Course 12: Additive Manufacturing for Industry 4.0

Course Objective: Additive Manufacturing (AM) is a technology supporting the sustainable rapid development of personalized complex design in various disruptive applications, especially in manufacturing and medical.
This course aims to build student competence in AM and related technology. The students will learn fundamental knowledge of Additive Manufacturing and Reverse Engineering (RE) and their applications in manufacturing, medical and other sectors. Besides, the students will be proficient in practice design for additive manufacturing.

Learning Outcomes:
The students on the completion of this course would be able to:

- CLO1: Apply knowledge on additive manufacturing, and reverse engineering in a variety of domains (apply);
- CLO2: Investigate process parameters for effective additive manufacturing (create);
- CLO3: Differentiate principles behind additive manufacturing and reverse engineering technologies available in the market (analyze);
- CLO4: Select an appropriate AM technology based on preset optimisation criteria (eg. cost, quality, time/ available resources) (evaluate);
- CLO5: Apply design for additive manufacturing (DfAM) in practice for the development of new products (apply);
- CLO6: Communicate effectively and work in a team environment (apply).

Prerequisite: Computer Aided Design

Course Outline:

Module 1: Additive Manufacturing Technologies – Principles and Applications

I. Additive Manufacturing Basic Concepts and processes
1. Additive Manufacturing workflow
2. Benefits & Limitations of Additive Manufacturing
3. Applications of 3D printing (Aerospace, Automotive, Robotics, Tooling, Healthcare, Design, Education etc.)
4. Main technologies (ISO/ ASTM DIS 52900:2018)

II. Solid- Based Additive Manufacturing Technologies
1. Material Extrusion
   Fused Deposition Modelling (FDM)
   Fused Filament Fabrication (FFF)
   Freeform Fabrication (FF)
2. Sheet lamination
   Laminated Object Manufacturing (LOM)

III. Powder-Based Additive Manufacturing Technologies
1. Powder Bed Fusion
   Multi Jet Fusion (MJF)
   Selective Laser Sintering (SLS)

Direct Metal Laser Sintering (DMLS)
Selective Laser Sintering (SLS)
Electron Beam Melting (EBM)

2. Direct Energy Deposition
   Laser Engineering Net Shape (LENS)
   Electron Beam Additive Manufacturing (EBAM)

IV. Liquid-Based Additive Manufacturing Technologies

1. Vat photopolymerization
   Stereolithography (SLA)
   Digital Light Processing (DLP)
   Continuous Digital Light Processing (CDLP)
2. Material Jetting
   Material Jetting (MJ)
   NanoParticle Jetting (NPJ)
   Drop on Demand (DOD)
3. Binder Jetting

Module 2: Data Interfacing for Additive Manufacturing

V. STereoLithography (STL) Models

1. ASCII STL
2. Binary STL
3. Color in binary STL
4. Facet normal
5. Use in 3D printing
6. Use in other fields
7. STL processing software

VI. Slicing Techniques

1. STL-based Slicing
2. Direct Slicing
3. Slicing Software

VII. Reverse Engineering for Additive Manufacturing Applications

1. Reverse Engineering Technologies
2. Reverse Engineering Workflow
3. From Physical to Digital: Meshes and Solids

Module 3: Design for Additive Manufacturing

VIII. Optimization of 3D printing process parameters

1. Machine preparation and settings
2. Design rules for 3D printing
3. Part quality (layer height, line width etc.)
4. Part shell (wall thickness, top/bottom thickness, bottom pattern initial layer etc.)
5. Part infill (infill density, infill pattern, infill support etc.)
6. Material characteristics (printing temperature, flow rate, diameter etc)

7. Printing speed and travel
8. Post-processing
9. Technology specific parameters

IX. <u>Influences, complementarity and Synergy in AM and conventional technologies</u>
    1. CNC manufacturing
    2. Injection molding
    3. Laser cutting & engraving
    4. Stamping & cold plastic deformation

X. <u>Macro environment of AM</u>
    1. Workforce of the future
    2. Intellectual property issues
    3. Standards
    4. Quality assurance
    5. Manufacturing and Supply chain
    6. Product design
    7. Digital thread & Industry 4.0
    8. European policies

XI. <u>AM Business models and reshaping production</u>
    1. Cloud manufacturing

SHAPEWAYS (www.shapeways.com)
3D HUBS (www.3dhubs.com/)
SCULPTEO (www.sculpteo.com)
MATERIALISE (www.materialise.com/)
3D PRINT (www.3dprint.com)
3 x 3D – 3DPBM (https://www.3dpbm.com/),
PULSE (www.3dprintingmedia.network/),
INDEX (https://www.3dprintingbusiness.directory/)
FAB LAB (www.fablabconnect.com)

XII. <u>Case Studies/Group Projects</u>

<u>Laboratory Sessions</u>:
During each laboratory students undertake the following activities:
identify a need, design & develop a CAD model of a product, simulate the working movements in the CADA environment, optimize the 3D printing parameters for the function of the product, 3D print the product components, post process each component, assembly the product and demonstrate functionality.

<u>Laboratory 1</u>
Design and 3D print a master part; manufacture a silicone mold for rapid casting of epoxy resin.

<u>Laboratory 2</u>
Design and 3D print a non-demountable assembly (ex.: a whistle with the pellet inside);

<u>Laboratory 3</u>

Design and 3D print a functional gear assembly (use cylindrical, helical, conical or rack gears);

Laboratory 4
Reverse engineering of a mechanical part (engine cover and) and of an amorphous part (body part – hand, wrist)

Laboratory 5
Design and 3D print three joint types - cylindrical, spherical/ toroidal, universal joints (recommended application omni wheel)

Laboratory 6
Design and 3D print a Lithophane application (used pictures must be taken during the laboratory; a support must be designed for the 3D printed picture in order to incorporate the light source)

Laboratory 7
Design and 3D print a complex assembly with at least 8 moving parts (choose between: a mechanical iris or an adaptable phone/ camera mount)

Learning Resources:

Textbook: No designated textbook, but class notes and handouts will be provided
Laboratory: PPT handouts, necessary equipment, tools and consumables

Reference books:

1. ISO/ ASTM DIS 52900:2018 (E), (2018), Additive manufacturing – General principles – Terminology, ISO/ ASTM International 2018.
2. Wohlers T., (2018), Wohlers Report 2018, 3D Printing and Additive Manufacturing State of the Industry: Annual Worldwide Progress Report, Wohlers Associates, ISBN ISBN 978-0-9913332-4-0.
3. Redwood B., Schöffer F., Garret B., (2017), The 3D Printing Handbook: Technologies, design and applications, Editura 3D Hubs, ISBN 978-90-827485-0-5.
4. Zhang J., Jung Y.G., (2018), Additive Manufacturing: Materials, Processes, Quantifications and Applications, Elsevier, ISBN 978-0-12-812155-9
5. Gibson I., Rosen D., Stucker B., (2015), Additive Manufacturing Technologies - 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing, Editura Springer, ISBN 978-1-4939-2112-6.
6. Page T., (2012), Design for Additive Manufacturing: Guidelines for Cost Effective Manufacturing, LAP Lambert Academic Publishing, ISBN 384732294X.
7. Barnatt C., (2013), 3D Printing: The Next Industrial Revolution, CreateSpace Independent Publishing Platform, ISBN-13: 978-1484181768.
8. Marchese K., Gorham R., Joyce J., Sniderman B., Passaretti M., (2017), 3D opportunity for business capabilities - Additive manufacturing transforms the organization, Deloitte Insights, Available at: https://www2.deloitte.com/content/dam/insights/us/articles/3256_3D-opportunity_AM-capabilities/DUP_3D-opportunity_business-capabilities.pdf,
9. Öberg C., Shams T., Asnafi N., (2018), Additive Manufacturing and Business Models: Current Knowledge and Missing Perspectives, Technology Innovation Management Review, Available

at:
https://timreview.ca/sites/default/files/article_PDF/Öberg_et_al_TIMReview_June2018.pdf

Teaching and Learning Method:

The teaching is done via lectures, laboratories and project sessions by the instructor. Tutorial sessions are conducted on the use of tools in each subject. The learning methods include group discussion, individual/group assignment and group project/case study.

Time Distribution and Study Load:
Lectures: 15 hours
Laboratories: 45 hours
Group project/Tutorials/Assignments/Self-study: 70 hours
Workshops for Group project preparation: 30 hours

Time Allocation

Session	Activities	Time allocation
I. Additive Manufacturing Basic Concepts and processes	Lectures Other activities: · Tutorials on generating STLs · Quizzes · Out-of-class group discussions · Individual Assignments	2 hours 10 hours
II. Solid- Based Additive Manufacturing Technologies	Lectures Laboratories (L1) Other activities: · Tutorials on generating STLs · Quizzes · Out-of-class group discussions · Individual Assignments	2 hours 6 hours 10 hours
III. Powder-Based Additive Manufacturing Technologies	Lectures Other activities: · Tutorials on generating Gcodes · Quizzes · Out-of-class group discussions · Case Studies (in group)	2 hours 10 hours

IV. Liquid-Based Additive Manufacturing Technologies	Lectures <u>Other activities</u>: · Tutorials on generating Gcodes · Out-of-class group discussions · Group Assignments	2 hours 5 hours
V. STereoLithography (STL) Models	Lectures Laboratories (L2) <u>Other activities</u>: · Tutorials on using Cura & Simplify 3D · Out-of-class group discussions · Group Assignments	1 hours 6 hours 5 hours
VI. Slicing Techniques	Lectures Laboratories (L3) <u>Other activities</u>: · Tutorials on using Cura & Simplify 3D · Out-of-class group discussions · Case Studies (in group)	1 hours 6 hours 5 hours
VII. Reverse Engineering for Additive Manufacturing Applications	Lectures Laboratories (L4) <u>Other activities</u>: · Tutorials on using Meshmixer · Out-of-class group discussions · Group Projects	1 hours 6 hours 5 hours
VIII. Optimization of 3D printing process parameters	Lectures Laboratories (L5) <u>Other activities</u>: · Tutorials on using Cura · Out-of-class group discussions · Group Projects	1 hours 7 hours 5 hours
IX. Influences, complementarity and Synergy in AM and conventional technologies	Lectures Laboratories (L6) <u>Other activities</u>: · Tutorials on using Cura · Out-of-class group discussions · Group Projects	1 hours 7 hours 5 hours
X. Macro environment of AM	Lectures <u>Other activities</u>: · Tutorials on using Cura · Out-of-class group discussions · Group Projects	1 hours 5 hours

XI. AM Business models and reshaping production	Lectures Laboratories (L7) <u>Other activities</u>: · Tutorials on using Cura · Out-of-class group discussions · Group Projects	1 hours 5 hours
X. Group Projects	<u>Project requirements:</u> Project themes are selected individually by each student and they are validated by the teaching professor. If the university infrastructure allows it, I would suggest that the products have three main "layers": mechanical structure, electrical structure and software. Selected products should have more than 10 mechanical components which are manufactured by FDM. <u>Mandatory minimum project structure:</u> Chapter 1. Product planning and mission statement Chapter 2. Product specifications (in correspondence with available infrastructure for implementing the project module) Chapter 3. Concept generation and selection Chapter 4. Detailed design for Additive Manufacturing (DfAM) Chapter 5. Optimization of 3D printing parameters for each component Chapter 6. Build platform optimization and 3D printing Chapter 7. Post processing of components Chapter 8. Assembly and functionality testing of the product <u>Activities:</u> · Weekly group meeting · Weekly progress report · Midway report and presentation · Final report and presentation	30 hours

<u>Evaluation Scheme</u>: The final grade will be computed according to the following weight distribution: Mid-semester examination 20%, assignments and group projects 50%, final examination 30%. In final grading,

An "A" would be awarded if a student shows a deep understanding of the knowledge learned through home assignments, project works, and exam results.
A "B" would be awarded if a student shows an overall understanding of all topics.

A “C” would be given if a student meets below average expectation in understanding and application of basic knowledge.
A “D” would be given if a student does not meet expectations in both understanding and application of the given knowledge.