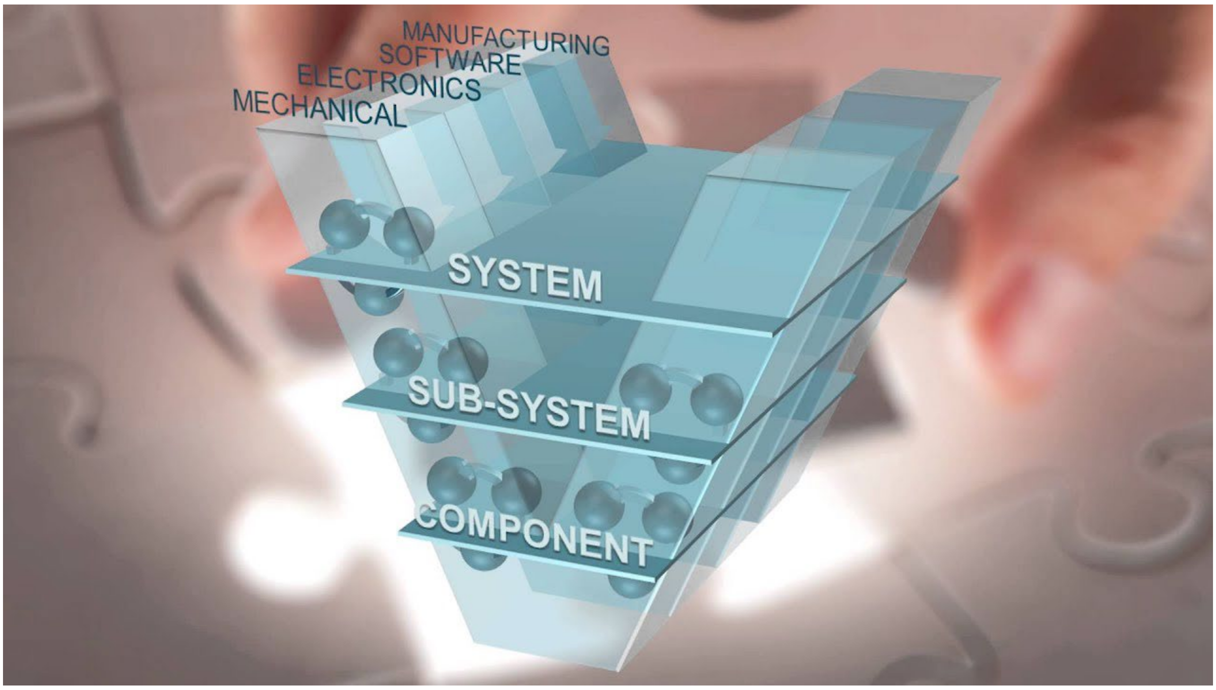
SYLLABUS – CME4481 SYSTEMS ENGINEERING DESIGN



STUDY LOAD	5 ECTS
EDUCATION PERIOD	Q3 Start: February 2022
CONSTRUCTORS	Prof. Dr. Ir. A.R.M. Wolfert Dr. Ir. R. Binnekamp

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1 GENERAL INFORMATION

Systems Engineering Design (SED) is a powerful design approach to get from a semi-unstructured multi-stakeholder set of vague and messy goals and needs to a well-defined set of requirements and complementary socio-technical systems. In this course a best fit for common purpose design methodology to design for complex interconnected systems using multi-objective optimization techniques. Within this approach both the subject preference function model (human) and the physical object behavior model (engineering asset) will be integrated. In other words, to design socio-technical systems one needs a sound and integrative mathematical approach (open glass box modelling) to support participatory decision making on new engineering artefacts (open source participation and open ended system theory). It will be demonstrated that this best fit for common purpose design methodology also can be used for Project management and/ or Operations management planning applications.

The alternative view within this course is to combine multi-objective (non-)linear systems optimization and the theory preference function modeling in a constructivist design methodology, using mathematical simulation and modelling. This Open Design Systems approach is distinctive from pure engineering optimization methods. Within this approach the main concepts of systems design for 'tY-s', decision and development are linked with a self chosen System of Interest (SoI):

1. Systems theory and thinking and design as problem (dis)solving;
2. Hard engineering asset systems (technical-physical) vs. soft human management systems (social);
3. A posteriori multi-actor design decision systems;
4. A priori multi-actor design decision systems;
5. Non-linearity in mathematical models for design/decision systems;
6. Best fit for common purpose.

1.1 Teaching concept: Open Design Learning (ODL)

The Open Design Learning concept (ODLc) is an innovative educational concept for higher education. It is a reflective, creative and engaged learning approach that opens human development and unlocks new knowledge and solutions. ODLc stimulates students' curiosity, clarity and creativity. ODLc teachers and students are working in an open spirit levelling relation.
The ODL approach connects the inner personal learning ego and the outer real world eco. ODL integrates the student's learning and development via the U-model with the engineering system development via the V-model. Here the U-model constitutes experiential learning with an open mind, open heart, and open will design approach. The V-model represents an engineering system development process from an open-source, open-ended, and open glass-box modeling design approach.
The students and the teachers cooperate in a living dialogue in- and on-action. This co-reflective dialogue creates an open space where alternative views can co-exist and new insights can be conceived. Students learn via a self-chosen system of interest arriving at an original response demonstrating their individual learning achievements. The ODLc forms the fundamental basis for creating 'open, integrative and persistent learners' concerned about solving future world problems. For more information on Open Design Learning (ODL) and it's concepts, see: www.open-design.school.

For this course the ODLc is implemented as follows. Every week students are asked to study specific concepts and apply these to their self-chosen Service Provider of Interest (SoI) by means of a self-created response and related open-glass-box (computer) models. The teachers incite the EAM concepts as a reflective practitioner using both reference books and dialogue questions from the students. The students have 2 hours of these concept and dialogue sessions and 4 hours of reflective (computer) work sessions per week for a number of weeks. During the work sessions, students can work on their ODL response under supervision of the teacher/constructor. On top of this, masterclasses are used where students and constructors co-reflect on a group's concept translation.

This year's course is structured as follows:

- Each week on Monday we devote the first hour to a dialogue session, the second hour is devoted to the introducing of that week's new concept.
- Each week on Thursday we devote 4 hours to practical computer work sessions. These sessions allow students to work on their ODL response under supervision of the teacher/constructor.
- During the course a number of masterclasses are scheduled that are meant for feedback from the teachers/constructors on the work of selected groups.

After this course students should be able:

- To be familiarized with and understand state-of-the art systems engineering management systems concepts, principles and practices, by (i) *dialoguing* these with the constructors, (ii) *navigating* through the system engineering management reference documents and (iii) *engaging* to a self-chosen real-life System of Interest (SoI).
- To relate and examine these abstract systems engineering management concepts, by (i) *constructing* SoI specific (computer) models, (ii) *dialoguing* with these models and (iii) *experiencing* these with the SoI and its reflective practice.
- To rework and transform the SoI specific systems engineering management concepts observations, by (i) *transforming* and *linking* the dialogues and experiences into new insights and (ii) *developing* improvement results where applicable.
- To form an individual judgement and appraise these new insights/results by means of a *conspection* between these and the original concepts within the specific context of the SoI.
- To create an original Open Design Learning (ODL) response that (i) *integrates* all concepts, (computer) models, new insights and developed results and (ii) *demonstrates* the internalization process of the aforementioned learning goals and *conveys* the ODL achievements.

1.2 Reflection(1) & introduction: Concept sessions

The session on Monday starts with a dialogue session where the teachers go over the different questions that emerged during the practical work session of the previous week. Students can also upload particular questions by sending an email to D.Zhilyaev@tudelft.nl each Friday before the Monday's session (in advance).
The second part of Monday's session is about introducing the new concept. This new concept is what needs to be translated towards your own SoI. The Monday session is an on campus session (also made available on Collegerama as soon as it is ready).

1.3 Transformation: Practical work sessions

The practical work sessions take place each Thursday. This is a session where you can get feedback from your teachers. During the first weeks these sessions are mainly about: 1) getting into mathematical computer modeling, and 2) connecting to your SoI with your teachers to make sure that it is suitable as a learning vehicle. These sessions are on campus work sessions (there is max. 30 minutes online support available for those groups that unable to attend).

1.4 Reflection (2): Masterclass sessions

A masterclass is a short event in which one or more groups share their **work in progress** followed by feedback from the teachers. There is no formal evaluation. The goal of a masterclass is to identify a group's issues, problems, ideas and opportunities that mostly also apply to other groups.
For this course there will be two masterclasses, planned in week 5 and in week 8. The *first* masterclass all groups have to present their ODL response using their poster as work in progress (bear in mind that you should take a physical poster with you so that all other groups will be able to get insight in your work). The *second* masterclass is for a limited number of selected groups. Here, each group presents their work and will receive feedback on their work in progress (bear in mind that here we are using the room beamer to present your poster).

We have experienced masterclasses to be very useful, both by the students who share their work and by the attending students..

1.5 Learning vehicle: the System of Interest

At the start of this course groups of 2 must be formed and each group must choose a System of Interest (SoI), a real-life (civil) engineering system. In order to be able to convert all course concepts it is important that the SoI meets the following criteria:

- The engineering system is under consideration (early design phase) or has been built;
- The engineering system can be a real estate or infrastructure system;
- There should be at least three stakeholders involved that have conflicting interests/objectives;
- The design variables should be non-binary (yes/no problems)
- The students are able to get in touch with practitioners who can provide information about the design/development process or there is ample information on the design/development process available.

The SoI must be approved by the lecturers. The first few practical sessions allow you to discuss the candidate SoI with your teachers. The SoI must be approved by the lecturers via upload on Brightspace. Approval is based on a short document that you upload **latest 18 February**. This proposal contains a short description of your SoI, how you are connected and how you plan to obtain the required information.

1.6 Deliverable: the ODL response

The ODL response gives an overview of all the concepts transformations. All of these transformations should be presented in a poster format (at least A2 size). The computer model(s) are a separate part of your ODL response. The ODL response illustrates how the general concepts have been linked and evaluated to the self-chosen SoI using a: 1) logical review and/or 2) computer model(s).

Some hints for finalizing your response:

- Take care of your response's signal to noise ratio. For each piece of information, ask yourself: would it hurt the line of reasoning if I left it out? Usually less is more. Note: the response is not a day to day report of what you have done.
- Your final response can be achieved by backwards engineering. After you have translated all concepts you will have enough of an overview to put all parts together into a coherent and well-structured response.
- Do not repeat what is in the reference material. Your response will be unique because you used reference material to link it to your SoI.
- Only use references that support your line of reasoning.

Students should demonstrate how and/or if these concepts are being utilized and the rationale behind its specific use(fullness). **The final ODL response needs to be handed in no later than 15 April 2021.**

1.7 Judgment: the ODL commendation

The Open Design Learning commendation principle will be applied as a grading rubric for the ODL response. Both the SoI content characteristics, and the student's learning process are integrated within these commendation principles.
We call it 'commendation' because when we grade your response, we start from a grade of 10 and only deduct points if aspects are missing/only partially worked out.

Commendation Categories	**Relates to:**	**Expressed in (the making of) the ODL response:**
Connect	Learning process	Showing courage, being curious, being a

		creative problem solver. Engagement factor.
Construct	Model / concept transformation, improvement proposals and verification	Showing proper concept conversion, conceptions for improvements, correctness in modeling. Going the extra mile in concept conversion. Content factor.
Conclude& Conspect	Developed results, validation and reflection	Showing a cyclical approach, dealing with completeness, conspection of own work. Overview factor.
Convey	Reporting and presenting the response	Showing a clear line of reasoning. Being concise (signal to noise ratio). Not copying reference material. Straightforward factor.
Convince	Response speaking to / arousing the imagination	Being cogent and demonstrating a critical attitude. Compelling factor.

After handing in the ODL response your will receive your grade. To pass the course your ODL commendation grade should be higher than or equal to 6. After commending your ODL response **one plenary open dialogue session** (max. 3 hours, somewhere between **week 12 and 14** to be announced) with one of the constructors will be scheduled. Only during this session(s) we can reflect on your ODL response: bear in mind, the outcome of this reflection can result in a lower/equal/higher grade.

- If your grade is higher than or equal to 6 you can learn the rationale behind this commendation. This does not mean that you can use the provided feedback to improve your response and re-upload to get a higher grade.
- If your grade is below a 6 your will receive (prior to the session) a constructive and written proposal for improving your ODL response with a specific deadline. During the aforementioned session you can discuss this proposal in more detail on how to update your ODL response which will be commended with a maximum grade of 6.

2 WEEKLY COURSE CONTENT: THE ODL CONCEPTS

The course consists of two meetings every week: 1) a dialogue and concept introduction session and 2) a reflection and practical work session.

Wk	Date	Monday session (dialog/concept)	Thursday session (practical)	Addendum reader section***
1	7-10 Feb	**Concept 1: Systems thinking and design as problem solving –** modelling, mathematical models, optimization problems, design/decision making problems, utility and preference, design variables, objective functions, constraints.	Work on modelling the computer/urban multi-stakeholder problem.	**Computer/urban planning problem** in words and its mathematical representation as a linear programming optimization problem concerning different stakeholder.
2	14-17 Feb	**Concept 2: Hard engineering systems versus soft management systems –** research and development, the science of the artificial, V-model, SBS/WBS/RBS/FBS, design for -ty.	Work on modeling your SoI's design/decision making problem. Shopping mall problem in words and its mathematical representation as a multi-objective multi-stakeholder linear programming optimization problem.	**Shopping mall problem** in words and its mathematical representation as a multi-objective multi-stakeholder linear programming optimization problem.
3	21-24 Feb	**Concept 3: A posteriori multi-actor design decision systems –** multiple objective functions, constraint method, goal programming, preference measurement, preference function measurement modelling, choice and preference, scales, alternatives, scores, weights, function versus algorithm. Function (arithmetic mean) vs search algorithm (Tetra aggregation).	Work on entering the different design configurations in Tetra.	Use Tetra to select the most preferred design alternative (this will introduce linear preference functions).
4	28-3 Mar	**Concept 4: A priori multi-actor design decision systems –** a posteriori sub-optimal vs a priori optimal. Single actor optimal solutions versus group optimal solutions, compromise versus synthesis, preference function modeling aggregated preference rating. Monetarization vs. preference.	Assuming linear relationships between design variable values and preference ratings convert your model so that you can find the group optimum by optimizing on overall group preference.	**Shopping mall problem revisited** as multi-objective multi-stakeholder problem using linear preference functions to find group optimum using the arithmetic mean as the aggregation algorithm.
5	7-10 Mar	**Masterclass**		
6	14-17 Mar	**Concept 5: Non-linearity in mathematical models of design decision systems –** linearity versus non-linearity, global versus local optima. Limitations of linearity and limitations of non-linearity, topology of search algorithms (GA/etc.).	Model your design decision making problem having non-linear equations linked to the Tetra algorithm for aggregating preference ratings.	**Shopping mall problem revisited** as multi-objective multi-stakeholder problem having non-linear preference functions using Matlab and link to Tetra. **Apartment design problem** multi-objective problem using non-linear preference functions and non-linear relations between variables using Matlab and link to Tetra.
7	21-24 Mar	**Concept 6: Best fit for common purpose-** a multi-stakeholder design optimization methodology for construction management.	Finalize modeling your design decision making problem having non-linear equations linked to the Tetra algorithm for aggregating preference ratings.	Draft paper best for common purpose.
8	31 Mar	**Masterclass conspection. THURSDAY!**	Integrate all concepts into one overarching line of reasoning within your ODL response.	-

* if you have a dialogue question you need to upload these each Friday before the Monday's session (in advance).
** This proposal contains a short description of your SoI, how you are connected and how you plan to obtain the required information.
*** See the Addendum Reader Best Fit for Common Purpose.

In the following 6 sections practical guidelines (session practicals, work practicals, literature, etc.) are given for each weekly concept mentioned in section 1.1 and the lecture schedule.

Concept 1: Systems thinking and design as problem solving

Systems thinking is a powerful concept where problems are to be solved by looking at systems as being parts of more generic systems instead of looking at elements of the system itself. Mathematical models can be used to represent systems. Such models allow for simulation so that different solutions to problems can be analyzed on their effectiveness of solving the problem at hand. Optimization models are a specific type of models that allow for automatically search for an optimal solution as long as the optimization criterion is well defined. The optimization criterion relates to utility/value/preference. In real life constraints apply that bound the so-called solution or design space.

Reference material: Blanchard chapter 1 and/or Ackoff Part 1.

ODL response building block: see course table.

Concept 2: Hard engineering systems vs. soft management systems

Solving design and decision making problems is distinct from analyzing them. While the former entails the development of a new system (physical or abstract), the latter entails the research of existing systems. The related processes are formally opposite. Research is directed from the empirical world to the mind (understanding), development is directed from the mind to the empirical world (improvement).
Multi-objective system optimization (or Operations research as mathematical modelling) makes use of systems thinking to model and solve design and decision problems. Classical engineering design problems only incorporate physical variables (all part of the International System of Units). Such problems relate to 'hard systems' because the constraints for such problems relate to physics and cannot be changed. When applied to societal systems, involving stakeholders, also psychological variables come into play. Psychological variables are subjective as they relate to a person while physical variables are objective as the relate to an object. This has the implication that constraints of mathematical models that represent social systems are not fixed but negotiable. These systems are therefore called 'soft systems'.
Societal needs are multi-faceted, in other words, not one size fits all. Taking into account all facets means that the to be designed system needs to meet different sets of design criteria. Whereas Vitruvius limited the set to 3 criteria - aesthetics, robustness and functionality - modern day engineering systems need to be designed against a multitude of design criteria relating to a multitude of stakeholders, this is the starting point for the design for ty's.

Reference material: Blanchard chapter 2 and Roozenburg Section 3.3 and 5.5, Guideline SE section IV.4.

ODL response building block: see course table.

Concept 3: A posteriori multi-actor design decision systems

It is not uncommon that stakeholders have opposing objectives. If this applies to a design decision making problem then there are multiple objectives to optimize on. This means that there are as many optimization models and solutions as there are objectives. As only one solution can be selected we need a way of finding which solution is most preferred by the group of stakeholders. For this we make use of multi-criteria decision making and consider each of the solutions as alternatives that needs to be rated on overall preference.
There is however a fundamental problem with current methodologies for measuring preference. Just as in physics, there can only be one correct measuring methodology, no more. Preference function modeling is a new theory of measurement that is based on a strong mathematical foundation. We use Tetra, the software implementation of PFM to find the alternative with the highest overall preference rating.
A limitation of this procedure for finding the group optimum is that all alternatives to choose from are compromise solutions because they are geared towards the interests of one stakeholder.

Reference material: Blanchard chapter 7, and Barzilai chapter 3, Dyme chapter 8.

ODL response building block: see course table.

Concept 4: A priori multi-actor design decision systems

There are alternative ways for solving multi stakeholder problems i.e. goal programming, the constraint method, monetization. These are not without their problems, however. By having the stakeholders express their preferences for 'synthetic' alternatives up front we introduce a preference-based design decision system that works towards synthesis instead of compromise.

Reference material: Zhilyaev and/or Binnekamp chapter 6 and Fisher part II.

ODL response building block: see course table.

Concept 5: Non-linearity in model equations

Linear optimization models consisting of only linear mathematical equations yield a global optimum given the optimization criterion. From a mathematical/logical point of view, this optimum cannot be improved. Non-linear optimization models also contain non-linear equations. Non-linearity means that we cannot be certain that the optimum that is found is the 'real' optimum. Depending on the type of optimization algorithm and its starting point different optima will be found.

Reference material: Blanchard chapter 9 and Zhilyaev.

ODL response building block: see course table.

Concept 6: Best fit for common purpose

Engineering systems are always designed to serve a specific purpose. This purpose is derived from a set of, usual vague and messy starting points. These starting points are the needs from society, something that needs improvement or simply cannot be done yet. Systems engineering is a way to methodically make the transition from needs to requirements. The end result of the systems engineering process, the engineering artefact, can be verified using the stated requirement and validated given the needs.

Reference material: Blanchard chapter 6 and/or Zhilyaev, Van Gunsteren chapter 2.

ODL response building block: see course table.

3 REFERENCE MATERIAL

The following books and scientific articles will be used for this course.

General:

- Blanchard, B.S. and Fabrycky, W.J., "Systems Engineering and Analysis" Print: 5th edition July 2013.
- Binnekamp; Heukelum; Wolfert ;Zhilyaev (2022) Reader - Open Design Systems (addendum to this reader).
- Zhilyaev, D. ; Binnekamp, R. ; Wolfert, A.R.M. / Best Fit for Common Purpose : A Multi-Stakeholder Design Optimization Methodology for Construction Management . In: Buildings. 2022 ; Vol. 12, No. 5.

Extra:

- Ackoff, R.A., "Ackoff's Best". Wiley, 1999.
- Barzilai, J. "Preference Function Modelling: The Mathematical Foundations of Decision Theory" in: Trends in Multiple Criteria Decision Analysis, Springer, 2010.
- Binnekamp, R., "Preference-based Design". IOS Press, 2010.

- Dyme, C.L, and Little, P., “Engineering Design: A Project-Based Introduction”, 2nd Edition ISBN-13: 978-0471256878, 2003.
- Fisher, R. and Ury, W.L., “Getting to Yes”. Penguin, 1991.
- Roozenburg, N.F.M. and Eekels, J., “Product Design: Fundamentals and Methods, ISBN-13: 978-0471954651, 1995.
- Van Gunsteren, L.A., "Quality in Design and Execution of Engineering Practice" ISBN978-1-61499-251-6 (print) | 978-1-61499-252-3 (online), 2013.