ENME 416/744: Additive Manufacturing

Course Syllabus

Spring 2021

Catalog Description

Additive Manufacturing; (3 Credits) Grade Method: REG/P-F/AUD.
Prerequisites: ENME 272 and ENME 331 (or Equivalent)

Provide an introduction to a wide range of fundamental additive manufacturing (colloquially referred to as "three-dimensional (3D) printing") approaches, including extrusion-based deposition, light-based photocuring, powder bed-based processes, and inkjet-based methods. Cultivate a "design-for-additive-manufacturing" skillset that leads to successful 3D prints. Combining computer-aided design (CAD) and computer-aided manufacturing (CAM) methodologies to produce 3D printed designs. Fabricate 3D mechanical objects using two of the 3D printing technologies on campus. Execute a final project that demonstrates how additive manufacturing strategies can overcome critical limitations of traditional manufacturing processes.

Course Information

This course serves as a general introduction to the underlying concepts of state-of-the-art 3D printing technologies. Students will utilize CAD software to design demonstrative 3D objects. Students will submit CAD designs, which will be printed by Terrapin Works using two distinct 3D printing technologies on campus: Fused Deposition Modeling (FDM) and PolyJet Printing. The projects will provide students with an opportunity to observe print differences in terms of feature resolution, geometric complexity, and material versatility. Students will leverage these experiences to execute a final project that takes advantage of the unique capabilities of 3D Printing. Students will also gain experience with *soft* skills through course deliverables including a "conference-style" oral presentation and a "journal-style" written manuscript.

Course Format

The course is online (*Zoom details via Canvas*) three times per week: MWF 1:00-1:50 PM

Instructor

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Teaching Assistants

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Course Slack

Students are expected to join the course Slack *via* this link.
Note: The vast majority of communications regarding the course will be handled through Slack.

ASSESSMENT/GRADING POLICY

It is the policy of the course instructors to apply the same performance expectations to all course participants regardless of their academic, employment, or linguistic background. Student grades will be assessed as follows:

Undergraduate Students | ENME 416		Graduate Students | ENME 744	
5%	Online Class Participation	5%	Online Quizzes
5%	Online Quizzes	20%	Midterm Exam 1
20%	Midterm Exam 1	20%	Midterm Exam 2
20%	Midterm Exam 2	5%	Case Study Presentation
12.5%	Team Design Project 1* (7.5% Instructors | 5% Class)	12.5%	Team Design Project 1* (7.5% Instructors | 5% Class)
12.5%	Team Design Project 2* (7.5% Instructors | 5% Class)	12.5%	Team Design Project 2* (7.5% Instructors | 5% Class)
25%	Team Final Project* Oral Presentation: 12.5% (10% Instructors | 2.5% Peer) Journal Paper: 12.5%	25%	Team Final Project* Abstract: 5% Oral Presentation: 10% Written Deliverable: 10%
* Individual Project Grades = ***Overall Project Grade*** × ***Teammate Peer Review Score***			

Note: All assignments will be graded on a curve with respect to the class. Additionally, graduate students will be held to a higher, graduate-level standard during grading.

TEXTBOOK/READINGS

Due to the evolving nature of additive manufacturing technologies, no single textbook currently covers all of the topics that will be discussed in this course. As such, there is no required textbook for the class. The vast majority of course content will be freely available *via* course lecture notes, website content, and academic papers accessible through the UMD network. For a deeper understanding of the course subject matter, optional recommended texts include:

1. Ian Gibson *et al.*, "Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing," Springer, 2015, ISBN 9781493921126.
2. Andreas Gebhardt, "Understanding Additive Manufacturing," Hanser, 2011, ISBN 9783446425521.

ACADEMIC INTEGRITY AND STUDENT CONDUCT

Please review the university policy on academic integrity and academic dishonesty at http://www.ugst.umd.edu/courserelatedpolicies.html. Additionally resources can be found at http://www.jpo.umd.edu/ and http://www.studenthonorcouncil.umd.edu/code.html. Also note that all work of anyone other than the student(s) must be referenced appropriately. The course instructor may use plagiarism checking software and/or request evidence of references for any submitted work and deliverables. To read more about avoiding plagiarism, please visit the Purdue Online Writing Lab (http://owl.english.purdue.edu/owl/resource/589/01/).

Team Design Challenges (DCs)

Two major "*midterm projects*" will be assigned, with undergraduate students (ENME416) working in teams of five and graduate students (ENME744) working in teams of four:

- **Design Challenge 1 – Bridge |** Students will design a lightweight bridge structure for 3D printing *via* Fused Deposition Modeling (Makerbot Replicator). The goal is for the bridge (including designed support structures) to cost as little as possible, yet able to support a weight of ~20 lbs. Grading of this challenge is designed to benefit students who take risks to push the limits of 3D printing. (*Hint: Do not play it safe and overdesign a bridge that can hold 50 lbs.!*)
- **Design Challenge 2 – Stent |** Students will design a macroscale reconfigurable stent that comprises one fully assembled member for 3D printing *via* Binder Jetting (HP MultiJet Fusion). The goal is for the print to initially exhibit the smallest *compressed* diameter possible, yet reconfigure and be able to maintain the largest *expanded* diameter possible.

It is strongly recommended that students use SolidWorks CAD software (available on campus and *via* the UMD Virtual Computing Laboratory) to design their components and submit their STL files. The main final deliverable for both assignments will be a ~10-minute oral presentation, which includes a live demonstration of the print and will be peer reviewed by students in the course.

Online Quizzes and Midterm Exams

Five short online quizzes and two 1-hour midterm exams will be accessible through Canvas. Students will have the option of taking each quiz at any point during an assigned 24-hour period. Although the quizzes may not be taken during class time, it is recommended that students take the midterm exams during the allotted class time or office hours, which will provide an opportunity to ask the instructor questions if needed. The quizzes and exams are designed to enable students to apply their knowledge of the manufacturing technologies covered in the course, drawing from course-based experiences to think critically and apply a "design-for-additive-manufacturing" skillset. Due to the abstract nature of such questions, the quizzes and midterm exams will be open-book and open-note; however, no collaboration of any kind is allowed with anyone else at any point during the 24-hour period of a quiz or exam. For the midterm exams, discussion with any other students is prohibited until after the lecture covering the midterm solutions.

Team Final Design Project

Undergraduate student teams (ENME416) will be assigned a final design project based on using multi-material PolyJet 3D printing for soft robotics. The goal is for students to work in teams of five to design, print, and experimentally test a soft robotic finger that exhibits the largest amount of deflection under an applied pressure (using a syringe). Graduate student teams (ENME744) in will propose and provide a proof-of-concept demonstration of an additive manufacturing-enabled technology that exemplifies how the unique capabilities of a specific additive technology can overcome critical limitations of a conventional manufacturing approach. Both sets of projects should include a quantitative experimental study with appropriate controls (*e.g.*, printing at least one positive and/or one negative control design) and statistical analysis/hypothesis testing. At the end of the semester, students will present their designs, methods, results, and conclusions as both a 'conference-style' oral presentation and a 4-page written document. For undergraduates, the document will be a journal manuscript formatted as a *Communication* for an RSC journal. Graduate students are encouraged to submit their final report in the aforementioned journal format; however, if another format is more relevant to their field or career goals (*e.g.*, proposal, report, different journal), an alternative format can be used following approval by the course instructor.

PARTICIPATION | UNDERGRADUATE STUDENTS ONLY

Lecture attendance and participation accounts for 5% of the final grade for undergraduate students. Given the online format of the course, the lectures will include instances for student participation (*e.g.*, Zoom polls, annotations, and whiteboard).

3D PRINTING CASE STUDY PRESENTATIONS | GRADUATE STUDENTS ONLY

Students will present an engineering case study on a particular situation for switching from a conventional manufacturing technology to an additive manufacturing one either: (*i*) from their own industrial experience, or (*ii*) from an unrelated company. Each student will present a ~10-min oral presentation summarizing the key metrics used for evaluations (*e.g.*, cost, performance, time, *etc.*) and the associated benefits/weaknesses of additive *versus* conventional manufacturing for the case.

COURSE CONTENT

The course will cover a variety of topics related to advanced manufacturing, broadly divided into four core themes:

1. **Brief Review of General Manufacturing Approaches**
    - Conventional Manufacturing & Computer-Aided Design (CAD)
2. **Computer-Aided Manufacturing (CAM) for Additive Manufacturing**
    - Layer Slicing; Infill/Hatching Structure, Density, and 'Shell' Selection; Support Structure Integration; Voxel/Deposition Point Considerations
3. **Fundamental Additive Manufacturing Approaches**
    - Extrusion-Based Deposition (*e.g.*, Fused Deposition Modeling (FDM)/Fused Filament Fabrication (FFF), Direct Ink Writing (DIW), Robocasting, Bioprinting)
    - Vat Photopolymerization (*e.g.*, Stereolithography (SLA), Digital Light Processing (DLP), Direct Laser Writing (DLW), Volumetric 3D Printing, *etc.*)
    - Powder Bed Fusion (PBF) (*e.g.*, Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Electron-Beam Melting (EBM), *etc.*)
    - Material Jetting and Binder Jetting (*e.g.*, MultiJet Modeling (MJM), PolyJet Printing, MultiJet Fusion (MJF), *etc.*)
4. **Special Topics for Additive Manufacturing**
    - Post Processing; Support Design & Removal; 4D Printing; Emerging Applications

STUDENT OUTCOMES

The course primarily contributes to the following student outcomes at low (**L**), midrange (**M**), or high (**H**) levels, including an ability to:

- design and conduct experiments, as well as to analyze and interpret data (**H**)
- function on inter-disciplinary teams (**M**)
- identify, formulate, and solve engineering problems (**M**)
- understand professional and ethical responsibility (**L**)
- communicate effectively (**H**)
- use techniques, skills & modern engineering tools necessary for engineering practice (**M**)
- think critically about the design-for-manufacturing process with respect to non-traditional additive manufacturing technologies (**H**)
- provide constructive feedback to peers through peer-review processes (**M**)

COURSE SCHEDULE (*TENTATIVE*)

Week	Topics	Deliverable
Jan. 25	• Course Overview and Goals • Review: Conventional Manufacturing (*Extra: SolidWorks*) • Extrusion-Based Deposition I (*Extra: FEA Demo*)	
Feb. 1	• Extrusion-Based Deposition II • *Extrusion-Based Deposition Guest Lecture* • Robocasting & Direct Ink Writing	• ***Quiz 1 – Feb. 5***
Feb. 8	• Vat Photopolymerization (*Extra: SLA Guest Lecture*)	• ***DC 1 .STL/.TXT Files Due Feb. 10***
Feb. 15	• Direct Laser Writing (DLW) (*Extra: DLW Guest Lecture*) • *Presenting Scientific Content* • Midterm Exam 1 – *Review Lecture*	• ***DC 1 Prints Ready*** • ***Quiz 2 – Feb. 17***
Feb. 22	• **Midterm Exam 1 (Sept. 22)** • Midterm Exam 1 Solutions/Results • MultiJet/PolyJet Printing I	• ***DC 1 – Iteration 2 Files Due Feb. 24***
Mar. 1	• MultiJet/PolyJet Printing II • *MultiJet/PolyJet Printing Guest Lecture* • **Design Challenge 1 Team Presentations & Demos**	• ***DC 1 – Iteration 2 Prints Ready*** • ***Quiz 3 – Oct. 9***
Mar. 8	• **Design Challenge 1 Team Presentations & Demos** • NanoParticle Jetting & Final Project Review	• ***DC 2 .STL Files Due Mar. 12***
Mar. 15	*[Spring Break]*	
Mar. 22	• Selective Laser Sintering (SLS) • Selective Laser Melting (SLM) (*Extra: SLM Guest Lecture*) • Electron Beam Melting (EBM)	• ***Final Project Abstracts Due Mar. 26 (ENME744)***
Mar. 29	• Binder Jetting • 4D Printing • Writing a Journal Paper (*Extra: Meshmixer Tutorial Series*)	• ***Quiz 4 – Mar. 22*** • ***DC 2 Prints Ready*** • ***Quiz 5 – Oct. 30***
Apr. 5	• Midterm Exam 2 – *Review Lecture* • **Midterm Exam 2 (Apr. 5)** • Midterm Exam 2 Solutions/Results	
Apr. 12	• **Design Challenge 2 Team Presentations & Demos**	• ***Final Project .STL Files Due Apr. 12***
Apr. 19	• **3D Printing Industry-Related Case Study Presentations from ENME744 Students**	• ***Final Prints Ready***
Apr. 26	• Additive Manufacturing for Social Change • Bioinspired Additive Manufacturing Applications	
May 3	• State of the Art • **Final Project "*Conference-Style*" Oral Presentations**	
May 10	• **Final Project "*Conference-Style*" Oral Presentations**	• ***Final Papers Due May 12***