UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

Course guide
480021 - MMSS - Fundamentals of Mathematical and Systemic Sustainability Modelling

Last modified: 12/06/2023

Unit in charge:	Barcelona School of Civil Engineering
Teaching unit:	724 - MMT - Department of Heat Engines.

Degree:	MASTER'S DEGREE IN SUSTAINABILITY SCIENCE AND TECHNOLOGY (Syllabus 2013). (Compulsory subject).

Academic year: 2023   **ECTS Credits:** 5.0   **Languages:** English

LECTURER

Coordinating lecturer:	MARTI ROSAS CASALS

Others:

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
2. The ability to apply, critically and effectively, conceptual frameworks, data collection and processing techniques, applied statistics, mathematical modelling, systems analysis, geographic information systems, information and communication technologies and industrial ecology to meeting the challenges of sustainability and sustainable development.
3. The ability to apply, critically analyse results and assess valorisation theories, approaches and methods in the fields of food and rural development and agricultural, water, energy, building construction, transport and spatial engineering.
CE03. The ability to critically analyse theories and perspectives on the traits and properties of the geosphere and biosphere that facilitate and frame the development of socio-environmental systems, as well as the main challenges posed by climate change.

Generical:
1. Develop and / or implement innovative ideas in a research context by identifying and formulating hypotheses and by submitting to prove objectivity, consistency and viability.

Transversal:
4. FOREIGN LANGUAGE: Achieving a level of spoken and written proficiency in a foreign language, preferably English, that meets the needs of the profession and the labour market.

5. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.

Basic:
CB9. That students can communicate their conclusions-and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously.

TEACHING METHODOLOGY

The following teaching methods will be used in the development of the course:

Lecture or conference (EXP): Sharing knowledge through lectures by professors or by external guest speakers.
Problem solving and case studies (RP): group decision exercises, debates and group dynamics, with the teacher and students in the classroom; class presentation of an activity carried out individually or in small groups.
Carry out a project, activity or work of reduced scope (PR): to carry out, individually or in a group, of a homework assignment of reduced complexity or scope, applying knowledge and presenting results.
Evaluation Activities (EV).

Training activites:

The following training activities will be used in the development of the course:

Face-to-face

Theoretical classes and conferences (CTC): knowledge, understanding and synthesis of contents presented by the lecturer (professor) or by guest speakers.
Practical classes (CP): participation in group exercises, as well as discussions and group dynamics, with the teacher and other students in the classroom.

Remote

Carry out a project, activity or work of reduced scope (PR): to carry out, individually or in a group, of a homework assignment of reduced complexity or scope, applying knowledge and presenting results.
Autonomous study (EA): study or development of the subject individually or in groups, understanding, assimilating, analysing and synthesising knowledge.

LEARNING OBJECTIVES OF THE SUBJECT

At the end of the course, each student should be able to:

Understand the systemic dimension of the sustainability concept, the characteristics and properties that define its time-dependent dynamics, as well as some of the subtleties that enhance and constrain the relations among the many actors present in a socio-ecological system.

Efficiently apply mathematical and statistical techniques and tools to analyse and tackle with some of the sustainability challenges.

Critically integrate and analyse results coming from the application of mathematical and statistical models in the definition of sustainable solutions and strategies.

STUDY LOAD

Type	Hours	Percentage
Self study	80,0	64.00
Hours small group	9,0	7.20
Hours medium group	12,0	9.60
Hours large group	24,0	19.20

Total learning time: 125 h

CONTENTS

1.Introduction to systems thinking and complexity

Description:
Systemics can be considered a new name for inquiries related to systems theory and systems science. It is defined as an emerging field of science that studies holistic systems and attempts to develop mathematical software frameworks, engineering, and philosophy in which physical, mental, cognitive, social and metaphysical systems can be studied. Complexity arises when we observe reality under a systemic point of view. It is the quality of those systems composed of various elements and therefore it is present in fields such as philosophy, epistemology, physics and biology, sociology, computer science, mathematics, and the sciences of information and communication or ICT. The problems associated with the concept of sustainability are often systemic, holistic and complex.

Specific objectives:
(a) Present systemics from its historical developmental process, from cybernetics, information theory and general systems theory.
(b) Recognize some common principles in different fields that arise from this holistic view.
(c) Present the concept maps as a basic tool to represent the systemic relations.
(d) Present the different definitions of complexity applied to economic, social, natural and biological systems.
(e) Recognize patterns related with the complexity which these systems present.
(f) Provide examples of problems related to sustainability that can be analyzed under the conceptual framework and tools of complexity science.

Related competencies :
CE03. The ability to critically analyse theories and perspectives on the traits and properties of the geosphere and biosphere that facilitate and frame the development of socio-environmental systems, as well as the main challenges posed by climate change.

Full-or-part-time: 18h 15m
Theory classes: 5h 15m
Self study : 13h

2. Introduction to modelling

Description:
A model (in general and here, mathematical) is a way to express attributes and relationships of a system in a simplified way. It is characterized by containing variables, parameters, entities and quantitative relationships between variables and/or entities. It is used to study behaviours of complex systems in situations difficult to observe in reality.

Specific objectives:
(a) Provide different ways of modelling and its classification.
(b) Understanding the differences between modelling and simulation.
(c) Provide fundamental programming concepts and present NetLogo as a fundamental environment and tool to computational modelling.

Related activities:
A1

Full-or-part-time: 12h 10m
Theory classes: 3h
Guided activities: 1h 40m
Self study : 7h 30m

3. Equation modelling

Description:
The best known mathematical models are those based on differential and difference equations in order to characterize the dynamic evolution (i.e., in time) of the systems under study. Despite their simplicity, some models show sensitivity to initial conditions, a fact that make their temporal behaviours chaotic and impossible to predict in the long term.

Specific objectives:
(a) Present the differences between discrete and continuous dynamic models, stressing the differences between linear and nonlinear systems.
(b) Present causal diagrams as the natural evolution of conceptual maps.
(c) Present flow diagrams as the evolution of causal diagrams and, at the same time, as the foundation of system dynamics.
(d) Present the stability analysis as an essential tool to characterize the dynamic behavior of system models.

Related activities:
A2

Related competencies :
CE13. The ability to apply, critically analyse results and assess valorisation theories, approaches and methods in the fields of food and rural development and agricultural, water, energy, building construction, transport and spatial engineering.

Full-or-part-time: 51h
Theory classes: 14h
Guided activities: 2h
Self study : 35h

4. Agent-Based modelling

Description:
An agent-based model is a type of computational model that allows the simulation of actions and interactions of autonomous individuals in an environment, and to determine what effects they produce in the whole system. These models simulate the simultaneous operations of multiple entities (agents) in an attempt to recreate and predict the actions of complex phenomena, and that may be emerging from the most basic (micro) to the highest level (macro).

Specific objectives:
(a) Recognize the need for computer programming as the essence of agent based modelling.
(b) Present the characteristics and properties of agent based models and also how to communicate them.
(c) Recognize emerging patterns as the outcome of the processes of interaction between agents.
(d) Analyse and understand agent-based models and their parameterization and calibration.

Related activities:
A3

Related competencies :
CE04. The ability to apply, critically and effectively, conceptual frameworks, data collection and processing techniques, applied statistics, mathematical modelling, systems analysis, geographic information systems, information and communication technologies and industrial ecology to meeting the challenges of sustainability and sustainable development.
CE13. The ability to apply, critically analyse results and assess valorisation theories, approaches and methods in the fields of food and rural development and agricultural, water, energy, building construction, transport and spatial engineering.

Full-or-part-time: 37h 30m
Theory classes: 10h 30m
Guided activities: 2h
Self study : 25h

ACTIVITIES

A1. INTRODUCTION TO PROGRAMMING

Description:
Follow the NetLogo tutorials on agent based modelling.

Specific objectives:
Become familiar with the programming language and the interface of the NetLogo program.

Material:
· NetLogo (http://ccl.northwestern.edu/netlogo/)
· NetLogo Tutorials (http://ccl.northwestern.edu/netlogo/docs/)

Related competencies :
CT4. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.

Full-or-part-time: 3h
Self study: 3h

A2. Poulation growth with an equation model

Description:
In groups of 4 - 5 people, they are asked to implement a computational model of population growth with equations, based on real historical population growth data and to discuss the results of the projections at 5, 10 and 20 years.

Specific objectives:
Delve into and apply the knowledge acquired throughout the unit.

Material:
NetLogo
Historical population growth data (Bibliography)

Delivery:
Computational model with NetLogo

Related competencies :
CG02. Develop and / or implement innovative ideas in a research context by identifying and formulating hypotheses and by submitting to prove objectivity, consistency and viability.
CE04. The ability to apply, critically and effectively, conceptual frameworks, data collection and processing techniques, applied statistics, mathematical modelling, systems analysis, geographic information systems, information and communication technologies and industrial ecology to meeting the challenges of sustainability and sustainable development.
CT4. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.

CB9. That students can communicate their conclusions-and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously.

Full-or-part-time: 25h
Self study: 25h

A3. Population growth with an agent-based model

Description:
In groups of 4 - 5 people, they are asked to implement a computational model of population growth with agents, based on the model chosen as the most convenient in activity A2.

Specific objectives:
Delve into and apply the knowledge acquired throughout the unit.

Material:
NetLogo

Delivery:
NetLogo agent-based model

Related competencies :
CG02. Develop and / or implement innovative ideas in a research context by identifying and formulating hypotheses and by submitting to prove objectivity, consistency and viability.
CE04. The ability to apply, critically and effectively, conceptual frameworks, data collection and processing techniques, applied statistics, mathematical modelling, systems analysis, geographic information systems, information and communication technologies and industrial ecology to meeting the challenges of sustainability and sustainable development.
CB9. That students can communicate their conclusions-and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously.

Full-or-part-time: 16h 40m
Self study: 16h 40m

GRADING SYSTEM

EV1: Written test (PE). 35%
EV2: Written test (PE). 35%
EV3: Individual or group coursework (TR). This includes results and reports and their oral presentation. 30%

BIBLIOGRAPHY

Basic:
- Norberg, J.; Cumming, G.S. Complexity theory for a sustainable future. New York: Columbia University Press, 2008. ISBN 9780231134606.
- Erdi, P. Complexity explained [on line]. Berlin: Springer, 2008 [Consultation: 02/02/2021]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007%2F978-3-540-35778-0. ISBN 9783540357773.
- Grimm, V.; Railsback, S.F. Individual-based modeling and ecology. Princeton and Oxford: Princeton University Press, 2005. ISBN 9780691096667.
- Casti, J.L. Would-be worlds: how simulation is changing the frontiers of science. New York: John Wiley and Sons, 1997. ISBN 9780471196938.

Complementary:
- Aracil, J. Introducción a la dinámica de sistemas. 3a ed. Madrid: Alianza, 1986. ISBN 8420680583.
- Railsback, S.F.; Grimm, V. Agent-based and individual-based modeling: a practical introduction. Princeton: Princeton University Press, 2011. ISBN 9780691136745.
- Miller, J.H.; Page, S.E. Complex adaptive systems: an introduction to computational models of social life. Princeton, New Jersey: Princeton University Press, 2007. ISBN 9780691127026.

RESOURCES

Other resources: