Savitribai Phule Pune University
Faculty of Science & Technology

Curriculum/Syllabus
For
Honors in "3D Printing"

Bachelor of Engineering
(Choice Based Credit System)

Honors in Major Disciplines of Mechanical Engineering, Mechanical Engineering (Sandwich) Production Engineering, Production Engineering (Sandwich), Automobile Engineering and Civil Engineering - (2019 Course)

Board of Studies – Mechanical and Automobile Engineering
(With Effect from Academic Year 2021-22)

Savitribai Phule Pune University

Board of Studies - Automobile and Mechanical Engineering

Undergraduate Program - Mechanical Engineering (2019 pattern)

Honors in "3D Printing"

Course Code	Course Name	Teaching Scheme (Hrs./week)			Examination Scheme and Marks						Credit			
		TH	PR	TUT	ISE	ESE	TW	PR	OR	Total	TH	PR	TUT	Total
Semester-V														
302011MJ	Additive Manufacturing Technology	4	-	-	30	70	-	-	-	100	4	-	-	4
302012MJ	Modelling Lab	-	2	-	-	-	50	-	-	50	-	1	-	1
	Total	**4**	**2**	**-**	**30**	**70**	**50**	**-**	**-**	**150**	**4**	**1**	**-**	**5**
Semester-VI														
302013MJ	Design for Additive Manufacturing	4	-	-	30	70	-	-	-	100	4	-	-	4
	Total	**4**	**-**	**-**	**30**	**70**	**-**	**-**	**-**	**100**	**4**	**-**	**-**	**4**
Semester-VII														
402014MJ	Additive Manufacturing System Design	4	-	-	30	70	-	-	-	100	4	-	-	4
402015MJ	3D Printing Lab	-	2	-	-	-	50	-	-	50	-	1	-	1
	Total	**4**	**2**	**-**	**30**	**70**	**50**	**-**	**-**	**150**	**4**	**1**	**-**	**5**
Semester-VIII														
402016MJ	3D Printing Applications & Entrepreneurship	4	-	-	30	70	-	-	-	100	4	-	-	4
402017MJ	Seminar	-	-	2	-	-	50	-	-	50	-	-	2	2
	Total	**4**	**-**	**2**	**30**	**70**	**50**	**-**	**-**	**150**	**4**	**-**	**2**	**6**

Abbreviations: TH: Theory, **PR**: Practical, **TUT**: Tutorial, **ISE**: In-Semester Exam, **ESE**: End-Semester Exam, **TW**: Term Work, **OR**: Oral

1.Rules and Regulations for Honors / Minors Programs

R1.1 It is absolutely not mandatory to any student to opt for Honours or Minors Program. Choice is given to individual student to undertake Honors/Minors programs from the third year engineering (Fifth Semester) to fourth year engineering (Eighth Semester). Honors/Minors programs will be opted from offered programs by SPPU. Once selected he/she will not be permitted to change the Honors/Minors program in forthcoming semesters.

R1.2 The registration for Honors/Minors Programme will lead to gain additional credits to such students. The result of Honours/Minors Program will get reflected in ledgers to be maintained at University only. After the completion of the Honors/Minors program by concerned students, details of credits earned in Honors/Minors program be printed in the mark sheet of eighth semester. For those students, who will not be able to complete Honors/Minors program, details about the additional credits earned will not get printed.

R1.3 Credits earned through registration and successful completion of the Honors/Minors Programme will **not** be considered for the calculation of SGPA or CGPA.

As per the standard practice, SGPA and CGPA calculations will be done with common base only by considering mandatory credits assigned for the Bachelor programme as per the structure approved by the Academic Council.

R1.4 Students once registered for the programme need to complete all credits assigned for the specific Honors and Minors Programme in the period of 4 years from the Semester-V. Degree with

Honors/Minors will be awarded only after the completion of Honors/Minors Programme along with respective UG program degree.
Student may opt to cancel the registration for Honors/Minors within this period of 4 years. After 4 years expire automatically Bachelor's degree will be awarded to such a student provided he/she has earned the credits needed for graduation.
R1.5 Backlog Honors/Minors courses will not contribute in the decision of A.T.K.T.

2. Examination Scheme:

R2.1 Examinations for Honors/Minors Program will get organized at the University Level. Question paper will be common for all students who had opted/registered for the specific Honors/Minors Program. Evaluation of answer books for Honors/Minors program will be done at the university level.
R.2.2 Additional examination fees as per prevailing rules and regulations will be charged from those students who had registered for Honors/Minors Program to match the expenses for paper setting and the assessment of answer books at the CAP Centre.

Instructions:

- Minimum number of Experiments/Assignments in PR/Tutorial shall be carried out **as mentioned in the syllabi** of respective courses.
- Assessment of tutorial work has to be carried out similar to term-work. The Grade cum marks for Tutorial and Term-work shall be awarded on the basis of **continuous evaluation.**

302011MJ: Additive Manufacturing Technology					
Teaching Scheme		**Credits**		**Examination Scheme**	
Theory	**4 Hrs./Week**	**Theory**	**4**	**In-Semester**	**30 Marks**
				End-Semester	**70 Marks**

Prerequisites: Solid Modelling& Drafting, Engineering Materials

Course Objectives:

1. To know the principle, methods, possibilities and limitations as well as environmental effects of Additive Manufacturing technologies.
2. To be familiar with the characteristics of the different materials those are used in Additive Manufacturing technologies.
3. To explore the potential of additive manufacturing in different industrial sectors.

Course Outcomes:

On completion of the course the learner will be able to;

CO1. Understand the fundamentals of Additive Manufacturing Technologies for engineering applications.

CO2. Understand the methodology to manufacture the products using extrusion-based deposition technologies and study their applications, advantages and case studies.

CO3. Understand the methodology to manufacture the products using light based photo-curing technologies and study their applications, advantages and case studies.

CO4. Understand the methodology to manufacture the products using laser-based melting& light engineered technologies and study their applications, advantages and case studies.

CO5. Evaluate the process parameters of AM technologies to improve the quality of the parts produced.

CO6. Able to apply knowledge of additive manufacturing for various real-life applications.

Course Contents

Unit 1	**Additive Manufacturing (AM) Overview**

Introduction to AM, Historical Development, Additive v/s Conventional Manufacturing, Role of AM in Product development cycle, Rapid prototyping, Relevance of AM in Industry 4.0, Current industry and manufacturing trends driving AM, AM Process-Chain, Reverse engineering, Advantages, Types of materials, Classification of AM Processes (Process-based, material form-based, application-based - direct and indirect processes and Micro- and Nano-additive processes), Process Planning for Additive Manufacturing.

Unit 2	**AM Processes & Extrusion-based Deposition Technologies**

Additive manufacturing processes: Extrusion, Jetting, Photo-polymerization, Powder bed fusion, Direct-write, Sheet lamination, Directed-energy deposition and the latest state of the art processes

Process and mechanism, Materials, Process Physics, Parameters, Benefits, Drawbacks, Limitations and Applications of

Extrusion-Based Deposition: Fused Deposition Modeling (FDM), Fused Filament Fabrication (FFF), Direct Ink Writing (DIW), Robocasting, Bio-printing.

Unit 3	Light Based Photo-curing Technologies
Process and mechanism, Materials, Process Physics, Parameters, Benefits, Drawbacks, Limitations and Applications of **Light-Based Photo-curing**: Stereolithography (SLA), Digital Light Processing (DLP), Direct Laser Writing (DLW), Continuous Liquid Interface Production (CLIP)	
Unit 4	**Laser-Based Melting& Light Engineered Technologies**
Process and mechanism, Materials, Process Physics, Parameters, Benefits, Drawbacks, Limitations and Applications of **Laser-Based Melting**: Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS), Selective Laser Melting (SLM), Electron-Beam Melting (EBM), Laser Blown Powder, Laser Wire Deposition, Laser Engineered Net Shaping (LENS)	
Unit 5	**Inkjet(droplet)Based Deposition and Fusion Technologies**
Process and mechanism, Materials, Process Physics, Parameters, Benefits, Drawbacks, Limitations and Applications of **Inkjet(droplet)-Based Deposition and Fusion**: Multi-jet Modeling (MJM), Polyjet Printing, Nanoparticle Jetting, Binder Jetting, Multi-Jet Fusion, Color-jet Printing (CJP), **Energy Deposition Techniques**: Plasma/TIG/MIG/Arc Deposition, Electron Beam-based DED, Direct Metal Deposition (DMD), 3D Laser Cladding.	
Unit 6	**Case Studies, Application and Special Topics**
C**ase Studies and Application of AM**: 3D printing in prominent industries (Aerospace, Electronics, Defense, Automotive, Construction, Architectural, Machine-Tools), Other industrial applications (Health-Care, Personalized Surgery, Bio-medical Applications, Assistive Devices, Food-Processing, Food & Consumer Applications, Art, Fashion, Jewelry, Toys & Other Applications, etc), **Special Topics:**4D/5D Printing, Bio-printing, Bio-materials, scaffolds and tissue and Organ Engineering, Mass Customization and Future trends.	
Books and other resources	
Text Books: 1. Chua Chee Kai, Leong Kah Fai, "3D Printing and Additive Manufacturing: Principles & Applications", 4th Edition, World Scientific, 2015 2. Amit Bandyopadhyay, Susmita Bose, "Additive manufacturing", CRC Press, Taylor & Francis Group, 2016 3. Ian Gibson, David W. Rosen, Brent Stucker "Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing" Springer, 2010	
References Books: 1. L. Lu, J. Y. H. Fuh and Y.S. Wong, "Laser-Induced Materials and Processes for Rapid Prototyping", Springer, 2001 2. Andreas Gebhardt and Jan-Steffen Hötter, "Additive Manufacturing: 3D Printing for Prototyping and Manufacturing" Hanser Publishers, Munich, 2016. 3. Ben Redwood, FilemonSchöffer& Brian Garret, "The 3D Printing Handbook: Technologies, design and applications", 3D Hubs B.V. 2017 4. Ehsan Toyserkani, Amir Khajepour, Stephen F. Corbin, "Laser Cladding", CRC Press, 2004 5. Andreas Gebhardt, "Understanding Additive", Hanser Publishers, Munich, 2011 6. Ben Redwood, Filemon Schöffer & Brian Garret, "The 3D Printing Handbook – Technologies, Design and Applications" Part One:3D Printing Technologies and Materials, 3D Hubs, 2017 7. Chee Kai, Kah Fai, Chu Sing, 'Rapid Prototyping: Principles and Applications", 2nd Ed., 2003 8. D. T. Pham and S.S. Dimov, "Rapid Manufacturing" Springer, 2001 9. Rupinder Singh J. Paulo Davim, "Additive Manufacturing - Applications and Innovations" CRC Press Taylor& Francis Group, 2019	

10. I. Gibson, D. W. Rosen, B. Stucker, “Additive Manufacturing Technologies” Springer, 2010
11. L. Jyothish Kumar, Pulak M. Pandey, David Ian Wimpenny, “3D Printing and Additive Manufacturing Technologies” Springer, 2019

Web References:

1. NPTEL Course on Fundamentals of Additive Manufacturing Technologies by Prof. SajanKapil, IIT Guwahati, https://onlinecourses.nptel.ac.in/noc21_me115/preview
2. Introduction to Additive Manufacturing, https://www.youtube.com/watch?v=LCQoi10cGTo NPTEL IIT Kanpur, “Rapid Manufacturing”, Dt. Janakarajan Ramkumar Prof. Amandeep Singh, https://onlinecourses.nptel.ac.in/noc20_me50/preview

302012MJ: Modelling Lab					
Teaching Scheme		**Credits**		**Examination Scheme**	
Practical	**2 Hrs./Week**	**Practical**	**1**	**Term Work**	**50 Marks**

Prerequisites: Engineering Graphics, Solid Modelling & Drafting

Course Objectives:

1. Apply Conceptual Design and Geometric Modeling for AM
2. Manipulate various Data formats
3. Convert part file into STL format and Repair using different software tools
4. Determine part orientation for minimum build time and part errors

Course Outcomes:

On completion of the course, learner will be able to

CO1. Develop CAD models for 3D printing, Select and use correct CAD formats in the manufacture of 3D printed parts
CO2. Import and Export CAD data and generate STL file/s
CO3. Identify STL file problems and apply Repair Algorithms
CO4. Develop STL file for CAD models with appropriate Support Structures and Orientation
CO5. Apply techniques of CAD and Reverse Engineering for Geometry Transformation
CO6. Make use of Point Cloud Data (PCD) to reconstruct Industrial and Medical components

Guidelines for Laboratory Conduction

The student shall complete the following hands-on activities as a Term Work under the guidance of concerned faculty member. The open source software shall be preferred for conduction of practical.

Term Work

The learner shall complete minimum 10 of the following activities as a Term-Work:

List of Practical

1. Identification of a product for Additive Manufacturing and its Geometric Modeling
2. Working with CAD Data Exchange formats
3. Slicing of corrected STL files
4. Identification of problems associated with STL file
5. Object Scanning using 3D Scanner
6. Conversion of CT/MRI Medical scan data into STL file
7. Application of Repair Algorithms to make error-free CAD models
8. Part orientation, Support structure and Tool Path generation
9. Estimation of Build-time and Material for Model and Support structure generation
10. Simulation for optimization of Build-time and Material consumption
11. Generation of Tool Path data for 3D Printing of the physical part on RP machine
12. Industrial Visit and Report on visit to AM facility

302013MJ: Design for Additive Manufacturing					
Teaching Scheme		**Credits**		**Examination Scheme**	
Theory	**4 Hrs./Week**	**Theory**	**4**	**In-Semester**	**30 Marks**
				End-Semester	**70 Marks**

Prerequisites: Solid Modelling & Drafting, Engineering Materials, Additive Manufacturing Technology

Course Objectives:

1. To understand the importance of product design considerations for additive manufacturing
2. To be familiar with the characteristics of the different materials used in Additive Manufacturing technologies
3. Learn to create physical objects that satisfy product development/prototyping requirements

Course Outcomes:

On completion of the course the learner will be able to;

CO1. Select the suitable material and process for fabricating a given product
CO2. Design and develop a product for AM Process
CO3. Understand and analyze the additive manufacturing process to predict the build behavior.
CO4. Understand and apply the requirements for pre-processing, in-situ processing and post-processing
CO5. Create, manipulate and optimize the component to be printed using AM
CO6. Apply techniques of CAD and reverse engineering for geometry creation and transformation.

Course Contents

Unit 1	**Design for AM**

AM technology selection, Build strategies, Minimum feature size, Surface finish, Elimination of support structures, Guidelines for internal geometry like flow paths, cooling channels, cavities and others, Guidelines for making lightweight objects, Guidelines for making functionally gradient objects, DfAM: Process specific strategies, Rules and Recommendations

Unit 2	**Materials Science for AM**

Multi-functional and Multi-graded materials in AM, Role of solidification-rate, Evolution of non-equilibrium structure, Micro-structural studies, Structure-Chemical property relationship, Mechanical properties of materials

Materials: Metals, Polymers, Ceramics & Bio-ceramics, Composites, Hierarchical Materials, Biomimetic Materials, Shape-Memory Alloys, 4D Printing & Bio-active materials, Material selection

AM Material specific Process Parameters: Processes, Heat or Chemical Treatments, Phase Transformations, Process Selection for various applications and Material Science Considerations

Forms of raw material: Preparation, desired properties

Support Materials: Properties, Applications, Strategies, material and technology specific support structures, and support structure removal process

Unit 3	Mathematical Models for AM

Limitations of AM Systems: Defects and its rectification, Form, fit, function trade-off, time Vs cost

Mathematical models for AM: Selection of AM technologies using decision methods, AM process plan, Introduction to models for Monitoring and control of defects, Transformation, Distortion control methods

Chemical behavior of materials: Integration of chemistry, phase-equilibria, and Thermodynamics of a Materials and allied systems

Transport phenomena models: Temperature History, Fluid Flow History, Material Composition

Residual history: Stresses, Thermal Strains, Warpages, etc

Process Monitoring and Control: Defects, Geometry, Temperature, Composition and Phase Transformation

Unit 4	Process Design in AM

Pre-processing, In-Situ processing and Post-Processing for AM

3D Slicing and Multi-axis Path Planning: Classification and Types of slicing, 3D Slicing Strategies

Path Planning: Classification and Types of 2D and 3D Path Planning, Path Sequencing Strategy, Techniques of multi-printing modes

Post-Processing techniques: Requirements and Techniques, Support Removal, Sanding, Acetone treatment, Polishing, Heat treatments, Hot isostatic pressing, Materials science, Surface enhancement Techniques and its Material Science

Analysis of AM's error sources

Unit 5	Digital 3D Model Creation and Topology Optimization for AM

Digital input for AM, Layer Slicing, Infill Structure Techniques and it's Selection, Support Structure Integration, Voxel/Deposition Point Considerations,

CAD Data Exchange: Software Tools vs. Requirements, Sculpting & Repairing Data, 3D creation or reconstruction, Issues faced during 3D model creation, AM CAD Data/file formats for Engineering and Non-Engineering Applications, CAD Standards, Tool Path file formats, Software Customization & Automation

Analysis & Optimization: Algorithms, Use of FEA, CFD Techniques, Continuum and Discrete Element Methods, Topology Optimization and Use of Software

Point Cloud and other Scanned Data Processing: Translation, Data loss, Repair, Detail on NURBS, Model Validation

Standards: CAD specific and Material specific ISO and ASTM Standards

Unit 6	Reverse Engineering (RE)

Conventional use of Reverse Engineering Procedure, Digitization Methods,

Measuring Devices: Classification and Types, Advantages, Disadvantages, Limitations

3D Scanning: Scanning Process ,3D Scanners(Classification and Types,)

Software: Medical image control system software, Engineering Scanning and Data Conversion Software

CAD Model Construction: Point Clouds Data, Pre-processing, Point Clouds to Surface Model Creation, Classification and Types, NURBS surface model generation and its software use, Medical Data Processing, Data Handling and Reduction Methods

Scanned Geometry Refinement: Smooth the Surface, Remove Bumps and Blobs, Cleanup, Repair, other relevant Techniques

Applications of RE: Product Development and Manufacturing, Entertainment, Biomedical Engineering, etc

Books and other resources

Text Books:

1. Ali K. Kamrani, Emad Abouel Nasr, "Engineering Design and Rapid Prototyping" Springer, 2010
2. Ben Redwood, Filemon Schöffer& Brian Garret, "The 3D Printing Handbook – Technologies, Design and Applications" Part Two: Designing for 3D Printing, 3D Hubs, 2017
3. Chee Kai Chua, Chee How Wong, Wai Yee Yeong' "Standards, Quality Control, and Measurement Sciences in 3d Printing and Additive Manufacturing" Academic Press, 2017
4. Liza Wallach Kloski and Nick Kloski, "Getting Started with 3D Printing" Part III CAD Tutorials, Maker Media, 2016

References Books:

1. Leary Martin, "Design for Additive Manufacturing (Additive Manufacturing Materials and Technologies)" , Elsevier, 2019
2. Andreas Gebhardt, "Understanding Additive", Hanser Publishers, Munich, 2011
3. Rupinder Singh J. Paulo Davim, "Additive Manufacturing - Applications and Innovations" CRC Press Taylor & Francis Group, 2019
4. T. S. Srivatsan, T. S. Sudarshan, "Additive Manufacturing - Innovations, Advances, and Applications" CRC Press Taylor & Francis Group, 2016
5. Steinar Killi, "Additive Manufacturing - Design, Methods and Processes", Pan Stanford Publishing Ltd 2017
6. Larry Dosser , Kevin Hartke , Ron Jacobsen , Sarah Payne, "Additive manufacturing technology review - From prototyping to production: Additive Manufacturing Handbook", Routledge, 2017
7. Hwaiyu Geng, " Manufacturing Engineering Handbook", Second Edition, McGraw Hill, 2016
8. Bill Macy, " Reverse Engineering for Additive Manufacturing", Handbook of Manufacturing Engineering and Technology, Springer, 2014

Web References:

1. NPTEL IIT Madras, "Design for Additive Manufacturing", Prof. G. Saravana Kumar https://www.youtube.com/watch?v=gcia0aqZMf0
2. NPTEL IIT Guwahati, "Mathematical Modeling of Manufacturing Processes" Lecture 31 - Principle and development of additive manufacturing technologies-1, Prof. Swarup Bag
3. https://www.youtube.com/watch?v=7L42aRs68WI
4. NPTEL-NOC IITM, DFAM approach, "Simulation tools for AM, Design needs" mod06lec23 - Design for Additive manufacturing (DfAM) for Metal Printing, Mr. Vaman Kulkarni, Ex. Director Honeywell Technology, Bangalore; https://www.youtube.com/watch?v=I-0E-eiJdWk
5. NPTEL Course on Fundamentals of Additive Manufacturing Technologies by Prof. Sajan Kapil, IIT Guwahati, https://onlinecourses.nptel.ac.in/noc21_me115/preview