considering the specific needs of Louisiana, a comprehensive project plan was developed. The main objective was to find a sustainable method for fabricating filament feedstock for fused deposition modeling (FDM) 3D printing processes, focusing on recycling composite materials from end-of-life boats. The project involved collecting samples from abandoned boat hulls, classifying them, mechanically recycling the collected material through grinding, fabricating short-fiber reinforced composite filament for FDM 3D printing, and conducting tensile tests on 3D-printed parts. The study included varying fiber-glass content levels (5%, 10%, 15%, and 20%) to analyze their effects on tensile strength. The test specimens were 3D printed and tested following the ASTM D638 standard. The findings were presented at the senior design meeting, attended by ET faculty, students, and industry partners. Through this project, students enhanced their skills in experimental design, problem-solving, understanding ASTM standards, and technical reporting.

4.1.3. An analysis of 3D printing materials for generative design applications. This research project centered on the integration of generative design and additive manufacturing. generative design software programs utilize specialized material characteristics libraries to develop 3D models of products. These libraries use specific material properties within their generative design solutions. Notably, 3D printed components exhibit anisotropic mechanical characteristics, wherein the mechanical properties of the parts vary based on the printing orientation. The primary objective of this study was to systematically identify and analyze the mechanical properties of selected 3D printing materials employed in specific 3D printing technologies. This analysis was conducted through comprehensive mechanical testing of 3D printed components. In the initial stage, specimens were 3D printed in accordance with ASTM D638 standards, employing both SLA and FDM technologies. Specifically, Formlabs Form2 3D printers were utilized with clear resin (RS-F2-GPCL-04) for the SLA technology, while Markforged Mark2 3D printers were employed with microcarbon fiber-filled nylon (Onyx) for the FDM technology. The test specimens were printed in various orientations, as depicted in Fig. 7.

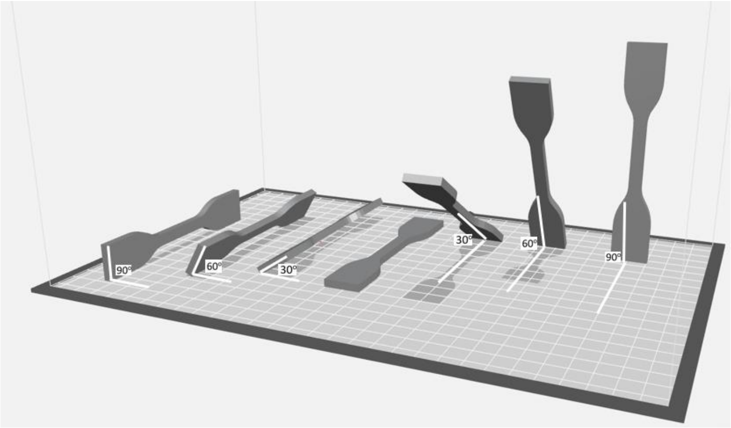


Fig. 7. Printing orientations of the 3D printed samples.

The derived mechanical data was subsequently integrated into the generative design module of Fusion 360. The outcomes of this study were validated through the design and testing of parts featuring diverse experimental geometries as shown in Fig. 8.

Fig. 8. 3D printed test parts with various designs.

The funding for this project was provided by the Louisiana Space Grant Consortium through its LaSPACE Undergraduate Research Assistantship program. This financial support facilitated the engagement of a mechanical engineering technology student, enabling his employment during his enrollment in the senior design class for two semesters. His work was presented at the ASEE Gulf-Southwest Conference [24].

Through this project, the undergraduate research assistant underwent a comprehensive learning experience encompassing scientific literature review techniques, data collection methodologies from existing literature, critical analysis, and the formulation of a research project. Proficiency was acquired in the exploration of ASTM standards pertinent to specific materials and processes, fostering familiarity with ASTM standards and protocols for the tensile testing of 3D printed test specimens. Practical skills were developed in the operation of a computer-controlled universal testing machine, coupled with a thorough understanding of associated safety protocols. Furthermore, the undergraduate assistant gained in-depth knowledge of various 3D printing technologies, their operational principles and practical applications. Proficiency in 3D computer-aided design (CAD) modeling and Finite Element Analysis was achieved through hands-on experience with the SolidWorks CAD software program. Additionally, the undergraduate assistant practiced generative design methodology on the Fusion 360 Generative Design software program. Moreover, the undergraduate assistant grasped the fundamental concept of "design of experiments “to create test specimens and test groups. This involved manipulating the printing parameters of the 3D printing process and components. Statistical analyses, including analysis of variance, were conducted using Minitab software, contributing to a robust understanding of experimental design and statistical methodologies.

4.1.4. Verifying concrete surface resistivity results using RCPT. This research project was initiated by requests from local concrete industry partners who had problems with their concrete mixture passing the surface resistivity (SR) test requirement. The project included 3 senior ET students (Construction concentration) and one faculty advisor. However, the team also received technical support and loaned equipment from the Louisiana Department of Transportation and Development (LaDOTD) and other local construction companies.

Concrete surface resistivity test is a relatively new simple test that aims to evaluate the concrete permeability through measuring the electrical resistance of the concrete surface. The higher resistance means that the concrete is less permeable which can provide better protection against reinforcement corrosion. However, the test results can be very sensitive to some other factors including the curing conditions, moisture content, chemical composition and shape of the aggregate used. The American Association of State Highway and Transportation Officials (AASHTO) first issued a testing standard for SR around 2015 (AASHTO T358) but there is no official ASTM standard yet. On the other hand, RCPT test is a classical test that is well established for decades (ASTM C1202 and AASHTO T277)

As of 2016, the LaDOTD has made the SR test the standard for testing and accepting the permeability of concrete mixture to replace the more accurate but much more completed rapid chloride penetration test (RCPT). The SR test was also replacing the RCPT test in many other agencies and organizations. This is mainly due to the simplicity and cost efficiency of the SR test compared to RCPT. SR test typically requires no to minimum sample preparation and the testing itself can be finished within 3-5 minutes (see Fig. 9). On the other hand, RCPT test sample cutting, preparation and conditioning takes between 48-72 hours while the testing time is 6 hours (see Fig. 10). Moreover, the equipment needed for the SR test cost around $3,000-$5,000 while the equipment needed for RCPT costs more than $15,000.

The problems arose when local contractors started to have multiple problems with SR testing results for concrete made with locally sourced aggregates. These problems included inconsistent results and falling to achieve the required resistivity with typical mixtures. These problems increased to the point that they had to ship aggregates from out-of-state to satisfy the requirements which significantly increased the cost and affected local suppliers. The research team aimed to compare the results for both tests (SR and RCPT) for concrete made with local aggregate with different sizes and shapes. Additionally, the effect of different curing conditions was also investigated. The project involves many challenges for the students who were not familiar with either test as they are not included in any of the courses on ET curriculum. Moreover, the sample preparation and testing required a significant learning and training process especially for the much more complicated RCPT test. However, at the end of the 2-semester project, the students were able to to develop an acceptable level of knowledge, experience and skills related to concrete testing standards in general and the permeability standards tests in particular.

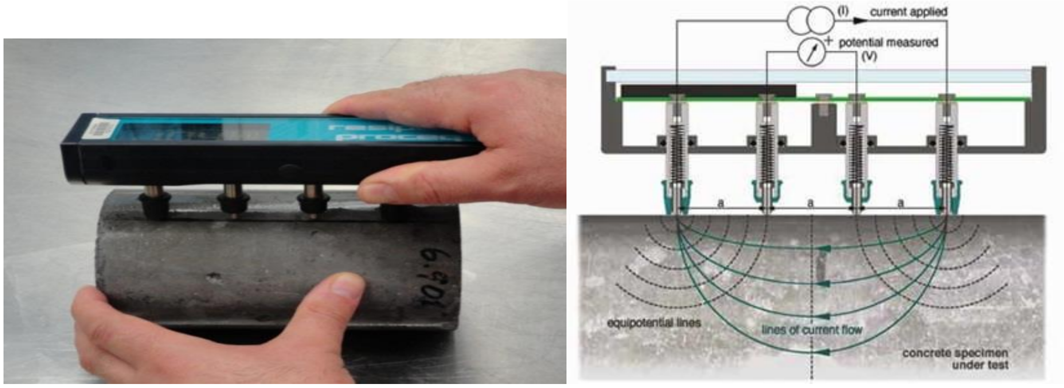


Fig. 9. Testing process (left) and concept (right) of SR test.

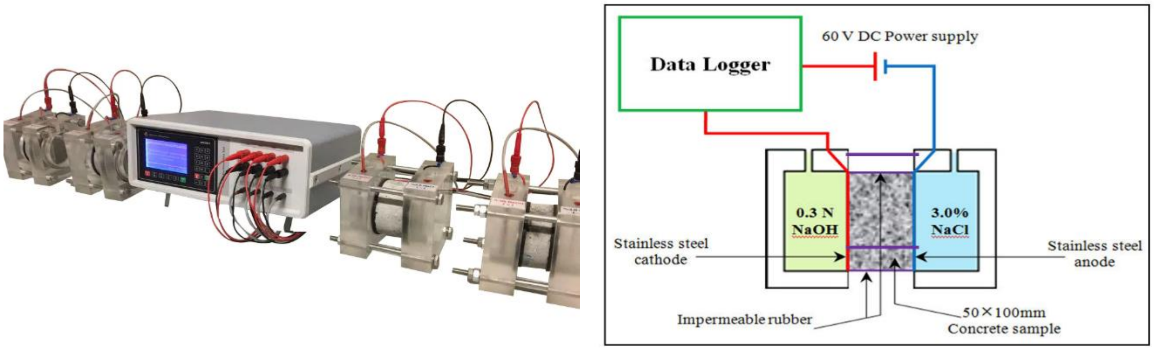


Fig. 10. Testing process and equipment (left) and concept (right) for RCPT test.

4.2. Sample OSHE Capstone Projects

4.2.1. OSHE 341: Air Quality, Health and Productivity. The following is a summary of the project titled “Performance Evaluation of Mechanical Ventilation Systems in the Indoor Environments: Air Quality, Health and Productivity.”

The quality of air inside of the built environments and other enclosed spaces is one of the growing concerns to human health, comfort, and productivity [25]. For decades, humans have recognized that indoor air is a source of exposure to myriad pollutants that can cause health impacts [26]. Research and development in this field has resulted in a body of evidence showing the correlation of poor IAQ to human health, comfort and productivity [27-29]. Recognizing this significant association, standards and guidelines have been issued by the WHO, U.S. EPA), the ANSI/American Society of Heating and many government agencies around the world for major indoor air pollutants to protect human health [30-32]. These guidelines regulate pollutants that can cause health including infiltration from outdoor through building cracks, open windows and doors, and incoming guests and visitors. Other airborne contaminants highly correlated with poor IAQ and poor health are building material such as asbestos, formaldehydes, volatile organic compounds, off-gassing from carpets and walls, and products used indoors by janitors.

Since we spend approximately 90-95%, compromising with the guidelines for IAQ can produce undesired effects to occupants including compromising with comfort, health, and lower productivity. In such circumstances, the role of ventilation systems, both natural and mechanical, in built environments cannot be underestimated in the transmission of outdoor air pollutants into the indoor environments, nor can it be in isolation with keeping the quality of the air in the indoor environments to the minimum regulatory and voluntary guidelines and standards [33-35].

Recognizing that there is a significant relationship between ventilation systems in the built environments and their effects on health, comfort and productivity, an academic project within OSHE-341 "Industrial Hygiene Field Evaluations" was tasked to students to undertake it as a term paper project. As building ventilation rates have historically evolved from the 19th century through improvements [36], student projects involved measuring ventilation rates or studies on the preliminary assessment of technical performance of the mechanical ventilation systems and impacts on the indoor air quality of a newly built and commissioned building on campus.

Students' activities involved measurements of the incoming air through the diffusers, duct sizes, and other key parameters of indoor air quality. The temperature (T, ºC) and relative humidity (RH, %) are indicators of thermal comfort [37]. All these IAQ parameters were analyzed relative to the occupants' size in a room, classroom, or conference rooms. The data was compared to the WHO and U.S. EPA guidelines and standards for IAQ. The volumetric air flow rate (Q, cfm) data for each room, classroom, and conference room, was measured by a device called air flow capture hood, A TSI, Inc. Model 8330 whose principle of operation is primarily based on the velocity pressure, Vp (associated with the kinetic energy of the moving airstream and exerted in the direction of flow) and static pressure (Sp) (or potential energy component of the moving airstream) [38]. Both of these two parameters are important in mechanical ventilations systems because they give rise to the total pressure (Tp) inside of the ventilation ducts, and the ability of the air to move/flow. The value of Q, in cfm units, is automatically computed, and read off of the digital screen of the instruments. The Q value is then used to obtain the Air Changes Per Hour (ACH) (equation 1.0).

$$\frac{CFM * 60}{RoomVolume} \qquad \text{Eq. 1}$$

The ACH was compared to the recommended by the ANSI/ASHRAE guidelines ANSI/ASHRAE Standard 62.1-2022 and 62.2-2019 both of which are recognized standards for ventilation system design and acceptable IAQ [35]. These two ANSI/ASHRAE standards specify the minimum ventilation rates and other parameters requirements for indoor environments in order to minimize any potential human health effects of poor IAQ [35].

In estimating the carbon dioxide (CO_2) concentration levels as a function of time t, we assumed as recommended by other scholars in this field that the levels were related to the generation rate G, and the ventilation rates and the volume of the rooms [38].

$$C = \frac{G}{Q}\left[1 - \exp\left(\frac{-Qt}{V}\right)\right]$$ Eq. 2

Case 1 ($C_1 = 0$ at $t_1=0$ & $G>0$)

$$C_{\max} = \frac{G}{Q}$$ Eq. 3

Case 2 ($t >> t_1$, and $G>0$)

Where G is the generation rate

Values of CO_2 levels were primarily assumed based on the human inhalation and exhalation rates, and/or from the outdoor environments was estimated by using two approaches (Equation 2.0 and 3.0) as proposed by [38].

The instantaneous or real-time-measurements of CO_2 contaminant was determined by previously calibrated direct instruments, and levels used as surrogate for poor IAQ [39].

Five student groups completed this project and the results from the first group are shown as a sample below. The IAQ data was computed using the formula presented above and data entered into a Table 3 and Table 4 below.

Table 3. IAQ data parameters collected in various spaces in four days.

	RM1 (conference room) (Volume = 4800 ft^3) Occupancy: 22 people					**RM2 (Main office) (Volume = 3600 ft^3) Occupancy: 4-6 people**					**RM3 (office) (Volume = 1229 ft^3) Occupancy: 1 to 2 people**					**Day of the week**
Group 1 of Students	CO_2 (ppm)	RH (%)	T (ºF)	Q (ft3/ min)	ACPH (-)	CO_2 (ppm)	RH (%)	T (ºF)	Q (ft3/ min)	ACPH (-)	CO_2 (ppm)	RH (%)	T (ºF)	Q (ft3/ min)	ACPH (-)	
	850	55	72.8	106	1.33	883	63	70.2	134	2.23	730	59	68.2	110	5.37	1
	823	62	73.2	130	1.63	907	58	69.8	81	1.35	482	52	69.8	121	5.91	2
	949	52	80	105	1.31	803	60	70.5	95	1.58	624	63	70.8	112	5.47	3
	803	53	77.5	108	1.35	792	65	70.4	105	1.75	704	5	70.1	109	5.32	4

Table 4 Data for CO_2 levels in units of mg/m^3 and %

	RM1 (conference room) (Volume = 4800 ft^3)		**RM2 (Main office) (Volume = 3600 ft^3)**		**RM3 (office) (Volume = 1229 ft^3)**		**Day of the week**
Group 1 Students	CO_2 (mg/m^3)	CO_2 (%)	CO_2 (mg/m^3)	CO_2 (%)	CO_2 (mg/m^3)	CO_2 (%)	
	1529.7	0.085	1589	0.088	1313.7	0.073	1
	1481.1	0.082	1682.2	0.091	867.4	0.048	2
	1707.8	0.095	1445	0.080	1122.9	0.062	3
	1445.1	0.080	1425	0.079	1266.9	0.070	4

5. Conclusion

To supplement the lack of industrial standards implementations on the engineering technology and related fields, the senior design and capstone projects are used to give students both the knowledge and hands-on skills needed for some important standards. This methodology satisfied the requests from industrial partners and allowed better implementations of learning outcomes. Students who participated in these projects could cumulate good experience in utilizing standards in their engineering design.

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