COURSE OUTLINE

(1) GENERAL

SCHOOL	Social Sciences		
ACADEMIC UNIT	Department of Cultural Technology and Communication		
LEVEL OF STUDIES	Postgraduate Studies		
COURSE CODE	UA-EC3	SEMESTER	2
COURSE TITLE	Sustainable Manufacturing and Industry 4.0		

INDEPENDENT TEACHING ACTIVITIES *if credits are awarded for separate components of the course, e.g. lectures, laboratory exercises, etc. If the credits are awarded for the whole of the course, state the weekly teaching hours and the total credits*	WEEKLY TEACHING HOURS	CREDITS
Add rows if necessary. The organisation of teaching and the teaching methods used are described in detail in section (4).	3	6

COURSE TYPE *general background, special background, specialization, general education, skills development*	specialised general knowledge, skills development (technical)
PREREQUISITE COURSES	No
LANGUAGE OF INSTRUCTION AND OF ASSESSMENT	English
MODE OF TEACHING *in-person (%)* *synchronous distance learning (%)* *asynchronous distance learning (%)* *(In the case of synchronous distance learning, the total weekly duration of teaching is recorded)*	The course is delivered exclusively through synchronous distance learning. Each weekly lecture lasts 180 minutes.
AVAILABILITY TO ERASMUS STUDENTS	No
COURSE WEBSITE (URL)	TBA

(2) LEARNING OUTCOMES

Learning Outcomes

The course learning outcomes, specific knowledge, skills and competences of an appropriate level, which the students will acquire with the successful completion of the course are described.

Consult Appendix A

- *Description of the level of learning outcomes for each qualifications cycle, according to the Qualifications Framework of the European Higher Education Area*
- *Descriptors for Levels 6, 7 & 8 of the European Qualifications Framework for Lifelong Learning and Appendix B*
- *Brief Guide for drafting Learning Outcomes*

After the successful completion of the course, the student will be able to:

In terms of knowledge:

- Critically evaluate the principles of environmentally sustainable manufacturing and assess how lifecycle assessment (LCA) and environmental indicators inform decision-making within Industry 4.0-enabled production.
- Analyse the core technologies of Industry 4.0 (AI, IoT, CPS, robotics, digital twins, MES, AM) and explain how their integration supports the development of intelligent, sustainable, and circular manufacturing systems.
- Demonstrate an advanced understanding of ethical, human-centred, and social sustainability considerations in digitalised manufacturing, including issues of fairness, transparency, safety, ergonomics, and worker well-being.

- Discuss the strategic role of standards (ISO 59000, ISO 14040/44, ISO/IEC JTC 1/SC 42, CEN/CENELEC, ETSI) in enabling responsible, interoperable, and sustainable Industry 4.0 operations.

In terms of skills:

- Apply design principles based on digital manufacturing workflows using data-driven tools, digital threads, additive manufacturing, robotics, and IoT-based monitoring systems.
- Integrate sensor systems, process-monitoring tools, and control strategies to optimise energy efficiency, resource use, and operational sustainability across manufacturing processes.
- Apply simulation and digital twin methodologies (e.g., virtual commissioning, discrete-event simulation, factory-scale DTs) to analyse, evaluate and optimise manufacturing layouts, automation systems, and circular flows.
- Assess AI-enabled manufacturing solutions for circularity (automated inspection, quality prediction, prognostics, resource optimisation), including their robustness, scalability, and ethical implications.
- Analyse digital and circular supply-chain models, including DPPs, ERP integration, and master-data management, and formulate business cases for circular digitalisation.

In terms of responsibility and autonomy:

- Drive initiatives for strategic transformation that integrate Industry 4.0 technologies with circular economy principles to create sustainable, resilient manufacturing systems.
- Take responsibility for ethical, safe, and socially sustainable deployment of digital technologies, considering impacts on workers, communities, and organisational governance.
- Manage cross-functional projects implementing digital manufacturing systems (IoT, MES, robotics, distributed manufacturing) in complex and unpredictable industrial environments.
- Exercise critical judgement in evaluating cybersecurity, data integrity, and digital-trust frameworks required for connected and circular manufacturing ecosystems.
- Synthesise regenerative and circular manufacturing concepts, such as biodiversity stewardship, material recirculation, bio-based materials, to propose future-ready sustainable factory models.

General Competences

Taking into consideration the general competences that the degree-holder must acquire (as these appear in the Diploma Supplement and are stated below), at which of the following does the course aim?

Search, analysis and synthesis of data and information, with the use of the necessary technology
Adaptability to new situations
Decision-making
Working independently
Team work
Working in an international environment
Working in an interdisciplinary environment
Production of new research ideas
Project planning and management
Respect for difference and multiculturalism
Respect for the natural environment
Showing social, professional and ethical responsibility and sensitivity to gender issues
Criticism and self-criticism
Production of free, creative and inductive thinking
……
Other…
…….

Upon successful completion of the course, students will be able to:

- Search for, analysis, and synthesis of data and information using digital and analytical tools in the field of sustainable manufacturing.
- Develop decision-making skills to evaluate solutions for sustainable manufacturing based on sustainability, ethics, and digital evidence.
- Improve their teamwork and leadership in interdisciplinary, multicultural, and international contexts.
- Develop an ethical, responsible, and sustainable thinking mindset for industrial and business environments.
- Work in a strategic, innovative, and systems-oriented thinking framework for guiding sustainable manufacturing transformation.
- Improve their communication skills for conveying complex ideas to diverse professional audiences.
- Build a respect for the natural environment and sensitivity to social and ethical dimensions of technology.

(3) COURSE SYLLABUS

UA-EC3: Sustainable Manufacturing and Industry 4.0 examines how Industry 4.0 technologies such as AI, robotics and IoT can be integrated into manufacturing processes to promote sustainability. Students will explore how these digital technologies help achieve a more efficient, sustainable manufacturing system that aligns with circular economy principles, focusing on reducing waste and optimizing resource use.

The course consists of 13 lectures, as presented below:

1. **Environmentally sustainable manufacturing (Instructor: DTU).** This lecture introduces the goals and principles of environmentally sustainable manufacturing and explains how LCA is used to quantify environmental impacts. Students also explore how Industry 4.0 technologies support sustainability assessment and data-driven optimisation.
2. **Human-centred, ethical, and socially sustainable manufacturing (Instructor: DBL).** This lecture examines how human-centred design, ethics, and social sciences shape sustainable manufacturing systems. Students analyse fairness, worker well-being, inclusion, and the societal impacts of digitalisation and automation.
3. **Introduction to the Industry 4.0 Paradigm (Instructor: POLIMI).** This lecture introduces core Industry 4.0 technologies—AI, robotics, IoT, CPS, and data analytics—and how they create intelligent, connected production systems. Students explore global adoption trends, challenges, and best practices shaping digital transformation.
4. **Fundamentals of digital manufacturing (Instructor: UNL).** This lecture outlines how digital tools, data-driven workflows, AM, robotics, and digital threads transform traditional production. Students learn how digital models and real-time lifecycle data enhance efficiency, quality, and responsiveness.
5. **Process monitoring and control for resource-efficient manufacturing (Instructor: UM).** This lecture explains how real-time monitoring, sensor integration, and process control enhance resource efficiency and production reliability. Students examine MES systems, condition monitoring, predictive maintenance, and smart manufacturing architectures.
6. **Factory automation and simulation for resource-efficient manufacturing (Instructor: ZELUS).** This lecture explores simulation-based factory design, including discrete-event simulation and virtual commissioning, to improve layouts and automation. Students study IoT, digital twins, AI-driven energy optimisation, and ESG monitoring for sustainable operations.
7. **Introduction to circular supply chain digitalisation (Instructor: UMA).** This lecture introduces supply chain digitalisation technologies such as DPPs, ERP systems, and master data management. Students analyse how digital tools enable circular supply-chain models and how to build a business case for supply-chain transformation.
8. **Introduction to distributed manufacturing (Instructor: UNL).** This lecture explains how decentralised and digitally coordinated manufacturing supports resilience, flexibility, and localised production. Students explore Manufacturing-as-a-Service, supply-chain autonomy, and implications for European technological sovereignty.
9. **Artificial Intelligence enabled smart circular manufacturing (Instructor: CRS).** This lecture examines AI applications in manufacturing, including quality prediction, automated inspection, prognostics, and resource optimisation. Students evaluate AI's role in circular strategies and the ethical considerations around responsible deployment.
10. **Digital Twin enabled smart circular manufacturing (Instructor: UNINOVA).** This lecture introduces digital twins as virtual representations of manufacturing assets and processes for real-time monitoring and optimisation. Students explore emerging DT frameworks, factory-scale implementations, and challenges in deploying DT-based circular systems.
11. **Applications of human-centric technologies and industry 5.0 for smart circular manufacturing (Instructor: CEA).** This lecture introduces Operator 5.0 and human-centric technologies that enhance safety, ergonomics, and collaboration with robots and CPS. Students explore AR/VR/XR, wearable sensors, the industrial metaverse, and ethical considerations in Industry 5.0 design.

12. **Towards circular and regenerative factories (Instructor: HYPE).** This lecture explores regenerative manufacturing strategies that restore ecosystems, improve resource stewardship, and support biodiversity. Students also examine 3D printing applications and the use of recycled and bio-based materials in regenerative factory design.
13. **The role of standardisation in digital sustainable manufacturing (Instructor: CYS).** This lecture examines key European and international standards (ISO, IEC, CEN/CENELEC, ETSI) that support interoperable and sustainable digital manufacturing systems. Students learn how standards guide DPPs, LCA, IoT/M2M communication, AM technologies, and AI governance.

(4) TEACHING AND LEARNING METHODS - ASSESSMENT

MODE OF TEACHING *Face-to-face, distance learning, etc.*	Distance Learning
MODE AND FREQUENCY OF COMMUNICATION WITH THE STUDENTS	Synchronous distance communication on a weekly basis, asynchronous on a daily basis through LMS platform
ENSURING THE MODE OF COMMUNICATION AMONG STUDENTS *Team assignments and discussions, collaborative learning platforms with the use of AI, video conference, QA sessions, κ.α.*	Weekly assignments, discussions through dedicated discussion forum, dedicated space per module on the learning platform, schedule video conference meetings through MS Teams, dedicated QA sessions per module
USE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY *Use of ICT in teaching, in laboratory training, in the communication with students*	Use of ICT in Teaching, Communication with students Online Platforms will be used for teaching, tutorials, students' guidance, students' self-assessment and support on group projects
TECHNOLOGICAL EQUIPMENT REQUIREMENTS	PC /laptop for video conference meeting
PLAGIARISM POLICY/ PLAGIARISM DETECTION TOOLS	Gradescope, Turnitin
ARTIFICIAL INTELLIGENCE POLICY *(1) The use of Artificial Intelligence is prohibited in all circumstances* *(2) The use of Artificial Intelligence is allowed only with the permission of the instructor* *(3) The use of Artificial Intelligence is allowed only with an explicit reference to the literature* *(4) Students are free to use Artificial Intelligence*	The use of Artificial Intelligence is allowed only with an explicit reference to the literature. Additionally, students are free to use AI provided by the master programmes for contacting stimulations, practicing purposes, etc.
ORGANISATION OF TEACHING *The mode and methods of teaching are described in detail.* *Lectures, seminars, laboratory practice, fieldwork, study and analysis of bibliography, tutorials, work placements, clinical practice, art workshop, interactive teaching, educational visits, project, essay writing, artworks, etc.* *The student's study hours for each learning activity are stated, as well as the hours of independent study, according to the principles of the ECTS.*	(see table below)

Activity	*Semester workload*
Lectures	39
Participation in forum discussions	16,5
Study, analysis of bibliography and supplementary consolidation activities	73,5
Self-Assessment Evaluations	21
Course total	**150**

STUDENT ASSESSMENT *Description of the assessment method* *Language of assessment, methods of assessment, formative or summative assessment, multiple choice questions test, short answer questions, essay questions, problem solving, written work, essay/report, oral examination, public presentation, laboratory assignment, clinical examination of patient, art interpretation, other*	Students will be evaluated at the end of course based on a multiple-choice examination. The assessment formula is the following: Self-Assessment Evaluations: 50% Final Assessment in the form of multiple-choice questions: 50%

Specifically-defined evaluation criteria are given, and if and where they are accessible to students.	

(5) RECOMMENDED BIBLIOGRAPHY

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[3] T. Böttjer, D. Tola, F. Kakavandi, C. R. Wewer, D. Ramanujan, C. Gomes et al., "A review of unit level digital twin applications in the manufacturing industry," CIRP Journal of Manufacturing Science and Technology, vol. 45, pp. 162–189, 2023.

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[10] E. Kavakli, J. Buenabad-Chavez, V. Tountopoulos, P. Loucopoulos, and R. Sakellariou, "Specification of a software architecture for an Industry 4.0 environment," in Proc. 6th Int. Conf. Enterprise Systems (ES), Limassol, 2018, pp. 36–43, doi: 10.1109/ES.2018.00013.

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[13] L. Piscicelli, "The sustainability impact of a digital circular economy," Current Opinion in Environmental Sustainability, vol. 61, Art. 101251, 2023, doi: 10.1016/j.cosust.2022.101251.

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