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Open Design Systems

A.R.M. (Rogier) Wolfert

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Current systems design and decision management methodologies can be single-sided, ignoring or failing to capture the dynamic interplay between multi-stakeholder preferences ('what they want') and system performances ('what they can'). In addition, these methodologies often contain fundamental modelling errors and do not provide single best-fit solutions. This leaves designers or decision-makers without unique answers to their problems. Above all, mainstream higher education primarily applies instructivist and research-based learning methods, and therefore does not adequately prepare students for designing solutions to future complex problems.

This book introduces both a state-of-the-art participatory design methodology (Odesys), and a design-based learning concept (ODL), which together overcome the aforementioned issues. Odesys is a pure act of open design integration to confront conflicting socio-technical interests and is the key to unlocking these complexities to deliver socially responsible systems. Odesys' design engine, the Preferendus, enables stakeholders to cooperatively identify their best-fit design synthesis. It employs a novel optimisation method that maximises the aggregated preferences, integrating sound mathematical and extended U-modelling via open technical-, social-, and purpose cycles. The art of ODL is a constructivist design-based and well-proven learning concept fostering students' design capabilities to become open and persistent problem solvers. It is a reflective, creative, and engaged learning approach that opens human development and unlocks new knowledge and solutions.

The author also introduces new management features such as the corporate social identifier (CSI), the 'socio-eco' threefold organization model and U-model based open loop management. Finally, the author places Odesys & ODL within the integrative context of empiricism, rationalism, spiritualism, and constructivism to unite the open design impulse.

This book will be of interest to both academics and practitioners working in the field of complex systems design and managerial decision-making, and functions as a textbook on systems design and management for master students from diverse backgrounds.

Prof.dr.ir. A.R.M. (Rogier) Wolfert has worked with R&D groups at various (inter)national universities and research institutes for the past 30 years. Since 2013, he has been professor of engineering asset management at Delft University of Technology. Over the past 20 years, he has also established a proven industrial track-record in which he has been involved in the design and management of various types of infrastructure. He considers both the 'outer' observation and the 'inner' experience as companions on his journey into the emerging future.

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OPEN DESIGN SYSTEMS

Research in Design Series

Aims & Scope

The book series Research in Design Series (RIDS) covers the discipline of design methodology and is intended for those who are involved in the methodology and technology of design from a scientific, practitioner or educational point of view. Individual volumes deal with historical, philosophical, engineering, and scientific aspects of design methodology and may cover implications for the training of engineers and in technology education. Contributions from various disciplines are welcomed.

Volume 10

Previously published in this series:

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Vol. 8	M. Eekhout and P. van Swieten, The Delft Prototype Laboratory
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Preface

'Odesys, a pure act of socio-technical design integration to confront conflicts and dissolve problems with and for people.'

Why, so often,

.... do we build what nobody wants?

.... do engineers optimise their solutions based only on physical capabilities and fail to consider the stakeholders' desires?

.... do policy makers keep the decision-making process non-transparent and non-participatory?

.... do conflicts stem from failed attempts to constructively design?

.... do we continue to democratically govern through past compromises instead of socially designing future syntheses?

These are typical questions arising from real-life experiences within the public space, our built environment and infrastructure management practices. The actual answer to these questions is that socio-technical problems are often solved from a one-sided point of view, without considering the fact that the problem is multi-faceted. Misrepresenting this complex and interconnected problem nature results in what we call 'bridges to nowhere' solutions. Therefore, a participatory process that does justice to both the 'hard' technical and 'soft' social aspects within solving these problems is needed. It is thus crucial to truly connect and bridge the gap between human preferences ('desirability') and system performances ('capability') using transparent models for complex systems design and integration solutions ('feasibility'). These models offer unprecedented opportunities and 'bridges to anywhere' solutions. Moreover, if stakeholders dare to confront their conflicts and put their 'cards' openly on the table, pure best fit for common purpose design solutions will become possible. Designing is thus a matter of conflict dissolution.

The state of the art design methodology Open Design Systems ('Odesys'), as introduced in this book, enables all the aforementioned and answers the above questions. It is Odesys' purpose to foster adoption of civil infrastructures that surround us every day through a multi-system level socio-technical approach, supported by sound mathematical open-glass box models as means of observation during participatory design and collaborative decision-making. Here, systems thinking and a stakeholder-oriented focus is required to search for different solutions within an open-ended solution space, uniting both capability (technics) derived from the system properties, and desirability (economics) derived from individual subject's objectives. This will result in an open dialogue and co-design approach that enables a-priori best-fit for common purpose design synthesis dissolution, rather than a-posteriori normative design compromise absolution. This makes Odesys a pure socio-technical systems integration methodology that offers a wide range of multi-objective design and decision making applications, uniting stakeholder preferences ('what a human wants') and physical assets performances ('what a system can deliver'). Moreover, classical multi-objective design optimisation methods suffer from fundamental mathematical flaws and do not provide a single best-fit design configuration, but rather a set of design alternatives. This leaves designers without a unique solution to their problems.

As part of this Odesys methodology, a new Integrative Maximised Aggregated Preference (IMAP) optimisation method for maximising aggregated preferences is introduced. According to classical decision theory, decisions are based on preference. Here, preference is an expression of the degree of 'satisfaction', and it describes the utility or value that something provides. That is why we translate all the different stakeholder objectives (including money) into one common preference domain to find a best-fitting aggregated optimum. The IMAP method forms the basis of a new software decision support tool called the Preferendus, in which individual stakeholder preferences, social objective- and technical design performance functions are integrated into one aggregated preference function. Here, Odesys combines the state of the art mathematical principles of Preference Function Modeling (PFM) with both the extended social threefolding theory and the models from the organizational development theory-U. Odesys takes the mathematical application of the PFM theory a step further by extending it from an a-posteriori evaluation to an a-priori design methodology. Moreover, it uses PFM based multi-criteria decision analysis and the social threefolding theory to derive the so-called Corporate Social Identity (CSI) indicator, which is an expression to identify the socio-eco purpose and corporate responsibility of an organization. Odesys also introduces a new threefold modeling framework linked with the open-ended Odesys U-diagram, that connects the socio-technical design process, through a three-layer metamorphosis of picture-purpose and prototype and incorporates three open-ended design loops: (1) open config – technical cycle, (2) open space -social cycle and (3) open source - the purpose cycle. Odesys' added value and use are demonstrated for design and decision applications within a real-life engineering management and service provisioning context showing how to achieve pure 'best-fit' for common purpose solutions.

First of all, this book can be used by academic colleagues working in the field of complex systems design. The methodology is not limited to infrastructure and building applications in public space, but Odesys and its IMAP/Preferendus can also be used for a much broader range of participatory design and decision-making problems. Problems that need to be solved within a socio-technical context, where multiple stakeholders with different conflicting interests are seeking to arrive at the best solutions for common solutions or where stalemate situations need to be dissolved through transparent conflict management. Therefore, this book is also of interest to industrial professionals working within public and/or private organizations, where socio-technical decision-making can be both hardened and opened by the Odesys principles and its Preferendus. Only this will enable organizations or cooperating organizations, where old so-called democratic top-down control decision-making processes govern, to transform themselves into sociocratic bottom-up organizations where participatory and open-minded design processes result in future-oriented socially responsible synthesis solutions.

Secondly, this book serves as the primary reference material for a substantial number of TU Delft systems design and management courses for master students (MSc) from diverse backgrounds. All of these integrative engineering and management courses are being conducted along the principles of the state of the art educational ODL concept. ODL is a constructivist and design-based learning approach ("learn to design by real-life designing") where students actively develop new solutions originating from their inner and outer designs. It forms the fundamental basis for creating 'open, integrative and persistent learners' concerned about dissolving future world problems. ODL, like Odesys, is not limited to education within a technical context. It is in fact an educational concept that in principle can be used in any discipline where there is an openness to apply design-based learning to develop what does not yet exist, instead of instructivist research-based learning which investigates what already exists.

Thirdly the name of this book, Odesys, is not just an abbreviation, but is inspired by Odysseus, who was a legendary Greek king of Ithaca and one of the most influential Greek problem solving champions. To become a true Odesys engineer, three typical sayings from the famous Odysseus stories might be companions on your personal problem solving journey:

- 'Find an Odysseus ruse, like the Trojan horse', meaning a creative way out of a seemingly insoluble problem;
- 'Be able to choose between Scylla and Charybdis', meaning how to find/ secure the golden mean even in the case where one has to (merely) balance between 'two evils';

- ‘Make use of Cassandra information‘, meaning a prophecy of doom that later proves to be correct and in particular based on true relevant information that one should not or does not want to hear.

In closing, I would first like to sincerely acknowledge Ruud Binnekamp and Harold van Heukelum for their valuable support, their co-creation activities and their constructive feedback on designing and developing this book. I really enjoyed our joint Odesys expedition. Moreover, the editorial help of students Lukas Teuber and Matt Julseth was much appreciated. In addition, I wish you as a reader a true Odesys journey that starts from an open-minded and ’con-scientific’ perspective, a perspective that goes beyond a purely materialistic-physical one. Also, I wish you much success in using Odesys & ODL in your specific context and discovering its added value as spiritual mind and physical matter converge. I plead for a synthesis solution of a dual gesture: outward opening and inner deepening to unite the open design impulse. I invite you to contribute to this ongoing development effort so that Odesys & ODL will not only mature, but also spread its wings to cover domains other than just the engineering management domains. Finally, I am convinced that everyone has a designer within themselves; it is the pure art of Odesys & ODL to awaken this inner designer.

Delft,
June 2023

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Contributions

In this section, we present the most important new Odesys contributions in this book. These are deltas drawn in comparison with earlier important works by several leading academicians within the field of socio-technical design, organizations management, mathematical modeling within engineering physics and/or management sciences, education- and/or research development (see the Bibliography for their main reference works). Note that the author had the privilege of working with some of them at TU Delft, the University of Nizhniy Novgorod, and within various (inter)national workshops over the past 30 years. Partly based on their inspiration, we have developed the significant contributions of Odesys which are concisely summarized below.

<u>Contribution (1)</u>
Compared with earlier work of Ackoff, Van Gunsteren, Van Loon:

- Extension of the earlier open design principles by Van Gunsteren/Van Loon, with a human oriented threefold decision making U-model, comprising of a technical, social and a purpose cycle, enabling an idealized design metamorphosis ‘picture-purpose-prototype’.
- A full non-linear multi-objective design optimisation approach extended with (a) systems’ capabilities and human desirabilities, (b) technical design performance functions, as opposed to the linear program approach of objective functions only, (c) extended towards different domains of application, as opposed to architecture only.
- An integrative social threefolding based Preferendus for collective decision making, taking the collectivist utility based decision-making a step further.

<u>Contribution (2)</u>
Compared with earlier work of Barzilai:

- Extension of Barzilai’s Preference function modeling and measurement (PFM) principles from a pure multi-criteria decision analysis (MCDA) approach towards a multi-objective design optimisation (MODO) approach.

- A generalised mathematical threefold framework for multi-objective socio-technical design optimisation: i.e., a threefold modeling framework of integrative performance, objective and preference functions supported by a new optimisation method that enables the integrative maximisation of the aggregated preferences (IMAP).
- A full intergenerational genetic algorithm (GA) solver to search for the integrative maximum aggregated preference using PFM principles.

Contribution (3)
Compared with earlier work of Blanchard, Dym, Fabrycky, Little:

- A pure socio-technical design methodology supported by the qualitative Odesys U-model and the quantitative Preferendus which supports a design synthesis and goes beyond the usual one-side technical design methodologies as for example in the classical V-model.
- A new state of the art PFM based optimisation method IMAP that (a) suffers from fundamental mathematical flaws (b) provides a single best-fit design configuration, rather than a set of design alternatives following from classical approaches.
- A new socio-eco common interest diagram which for the basis for the social design cycle and design to best fit for common purpose. A translation and/or connection between common socio-eco interests and (a) the individual preference function (stakeholders individual desires) and (b) design performance functions (physical/mechanical object behaviour)

Contribution (4)
Compared with earlier work of Brüll, Glasl, Kahneman, Lievegoed, Scharmer:

- Extension of the Glasl's/ Scharmer's U-model and theory (a) to design and learning & development (b) incorporation of Kahneman's 'thinking slow' supported with open glass box modeling (c) integration of epistemological and ontological U-model approaches.
- Extension of social threefolding principles and elaboration to a service provider with the so-called economic, isonomic, and ecologic sub-parts and its socio-eco purpose. This also enables (a) the qualitative basis for the Preferendus (b) to quantify and evaluate the Corporate Social Identity (CSI) using the socio-eco purpose characteristics and PFM modeling.
- Quantitative support and transparent substantiation for Glasl's qualitative model of conflict escalation by confronting the conflict and the Preferendus 'getting into yes'.

Contribution (5)
Compared with earlier work of Metrikine, Neimark, Vesnitskii:

- Extension of the use of mathematical models of systems dynamics, which were primarily used to study wave dynamics phenomena in elastic systems (e.g. transition radiation and dynamic system behavior), to an approach for design optimisation. Incorporation of these physical system dynamics models into the IMAP/Preferendus.
- Automated search algorithm to find the optimal design parameters given different physical constraints and/or objective functions, including the integration surrogate modeling.
- Automated search for best-fit mitigation measures using an integrative approach of non-linear optimisation, probabilistic Monte Carlo simulation and PFM for dynamic control on-the-run (incl. Discrete Event Simulating (DES)).

Contribution (6)
Compared with earlier work of Eekels, Heusser, Roozenburg, Zajonc:

- Extension of Eekels/Rozenburg's R&D process flows, including a new 4-Quadrants model to position Odesys within the empirical R&D context.
- An extended 4-Quadrant model (compared to the pure empirical one, and elaborating Heussers's call for a 'new' science) to position Odesys within the con-science context, including open-ended research questions for further self schooling.
- Integration of the Glasl's/Scharmer's U-model with Zajonc's principles of the theory mind and its contemplative inquiry.

Contribution (7)
Compared with earlier work of Ackoff, Argyris, Biesta, Schön, Schieren:

- Extension of Steiner Waldorf education for Master students within the age of 21+ (so far this education concept has only been developed for students under 18-21 years of age).
- A new constructivist open design learning (ODL) concept that (a) educates future problem solvers and persistent learners (b) goes beyond research and inquiry based learning concepts such as organizational/experiential learning (c) integrates the human learning & development process, viewed from the general human (threefold) principles. This includes a new ODL U-model and other new concepts like the ODL response, ODL commendation and so on.
- A new way of design-based learning where students choose their own System of Interest (SOI) as an ODL learning vehicle, as opposed to a given and predefined casus that has already been solved by the teachers (such as in most of the existing PBL/CBL/CDIO education concepts). This includes Odesys' U-based modeling and the use of IMAP/Preferendus ('double-U').

Commendations

In this section, a number of collegial commendations are included from various scientific and industrial fields. These are drawn from different perspectives with a specific focus on parts of this book, such as design and decision science, mathematical modeling, socially responsible systems design, conflict management, design-based education, and industrial applications. Their substantive endorsements are given below.

Commendation (1)
"*Existing system design methodologies are one-sided because they ignore the dynamic interplay between preferences of the users (demand) and the physical performance of the engineering aspects (supply). Moreover, classical multi-objective optimisation methods contain fundamental modeling errors. Also, these classical multi-objective optimisation methods do not offer a best-fit design point but rather a set of design performance alternatives. This leaves designers without a unique solution to their problems. Finally, current multi-objective optimisation processes are rather disconnected from design and management practices because they lack deep involvement of decision makers in expressing their conflicting interests in one common preference domain.*
To overcome these shortcomings, the author of this well-written book offers a new open design system methodology and a novel integrative optimisation method which is based on maximising the aggregated group preference. Their added value and use are demonstrated in real-life design applications, which show how to arrive at a true best fit for one common-purpose design. This ground-breaking work is based on the highly original and effective Preference Function Modeling (PFM) methodology introduced and studied by Barzilai. Wolfert and his colleagues have converted PFM from an evaluation methodology into a design methodology, which I am certain will be of great interest and value to theoreticians and practitioners alike."

Simeon Reich (Doctor of Sciences)
Professor of Mathematics

Commendation (2)

"*It is a real essential advance that Wolfert integrates within the Odesys methodology, the ontological U-model we developed with my colleague Lemson of the Netherlands Institute for Organizational Development (NPI) with the epistemological and now widespread U-theory of Scharmer from MIT, into a holistic model of great practical value for strategic management, organizational development, design-based learning and conflict management. Particularly in my work as a mediator in dramatically escalated multi-party political conflicts, de-escalation was found to be easier by first finding a consensus on what the conflicting parties perceive as a horrible and undesirable future to be prevented, before they could agree on positive perspectives of a desired future and constructive ways to achieve it.*
Odesys has the potential to truly connect stakeholders and bridge the gap between their conflicting interests using transparent and participatory methods and models to first de-escalate their complex problems and then provide shared solutions."

Friedrich Glasl (Doctor of Sciences & honorary Doctor)
Professor of Conflict management & Organization development, founder of Trigon

Commendation (3)

"*An important challenge of systems design, whether it concerns roads, airplanes or government policies, is that it has to respond to engineering needs and wants of many different stakeholders. More than ever, next to research, engineering and management oriented institutes of higher education need to foster design capabilities. With a cutting-edge approach, embedded in a harmonious framing of pragmatic design activity and scientific inquiry, this book provides a rigorous solution for multi-stakeholder design problems. Wolfert further contributes with a constructivist, experiential design learning approach that recognizes stakeholder preferences and helps students to address socio-technical complexity in systems design.*
I strongly recommend this volume to educators of design, engineering and management, to researchers interested in preference-based optimisation, and to practitioners who are wondering how to create socially responsible systems."

Lóri Tavasszy (Doctor of technical Sciences)
Professor of Logistics systems & Freight transportation

Commendation (4)

"*The topic of integrating human preferences into system design optimisation is important. Over the years, many methodologies were proposed and used to tackle this issue. Nearly all of them suffered from some serious flaws caused by using inadequate ways to quantify and measure human preferences. Wolfert and his colleagues offer a novel and promising methodology to address the system design* *challenge through the Preference Function Modeling (PFM) that was developed by Barzilai over the last three decades. PFM was proven to overcome major flaws in previously used methods and as such it can become a highly useful and effective tool for future system designers seeking to take true account of the preferences of various stakeholders involved in the design.*"

Boaz Golany (Doctor of Sciences)
Professor of Data & Decision sciences

Commendation (5)

"*Our contemporary engineering challenges must increasingly meet multiple objectives which even become more complex. Not only technical feasibility or safety is required, but also economic feasibility, contractual compliance, social responsibility, environmental management and other requirements must be met simultaneously. Odesys has so far proved to be ideally suited for finding these best-fit solutions. Wolfert and his colleagues bring a new perspective within this field of design optimisation and operational excellence. Their new Preference Function Modeling (PFM) based design methodology Odesys, operationalised in the design and decision support tool the Preferendus, has been applied to several industry use cases. The Preferendus was capable of outperforming existing design/decision management approaches to searching for the most optimal synthesis for multiple stakeholder, ranging from planners, engineers, production managers and/or vessel captains.*
The developments the author describes in this book are of great significance in bringing the Odesys methodology to industrial value within a broad engineering management context."

Sander Steenbrink (Doctor of technical Sciences)
Director Corporate Research & Development at Boskalis

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Reading guide

This Open Design Systems (Odesys) book is split into three main parts:

I – Setting the Odesys scene. In the first part (Chapters 1-5), we set the Odesys scene by first defining our frame of reference and Odesys' key starting points and paradigms, including a view on world and man. We then put forward our perspectives on design and management within the context of science and engineering. We also present our view on how to mathematically model design and decision problems. In other words, we gradually zoom in from the science and engineering context and the respective positions of design and management, through the socio-eco management organization with engineering assets in order to finally mathematically- and U-model the participatory design and decisions related to these engineering assets considering the stakeholders' conflicting socio-eco interests.

Key topics that are introduced within this part are: (1) R&D methodologies and the 4-Quadrants models to position Odesys (2) the socio-eco organisation model as the basis for quality of service (QoS) engineering asset management (3) social threefolding and its laws and principles as the basis for the participatory socio-technical systems design integration and for the Corporate Social Identity (CSI) (4) the socio-eco design to best fit for common purpose diagram (5) the extended Odesys U-models for open loops management, designing and learning (6) preference function modeling (PFM) theory and its basic principles (7) PFM-based multi-criteria decision analysis (MCDA) and multi-objective design optimisation (MODO).

II – Odesys methodology and applications. In the second part (Chapters 6-8) we introduce the Odesys methodology, address the development gaps, and put forward both the state of the art IMAP optimisation method and the Preferendus design and decision support. We describe how Odesys and IMAP/Preferendus overcomes other existing shortcomings compared with contemporary and single-sided multi-objective design optimisation methods. Moreover, we present Odesys' U-model, including a threefold modeling framework, which incorporates three open-ended design loops: (a) open config – technical cycle, (b) open space - social cycle, and (c) open source - the purpose cycle.

Key topics that are introduced within this part are: (1) Odesys' mathematical formulation (2) the function of IMAP and the Preferendus (3) the threefold optimisation framework of preference-, objective- and design performance functions (4) the open-ended Odesys U-model and the technical, social and purpose cycles (5) formative Odesys examples as learning vehicles (6) summative real-life Odesys applications as design demonstrators (7) validation of IMAP/Preferendus synthesis with min-max compromise and or single-objective design solutions.

III – Educating the Odesys engineer. In the third part of the book we first academically position the Odesys engineer as a true systems integrator within the domains of scientific research and engineering development, closing the loop with Chapter 2. Next, with the knowledge of the required integrative position of the Odesys engineer, we present a fully congruent and new education concept with this, called Open Design Learning (ODL). With this we close the loop with Chapters 3 and 4, and introduce in addition to the open loop management and the open design U-models, a third U-model but this time for the ODL concept (ODLc).

Key topics that are introduced within this part are: (1) the 4-Quadrant model applied (2) the position of the Odesys engineer within both 4-Quadrant models (3) the key principles of the ODL concept (4) the ODL U-model as the basis for design learning.

We consider this book to be a never ending work in progress and therefore "open end" the book with a section on further developments and outreach. Linked to current Odesys conclusions, we outline the scope and potential for confronting the conflicts in various applications, including stalemate situations. Finally, the book is larded with so-called incitements (mainly included in Parts I and III) . These are contextual opening questions or problems to spark the reader's imagination for a particular topic, create awareness or provide food for thought.
Last but not least, all quantitative examples or design applications from Chapters 5, 7, and 8 have been worked out and can be found on the Odesys Github: `github.com/TUDelft-Odesys/`.

Part I

Setting the Odesys scene

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Chapter 1

Frame of reference

Before we introduce the open design system (Odesys) methodology, we first set the scene for the most important concepts, terms, principles, and definitions. These will be specifically coloured for their prominent place within the Odesys and open design learning (ODL) context. For the sake of clarity and to prevent confusion, we list these as a concise 'portal', and as used in this book.

1.1. Design, science, engineering & management

We will introduce the following concepts of design, engineering, and management, and place them in the scientific research and development context. First, we will define the 'broad' interpretation of design within the Odesys context.

Design

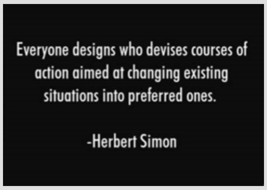
To design is to imagine and specify things that do not exist, usually with the aim of bringing them into the world. The “things” may be tangible – machines and buildings and bridges; they may be procedures – the plans for a marketing scheme or an organization or a manufacturing process. Virtually every professional activity has a large component of design, although usually combined with the tasks of bringing the designed things into the real world. So how does a designer reason? In a certain sense, design is the opposite of induction. The aim of induction is theoretical knowledge; design is aimed at a functioning thing. Induction is a process of abstraction and designing a process of concretization: an innoduction process, see Roozenburg & Eekels (1995). In contrast to research, designing is a future-oriented action, where a new articulation is created from the unknown (i.e., de-sign: ‘a not yet drawn mark’). The core of design, then, is the transformation of the functional needs of a new artefact into the description and manifestation of its true meaning and form.
In addition to its meaning as a verb (to design or designing), design can also be used as a noun. Design means (in a non-artistic sense) a plan or scheme in the

mind (inner) for a potential realization in the observed world (outer). According to Steiner (1995), development purpose is related to the inner human motive (i.e., ‘the impulse that gets you in motion/ gets you motivated’) that transforms a desire via an intent into an inner and/or outer design. According to Ackoff (2006), the so-called intentional or ‘idealized design’ serves as the motivator/stimulator for the devise and design process. A true living dialogue in the space between subject and object creates an open space where new designs can emerge. In the words of Goethe: ”only human can sense the interactive experience experiment as the mediator between subject and object”.

Incitement 1.1 Design, a broad perspective

(Prof. Herbert Simon’s research was noted for its interdisciplinary nature such as cognitive science, computer science, public administration, management, and political science. He won a Nobel Prize & Prof. Russell Ackoff was a pioneer in the field of operations research, systems thinking and management science).

For Simon and Ackoff, design is problem solving, is tinkering with artefacts. So, it was his key ambition to have design driven curricula. One can imagine a future in which our main interest in both science and design will lie in what they teach us about the world and not what they allow us to do in the world. Design like science is a tool for understanding as well as acting.
Moreover, Simon saw design theory as a bridge to connect ‘epistemic communities’ that are usually disconnected. In essence, composers, medical professionals, engineers, and managers are all doing the same thing. They are designing, i.e. they are ‘devising courses of action aimed at changing existing situations into preferred ones.’ Understanding the core underlying problem solving processes would enable these professionals to engage in meaningful conversation.
In everyday life, we solve all kinds of problems. Not just unpleasant ones but also fun ones. Consider the following travel commercial. ”From the moment you leave for the airport to the moment you arrive home after your holiday, we have organised your trip. Flights, car hire, transfers, activities, accommodations, meals, and stopovers. We can put together your personalised holiday, so you don’t have to worry about anything in Australia. We have a perfect plan in mind for you!” So, is a travel agency actually also a co-design office?



The following formal definition of engineering design is the most useful in the open design systems context, see Dym (2013): ‘Engineering design is a systematic, intelligent process in which engineers generate, evaluate, and specify solutions for devices, systems, or processes whose form(s) and function(s) achieve ‘stakeholder’ objectives and users' needs while satisfying a specified set of constraints. In other words, engineering design is a thoughtful process for generating plans or schemes for devices, systems, or processes that attain given objectives while adhering to specified constraints'. For further reading, see Ackoff (2006); Bohm (1994); Dym (2004); Roozenburg & Eekels (1995); Scharmer (2016); Steiner (1995).

Science

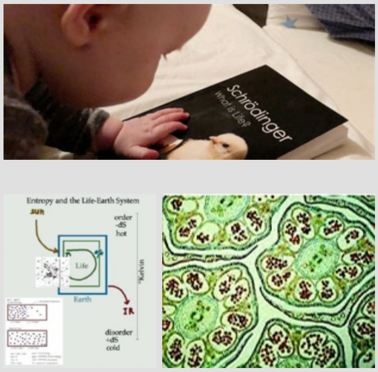
Science, any system of knowledge that is concerned with the physical world and its phenomena and that entails unbiased observations and systematic experimentation. In general, science involves a pursuit of knowledge covering general truths or the operations of fundamental laws. Science can be divided into different branches based on the subject of study. The physical sciences study the inorganic world and comprise the fields of astronomy, physics, chemistry, and the earth sciences. Social sciences like anthropology, psychology, management, and economics study the social and cultural aspects of human behavior. For further reading, see Bohm (1994); Bortoft (1996); Heusser (2016/2022); Roozenburg & Eekels (1995); Simon (2019).

Incitement 1.2 Mind and matter

(Prof. Erwin Schrodinger, physicist and Nobel Prize winner in physics)

What is life, mind, and matter?

"..And thus at every step, on every day of our life, as it were, something of the shape that we possessed until then has to change, to be overcome, to be deleted and replaced by something new. The resistance of our primitive will is the psychical correlate of the resistance of the existing shape to the transforming chisel. For we ourselves are chisel and statue, conquerors and conquered at the same time it is a true continued 'self-conquering' (Selbstüberwindung)..."



Engineering

Engineering is the pursuit of optimum conversion of the resources of nature to the purpose of humankind. The field has been defined as the creative process to design or to develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or to operate the same with full cognisance of their design with respects to an intended fit for purpose (quality of service). The words engine and ingenious (i.e., 'inborn nature') are derived from the same Latin root, in-generare/in-gignere, which means "to create or generate / to give birth." The early English verb engine meant "to contrive." Thus, the engines of war were devices such as catapults, floating bridges, and assault towers; their designer was the "engine-er," or military engineer. The counterpart of the military engineer was the civil engineer, who applied essentially the same knowledge and skills to designing buildings, streets, water supplies, sewage systems, and other projects. For further reading, see Blanchard & Fabrycky (2011); Dym (2013); Hastings (2014); Wasson (2015).

Management

Management (or managing) is the art and science of managing resources of a project or service providers. Management is setting the strategy of these organizations and coordinating the efforts of its people to accomplish its objectives through the efficient and effective application of available resources, such as financial, natural, technological, and human resources. Two concepts are used in management to differentiate between the continued delivery of products or services and adapting of products or services to meet the changing user needs. The term "management" may also refer to those people who manage an organization: managers. Because the term management is often confused with leadership, the following explains the difference between the two.

Incitement 1.3 Explanations using systems thinking

Take an automobile for example which is a simple mechanical system that you are all familiar with. Why is the motor in the front? Well, you probably know the reason, it was because it was originally called the horseless carriage. Therefore the motor was put where the horse was in front of the cart.
Do you think that somebody that did not know that can find that out by taking the automobile apart? The automobile was originally a six passenger vehicle, why? Why was it not five and not four, fifteen, or nine, why was it six? Will taking it apart tell you? Of course not.
How many of you have ever been to Britain? You know they drive on the wrong side of the road, why? Do you think that taking British cars apart is going to tell you why they drive on the left and we drive on the right? Of course not.
Seemingly questions about objects called systems cannot be answered by the use of detailed analysis (only).

Management versus leadership A manager is usually focused on controlling or dealing with situations, matter or people within the workplace which often involves constantly reassessing and adjusting results to measure efficiency and improve effectiveness. Note that management differs from leadership. Leadership tends to focus more on increasing fit for common purpose by motivating, inspiring, and encouraging others to pursue an idealized design rather than ensuring tasks are completed through management. So, management focuses on optimising the planning and execution of a process (fitness for only on effectiveness and efficiency, rather than fit for purpose), while leadership focuses on optimising a system as a whole (focus on fitness for purpose). For further reading, see Argyris & Schön (1995); Bower (1997); Scharmer (2016); Schön (1987); Senge (2006).

1.2. Systems engineering & thinking

Systems engineering is an interdisciplinary field of engineering and engineering management that focuses on how to design, integrate, and manage complex systems over their life cycles. At its core, systems engineering utilizes systems thinking principles to organize this body of knowledge and products. The field of systems engineering is related to systems thinking, and (open) systems theory.

System

A system is a group of interacting or interrelated elements that act according to a set of rules to form a unified whole, from Greek $\sigma\upsilon\sigma\tau\varepsilon\mu\alpha$, organized whole, a whole compounded of parts or a sum of the vital processes in an organism. A system is composed of sub-systems: e.g., in case of technical systems the sub-systems are the engineering assets (and its physical subsystems) and in organizational/social systems these could be the (sub)departments (and people). One could even further *zoom-in* to *object*/component or *subject*/person level respectively. A system, surrounded and influenced by its environment, is described by its boundaries, structure and purpose and expressed in its functioning: the so-called embedding systems dimensions. Systems can be further classified and discerned as *open* and *complex* systems.

System classification A system can represent both physical and non-physical artefacts. Physical systems can be technical and/or mechanical systems comprising of engineering assets and their components. These systems, also sometimes called deterministic systems, are characterized by the following features (a)'integrate the parts' (b) 'are causal' (c) neither the parts nor the whole are purposeful. On the contrary, non-physical systems can be social and/or biological systems comprising of their living (sub)parts. These systems, sometimes also called organic or human (related) systems, are mostly characterized by the following features (a)

'differentiate from the whole' (b) 'goal-oriented' (c) both the parts and the whole are purposeful, see Figure 1.1.
So, we can distinguish between systems consisting of living elements (subjects) and dead elements (objects or engineering assets). A special subclass of social systems are so called management systems. A management system is a set of policies, processes, and procedures used by a human or an organization to ensure that it can fulfill the tasks required to achieve its purpose and goals. Typical examples are planning-, information-, safety-, and/or organization systems.

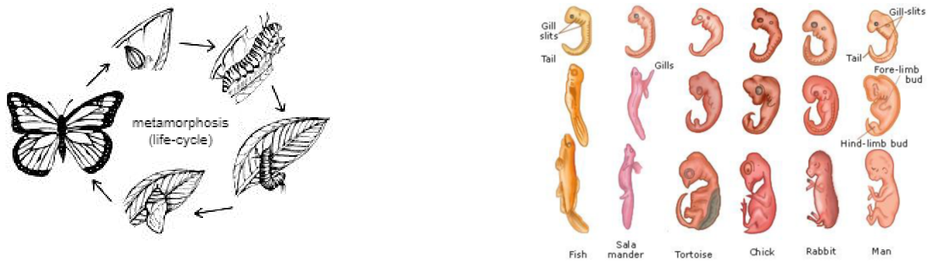


Figure 1.1: Purposive metamorphosis.

In addition, something remarkable can be observed when you consider a 'dead' mechanical system next to an organic 'living' system. For it is common knowledge that nature behaves as a threefolding system and a mechanical system mostly shows itself as a twofolding system, see Figure 1.2.

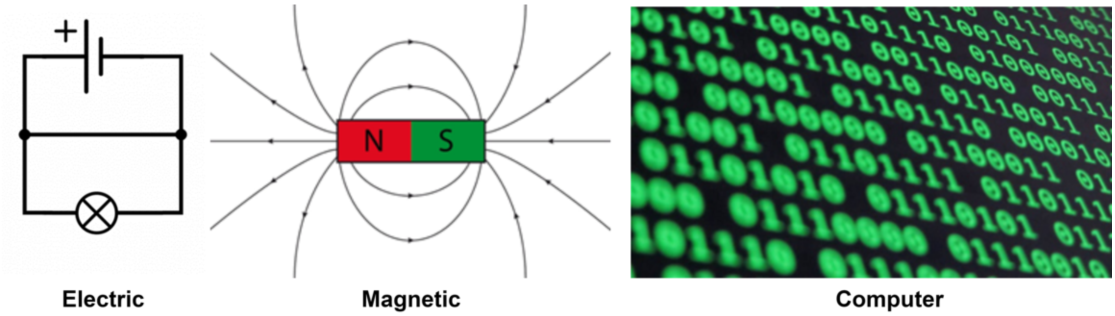


Figure 1.2: Twofold material/mechanistic system (digital 'under-nature').

An interesting fact when comparing multiple living threefolding systems is that there can be a so-called *inversion principle*, see Lievegoed (1996) and/or Figure 1.3
This means that if you compare plants and humans with each other, for example, they are actually a mirror image of each other and we will see this mirror image again later in organisational development within the context of society.

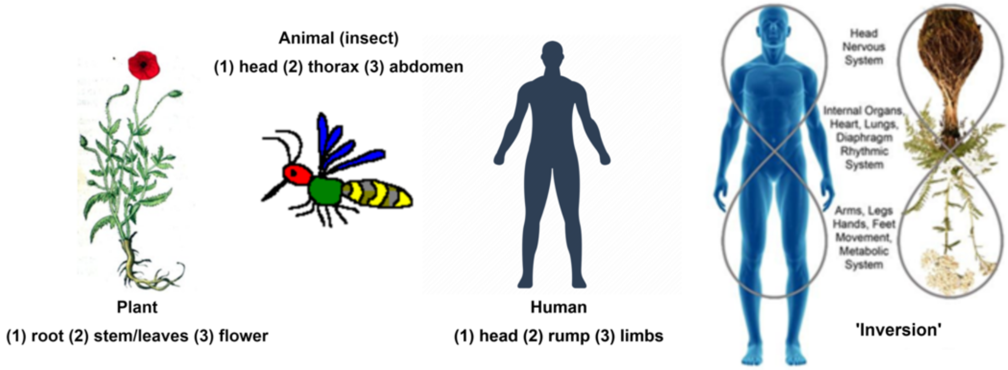


Figure 1.3: Threefold living/organic system (nature) and its inversion principle.

Complex systems A complex system is a system composed of many objects and/or subjects which may interact with each other. Examples of complex systems are organisms, infrastructures such as transportation or energy systems, software systems and/or social organizations (like companies or cities). Systems that are 'complex' have distinct properties arising from relationships or interactions between their sub-systems or between a given system and its environment, such as non-linearity, emergence, adaptation, and control loops, amongst others. A special class of complex systems are socio-technical systems. A socio-technical system is the term usually given to any combination of social and technical elements that exhibit purposeful behavior. Participative socio-technical system design is the key of this book.

Open versus closed systems The open systems that we know of are systems that allow interactions between their internal elements and the environment. An open system is defined as a "system in exchange of matter with its environment, presenting import and export, building-up and breaking-down of its material components. Closed systems, on the other hand, are held to be isolated from their environment. Equilibrium thermodynamics or dynamics of mechanical systems, for example, are fields of study that applies to closed systems. In social sciences, schematically, if there is an interaction or feedback loop between ideal and material or subjective and objective then the system is an open system, otherwise it is a closed system. A closed system offers a deterministic relationship. The idea of open systems was further developed in systems theory.

Incitement 1.4 Systems' emergence

Avalanches often occur in spots where the layers of snow are unstable. Cumulative forces build and push one another to extremes, at which point they can release unprecedented power in the mere blink of an eye. Whereas natural phenomenon can cause irreparable damage, this 'avalanche' rolls itself back up as if nothing has happened. Interlocking or uncovering rings regather themselves into emerging 'mountains'.

From the exhibition Momentum 2020 in Museum Voorlinden, by artist Zoro Feigl, see youtu.be/LEe4KiNSTHQ.

Systems theory

Systems are the subject of study for systems theory and other systems sciences. Systems theory is the interdisciplinary study of systems, i.e. cohesive groups of interrelated, interdependent parts that can be natural, social, or human-made. General systems theory is about developing broadly applicable concepts and principles, as opposed to concepts and principles specific to one domain of knowledge. It distinguishes dynamical or active systems from static or passive systems. Active systems are activity structures or components that interact in behaviors and processes. Passive systems are structures and components that are being processed. For example, a program is passive when it is a file and active when it runs in memory. Every system is bounded by space and time, influenced by its environment, defined by its structure and purpose, and expressed through its functioning. A system can be more than the sum of its parts if it expresses *synergy* resulting in *emergent* behavior.

Synergy, symbiosis, synthesis The term synergy originates from the Greek synergos, "working together", symbiosis from the Greek symbiosis, "living together" and synthesis from the Greek syntithenai, "to put together". Let us start by defining symbiosis. Symbiosis is any form of close and long-term biological interaction between two different biological organisms (with different properties/species). From this "living apart/separately but together" (i.e., a LAT relationship) emergence (also called system articulation) can occur. Or in other words, symbiotic life emerges from coexistence (e.g. think of the unique human speech formation or music, a coexistence of tones, rhythm, timbre through which music and speech experiences 'emerge'). Primal dune formation that begins with rippling patterns on the flat beach, created by wind or water, are an example of an emerging structure in nature. Other concepts which are closely related are synergy and synthesis. We will use synthesis in the context of design and symbiosis/synergy in the case of management and organisations. In all such cases, there is *emergence* because from the fusion of the parts an extra 'invisible' dimension can emerge so that it holds that the 'whole is greater than the sum of its parts'. Note (1): for all these 'syn-' concepts, multiple parts (greater equal two) can converge to emergence. We will use synthesis as an emergence of two and synergy as an emergence of three or more. Note (2): sometimes this concept is also applied to thinking or conversation between people. In this case, one refers to dialoguing or dialectical thinking in which through the 'union' of thesis (one) and antithesis (the other) a new synthesis emerges, see Buber (2004) or Hegel (2021). See Figure 1.4 and/or Figure 1.5 for an abstract representation of 'syn-concepts' and emergence and/or some typical emergent behavior examples, respectively.

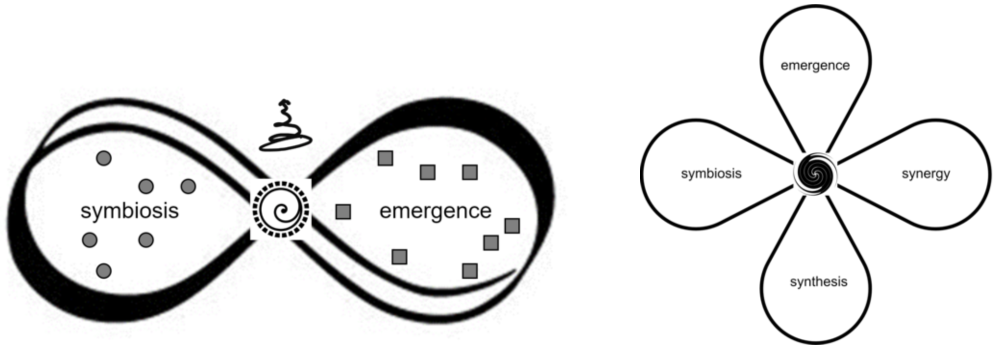


Figure 1.4: Conceptual representations of symbiosis, synergy, synthesis and emergence: a (perpetual) force of life.

Emergence (or emergent behavior) is a common feature of complex systems, which are characteristics of a system that are not apparent from the components individually, but emerge from the interactions, dependencies, or relationships they form when brought together in a system. Emergence broadly describes the appearance of such behaviors and properties, and has applications to both social and technical systems. It was already recognised by Aristotle (i.e., the '1+1+1=4' effect). Let us continue with some other high-level systems theory principles. Changing one part of a system may affect other parts or the whole system. It may be possible to predict these changes in patterns of behavior. For systems that learn and adapt, the growth and the degree of adaptation depend upon how well the system is engaged with its environment. Some systems support other systems, maintaining the other system to prevent failure. The goals of systems theory are to model a system's dynamics, constraints, conditions, and to elucidate principles (such as purpose, measure, methods, tools) that can be discerned and applied to other systems at every level of nesting, and in a wide range of fields for achieving optimised equifinality. See Figure 1.4 and/or Figure 1.5 for an abstract representation of syn-concepts and emergence and/or some typical emergent behavior examples, respectively.

Dynamical systems In mathematics, a dynamical system is a system in which a function describes the time dependence of a point in an ambient space, such as in a parametric curve. In physics, a dynamical system is described as a "particle or ensemble of particles whose state varies over time and thus obeys differential equations involving time derivatives". These can be either linear or non-linear systems with related differential equations. In linear systems, the effect is always directly proportional to the cause. In non-linear systems, a small perturbation may cause a large effect (see butterfly effect), a proportional effect, or no effect at all. At any given time, a dynamical system has a state representing a point in an appropriate state space. A state variable is one of the set of variables used to describe the behavioral state of a dynamical system, also known as a system's configuration. As an example think of a car's throttle position that, as a variable, determines the car's overall speed. In case of a manual gearbox the overall speed also depends on the selected gear, which is another variable. Note that system dynamics (as opposed to dynamical systems) is an approach to understanding the non-linear behavior of complex systems over time using stocks, flows, internal feedback loops, table functions, and time delays. Originally developed for organizations to improve their business processes, system dynamics is currently being used throughout the public and private sector for policy analysis and design.

Systems thinking

Systems thinking is an approach that views an issue or problem as part of a wider, dynamic system. It entails accepting the system as an entity in its own right rather than just the sum of its parts, as well as understanding how individual elements of a system influence one another.

When we consider the concepts of a car or a human being, we are using a systems thinking perspective. A car is not just a collection of nuts, bolts, panels and wheels. A human being is not simply an assembly of bones, muscles, organs and blood. The notion that the system as a whole has properties provided by the elements that individual elements cannot provide is called *emergence*: i.e., 'the whole is more than the sum of its parts' (see also the previous subsection). In a systems thinking approach, as well as the specific issue or problem in question, you must also look at its wider place in an overall system, the nature of relationships between that issue and other elements of the system, and the tensions and synergies that arise from the various elements and their interactions. According to Ackoff (1999), systems thinking combines analysis (zooming in) and synthesis (zooming out) in a three step process:

1. Identify a containing whole (system) of which the thing to be explained is part.
2. Explain the behavior of properties of the containing whole.
3. Then explain the behavior or properties of the thing to be explained in terms of its role(s) or function(s) within its containing whole.

Figure 1.5: Emergence and systems articulation (here different types of 'form' emergence).

A kind of similar way of systems thinking is, according to Simon (2019), the notion of properties of so-called 'hierarchical systems'. These are systems that are composed of interrelated subsystems, each of them being in turn hierarchic in structure until some lowest level of elementary subsystem is reached (for instance, animals including organs including tissues including cells). This hierarchy offers significant advantages in dealing with external complexity. Infrastructures and/or organizations, for instance, are hierarchically constructed artefacts created by human beings to navigate in an efficient and effective way. A good example of the use of systems thinking within the context of engineering asset management is the innovative multi-system intervention 3C concept, which was developed by Wolfert about a decade ago and has since been successfully applied, see Kammouh et al. (2021). Let us conclude with two other important concepts of systems thinking.

Phenomenology A special type of systems thinking is part of the phenomenological or Goetheanian science in which Goethe discerned a hidden relationship of system parts that explains how one form can transform into another form while being part of an underlying archetypal form or primeval phenomenon (Ur-phänomen). So, he suggested that researchers and developers seek the natural, lawful organizing ideas or archetype pattern behind specific natural phenomena or within (living) organic systems. They must adopt a more living, more humane, experiential approach aspiring to enter into the living essence of the living system zoomed into its primeval phenomenon (i.e., which appears or is seen as the basic element). The experimenter aspires to allow the phenomena to reveal its inherent order and system laws. While often invisible, these system laws are clearly objective, not subjective, and not invented by the experimenters. Goethe intuited the practice of rational science promoted a narrowing and contracting interplay between humanity and nature. A special and typical phenomenological or Goetheanian archetype is the human threefold of: (1) empiric (sense nerve); (2) rhythmic (heart lung);

(3) metabolic (organ limbs), which can be zoomed in and out within the human system including the use of the principle of self-similarity, see e.g. Heusser (2016).

Self-similarity A well-known concept from biology or mathematics implies the following. A self-similar object looks exactly or approximately like a part of itself, or in other words, the system as a whole has the same shape as one or more of its parts. Many objects in the real world are self-similar: parts of them exhibit the same properties at many scales. Self-similarity is a typical property of fractals, or spiral shapes and patterns (such as Romanesco broccoli which exhibits strong self-similarity). A special example of 'self-similarity' is the so-called Droste effect, see Figure 1.6. Finally, the Sierpiński triangle (sometimes spelled Sierpinski), is a fractal attractive fixed set with the overall shape of an equilateral triangle, subdivided recursively into smaller equilateral triangles (i.e., principle of self-similarity). This is one of the basic examples of self-similar sets—that is, it is a mathematically generated pattern that is reproducible at any magnification (zooming out) or reduction (zooming in). For further reading see, Ackoff (1999); Bortoft (1996); Heusser (2016); Velmans (2017); Varela (2017).

Figure 1.6: Self-similarity and the Droste effect.

Problem solving & systems thinking

Ackoff (1991, 1999) identifies four methods of 'problem solving': 1) Absolve, 2) Resolve, 3) Solve, and 4) Dissolve. His point was that the further you take your problem solving the more likely you will make the problem go away forever. There is even an extra twist: Absolving and Resolving do not count as solving the problem. Solving, though valid, involves current knowledge. If there is a known solution one shouldn't have to waste their time on it. As a manager, a paid problem solver, only Dissolving problems is a worthwhile use of time. Dissolving requires an open and non-conformist manager that is interested and connected to unknown problems and has the ability to develop new knowledge and prospective expertise for a resilient future.

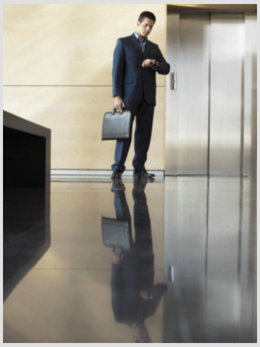
Incitement 1.5 An ups and downs elevator story

The manager of a large office building had been receiving an increasing number of complaints about the building's elevator service, particularly during rush hours. When several of his larger tenants threatened to move out unless this service was improved, the manager decided to look into the problem.

He called on a group of consulting engineers who specialized in the design of elevator systems. After examining the situation, they identified three possible courses of action: 1) add elevators, 2) replace some or all of the existing elevators with faster ones, or 3) add a central computerized control system so that the elevators could be 'routed' to yield faster service.

The engineers then conducted cost-benefit analyses of these alternatives. They found that only adding or replacing elevators could yield a large enough improvement of service, but the cost of doing either was not justified by the earnings of the building. In effect, none of the alternatives was acceptable. They left the manager with this dilemma.

The manager then did what a manager seldom does when he is anything less than desperate: he consulted his subordinates. He called a meeting of his staff and presented the problem to them in the formal of what he called a 'brain-storming' session. Many suggestions were made, but each was demolished. The discussion slowed down. During a lull the new young assistant in the personnel department, who had been quiet up to this point, timidly made a suggestion. It was immediately embraced by everyone present. A few weeks later, after a relatively small expenditure, the problem had disappeared. Full-length mirrors had been installed on all the walls of the elevator lobbies on each floor. The young personnel psychologist had reasoned that the complaints originated from the boredom of waiting for elevators. The actual waiting time was quite small, but it seemed long because of the lack of anything to do while waiting. He gave people something to do: look at themselves and others (particularly of the opposite sex) without appearing to do so. This kept them pleasantly occupied.



A systems thinking approach to problem solving recognizes the problem as part of a bigger system and addresses the whole system in any solution rather than just the problem area. A popular way of applying a systems thinking approach is to examine the issue from multiple perspectives, zooming out from single and visible elements to the bigger and broader picture. Systems thinking is best applied in fields where problems and solutions are both high in complexity. According to Simon (2019), ‘problem solving’ is design, that is tinkering with artefacts, and thus the ‘sciences of the artificial’ is a meta-design theory to solve problems.

For further ’systems’ reading, see Ackoff (1999); Blanchard & Fabrycky (2016); Bohm (1994); Dym (2013); Glasl & Lievegoed (2016); Lievegoed (1991); Lorenzelli (1995); Neimark, (1978, 2003); Senge (2006); Simon (2019); Thom (2019).

1.3. Modeling & models

Modeling allows for better understanding of a problem and presents a means for manipulating the situation to analyze the results of various inputs (“what if” analysis) by subjecting it to a changing set of assumptions. A model is an abstraction of reality or a representation of a real object or situation. In other words, a model represents a simplified version of something. It may be as simple as a drawing of house plans, or as complicated as a miniature but functional representation of a complex piece of machinery. A more usable concept of a model is that of an abstraction, from the real problem, of key variables and relationships. These are abstracted in order to simplify the problem itself.

Some models are replicas of the physical properties (relative shape, form, and weight) of the object they represent. Others are physical models but do not have the same physical appearance as the object of their representation. A third type of model deals with symbols and numerical relationships and expressions. Each of these fits within an overall classification of four main categories: physical models, schematic models (e.g. a logical diagram), verbal models, and mathematical models. Of particular interest to Odesys are the mathematical models.

Mathematical models

Mathematical models are perhaps the most abstract of the four classifications. These models do not look like their real-life counterparts at all. Mathematical models are built using numbers and symbols that can be transformed into functions, equations, and formulas. They also can be used to build much more complex models such as matrices or linear programming models. The user can then solve the mathematical model (seek an optimal solution) by utilizing simple techniques such as multiplication and addition or more complex techniques such as matrix algebra or Gaussian elimination.

Mathematical models can be classified according to their use (description or optimisation), degree of randomness (deterministic and stochastic), and degree of specificity (special or general). Of particular interest to Odesys are the mathematical optimisation models.

Mathematical optimisation models

An optimisation model is a mathematical representation of a real-world problem that is made up of three key features: 1) decision variables that define the degrees of freedom, 2) constraints that define boundaries that have to be respected, and 3) objectives that define the various (and often conflicting) goals to be achieved. Within the optimisation procedure a search is carried out to find the optimal configuration of decision variables that does not violate the constraints and performs best in relation to the objectives.
For general 'modeling' reading, see Ackoff (1991, 1999); Barzilai (2022); Blanchard & Fabrycky (2011), Neimark (2003) amongst many others.

1.4. Multi-objective optimisation

Multi-objective optimisation is an area of multiple criteria decision making that is concerned with mathematical optimisation problems involving more than one objective function to be optimised simultaneously. Multi-objective optimisation has been applied in many fields of science, including engineering, economics and logistics where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. Minimising cost while maximising comfort while buying a car, and maximising performance whilst minimising fuel consumption and emission of pollutants of a vehicle are examples of multi-objective optimisation problems involving two and three objectives, respectively.
For general reading on engineering design optimisation, see e.g. Hillier & Lieberman (2020); Martins & Ning (2021) amongst many others.

Optimisation problem formulation

In general, an optimisation problem can be mathematically represented in the following way:
Given: a function $U(x, y) : A \to \mathbb{R}$ from some set A to the real numbers, where A is constrained by y.
Sought: an element $x_0 \in A$ such that $f(x_0) \leq f(x)$ for all $x \in A$ ("minimisation objective") or such that $f(x_0) \geq f(x)$ for all $x \in A$ ("maximisation objective"), where x or x_0 are design/decision variables.

Design/decision variables

The variables x that the designer or decision maker has control over. A given set of these variables $x \in A$ values determine the state of the design/decision system and is considered a design configuration. Design variables determine the degrees of freedom of the design/decision system.

Constraints

In mathematics, a constraint is a condition of an optimisation problem that the solution must satisfy: $x \in A$, where A is constrained by the domain conditions y. The set of candidate solutions that satisfy all constraints is called the feasible set. So, in other words, constraints are a fixed set of requirements which cannot be violated in a given problem formulation. Constraints divide all possible solutions in two groups: feasible and infeasible. The set of candidate solutions that satisfy all constraints is called the feasible set. Constraints, when related to the social science (subjects/ stakeholders), can be considered negotiable: soft constraints. Contrary, constraints that are related to the natural sciences (objects/engineering assets) are not negotiable: hard constraints. Note that in modern mathematical language, the domain A is part of the definition of a function rather than a property of it.

Objective function

The function U is called an objective function, where the objective is a goal-oriented requirement which is to be followed to the greatest extent possible (either by minimisation or maximisation) given the problem's constraints. The objective function is called a preference function or fitness function for maximisation and a loss function or dissatisfaction function for minimisation. A feasible solution that minimises or maximises, if that is the goal, the objective function is called an optimal solution.

Object & subject

An *object* is something that is tangible and within the grasp of the senses. In physics, a physical body or object is an identifiable collection of matter.
A physical object, in engineering, is often called an engineering asset. A *subject* is a human, or a person, who has individual preferences, who makes his/her own decision and has a free will.

Solution space

The set of feasible design/decision alternatives: i.e., a set of possible candidate solutions, as defined by the constraints y (within the constrained domain A). The domain A of U is called the search space or the choice set, while the elements of A are called candidate solutions or feasible solutions (i.e., here A is the intermediate space spanned by the overlap of both the capability space (what the object can provide), and the desirability space (what the subject considers desirable). Note that this set can be empty in which case the design/decision making problem is infeasible.

Measurement

By an empirical system E we mean a set of empirical objects/subjects together with operations (i.e., functions) and possibly the relation of order which characterizes the property under measurement. A mathematical model M of the empirical system E is a set with operations that reflect the empirical operations in E as well as the order in E when E is ordered. A scale s is a mapping of the objects/subjects in E into the objects in M that reflects the structure of E into M. Measurement is the mapping of an empirical system E into a mathematical system M. The purpose of modeling/mapping E by/into M is to enable the application of mathematical operations on the elements of the mathematical system M (see Barzilai (2022)).

Preference

Preferences are central to design/decision theory because of the relation to human behavior. Preference literally means "to esteem or value (something) more than others, set before others in liking or esteem" and directly from Latin praeferre "place or set before, carry in front," from prae "before" + ferre "to carry". So, preference is a measure of human desirability. Preference is an expression of the degree of 'satisfaction' or 'well-being', and it describes the utility or value something provides. In other words, preference is a statement of an individual stakeholder's interest and a measurement of satisfaction (ophelimity): i.e. the fitness for purpose. Preference is also synonymous to choice/decision as one chooses/decides for those objects that one prefers (i.e. one prefers A over B expressed as $A \succ B$). The meaning of preference scores can only be derived from their relative position for which the ratio of differences is a real number expression. Scores are expressed as real numbers (scalar or bare quantity) on a defined scale from, for instance 0 to 100, where 0 is mapped to the 'worst' alternative and 100 is mapped to the 'best' alternative. Note that at least three alternatives are needed for the construction of proper preference scales that enable mathematical operations, for details see Chapter 5. The mathematical preference modeling foundations, including the economic theory, are laid down in Barzilai's preference function modeling theory. Moreover, the interested reader is also referred to Lacan's psychoanalytic model of desirability/subjectivity, see Desmet (2019). As conative states, desires are closely related to preferences. The difference between the two is that desires are directed at one object while preferences concern a comparison between different objects, of which one is preferred over the others. A desire (i.e., a moral wish rather than an instinct driven craving) is transformed via an intent/interest into a preference-based decision/design, see Steiner (1996). Note that money is not a property of an object but relates to a human's willingness to exchange money to satisfy desires related to the acquisition of the object and thereby a measurement of preference. Also note that economics in essence is all about balancing the fitness for purpose quality between supply and demand (object-subject). For further reading, see the pure economics work of Barzilai (2022) and/or Desmet (2019).

Preference function

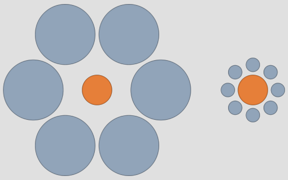
A function that relates objective design/decision variables (i.e., physical properties) values to subjective (i.e., psychological properties) preference ratings. This function links the social sciences domain (human subject) to the natural sciences domain (physical object). The correct mathematical modeling of preferences within the context of proper measurement scales are found in the pure economics work of Barzilai (2022). Note that principles and foundations of this novel theory are summarised as the preference function modeling/measurement (PFM) theory.

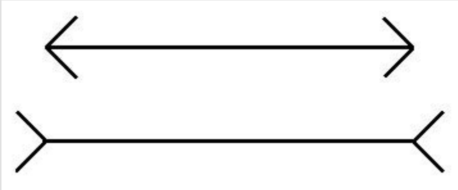
Preference aggregation

Preference aggregation is a key principle within design/decision making. It determines how individual preferences are integrated in group decision making, which is thereafter reflected in the design. A straightforward and commonly accepted approach for the aggregation of preferences is to use the weighted mean of the individual preference scores. However, this is not correct as the operations of addition and multiplication are not defined on these preference scores, Barzilai (2022). Instead, aggregation of preference scores should be done according to the mathematical operations that are defined in the one dimensional affine space. The overall group preference score is the synthesis that provides the "best" fit of all weighted (relative) scores for all different subjective objectives. In other words, the correct way of preference score aggregation, according to preference function modeling/measurement (PFM) theory, is based on finding the aggregated preference score that minimises the least-squares difference between this overall preference score and each of the normalised individual scores of all stakeholders' criteria.

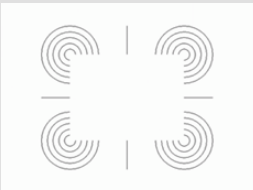
For doing so, we use the Tetra software which incorporates a solver based on the before mentioned preference aggregation (for Tetra see: `scientificmetrics.com`). We use PFM because it is based on a mathematical well-founded theory of preference measurement. Note that classical multi-criteria design/decision making analyses, including the Pareto analyses, which use the weighted arithmetic mean algorithm, contain modeling errors that render their outcomes meaningless.

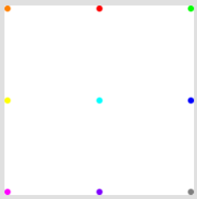
Incitement 1.6 Problem solving, connecting and observation





Look at the orange dot (above). Which of the two is bigger? You probably think it's the one on the right. Look at the two horizontal lines (above). The top one seems shorter, right? Our brain likes to see objects in relation to other objects to assess how big something is. Also remarkable is that your eyes project the image you see upside down and your brain converts it back the right way. Actually, we should reflect on this extraordinary collaboration. And what would this mean for our other inner senses processing? Would these also undergo a reversal process within inner self consciousness? Maybe a U-turn in the consciousness?
Look at the white square (below), can you observe four lines which span this square? Look at the white squared box below with the nine coloured points, can you connect these points by means of four lines? And what does this mean for your process of observing, sensing and generating?
Let's look again at observing. There seems to be an apparent contradiction between observing contents (objects) that are already there, and thinking as the activity that generates and connects understanding contents? What appears to me in the observation without me producing it, I might be able to connect this with the thought-contents (concepts and ideas) that I myself produce. Would insight arise in this way? And, would there also be a possibility of perceiving and observing our thoughts or thinking process? If so, what possibilities might this offer for gaining insights?





1.5. Odesys' common terms & definitions

In this section we will introduce some commonly used terms and define their interpretation within the Odesys context. Also, typical Odesys terms and their relation to similar terms and the most common abbreviations will be listed.

Purpose

Purpose means "intention, aim, goal; object to be kept in view; proper function for which something exists". Etymologically it is equivalent to Latin propositium "a thing proposed or intended". 'On- or for purpose' means "by design or intentionally". According to Steiner (1995), purpose is related to the inner human motive

(i.e., 'the impulse that gets you in motion/ gets you motivated') that transforms a desire/wish via an intent/interest into a (moral) design/decision. The intentional or so-called idealized design serves as motivator/stimulator for the devise and design process, see Ackoff et al. (2005, 2006). Note this is one of the reasons to develop the inner purpose via a self-chosen/motivated system of interest as part of the open design learning (ODL) concept.
Purpose is also directly linked to the concept of quality: i.e, real service quality or quality of service (QoS). Fit(ness) for purpose is a fair balancing act between user demand (wanted by the subject) and engineering asset supply (offered by the object) and expresses the system's QoS (on product delivery and/or ongoing during operation), which is in essence a pure economic balancing act. For further readings, see Ackoff (2006); Hastings 2014; Van Gunsteren (2013).

Principle of reflection

The principle of reflection is an essential element of modeling that states that operations within the mathematical system are applicable if and only if they reflect corresponding operations within the empirical system, see Barzilai (2022). For instance, the difference between two time events (year numbers 2010 and 2020) is defined because the operation of subtraction is defined in the mathematical system (one dimensional affine space) that represents time. Conversely, the addition of two year numbers is not defined in the one dimensional affine space that represents time and therefore the outcome has no empirical meaning. In technical terms, in order for the mathematical system to be a valid model of the empirical one, the mathematical system must be homomorphic to the empirical system (a homomorphism is a structure-preserving mapping). In a broader sense the principle of reflection also relates to the essence of engineering design where modeling plays a very important role as a reflection of the reality of object behavior. In most of engineering problems a reality test can be performed to check the validity of the model. However, for mathematical modeling of human behavior in the social sciences such a test is not readily available. Therefore in the social sciences domain one has to resort to meticulously scrutinizing each step in the process of sound modeling of human behavior, see Van Gunsteren (2022). This means that for the part of open design systems that deal with human behavior, one needs to make use of mathematical models that are based on proper axioms.

Incitement 1.7 Only right thinking does not determine reality!

In the outer world, in as much as this world is today dominated by outer science, when one speaks of knowledge, no doubt one will always say: Yes, knowledge, it must always result in the truth if one has right judgments, if one has thought the right thing. Lately, to characterize what is profoundly wrong in this supposition—that it must always come true in knowledge, in truth, when right judgments are made—we use a very simple equation, which we want to recount here again, showing that the right does not have to lead to reality.

"A little boy, who was always sent by his parents to get sandwiches on a Sunday morning, got 10 Euro and he got six sandwiches for it. If you bought one sandwich, it cost 2 Euro. But he always brought home six sandwiches for 10 Euro. The little boy wasn't very good at math, and he didn't care if it's true that he always takes 10 Euro with him, even though a sandwich costs 2 Euro and he still gets six sandwiches for his 10 Euro.
But then one Sunday they had a lodger, a university student and a good mathematician. He now saw that the little boy was going to the bakery, and that he was given 10 Euro. The student knew that a sandwich costs 2 Euro and he said: So you must take five sandwiches home with you. He could calculate well and he thought the right thing: one sandwich costs 2 Euro, he gets 10 Euro, so he will most certainly take five sandwiches home. But behold, the little boy came with six. Then the student said: "but that is completely wrong, because a sandwich costs 2 Euro and you have been given 10 Euro, you cannot possibly get six sandwiches, because for 10 Euro you only get five sandwiches from 2 Euro. One must have made a mistake or you have stolen a sandwich". On the second Sunday the boy again brought six sandwiches for 10 Euro. For it was customary in that place that on Sundays with five one always got one more, so that indeed, if one bought five sandwiches for 10 Euro, one got six. It was a very pleasant habit for the customers."

Well, the student thought very correctly, he made no mistake in his thinking, but this correct thinking did not correspond to reality. We must admit that right thinking does not reach reality because reality simply does not align itself with right thinking. You see, as in this case, it can thus be shown that in fact the most conscientious, complex ideas, which can only be thought out logically, can come out right, but can be completely wrong against reality. This can always be the case. Therefore, the principle of reflection should be applied especially to those things that arise purely from the mind.

U-model

The U-model forms the basis for the theory-U, which is a change management method based on the foundation of human experiences (integration of an open mind, heart and will) and more particular the principles of human learning and development behavior, see Scharmer (2016) and/or Figure 1.7. The U-model was originally developed by Glasl and his colleague Lemson from the Dutch Institute for

Organisational Development (NPI) as an open socio-technical process to come from a phenomenological diagnosis of the present state to designs for the future (drawing on Goethean/anthroposophical scientific principles by Steiner), see Glasl (1998) and/or Figure 1.7. They described a process in a U-formation consisting of three levels (technical and/or instrumental subsystem, social subsystem, and cultural subsystem). In general, this U-procedure (or method) transforms observations into intuitions and judgments about the present state and design/decisions about the future. The three stages represent explicitly recursive reappraisals at progressively advanced levels of reflective, creative, and intuitive insights, thereby enabling more radically open systems intervention and redesign. The stages are a metamorphosis from: a) phenomena - picture (a qualitative metaphoric visual representation), b) idea - purpose (the design idea or formative principle), and c) validation - prototype (is this fit for purpose?). The first three then are reflexively replaced by better alternatives (new idea new image new phenomena) to form the final design. In contrast to that earlier work on the U procedure, Scharmer's renewed theory-U starts from a different epistemological view (imagination, inspiration, intuition) that is grounded in Varela's approach to neurophenomenology, see Varela (1991), as opposed to the more ontological approach of Glasl's U-procedure (picture, purpose, prototype). It focuses on the process of becoming aware and applies to all levels of systems change and/or (re)design.

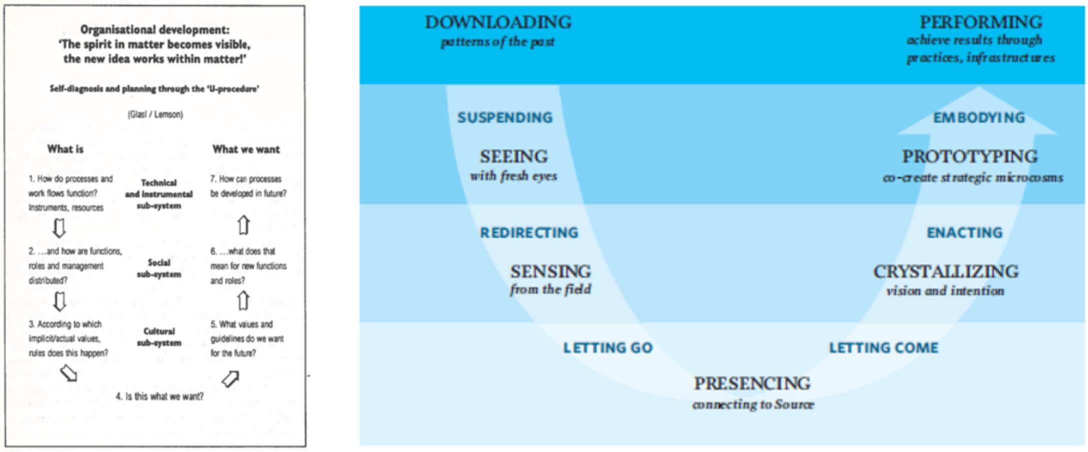


Figure 1.7: The basic U-diagrams from Glasl (left) and Scharmer (right), which will be our starting points as of Chapter 3 and onwards.

In this book, the U-model and/or theory-U has been further transformed, extended, and made specific for (1) open loops management (2) open design systems (3) educational purposes within the open design learning (ODL) method, see Binnekamp, Wolfert et al. (2020). Specifically, in this ODL process students combine both the human development principles following from the U-model theory and the engineering systems development principles according to the V-model theory (see Chapter 4,9). These U and V models theories seamlessly connect the open human and systems development, mainly because of their congruence. For further U-model readings, see Glasl (1998); Glasl & Lievegoed (2016); Scharmer (2016).

V-model

The V-model is a logical model or graphical representation of a systems design/ development life-cycle. It is used to produce rigorous design and development life-cycle models and engineering management models. The V-model summarises the main steps to be taken in conjunction with the corresponding deliverables within a system validation framework, or engineering asset/project life cycle design/development. It describes the activities to be performed and the results that have to be produced during service or product design/development.
The left side of the "V" represents the systems design decomposition of requirements, and creation of system specifications. The right side of the "V" represents systems integration of parts and their final verification and validation. Note here the formal distinction between verification and validation. Where verification is focused on checking whether subsystems meet their requirements, validation is focused on evaluating whether the system as a whole is working as intended. A systems engineer compiles a verification plan which describes how each subsystem will be verified against its specific requirements. However, before the verification plan is made a validation plan is compiled reflecting how the user needs as part of the operational concept design will be operationally evaluated as a working system. Together with the U-model, the V-model can be represented as a W-model which truly connects the human devise & design U-model with the systems design & develop V-model, forming an integrative open systems development approach (life-cycle: devise, design, construct, integrate, operate). For further V-model readings, see Blanchard & Fabrycky (2011); Wasson (2015).

Reflective practitioning

In general, a reflection process is termed as a cycle that must be repetitive. The four aspects of the reflective cycle are to teach, self-assess, consider, and practice. Reflective practice is said to be a process to learn from and through experiences on-the-run for the acquisition of new understandings and perceptions for practice. Reflection is a fundamental part of learning and teaching. It generally aims to enhance your professional knowledge and actions. The reflective practice is explained as a practice that helps a student to be aware of inherent learning and knowledge from their experience. Concepts such as double-loop learning, the learning society, and reflection in- or on action are now a part of education language. Note that where double-loop learning 'was over its top or ended', the U-model based learning and development started. For further readings, see Scharmer (2016); Argyris and Schön (1995); Palmer and Zajonc (2010).

Money

"Money" is not a (physical) property of an object, but rather relates to economics which is part of the social sciences (demand versus supply as driving factors for the pricing of goods). In other words, money is not primarily related to the object but to affordability as determined by the human subject. Let's look further at the quality and quantity of money, and in particular what a €50 note could demonstrate us. If we look at such a €50 note we can just consider it purely quantitatively and say this represents €50 as it says on the note. In a similar way you can also look qualitatively. We could say look at the essence of money and how is money used between people. Then we will recognise that money can represent a buy-, loan- or gift money form between people (threefold nature of money as a transaction means between people). When we consider these three types in more detail qualitatively, it can be concluded that buy-money has a "value for money (fairness)" character, that loan-money is about reciprocity ("mutuality") and carries an equal agreements nature, and that gift-money possesses unconditionality and/or "freedom" as a quality, see Figure 1.8 (note: we will return to this in detail later in this Chapter). This qualitative consideration is then no longer so much about the €50 purse, but what the essence of the interpesonal use of money represents. Even more simply, you can also separate quantitative and qualitative by simply looking at a word. The word may consist quantitatively of a number of letters but only a number of letters together in a correct order form a word, and that word together with other words gives a meaning only in its context. Both these perspectives complement each other and do not contradict each other.

Figure 1.8: The quantitative and qualitative meaning of money.

Living (design) dialogue

Dialogue assumes a conversation and a necessity to listen to the other. Its creator/'father' Martin Buber, see Buber (2004) indicated that a real discovery of a true 'I' lies in the encounter with 'You', and 'I' does not exist without a relation with 'You'. According to Buber, dialogue constitutes the basis of philosophy in general due to the fact that it is the only effective form of communication in contrast to one-sided expressions of opinions. In other words, in the space between one and the other (subject-object and/or subject-subject), a place can be found where new ideas can emerge. From this principle arises the so-called design dialogue as part of the U-model and/or the ODL concept. A design dialogue is a way of 'intuitive thinking' via concentrative inter-sensing-acting on practice that brings together awareness and insights as stepping stones towards the creation of new design. This living design dialogue is an active 'inner' dialogue with yourself and/or an 'outer' dialogue with the model that represents the design problem. For further readings, see Bohm (2004); Buber (2004); Palmer and Zajonc (2010); Scharmer (2016); Zajonc (2008).

Terms: differences, synonyms & abbreviations

Recognizing that terms are (mostly) used interchangeably in different areas of science and engineering, we want to facilitate the reader here by presenting some subtle differences and similarities of commonly used Odesys terms. Finally, the most frequently used abbreviations will be listed.

Methodology versus method Methodology refers to the overarching strategy and rationale of a research or development project. It involves applying from all available methods those that are of interest to a specific research or development project to arrive at the intended outcome (new knowledge or new product). For the overarching R&D methodologies, see the process flows in Chapter 2. Note that the Open Design Systems methodology is a particular colouration of this development process flow. Methods are the specific tools, techniques, and procedures which one can use either to: 1) collect data and investigate behavior (research) or 2) devise the new engineering product (development). For an overview of R&D method, see Appendix A.

Modeling versus simulation System's simulation is the operation of a model in terms of time or space, which helps analyze the performance of an existing (science) or a proposed (engineering) system. In other words, simulation is the evaluative process of using a model to study the performance of a system. It is an act of using a model for simulation. In other words, simulation is a process in which the sensitivities of an 'as-is' system are analyzed under different scenarios, and is hence the opposite of design, in which the parameters of the system are optimised to obtain new forward-looking solutions.

Experimenting versus observation Experimenting is the systematic observation of an existing (science) or proposed (engineering) system for the purpose of analyzing its performance. It is congruent to simulation, however, experimenting does not make use of a model. It is an act of using an experiment for observation.

Table 1.1: Terms & synonyms.

Term	Relates to and/or is synonymous with
Alternative	Variant, option, configuration
Conspection	Validation, appraisal, or reflection
Constraint (mathematics)	Boundary condition, required limit, or limit state.
Criterion	Design/decision/evaluation aspect
Decision making	Evaluation, selection, making trade-offs, assessing, appraising, or resolving
Delivery	Deployment or installation
Design (noun)	A plan, scheme (in the mind), or an idea
Design (verb)	Planning, creating, originating, generating, constructing, developing, or configuring
Design configuration	A design alternative, design solution, or design variant
Design point	An optimal design configuration
Desires	Needs, demands, or requirements
Emergence	The properties of a system as a whole that the parts do not have on their own or articulation
Functionality	Design to Y (tY) or design for value
Means	Resources
Object	A physical or engineering asset
Objective (mathematics)	Criterion, goal, target, need
Open glass-box	Antonym of black-box: open and transparent
Open-ended	Without an end date or planned way of ending or not a fixed end (no 0/1)
Preference	Value, utility, worth, satisfaction, or well-being
Preferendus	A software engine (tool) that integrates ODESYS, PFM and the IMAP algorithm
Purpose	Intent or ideal (idealized design)
Quality of Service	Functional performance or design tY aspects.
Solution space	To a design space, management space, feasibility space, feasible region
Stakeholder	Actor
Subject	A living human
Tetra	A software tool for PFM-based MCDA solving

Synonyms Throughout the book we will use different terminology depending on the specific context. To prevent confusion, we list the most frequently used terms alongside related terms and/or synonyms, see Table 1.1.

Abbreviations In this book, we will often use various abbreviations. In principle, when a new abbreviation is introduced, it will be entirely spelled out the first time. Here are the most important and common abbreviations spelled out and listed (see Table 1.2).

Table 1.2: Abbreviations.

Abbreviation	Meaning
CSI	Corporate Social Identity
DES	Discrete Event Simulation
EAM	Engineering Asset Management
GA	Genetic Algorithm
IMAP	Integrative Maximised Aggregated Preference
MC	Monte Carlo
MCDA	Multi Criteria Decision Analysis
MILP	Mixed Integer Linear Programming
MitC	Mitigation Controller
MODO	Multi Objective Design Optimisation
ODESYS	Open Design Systems
ODL	Open Design Learning
PDP	Project Development Plan
PFM	Preference Function Modeling/Measurement
QoS	Quality of Service
R&D	Research & Development
SAMP	Strategic Asset Management Plan
SODO	Single Objective Design Optimisation
SE	Systems Engineering
SoI	System of Interest
SOP	Service Operations Plan
3C	Centralize Cluster Calculate
4Q	4-Quadrant

Incitement 1.8 Reflective practitioning and system of interest

People who call themselves practitioners often think they are acting according to the most practical points of view. A closer look, however, will reveal that this so-called 'practical thinking' often has nothing to do with thinking, but consists of little else than further toil with inherited or handed over views and learned thinking habits. Therefore, in the educational process there will have to be reflection with the practitioner context, but always 'intuitive thinking' from the open will truly guide open design learning. Moreover, there are three things to consider if man is really to take up education in the sense of practical thinking: first, man must develop an interest in the external reality surrounding them, an interest in facts and objects. Interest in the world around us, that is the magic word for integrative learning. Passion and love for what we do, that is the second. Fulfilment in what we are thinking about, that is the third.
Whoever realises these three things: interest in the world around us, passion and love for what we do, and enjoyment in what we do and think about, will soon find that these are the most important requirements, which can be placed on a practical development of thinking. Besides cognition, shouldn't education also focus on an experiential context of the student's own choosing, integrating practical thinking with intuitive thinking?

1.6. Odesys' paradigms & views on world and man

With the mother statements "Everyone in the world must have access to clean drinking water" and "Every child must be able to go to school", nobody will disagree in principle. However, the worldview and paradigms from which we operate can cause fundamental differences in the related strategic directions for response. After all, these form the basis of our actions, the basis of the motive from which you consciously make decisions and implement these. As a result, a given problem can lead to very different actions or responses (i.e. design solutions) when acting, for example, from freedom and trust instead of coercion and control, or from a top-down versus a bottom-up approach. A schematic diagram capturing different strategic directions of response is seen in Figure 1.9. For further inspiration and/or reading, see the related societal and man views works of Desmet (2022); De Wit (2021); Van Egmond (2014); and/or Zoeteman (2009), amongst others.
Intermediate note: examining the UN's 17 global Sustainable Development Goals (SDGs) that form the basis of the so-called Agenda 2030 (see: `sdgs.un.org/goals`), we are struck by the absence of an overarching paradigm, such as that of,

for example, the social threefold order (an ordering principle that we will discuss in detail later in the Chapter). Moreover, we also miss a number of explicit running conditions and especially that of freedom of thought (following the philosophy of freedom from Chapter 2). These omissions, amongst others, negate all of these 17 goals and thus place them in the realm of social coercion. Indeed, this even deprives thinking of individual ability to distinguish: i.e., the human quality of thought comes under threat because it does not contain an ideal of human freedom.

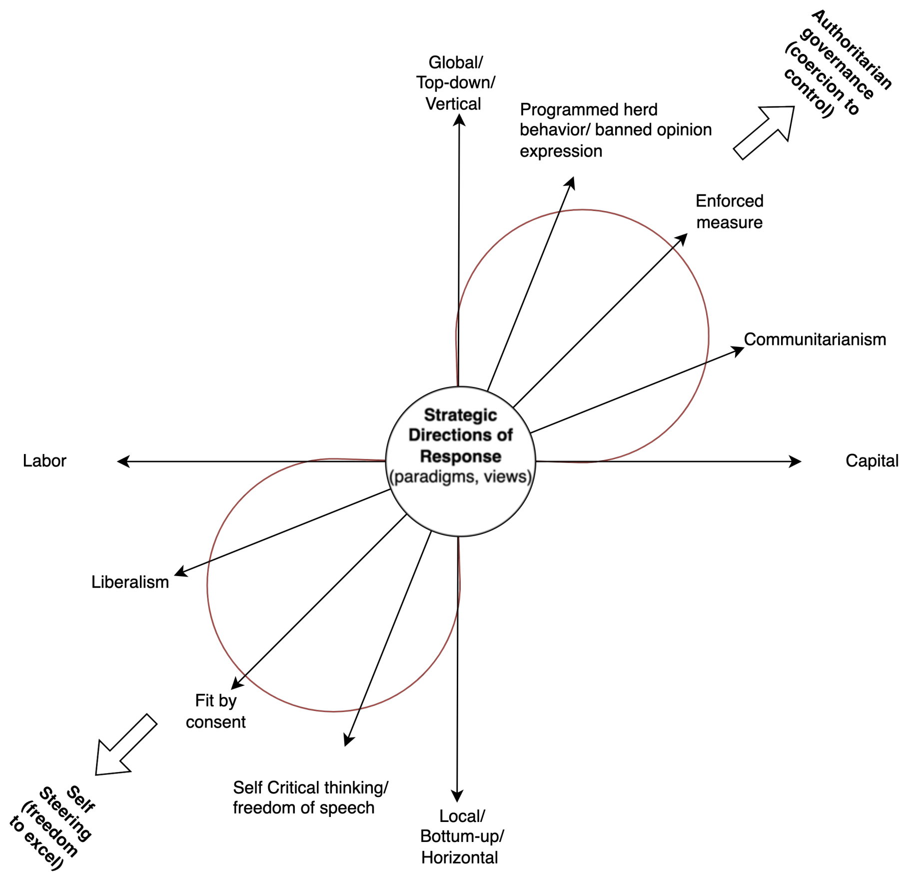


Figure 1.9: Strategic directions of response

These goals can even be explained as a supreme ideal of eliminating all distinctions between people and in certain areas, that is certainly appropriate. When we for example talk about human dignity, we argue that this should be equal, and that the value of all human beings is equal. However we can not then say that all people are equal and that they should all and everywhere fulfil these goals equally. Actually, these goals can be embraced by all of us, such as: 'improving the climate', 'equitable quality of education', 'promoting well-being', and 'improving

social cohesion': these are mother statements we can all agree on. So the problem is not so much these goals as such, but the means used to achieve them. For example, techniques are used to convince groups of people of predetermined content, through a-posteriori intransparent participatory processes where they were not involved in the solution with precisely a negative impact on human well-being. So how could we achieve engaged participation through open a-priori design processes best fit for local purpose? And does this not mean precisely a call for regional development goals (RDGs) rather than SDGs? Or another example, what students who have the future end up acquiring during their long period of educational development determines much for the future of all of us. We recognize that the state increasingly interferes with the form of education and is it actually their responsibility to determine the content of it? In any case, for both examples, we argue that if you control people, or a group of people, a little every day for long enough, after a long time they will be affected in the way they form their 'own' opinions and judgements, as it will impact their critical thinking abilities.
Within the Odesys philosophy, we aim to design new solutions for the future from the 'golden mean' principle (Aristotle) with 'man and his nature in the centre'. Further on in the book, it will become clear that these 'mensch' paradigms will not lead to a set of half-baked compromises, but to synthesis solutions based on a best fit for common purpose idea . This again, does not necessarily mean that everyone's preference is equal, but that these will be taken into account equitably in the design process. Moreover and in short, it is important to clarify these paradigms as a starting point. In other words, to arrive at a so-called 'idealised engineering design solution' for a particular problem within a human and embedding societal context, we need an integral human-centered world view. After all, according to the generally known principle "what you see is what you get (WYSIWYG)", you could argue that if you only see a human being as a machine (or vice versa) you also only find look-alike solutions. Therefore a balanced starting point here is a holistic view of man and the world in which engineering objects, with physical/ mechanistic properties (material), and living subjects, with spiritual properties (immaterial), interact.

Incitement 1.9 Threefold

'All good things come in threes' is a well-known saying. The 3 is also frequently encountered in other Dutch language, sayings, songs or traditions: e.g.,
Three times is a charm ('driemaal is scheepsrecht')
He looks as if he can't count to 3
One egg is not an egg, two eggs are half an egg, three eggs are Easter eggs
Three days of Carnaval, then on to Easter
3 times 3 is 9, everyone sings his own song
Big, bigger, biggest, or good better best etc.

Apparently, we do have a special relationship with the number 3, maybe it's in our blood, but in any case it has a magical attraction. According to Pythagoras, 3 is the first "true" number. It forms a geometric shape: the triangle, which stands for independence, solidarity and strength. In Chinese philosophy, there is a powerful statement about three:" The Tao made the one. The one has made two. One and two made three. Three has made the rest of things". Could humans and the world ultimately also rest on a primal triad?

Note that a trichotomy is a three-way classificatory division. Some philosophers pursued trichotomies. In mathematics, the law of trichotomy states that every real number is either positive, negative, or zero.

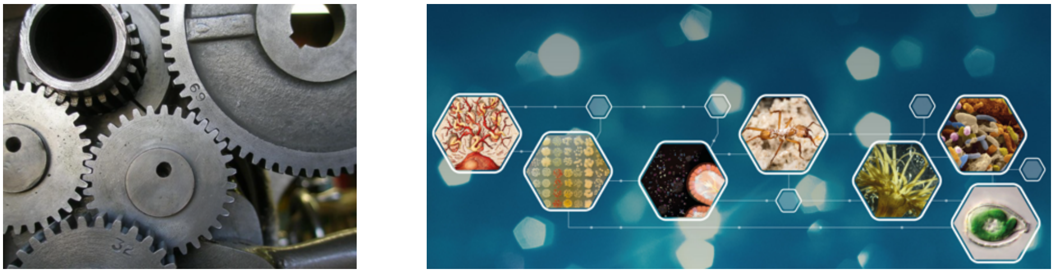
Key paradigms & starting points

Let us first distinguish the difference between a mechanical (technical or engineering) system and a living organic (human or social) system, as depicted in Figure 1.10. The mechanical system is characterised by the following features (a)'integrate the pieces' and (b) 'causal – as a result from (in-output). In contrast, the living organic system is characterised by (a)'differentiate from the whole' and (b)'purposive – towards a goal' : i.e., a living system is teleological (Aristotle: 'only nature is purposive'). Note: teleology is a reason or an explanation for something which serves as a function of its purpose, as opposed to something which serves as a function of its cause. And in particular, it characterises a living system by the concept of metamorphosis and often refers to the morphological and physiological changes an organism undergoes during its purpose-directed development. It should therefore be noted that only a human system can be goal-oriented and a mechanical system never of itself (this will come back later in Chapter 4, when we will talk about design which in itself is goal-oriented only through the actions and/or participation of man and his interests).

We can now ask ourselves, in the context of these two system types, what actually constitutes a society with different organisations and people? And so that brings us to our first paradigm, the paradigm of the 'social organism' This paradigm reads as follows (see e.g. Glasl (1998) and Lievegoed (1996, 2013), amongst others):

PI - 'the society, its organisations and their humans are a living social organism: a "bio-topos" which is a purposeful bio-dynamic system, rather than just a mechanical behaving system'

Note: we will see later that the engineering assets (the objects of a mechanical subsystem) of an organisation will also occupy a special place within this 'living' organism.



(a) A typical mechanistic system. (b) Typical living organic systems.

Figure 1.10: Mechanistic versus organic system

Besides this PI paradigm, we also need a holistic systems-thinking-based approach to study and/or improve these integrative social engineering systems. The following starting points are important here: (1) observation of both the subject and the object in its total context taking into account the so-called embedding system dimensions (e.g. societal, natural, regulatory etc.), (2) observing the system as a whole using zooming-in and zooming-out principles, (3) recognising and using the phenomena of systems emergence (or systems articulation), symbiosis and self-similarity, (4) systems can always be considered both qualitatively and quantitatively, (5) using the principle of human reflection with the real world.
The first four points speak for themselves and their reference principles within open design systems theory can be found in previous sections. However the fifth point, the principle of human reflection, deserves some clarification here (in addition to the principle of reflection as described in Chapter 1). Ultimately, the fifth aforementioned point, the principle of real-life human reflection leads to a new final paradigm with specific relevance to the engineering management context (which will be shown later in this Chapter and others).

This so-called principle of human reflection paradigm reads as follows, see for example Steiner (1996); Scharmer (2016); Heusser (2016), amongst others: i.e.,

PII – 'relate every (dynamic living) thing/being you see in the world to the general human or relate every living thing/being you see in the world to what you see in humans'

Note: this paradigm has far-reaching implications for problem solving within the context of designing and managing socio-technical systems. We will first see that in commonly used mathematical formulations of these types of problems, fundamental modeling errors arise when this paradigm is overlooked (see the Preferendus, IMAP, 3C and MitC concepts and their integrative modeling approaches as 'true' real-life answers to this). We will also see that, only from this paradigm combined with an open design systems thinking approach, socio-technical problems can be solved for the future. The current single-sided engineering view shows that zooming in and only using so-called 'meta-modeling' approaches (the term is misleading as it does not follow a meta- or integrative approach at all) does not overview the systems as a whole with unusable micro additions as a result, see the 3C concept developed by Wolfert and its multi systems intervention modeling approach as a 'true' real life answer to this, Kammouh et al. (2021). The latter element in particular, in the current publishing spirit that is driven by a perverse incentive (pure visibility drive), leads to an avalanche of papers that may be interesting to H-indices and the 'outside image' of the journal, but have no real-life value at all. Finally, current 'engineering education' (at least within technical universities) also shows an approach in which the principle of human real-life reflection is partly or sometimes even completely overlooked, resulting in far-reaching consequences for our current society (see the ODL concept and its integrative design learning approach as a future-oriented answer to this).
In summary, after all the above and particularly in the light of the last paradigm, we must now consider the generic nature of human beings more closely to let these characteristics return in the living developing engineering asset management organisation. Before we continue with the human view, here are some special quotes from Simon (2019), which help motivate why we need a human view within the Odesys design context: i.e.,
"...We can conclude that, in large part, the proper study of mankind is the science of design, not only as the professional component of a technical education but as a core discipline for every liberally educated person... Eventually it becomes clear that human beings themselves belong to the realm of the artificial. Indeed, they are probably the most important class of 'artifacts' given that they are able not only to create other artifacts but also to re-engineer themselves to best fit changing circumstances...".

Incitement 1.10 I am not I, who am I

(Juan Ramon Jimenez, poet)

I am not I.
I am this one
walking beside me whom I do not see,
whom at times I manage to visit,
and whom at other times I forget;
the one who remains silent while I talk,
the one who forgives, sweet, when I hate,
the one who takes a walk when I am indoors,
the one who will remain standing when I die.

The general human, a holistic perspective

This subsection can be seen as a perspective on the general human what we need to further interpret the PII paradigm from the previous section. We will provide specifics here of some specific characteristics when studying humans from a holistic perspective. These insights were gained mainly through Steiner's years of study of man, which was then also confirmed from other viewpoints and/or further elaborated by various (spiritual) scientists among them doctors/medics, biologists, and/or psychologists. We build on several of them in this book and we base the human view within the Odesys design and decision context on at least the works of: Barendregt (2022); Bohm (2004); Bortroft (1996); Desmet (2019); Dijksterhuis (2006); 2011), Gallagher (2013); Heusser (2016); Husemann (1994); Jung (2001); Kahneman (2013); Lievegoed (1996); Mosmuller (2018, 2021); Soesman (1998); Simon (2019); Varela (2017); Velmans (2017); Zajonc (1995, 2008), amongst others. This holistic view of man (and its nature) will be used in the further development of an organisation with its specific management and design processes. It provides insight to understand and improve such an organisation and its processes and systems within its societal context. Some key principles, elements, and/or properties of this man and world view are summarised hereafter. Note that we specifically developed the conclusions here and the figures, models, and/or diagrams hereafter, fit for the Odesys specific context of use in the rest this book. Only where images have been used one-to-one, the source will be specifically indicated (in the text). These pictures will not be described in detail because they speak for themselves (and have been described in detail in other books by the aforementioned scientists), but here the specific interpretation and use of what is relevant to the engineering asset management (EAM) and Odesys context will be briefly and further explained. The overarching starting point is the threefolding nature principle for the following *five* starting points.

(SP #1). Man's body, in other words his physical support structure, consists of three parts, three specific echelons/spheres/realms that are connected as unity. Everyone can observe these three structures when you see someone walking by, namely a (wo)man has a head, torso, and limbs. From this starting point, the following three subsystems can be distinguished, each with its own particular and internal physical autonomy (as further detailed in Figure 1.11):

- Empiric: head-nerve-sense system (upper pole)
- Rhythmic: heart-lung system (middle pole)
- Metabolic: organs-limbs system (under pole)

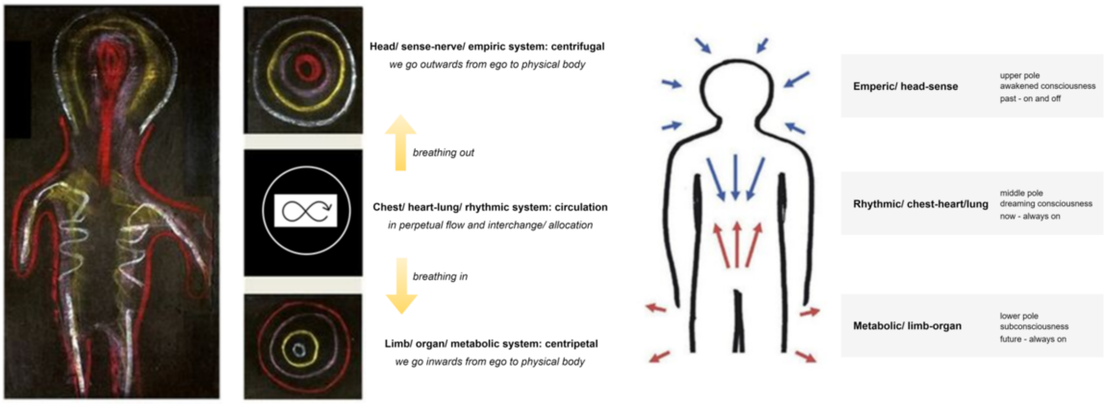
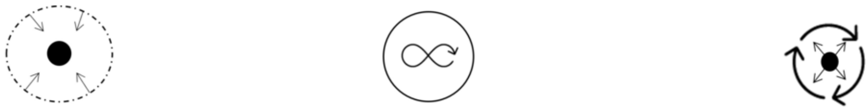


Figure 1.11: Threefold of the human body.

Note: following the self-similarity principle, it is also possible to zoom in further into other physical sub-systems of the body to then see a similar tripartite division. A special example of this is the study of an intestine/colon and its gut-wall. It turns out that this in itself again has a tripartite division of 'observation/ separation/ thinking', 'circulation/rhythm/feeling' and 'regeneration/ supply/ willing', which are represented as a tripartite sub-system in the gut-wall (see e.g. Huseman (1994) and/or Heusser (2016) among others for comprehensive medical studies and many other examples). A remarkable well known expression in this context is the following, "it is my gut feeling that we have to act like. . . .". Apparently, gut feeling says something about how to act and is thus linked to the will? For here, the notion of self-similarity is sufficient in itself.

Especially for analysing an organisational structure, with its different qualities within it, the following 'translation table' is important, see Figure 1.12. It shows the translation of the threefold view of man into an organic system: i.e., a tripartite/ threefold organisation, which basically breaks down into 'the eyes and ears', 'the heart', and the 'engines' of an organisation. We will use this translation table later in Chapter 3 for composing an organisational structure of the engineering asset management (EAM) organisation. With this, it will appear that we can structure the various organisational components and its identity, consider them more closely, and/or improve them from a qualitative (and later, as of Chapter 5, also from a quantitative) point of view.



Head/senses-man (empiric)	Chest-man (rhythmic)	Organ/Limb-man (metabolic)
characteristics & properties		
From the outside in	Flow/circulate and enable	From the inside out
Nerve-senses (outward)	Heart-lung (inward distributive/facilitative)	Organs (inward)
Re-sense (think)	Re-flow (feel)	(re)-Invest (will)
Awakened consciousness ('past /on and off')	Dreaming consciousness ('now / always on')	Subconsciousness ('future / always on')

Figure 1.12: Translation table (from human to a living system), as input for a threefold organisation.

(SP #2). In addition, we can recognise another tripartite division in human beings. The threefold of man into body/ soul/ mind, which allows us to distinguish between corpus ('carrier'), ego ('motivator'), and spirit ('unique self)'), see Figure 1.13.

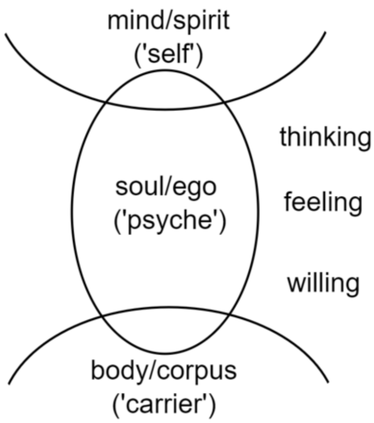


Figure 1.13: Threefold of human being, based on Lievegoed (1996, 2013).

The body ('carrier') is the physical carrier of the two other parts of beings. The soul ('psyche') in which inner momentum, feeling, sensing, and comprehension combines into a personal motive, is sometimes also known as the ego. The mind, sometimes called the spirit-self, provides the spiritual (unconscious) source to which the body is connected with the soul as the mediator. A symbiosis of these three parts of human being leads to emergence of the individual and unique 'I': i.e., individuation,

a process by which the individual self develops out of an undifferentiated unconscious, see Jung (2001); Lievegoed (1996, 2013); Steiner (1996); Varela (2017), amongst others.
This tripartite division is especially important for distinguishing between the organisational structure of man (how the body is built up), how man comes to act and behave, and how their experience and/or motive 'steers' this. The latter is in fact an inner process, an unobservable process for others, to which the act of designing or managing is most linked (after all, designing is 'making' a conscious plan or scheme from the mind to realized matter or action). In other words, the process of planning or designing is a process from inner sensing to outer realisation. We will see this in more detail later in the U-model theory and its application.

(SP #3). Subsequently, using the principle of self-similarity, the aforementioned threefold division can be further zoomed in to a more detailed division of the senses, resulting in the so-called twelve (inner-outer) senses, see Soesman (1998) and/or Figure 1.14. It should be noted that there are thus senses directly connected to the empiric system, which take care of external perception, say 'the eyes' of a social organism ('shedding light on matter'). The other senses are, as it were, tucked away inward and are therefore called the inner senses from which perception ('the heart of the matter'- intimacy representation) and movement ('the organic engines - warmth and energy) also originate.

Incitement 1.11

Quickly consider the following question: A bat and ball cost \$1.10. The bat costs one dollar more than the ball. How much does the ball cost?

A number came to your mind. The number, of course, is 10: 10¢. The distinctive mark of this easy puzzle is that it evokes an answer that is instinctive (impulsive), appealing, and wrong. Do the math, and you will see. If the ball costs 10¢, then the total cost will be \$1.20 (10¢ for the ball and \$1.10 for the bat), not \$1.10. The correct answer is 5¢. It is safe to assume that the fast and impulsive answer also came to the mind of those who ended up with the correct number — they somehow managed to control the (instinctive) impulse.

(SP #4). The fourth and final 'human' starting point links the process of design and decision making to the threefolding nature of man. We will now further describe the important so called M-threefold of motive-momentum-management: i.e., from motive and momentum arriving at a strategic action of response. To arrive at 'actions of response', a human basically has two main directions. First, they can act or react from antipathy or passion so that their soul motive falls, as it were, to an instinctive part of their nature (via the sentient body towards the physical body, as an instinct to ‘survive’). In this case, a human acts purely from their soul ego and drift-being resulting in impulsive and instinctive action. This instinctive or impulsive type of thinking is sometimes called ‘system-1’ or thinking fast, see Kahneman (2013). However, a human also has a second possibility to come to actions (or reaction). Namely, by connecting their own inner free will of the "self" with consciousness, rather than only through the ego, to come to designs or decision making. In this case, a human proceeds to conscious action by uncovering their own will and thus arrives at individual self-realisation and 'self-manmade decisions'. In other words, a person can connect their consciousness to their so-called "blind spot" or "silent self" from an object of desire through an intent rather than an instinct in order to arrive at an intuitive thought, see Steiner (1996); Dijksterhuis (2011); Mosmuller (2018) and/or Zajonc (2008).

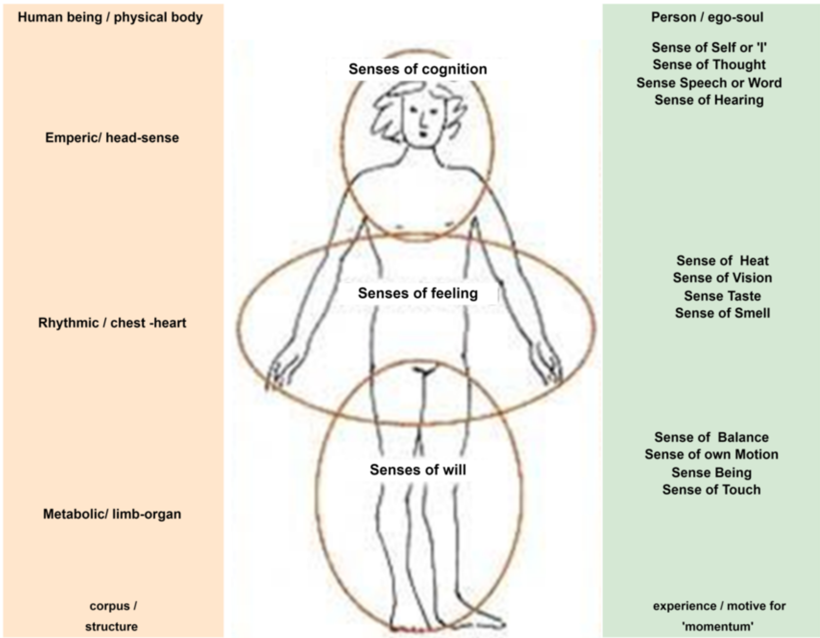


Figure 1.14: The link between the threefold man and the twelve senses.

Note: intuition means literally 'in-sight, looking inward, contemplation' (also called a spiritual perception as opposed to instinct which means natural prompting and is said to be blind, since it is an act of non-conscious or impulsive recognition). The resulting action or movement, (which is actually the resultant of the emerging I-force and the consciousness process mentioned earlier,) says something about man’s unique self and his individual purpose, which can be transformed into an ‘action of response’. We argue here that this intuitive thinking can also be complemented by a form of logical thinking that is also a formal process of the mind. This form of formal thinking is referred to as 'system-2' or thinking slow, see Kahneman (2013). This mode of thinking is one of deliberation (where deliberation is etymologically interpreted as the beginning of a liberation/freeing process). Deliberation is a process of thoughtful consideration of options, usually a-priori to joint decision-making. Deliberation emphasises the use of (deductive) logic and reason, as opposed to creativity or dialogue (inductive). Whereas deliberation is primarily seen as a logical act of reasoning with one's outer environment, intuitive thinking is an act of unlocking one's inner will. When the two coincide (are unified) then by definition this leads to a synthesis solution as a free thinking result (see dialectical thinking principles of Hegel (2021) and/or Steiner (1996)). We will see this unification process of intuitive and slow thinking later (Chapters 3, 4) on as an important foundation for Odesys's extended theory-U, that is a theory of redesign and change management, see Scharmer (2016) and/or Glasl (1998). For the time being we will suffice with the new integration of the aforementioned fast-slow (system 1-2) with the instinctive-intuitive thinking in the context of design and decision-making, resulting in the so-called nine-fold human design and decision making diagram, see Figure 1.15.

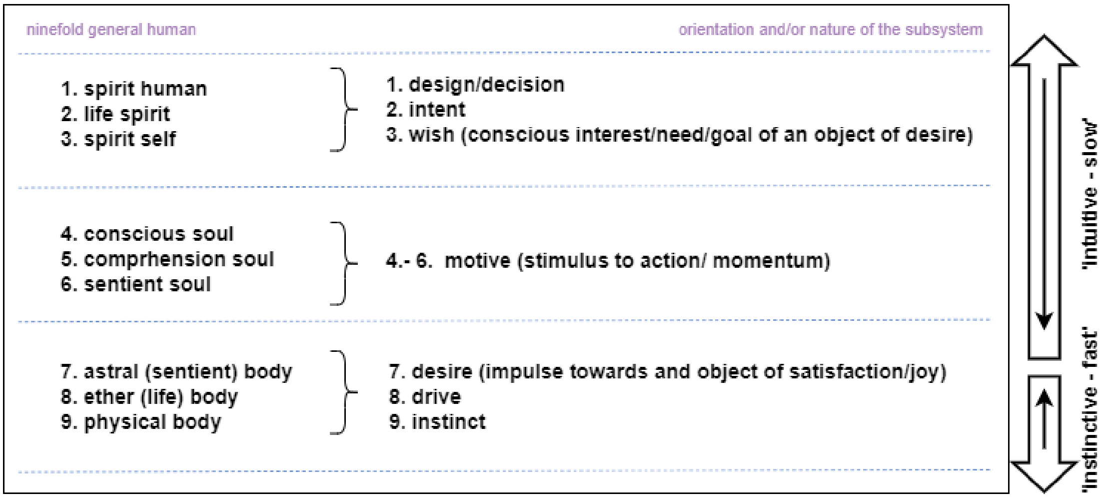


Figure 1.15: Ninefold of human being linked to design and decision making, further developed by Wolfert from Kahneman (2013) and Steiner (1996).

Note that the motive gives direction (a purpose) to the action; the impulse (stimulus to act or change of momentum) actually moves someone. For example, a person acts out of a sense of gratitude towards a helpful friend (motive) and gives him a present to thank him (impulse). Motives, individual or collective, are determined contextually or strategically from the consciousness, where drives or instincts are originating from the physical elements of the body. For Steiner, however, there is one exception later acknowledged and elaborated by Gallagher (2013); Mosmuller

(2018); Varela (2017), amongst others. Namely, if a person has their action stimulated by a freely produced "thought": i.e., an "intuition" (concept, idea), then the free will that produces this thought becomes a free will that can realize the thought, see Steiner (1995). So the thought is the motive force and the impulse comes from the thinking will, see also see Chapter 2. This intuitive act of thinking allows an individual to act freely: i.e., to design and to decide from an open mind, open heart and open will, which forms the basis of Glasl's U-procedure and/or Scharmer's theory-U. We will see there that this intuitive thinking is actually an up- and downward, a double, movement in which outer and inner coincide, resulting in a new decision or design (hence already the double arrow here), see Scharmer (2016) or Glasl (1998).

(SP #5). We have seen that a symbiosis of these three parts of human being leads to the individual 'I'. We might therefore now ask what it would mean if there were an imbalance or disintegration of the human threefold and its subsystems. What would happen if one of the realms took over or overpowered one or both of the others? What might happen if the principle of living apart but not together is applied? In that case a disruption of the articulation of the 'I', the identity of the individual, comes about. This is for us the definition of disease/illness: i.e., disease arises from, and/or is, a disunity of the human threefold. We will see later that this disunity/disintegration of the threefold can also lead to "social illness" within the societal context or within an organization. Therefore, as a manager, a (re)designer of an organizational context, we will have to be able to act as a kind of 'business doctor'(physician) who is able to integrate human knowledge and competencies into organizational art, which is the so-called dialectical 3-k integration which we will see later in the ODL concept (see Chapter 9, and note that '3-k' in Dutch stands for 'kennis-kunde-kunst').

The society, a social threefold perspective

An overarching starting point is that a society (zoomed out world around us) is a living organism which is not simply a sum of the individual subsystems, but a symbiotic system with an emerging social force as a result. As a next starting point we zoom out from the human threefold principle using the self-similarity principle, allowing us to recognise at least three kinds of independent societal dimensions/ spheres/ realms/ domains again (see Figure 1.16) : i.e.,

- Economic/ commercial (e.g., manufacture, service provider, contractor etc.);
- Political/ judicial (e.g. government, public administration etc.);
- Cultural/ spiritual (e.g., art-, media, science & education institutions etc.)

This threefold is called the social threefold ('trias societas') and is based on a social theory which originated in the early 20th century from the work of Steiner (2013), and later worked on by Brüll (2019); Large (2010); Selg (2011), amongst others. The conviction here is that when economy, culture, and polity are relatively independent of one another, they check, balance, and correct one another and thus lead to greater social health and progress. A healthy societal life is thus based on a division into three autonomous areas which are 'living apart but together' (i.e., a so-called LAT relation).

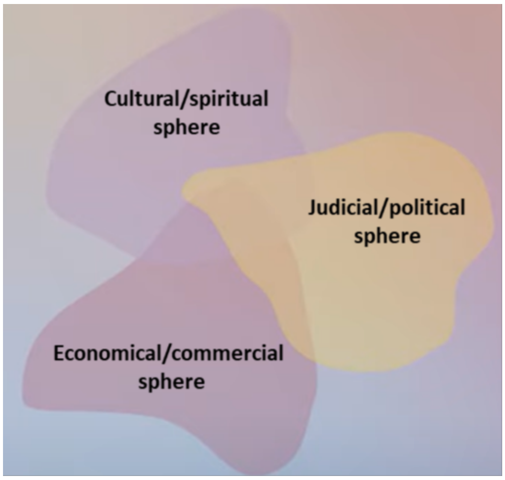


Figure 1.16: The social threefold.

Social threefolding aims to foster the main principles:

- Fraternity and associative cooperation in the economic life;
- Equality and human equality/ dignity for the conditions in the political life (rights and duties);
- Freedom and idealized design to create/manifest in the cultural life.

Intermediate notes: (1) didn't we already see this threefold with their specific qualities in the different forms of money (buy-fraternity, loan-equality and gift-liberty)? (2) the well-known 'trias politica' can be found in the essence of legal life via the self similarity principle, see Figure 1.17. The 'trias politica' consists, or should consist in a healthy situation, of three qualitative parts to serve, to accommodate and to create of laws, regulations and policies. (3) remarkably, these three qualities are similar to French Revolution's slogan, Liberté, Égalité, Fraternité. (4) zooming out into the 17th-18th centuries teaches us the following: at the time of the French Revolution, which was mainly about equality in legal life, Europe had two other revolutions a cultural revolution ('Sturm und Drang, Idealismus') from Germany and an industrial revolution from England (economic motive).

Steiner, amongst others (see e.g. Brüll (2019), Large (2010)), suggested the three would only become mutually corrective and function together in a healthy way when each was granted sufficient independence. He argued that increased autonomy for the three spheres would not eliminate their mutual influence, but would cause that influence to be exerted in a more healthy and legitimate manner, because the increased separation would prevent any one of the three spheres from dominating the others, as they had frequently done in the past.

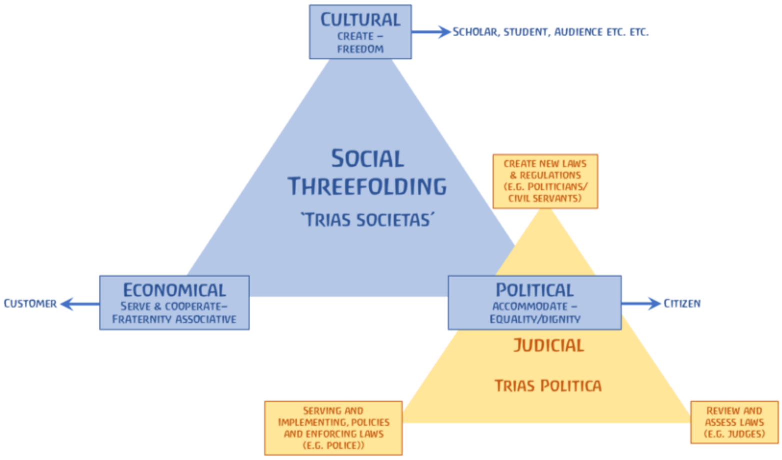


Figure 1.17: Trias societas/politica: the social threefolding realms and its self-similarity principle.

Recapitulating, we saw how the ordering principle, the social threefold division, divides societal life into three autonomous areas which are 'living apart but together' (LAT relation) and have specific embedding societal dimensions. Now the question remains how within the symbiosis of these three spheres, and from the interaction of the people within and between spheres, an emerging social force can result. For this we must consider the so-called prime social phenomenon, see Brüll (2019), Large (2010), Selg (2019). The gist of this phenomenon is as follows. When two people face each other, one always tries to rock the other to 'sleep' and the other always tries to stay 'awake'. This, to paraphrase Goethe, is the primordial phenomenon of social science. The social phenomenon takes place in the encounter of man with man and is ideally that which makes people rise above himself. So from the human interspace, the social force emerges in a human dialogue, see Buber(2004) and/or Bohm (2004). In other words, the emergent social force which characterises the social identity of a society originates from the human interspace acting from and between the tripartite societal realms. We can now also conclude that when there is an imbalance between the three realms because, for instance, one of the realms exerts a supremacy on the other(s), no healthy sociality can emerge: i.e., a sick or a-social society is a society with an unbalanced social threefold. Realising this can help both in the diagnosis and the remedy of this illness.

We end this subsection with the overview of the main threefolding models we have looked at so far, with their interrelationships and/or inversion principle of plant, man, and society, see Figure 1.18. We will regularly revisit these threefolding results in the following sections to better understand and model the act of managing and designing.

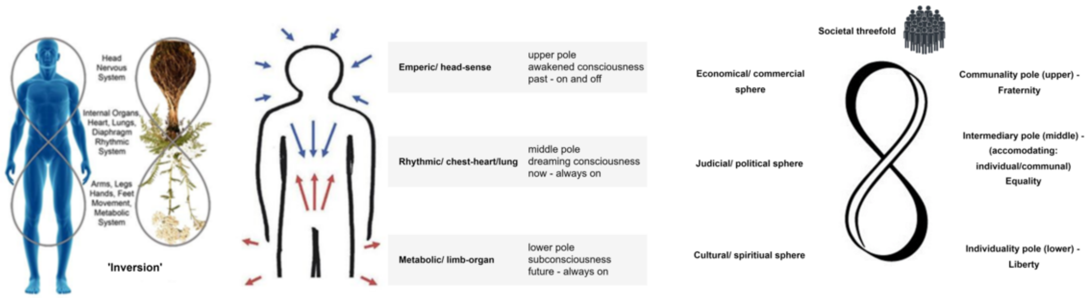


Figure 1.18: The threefold of plant, man and society and their inversion principle.

Note that within the societal systems economy is about cooperation in the world ('looking each other straight in the eyes and perceiving each other's need in the world') and is therefore connected to the upper pole area, that of observation and translation (from 'outside to inside'). Culture is the source for society (what would a society be without) and is therefore connected to the lower pole area of (re)generation and (re)purpose. This may sound counter intuitive but we will see later that creation and free individual will 'belong' in this area. Politics and its legal life is about setting conditions and policies and supporting the other areas, something typically linked to the middle pole area of equality and distribution.

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Chapter 2

Design in the context of science & engineering

Science (or research) and technology (or engineering development) are almost identical in the eyes of most people. This misconception originates in the enormous, and continuous, influence of science on technology. In this manner one may equate the methods of technology, including design methods, with the methods of scientific research. The honourable state of service of the methodology of scientific research probably contributes to this misconception. The methods of science have been contemplated – obviously with success – for several centuries, while the methods of technology have been the subject of study for only a few decades now. In this Chapter we explain first the fundamental differences between empirical science and technology, the differences in aim and in process, and how they interact and provide mutual assistance, based on a new state-of the art Research & Development (R&D) process flow diagram, as developed by Binnekamp and Wolfert.

Moreover, we will distinguish the difference between physical (object) and social (subject) sciences both from an empirical viewpoint and from a new four quadrant (4Q) model for the observable reality, as developed by Binnekamp and Wolfert and introduced for the first time here. Finally, we invite the reader to take a self-schooling path in order to understand the process of design which is a conscious human act from a plan or scheme in the mind towards matter for, and in connection with, other humans. We argue here that this process cannot be purely one-sidedly empirical. Therefore the empirical scope will be extended in another new four quadrant (4Q) model, as developed by Wolfert, in which object/subject forms one axis and matter/mind forms the other. The purpose of this new 4-Quadrant model is to facilitate the previously mentioned positioning question of Odesys within a holistic scientific context.

Bringing this Chapter out in the 'open' at all is exciting, of course. Especially since most scientists and designers a-priori often avoid the fact that science and engineering is more than just empiricism. Before you continue reading, we would like to share the following quote with you: "Ask us or dialogue with us and not only with yourself if you want to understand us....and, if you are really willing to empathize with us, don't just impose your existing interpretations on us, like many critics do". We hope this open-ended Chapter will contribute to a better understanding of the relation between the essence of open design systems and con-scientific perspectives on R&D. This is an invitation to open your mind, heart, and will for the remainder of the book that follows. Note: we will summarize in Sections 2.1 and 2.2 only the essential basic elements of R&D (research and development) for the Odesys methodology. These build on, and/or show, specific elaborations of the classic work of Roozenburg & Eekels (1995). An enlarged reference list for a more extended con-scientific perspective is included at the beginning of Section 2.3. Other important basic work references are included in the text.

2.1. Scientist versus engineer

The word science is derived from the Latin word scientia, meaning 'knowledge'. Science is defined as a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe. The word engineer (Latin ingeniator) is derived from the Latin words ingeniare ('to create, generate, contrive, devise') and ingenium ('cleverness'). Engineers are professionals who invent, design, analyze, build, and test machines, complex systems, structures, gadgets, and materials to fulfill functional objectives and requirements while considering the limitations imposed by practicality, regulation, safety, and cost. It is important to make this distinction because the line of reasoning and end result that scientists aim for is fundamentally different from that of engineers. Where scientists ('researchers') strive for knowledge acquisition, engineers ('developers') strive for design action. This closely relates to the two domains that humans function in: the domain of the material reality and the domain of the mind. Given these two domains we can distinguish two directions: 1) a process from the outside to the inside (from the material reality to the domain of the mind) that we call knowledge acquisition - and, 2) a process from the inside to the outside (from the domain of the mind to the domain of the material reality) that we call design action. The process from the outside to the inside is directed towards acquiring new knowledge of the world. The process from the inside to the outside is directed towards change of the world, i.e. designing/creating/developing new engineering solutions, see Figure 2.1. Both scientists and engineers start with a problem. This problem points to an unsatisfactory situation which one wants to change into a more satisfactory one.

Incitement 2.1 Science of the artificial

(Prof. Herbert Simon, interdisciplinary scientist and Nobel Prize winner in economics)

Some radical viewpoints on (humanity) 'sciences of the artificial', which could be used for engineering design conspection?

"... Eventually it becomes clear that human beings themselves belong to the realm of the artificial. Indeed, they are probably the most important class of 'artifacts' given that they are able not only to create other artifacts but also to re-engineer themselves to best fit changing circumstances (i.e. 'reconfigure the appreciative basis for their existence')."

" .. We can conclude that, in large part, the proper study of mankind is the science of design, not only as the professional component of a technical education but as a core discipline for every liberally educated person."

"... Human beings' external environment is complex, but their inner environment, the 'hardware', is straightforward. It consists of a system that is basically serial in its operation, that can process only a few symbols at a time and that is relatively slow to transfer information to long-term memory. Superimposed on this are sets of generic control and search-guided mechanisms, and memory-based learning and discovery mechanisms that permit the system to adapt with gradually increasing effectiveness to the particular environment in which it finds itself."

"... From a reading of evolutionary history — whether biological or social — one might conjecture that there has been a long-run trend toward variety and complexity. If there is such a trend toward variety, then evolution is not to be understood as a series of tournaments for the occupation of a fixed set of environmental niches, each tournament won by the organism that is fittest for that niche. Instead evolution brings about a proliferation of niches (i.e., a purposive accumulation)."

"... Our essential task — a big enough one to be sure — is simply to keep open the options for the future or perhaps even to broaden them a bit by creating new variety and new niches."

"... Many of us have been unhappy about the fragmentation of our society into two cultures. Some of us even think there are not just two cultures but a large number of cultures. If we regret that fragmentation, then we must look for a common core of knowledge that can be shared by the members of all cultures. A common understanding of our relation to the inner and outer environments that define the space in which we live and choose can provide at least part of that significant core."

For scientists the problem is that the available knowledge (a collection of factual statements about the world) is not aligned, or is insufficiently aligned, to the empirical facts. The facts are unassailable; hence the aim of scientific research is to change, and respectively expand, the collection of factual statements (which appeared to be insufficiently true) in such a manner that they align better with the facts. The scientist (researcher) aims to elaborate from existing observations of the past and of the empirical world a new comprehensive theory and/or knowledge that can explain these observations.

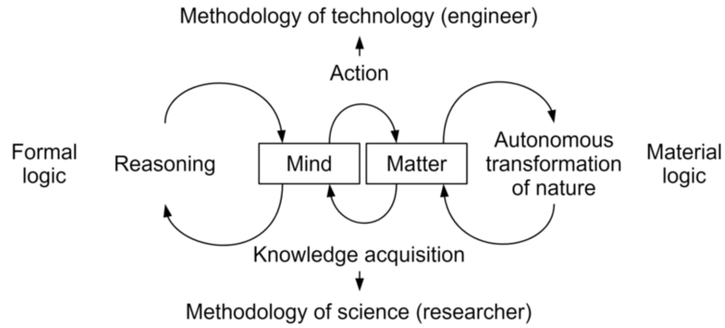


Figure 2.1: Methodology of science/researcher and technology/engineer (elaboration of Roozenburg & Eekels (1995)).

For engineers the problem at the onset is that the facts are not aligned with our values and preferences concerning these facts. And since (in the first instance) our values are unassailable, this discrepancy leads to us making it our aim to change the facts, i.e. changes to the material world. We want to create a material condition which agrees with our values and preferences. This requires design or development action, which requires technical means and must be engineered, i.e. designed. The engineer (developer/designer) aims to develop from an impossibility in the now and in the material world a fit for purpose artefact that transforms this impossibility into a new possibility in the future.

Figure 2.2: A scientist versus an engineer.

The essential scientist/engineer differences are summarized in Figure 2.2. For this picture, suppose a scientist and an engineer are both lying on the beach in the sun. The one wants to understand the relationship between the position of the sun and moon and the tidal movement and the other wants to develop a new product that can extract energy from the sun (and/or from tides, wind, or waves).

2.2. Empirical R&D, the 4-Quadrant model

Now that we have distinguished between scientists and engineers, we must also further define the methodologies and/or methods they use, because their processes are completely different. Clearly, research and development are somehow similar. They have the same number of elements which, moreover, relate to one another in a similar manner. One could conclude that technology is merely a form of applied science and that, if you have scientific research, you 'automatically' have technology and engineering development. We will show, however, that this train of thought, which is indeed widely prevalent, is incorrect. To do so, we will explain the essential methodological differences between the two process flows. Note that in this section we discuss R&D within empirical/observable reality context (within the open-ended con-science section 2.4 this will be elaborated further).

R&D methodologies

Figure 2.3 shows the basic process flows of scientific research and engineering development methodologies, one beside the other. We shall refer to these from now on as the research and development process flows, respectively. We will now outline the differences between these R&D process flows.

Two types of problems We already stated that both process flows begin with a problem. These problems appear to be different already:

- The research process flow is triggered by a discrepancy between current facts (derived from observations) and our existing knowledge. The aim of the process is adjustment of our knowledge to the facts. In other words, we want to understand something that we do not fully understand now. This is the scientific knowledge acquisition process.
- The problem at the onset in the development process flow is a discrepancy between current capabilities and our values. The aim of the process is adjustment of current capabilities (by means of the engineered system) to our values and preferences. In other words, we want to be able to do something we cannot do yet by changing the material world. This is the engineering design process.

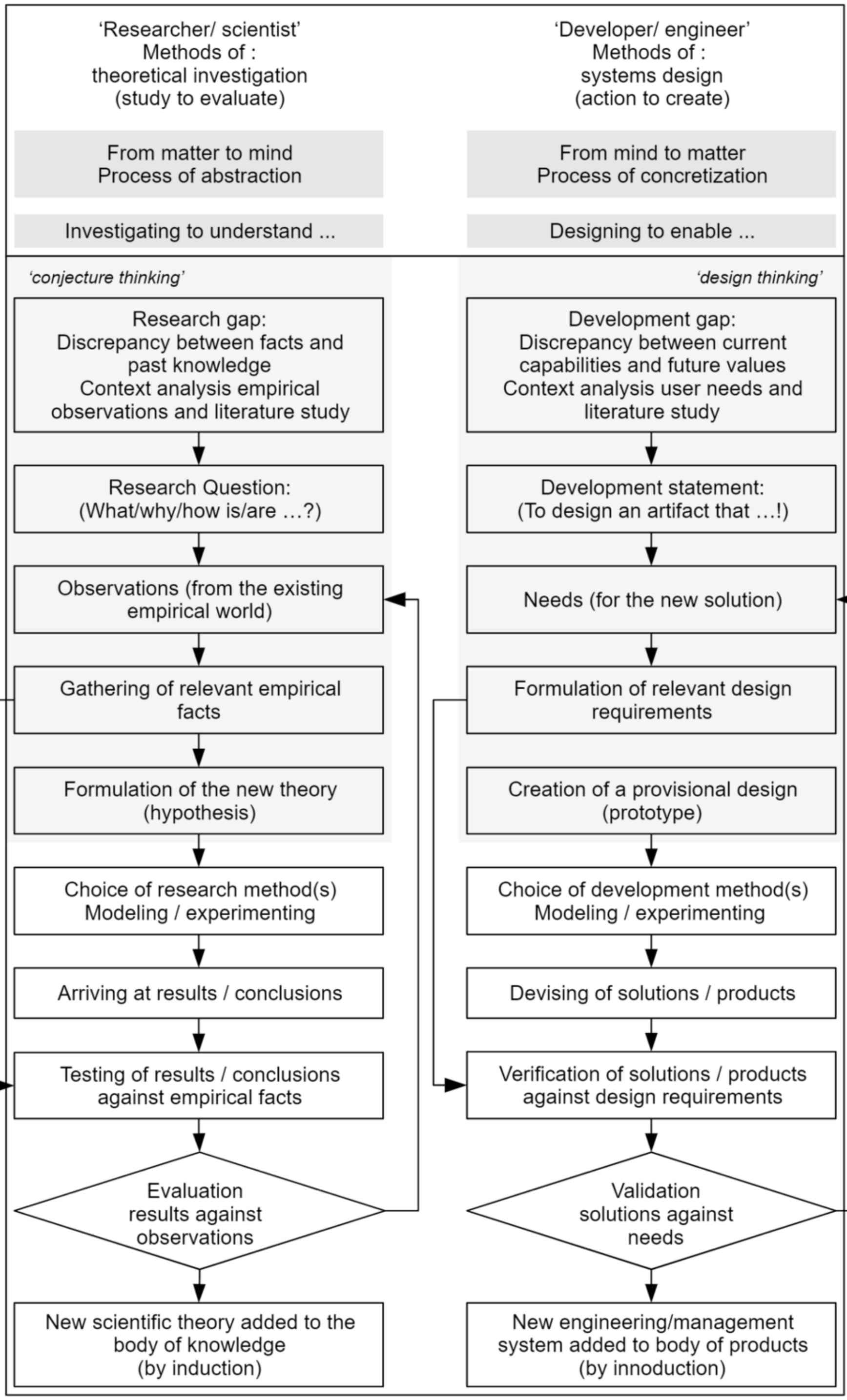


Figure 2.3: The Research and Development process flows, within an empirical/observable reality, further developed by Binnekamp and Wolfert from Roozenburg & Eekels (1995).

Observation versus needs Research occupies itself with the existing real world and with our representation thereof in factual statement. Development, on the other hand, occupies itself with a not yet existing, but (hopefully) feasible world, or worlds. The observation phase in research originally started with the observation of facts from the empirical world that did not agree with existing theory. In order to improve the theory, we need more than the establishment of one or a few 'anomalous' instances. We therefore need purposeful observation to show that the facts indeed do not agree with existing theory. This phase leads, by means of induction, to the construction of a hypothesis. The analysis phase in development is aimed at possible worlds guided by our needs. In this phase one can ask oneself in reasoning under what conditions a world that has been thought up will be both feasible and desirable. This phase leads, by means of deduction, to the set of requirements that the engineered system will be judged upon and a provisional design prototype as a first functional impression of the solution to the problem. Note that both the construction of a hypothesis and the creation of a prototype require creativity.

Results versus solutions The following two parallel elements of the two process flows are 'results' and 'solutions'. It should be possible to derive the phenomena to be explained or predicted by means of deduction, from the theoretical relationships acquired from induction. This is what one tries to do in the 'deduction phase'. We can state that deduction in the research process flow leads to a categorical explanation and/or prediction of one or more aspects of reality. Arriving at results is done by means of a chosen research method. The results will be tested against the hypothesis to prove the general validity of the new theory. The application of development methods will lead by means of 'innoduction' to a provisional solution that meets the user needs, see Roozenburg & Eekels (1995). This is what will be verified against the requirements. Appendix A contains an overview of the different research and development methods.

Testing versus verification Testing within scientific research can direct itself to the explanatory power or the predictive power of the postulated laws or theories. In view of the inductively acquired hypothesis, deductively a prediction has been made (with or without the help of an experiment) on facts to be observed in the future. In the testing procedure these facts are observed and compared with the prediction. Does it fit the observations? If not, to what extent do the observations 'support' the hypothesis, that is how 'true' is the hypothesis? During verification in the development process flow, comparisons are made as well, albeit not between fact and theory, but between (simulated) system behavior and the desired behavior of the system to be developed. Does the engineered system meet the requirements on all system levels? If not, what adjustments need to be made to (parts of) the system?

Evaluation versus validation In the research process flow 'evaluation' does not judge only on how well predictions fit observations. A decision is also taken of whether the goal laid down (improved theory) has been sufficiently attained, or whether more observations are required. Hence, the feedback arrow which runs in Figure 2.3 from the element of 'evaluation' back upwards. If the evaluation has been satisfactory, it is decided to add the knowledge which the process has yielded to the acreage of knowledge in the domain of the mind. Usually this takes place more explicitly in the form of a scientific publication. In the development process flow we encounter the element 'validation' at this level. As with research, validation does not judge only on whether or not the obtained solution meets the requirements, but also whether the goal (an improved system) has been sufficiently attained, or whether an adjustment of the needs is required. Finally, the decision can refer to choosing an attractive alternative from the collection of generated solutions. The process ends with the yield of a number of acceptable solutions, or - one decision step further - with the manufacturing or implementation of the most attractive solution, i.e. engineered system (artefact).

The 4-Quadrant R&D model

Natural science is one of the branches of science concerned with the description, understanding and prediction of natural phenomena, based on empirical evidence from observation and experimentation. Physics is a natural science that involves the study of matter (tangible objects) and its motion through space-time, including concepts such as energy and force. Technics (technology) as part of physics is the theory of practical/industrial arts/crafts and/or the application of such knowledge to achieve practical/industrial goals. *Social science* is one of the branches of science, concerned with the study of societies and the relationships among persons (living subjects) within those societies. Economics is a social science that studies the production, distribution, and consumption of products and services. Management as part of economics is defined as the organization and coordination of the (human) activities of business organizations to achieve defined objectives. Management consists of the interlocking functions of organizing, planning, controlling, and directing a (human) organization's resources in order to achieve its objectives.

We have now distinguished between the physics from the natural domain and management from the social domain and for this we have already made the distinction between *scientific research* (investigation) and *engineering development* (design). This allows us to define a research and development framework containing four types of R&D domains. Figure 2.4 shows the distinction between: 1) the research-oriented approach aimed at understanding, focusing on either physical objects or human organization processes, resulting in new knowledge following from a research question and, 2) the development-oriented approach aimed at enabling, focusing on either objects or processes, resulting in new solutions. Note: the Figure 2.4 is the so-called 4-Quadrant (4Q) model and was developed by Binnekamp and Wolfert, as an extension of Roozenburg & Eekels (1995).

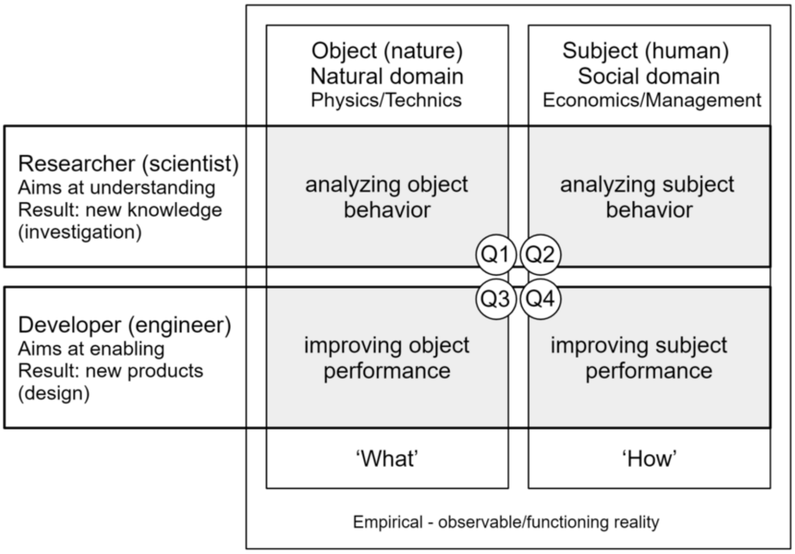


Figure 2.4: 4-Quadrant (4Q) model with four types of empirical R&D domains.

Depending on the quadrant, the methods used to arrive at the graduation deliverable will differ. Figure 2.5 shows typical methods, either for research (Q1/2) or development (Q3/4). Scientific research, when focusing on physical objects, makes use of research methods such as lab testing, statistical analysis, sensoring/monitoring, data mining, etc. Scientific research, when focusing on human organization processes, makes use of research methods such as case studies/focus groups, surveys/interviews, statistical analysis, evaluation, etc. Engineering development, when focusing on physical objects, makes use of development methods such as physical/numerical modeling, technical optimisation, product lab testing, proof of concept validation, etc. Engineering development, when focusing on human organization processes, make use of development methods such as systems modeling, multi-objective optimisation, simulation/programming, model testing and validation, etc. A more exhaustive list of research and development methods is provided in Appendix A.

Finally, the formal distinction made in this section between the scientist/ researcher and the engineer/developer does not imply that they work entirely in their own specific cycles and that the work of a researcher has no development components at all, or vice versa that a development/design project has no research component at all. For example, it is not uncommon that, before the start of a design process, more knowledge is required. For the acquisition of this knowledge the research cycle can be used. For instance, in order to optimise an engineering system the relation between the different engineering variables needs to be better understood. In other words, it can be that the engineer must carry out some (minor) empirical research as part of the development process. We emphasize that in that case the research cycle precedes the development cycle and the line of reasoning for the research cycle will be opposite to the development cycle as mentioned earlier. The main focus of the engineer, however, will be on the development cycle. Conversely, a researcher may need to design a specific experiment to answer their main question or to prove a hypothesis. For this, the researcher can go through a (mini) development cycle as part of the research process. The latter should not be referred to as 'research by design', which is a misleading term in the context of research and development because the main focus of the researcher is to acquire knowledge by designing an experiment as part of the research method (in this example).

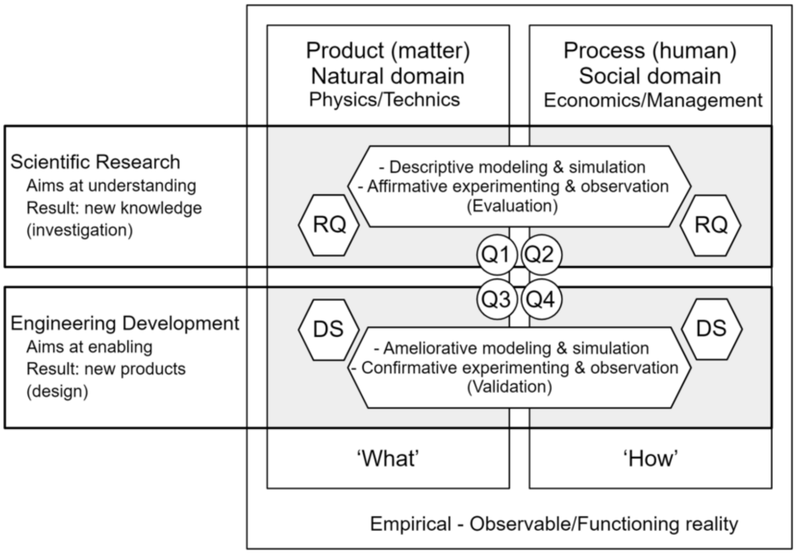


Figure 2.5: 4-Quadrant model of empirical R&D domains and the nature of their R&D methods.

4-Q model applied to a real-life project Let us consider the 'Rotterdamsebaan road project' aimed to improve the accessibility to The Hague and the region. For each quadrant we give examples of possible research questions (RQ) and development statements (DS) relating to this project and the related research or development process, see also Figure 2.6. Moreover, the interested reader in industrial R&D management and innovation is referred to Van Gunsteren & Vlas (2022). The example RQs and DSs read as:

Q1 - RQ: "What is the effect of the tunnel boring machine on the geometrical location of existing infrastructure?"
Such a question relates to the physical effects of the tunnel boring machine on its environment, such as existing real estate. It requires measuring over time the exact position of building components by means of measuring instruments. It would require lab testing of the instruments, statistical analysis of the acquired sensor and monitoring data over time, and possibly data mining. The end result would be insight into whether or not change of the geometrical position of building components can be attributed to the tunnel boring machine.
Q2 - RQ: "What is the relation between project management team composition and acquiring project sustainability goals?"
Such a question relates to gathering insight into the effect of team composition on the realization of certain project goals that determine whether or not goals with respect to sustainability have been achieved. It would require multiple case studies of which the Rotterdamsebaan road project would be just one, setting up and organizing surveys or interviews, and performing statistical analysis on the results obtained. The end result would be insight into which factors in relation to team composition contribute to achieving goals that define sustainability.

Q3 - DS: "To develop a machine that enables the re-use of existing asphalt for new roads." Such a statement relates to the design of a crushing, filtering, and mixing machine that maximises the output of asphalt material that is of good enough quality to be used for the new roads. It will require physical and/or numerical modeling of the recycling process, possibly in combination with lab testing and optimisation of the machine so that it can produce material of good enough quality. The end result would be a design of a first 'proof of concept machine'.

Q4 - DS: "To develop an optimisation tool that enables finding the optimal infrastructure intervention strategy for an infrastructure network."
Such a statement relates to optimising the timing of infrastructure interventions (e.g. maintenance, renovation, etc.) so that they have minimal impact on society. It would require modeling of the infrastructure network planning, optimisation of intervention measures using simulation, and finally testing and approving the created decision support model.

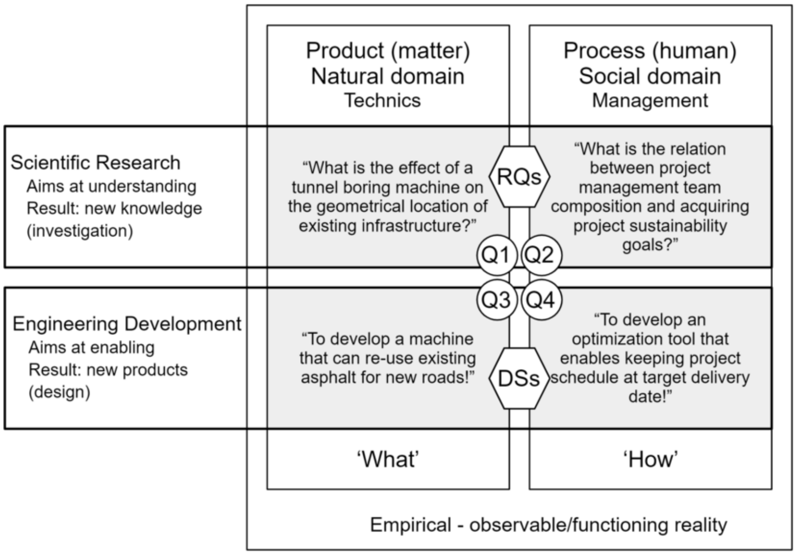


Figure 2.6: 4-Quadrant model of empirical R&D domains and types of research questions (RQ) and development statements (DS) for a real-life construction project.

4-Q model applied to an engineering management faculty We now consider research and development within both civil and/or offshore engineering and construction engineering and management domain. For each quadrant we give examples of possible research questions (RQ) and development statements (DS) relating to this faculty and the related research/development process, see also Figure 2.7. The example RQs and DSs read as:

Q1 - RQ: "What is the buckling behavior of I-section high strength steel columns?" Such a question relates to the physical behavior of a steel column. It requires lab testing where by means of measuring instruments the buckling strength under different conditions can be determined. It would involve mathematical modeling of the material behavior. The end result would be an improved insight into the material behavior.
Q2 - RQ: "What is the last planner system's (LPS) impact on project cultures in terms of partnering?"
Such a question relates to gathering insight into the effect of a specific project management control system on the project's culture and related associative organizational properties. It would require multiple case studies, setting up and organizing surveys or interviews, and performing statistical analysis on the results obtained. The end result would be insight into whether the application of the LPS has an effect on the project culture and related mutual understanding.

Q3 - DS: "To develop a pile driving system that enables the removal of piles without disturbing sea life."
Such a statement relates to the design of a pile driving machine that uses a novel pile driving technique such that vibrations and noise disturbance are minimised. It will require physical and/or numerical modeling of the pile driving process, possibly in combination with lab testing, and optimisation of the machine so that it can meet the stated requirements. The end result would be a design of a first 'proof of concept machine'.
Q4 - DS: "To develop an optimisation tool that enables keeping a project schedule at target delivery date."
Such a statement relates to mitigating the effects of risk events and project disturbances so that they have minimal impact on the project delivery date. It would require modeling of the network planning, optimisation of mitigation measures using simulation, and finally testing and approving the created decision support model.

Figure 2.7: Four types of R&D projects and related research/ development methods for an engineering management faculty.

Incitement 2.2 Ethics and morality

(Dr. Rudolf Steiner, philosopher/ humanities scientist)

A radical viewpoint on ethics and morality, which could be used for engineering design conspection?

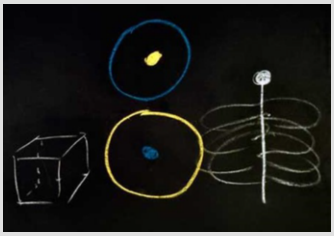
"... There is no separate science of good action. There are no general prescriptions for what people should do. Ethics can only exist as descriptive of facts. It can describe what norms and values were or are actually used by individuals or groups, identifying the motives and momentum that have worked or are working concretely in individuals."

"... Ethical research has only one fundamental hold: the ability of individual human beings to act freely. Free action occurs when the 'contradiction' between motive and impulse is removed by the fact that both coincide in pure intuitive thinking. It is not some interpretation of the term 'good' that is the criterion, but the understanding that free actions exist. The basis for ethics is the intrinsic ability of individual human beings to act freely."

"... Morality can only be created by a human being. Where an individual initiates something out of free will and thus from the idea, morality is created. The individual adds something from himself, out of the 'ego-reach' (from the inner self), to the world. The one who acts dutifully, maintaining standards obediently and decently, is by no means despicable, but neither is he moral. He continues the past without creating future. Moral is the action that creates future."

"... The so-called noble statement is actually an aberration: 'There is a need to educate people first, to improve morality'. Spiritual science, however, says: emphasis on this principle does not do it alone, but the means by which the soul can be ennobled must be imparted. For if by a spiritually directed worldview the souls are ennobled and sharpened, then circumstances and external relations, which are always a mirror image of what man thinks, will emulate. Not by circumstances are people determined, but, insofar as circumstances are social, these circumstances are made by people. If a man suffers under social conditions, he suffers in truth from what his fellow men inflict upon him."

What might this mean for the open design system and its outcomes? At least let it be food-for-thought during the conspection of socio-technical design synthesis outcomes...



2.3. Values of science & engineering

In this section, we want to capture the essential difference between the value of science and engineering. This ultimately determines how we can position design within the empirical R&D context (see further Chapter 9).

Scientific research

Any scientific theory lasts only until it is replaced by a 'better' one. This negation principle is based on Popper's falsification principle. A theory like 'all swans are white' is a theory that satisfies Popper's principle because it is falsifiable. The theory holds until the first non-white swan is seen. An important consequence of Popper's principle is that a theory can never be seen as the ultimate truth. A statement such as 'the science is settled' is therefore contrary to Popper's principle. Note: this means that a hypothesis and a related theory including its possible limitations will hold until it is overturned by a new one and the aforementioned limitations are (partially) dissolved.

The question then is how 'better' is defined as the motivation to exchange the old theory for the new one. For this, 'Ockham's razor' is used. Ockam's razor is a principle that states that when two explanations exist for the same phenomenon, the simplest explanation should be chosen. The principle of scientific progress is not complicated. A theory is used as an explanation for phenomena in reality. A useful example is the transition from the geocentric model of the universe to the heliocentric model. The old theory was that the Earth is at the center of the universe. However, this theory could not be used to explain why some planets exhibit retrograde motions. For example, Mars moves from right to left, but sometimes this movement is reversed, after which the planet continues from right to left. In order to be able to explain these movements, a complex system was used. Epicycles played an important role in this. These are auxiliary circles to be able to explain the retrograde movements. A new theory, where the sun was placed in the center, could explain these movements without having to use complicated models such as the epicycles. The new theory thus satisfies the principle of Ockham's razor and must be preferred over the old theory. A final important question within the context of (empirical) sciences and engineering is the issue of reliable 'verification and validation'. Reproducibility/replicability is a core principle in this. In all four quadrants, the reliability of knowledge and product acquisition or generation is paramount. Empirical claims about research and development should become credible not by the status or authority of their originator, but by the reproducibility of their supporting evidence as a means of verification. Scientists/researchers try to transparently describe the methodology and resulting evidence used to support their claims/hypotheses. Engineers/developers seek to demonstrate that their new product meets the user requirements it was designed for and that the result adds value. So as a result, we can state that verification: (1) in the empirical research/science context is about the replicability of the result of observation/new knowledge , (2) in the development/engineering design is primarily about the replicability of the constructed artefact/new product. (2) is most probably different for mind sciences (e.g. mathematics or logics), because of

its deductive axiomatic nature or specific other reasons (see next section).
Note that within the empirical context we argue that a distinction should be made between living and dead nature (between subjects and objects). Replicability/reproducibility assumes randomness in time and place (e.g. an experiment in which salt is dissolved in water can be repeated at any time and place with the same result). We argue that in the case of living nature there can never be 100% randomness and this is why in empirical social science sufficient repetition of and/or conditioning circumstances regarding a social experiment must be observed. In other words, one cannot apply to living nature one on one a purely materialistic-mechanistic research approach. Therefore there are even social scientists who go a step further and place their research approach under the denominator of (social) constructivism (instead of empirical sciences) in which the validation/ validity is 'more important' than the verifiability/ repeatability because knowledge and reality are actively created by social relationships and interactions (verification shift towards reproducibility of the construct rather than an exact replicability of the results, which is sort of similar to verification within an engineering design context, see next section).

The question remains how to deal with the conspection in an engineering design context, especially when it concerns socio-technical problem solving? We will address this fundamental question, particularly for the Odesys methodology, in more detail in the following sections.

Engineering development

Science deals with objective explanations of natural phenomena as stated before. Human values ideally have no place in this process. The opposite holds true for engineering development. The process of engineering development is initiated by a subjective discrepancy between what human society wants and what the current state of technology has to offer. What is considered the 'best' engineering solution is also subjective as it depends on human individual values and preferences. Therefore, there can be no single objective best solution. Could we thus conclude that design is not a part of empirical sciences (we return to this in the next section)?

As David Hume stated: "Beauty is no quality in things themselves: It exists merely in the mind which contemplates them; and each mind perceives a different beauty. One person may even perceive deformity, where another is sensible of beauty; and every individual ought to acquiesce in his own sentiment, without pretending to regulate those of others. To seek the real beauty, or real deformity, is as fruitless an inquiry, as to pretend to ascertain the real sweet or real bitter."

Ethics relates to moral values. Because engineering is tied to values and/or preferences it must therefore also relate to ethics. As Steiner stated: "There is no separate science of good action... and, the basis for ethics is the intrinsic ability of individual human beings to act freely" (see incitement 2.2). Should engineers still be critical of the technology that is their livelihood, or should they only be interested in making their machine work, indifferent to any long-term social impact? For example, the American Society of Civil Engineers answered this question by adopting a code of conduct for their members (already in 1914). According to this code engineers uphold and advance the integrity, honor, and dignity of the engineering profession by: 1) using their knowledge and skill for the enhancement of human welfare and the environment, 2) being honest and impartial and serving with fidelity the public, their employers, and clients, 3) striving to increase the competence and prestige of the engineering profession, and 4) supporting the professional and technical societies of their disciplines (see: asce.org/career-growth/ethics/code-of-ethics).

The question then arises how to value the 'enhancement of human welfare and the environment' of a given engineering artifact. If we take a military drone, specifically engineered for destruction: did the engineers working on this project enhance human welfare and the environment? We can also take a Dutch brewery called Gulpener that recently re-engineered their brewery installation and takes pride in how it values socio-eco principles. Although both examples are value driven, we can use Maslov's theory of the hierarchy of motivation/needs, for example, to add some perspective to the valuation of engineering activities. At the bottom of human needs, according to Maslov, are physiological/ biological needs that are vital to human survival. Some examples of physiological needs include food, water, and breathing. The military drone may also relate to this level as it closely relates to needs for survival. At the top are transcendence needs. "Transcendence refers to the very highest and most inclusive or holistic levels of human consciousness, behaving and relating, as ends rather than means, to oneself, to significant others, to human beings in general, to other species, to nature, and to the cosmos, see Maslow (1971). The Gulpener brewery, considering their socio-eco purpose motivation, would relate to this holistic human conscious level.

Designing leads to the blueprint of the product plus directions for its particular use. These in turn are, as a description of a larger class of possible realizations, of a general nature. Therefore engineering designing follows a line of reasoning from general to general which Roozenburg & Eekels (1995) call innoduction. Note that this innoductive line of reasoning is also applicable to pedagogy. Ideally the final design best represents all stakeholder values and preferences. In that case the optimal design solution is a mirror of all stakeholders values and preferences. The validation step is where this check is carried out: Does the proposed design solution indeed meet the users common socio-eco interests and is the designed artefact to the valuable for the user? So, outcome verification shifted towards reproducibility of the construct rather than an exact replicability of the results, and has thus become, so to speak, secondary to validation (human value validation which is 'random' by nature, and process verification rather than result verification)! According to this reasoning, we could conclude that engineering design is an academic discipline while maybe not belonging to the empirical sciences, which we will further explore in the next section.

Incitement 2.3 From mind to matter

Three men talk about their just-completed fence in a garden. They see the center-to-center distance of the posts they observe, the type of wood used, they measure the height of the fence and run through a few other design variables.... These same three men (two residents of the house to which the garden and fence belong and a friend who maintains their garden) were talking some time ago with local residents, contextual stakeholders, who also live in this environment. They talked about how to fit a new fence within the neighboring gardens, they discussed when it would be most convenient for this fence to be constructed, and many other common interests to design a new fence.... The same three men (one is an artist singer, the second an arborist, and the third a professor) talked about their ideals in art, nature, and education. From these idealized design principles, they intended to create an artful fence in which the tree would recur as a very essence with beautiful branches and where the design process would be open-ended by nature. One good evening, they had a 'gut intuition' and made a sketch based on a woven fence and then built it accordingly...

The question now is, do we see their three stories reflected in the end result or is this just a bare fence? Can we observe their ideas back in the created artefact, are these in there, or are these only in the three men or in both? And, what does this answer mean for art and architecture history, where the 'creator' is mostly no longer there (who or what then does tell his "story")? How did that path from mind to matter really unfold and how did their 'gut intuition' come about? Finally, can we actually see the gravity and normal force(s) from the chair standing by the fence? And are these forces a cause or an effect of something? And how do we model and determine these forces?

2.4. Con-science, the extended 4-Quadrant model

In this open-ended section, we first call for an extension of current mainstream materialistic science to a holistic science from the whole human both with its inner and outer world: i.e., a science from a spiritual consciousness as a continuation of pure sensorial empirical science. Both of these are complementary and form sciences as a whole, as indicated for instance by Goethe, see Bortroft (1996). We therefore term this integrative form of science here: con-science (with a reference to a conjunction of conscious and science: con-science, as conceived by Wolfert). Secondly, in this section we give an initial impetus for scientists and/or students to transform within themselves to embark on a new integrative path of intuitive thinking and develop within themselves a different kind of scientificity: i.e., 'food for thoughts'. So if you dare to take seriously at all that science is not bounded by the physically sensible, perhaps for the time being only as a hypothesis, then it is possible to start familiarising yourself with this extension and then assess for yourself what this scientificity and intuitive thinking schooling could offer (towards a holistic scientist or an ζ-engineer, see Chapter 9). Third, we conclude this section with some research questions for further self-exploration. If readers engage with these, it will help them better understand Odesys' position within this holistic science context (see further Chapter 9). After all, humans as designers design from mind towards matter for and in connection with other humans. We argue here that this position cannot therefore be purely one-sidedly empirical. We leave it to the reader to determine (t)his position after reading this section. Finally, it requires from the reader, first of all, an open-mind to enable a movement from science to con-science (in Dutch from 'wetenschap naar gewetenschap'), a journey on the edges or boundaries of the empirical/ materialistic science.

In addition to Wolfert's (practical) experience and many years of being connected with and/or training within this con-scientific context, the following references are also works on which the following sub-sections are based in part and are recommended for interested readers who would like to further educate or develop themselves in this field: e.g., Barendregt (2022); Bortoft (1996); Gallagher (2013); Hegel (2018, 2021); Heusser (2016, 2022); Husemann (1994); Katz (2011); Mosmuller (2018, 2021); Selg (2022); Simon (2019); Soesman (1998); Steiner (1995, 1987); Steiner & Mulder (2022); Varela (2017); Van Lommel et. al (2009); Velmans (2017); Zajonc (1995, 2008).

Natural-matter, formal-mind & phenomenology

We argue here that the open design process cannot be purely one-sidedly empirical. Therefore the empirical scope will have to be extended in another new four quadrant (4Q) model in which object/subject forms one axis and matter/mind forms the other. The purpose of this new 4-Quadrant model is to facilitate the previously mentioned positioning question of Odesys within a holistic science context. Before introducing this extended model, we will first distinguish three areas within science: natural-matter, formal-mind and phenomenological sciences.

Physics as part of natural-matter sciences In Greek-Roman times, man began describing cosmic movement in familiar modeling based on the geocentric worldview of Ptolemaeus: the earth at the centre and the sun and moon circling around it, the planets whirling in intricate orbits between them and the fixed stars in stable distribution across the sky dome as a spinning background. Then around 1540, Copernicus appears on the scene. He posits that the sun is in the centre: the heliocentric worldview, with which, incidentally, he also came into conflict with the church that proclaimed the geocentric worldview. In the early 1600s, a new researcher named Kepler stands up. Among other things, he concludes, partly based on the empirical preliminary work of his teacher Brahe, that the planet Mars does not follow a pure circular orbit. In the years between 1609 and 1919, he describes three new laws of motion, and with these we see Kepler slowly moving towards a mechanistic worldview.

Then, in 1687, Newton appears on the scene with his main work Philosophiae Naturalis Principia Mathematica (note part of philosophy sciences). In it, he formulates his four laws of nature in which (gravitational) force now plays a role instead of motion-causing planets spirits. Newton in this way breaks with Aristotle's 2000-year-old thesis that everything falls down because the centre of the earth is the 'natural place' of matter, but in the cosmos this does not apply according to him. Incidentally, over two centuries later, Steiner (1987) points out that Newton's understanding of Kepler's third law is purely mathematical. Such a step requires abstraction that separates experience from science. While that was necessary for the next step in our consciousness and development, this purely mechanistic view does not help us to prepare for the next step. He further points out the curious thing in Kepler's third law in which time is squared. What is essentially happening then? Perhaps this is a hint to approach time differently than we are used to in our present time. Time should perhaps be linked less as a fourth dimension to our physical three-dimensional space, but rather as something that is essentially non-physical, showing itself in our physical world as linear chronological time (an 'independent' one-dimensional affine space).

To this day, the gravity force remains a riddle. It can be computed fine and is very useful in engineering, but what is essential remains a mystery. For how can In empty space bodies attract each other (note: so are we dealing here with a law of nature based on thoughts alone?). In May 1920, Einstein gave a lecture in Leiden in which he reintroduced the now abandoned idea of ether as a medium based on his general theory of relativity but now as an imponderable non-physical medium. Later, Einstein says that empty space becomes curved in the presence of a (large) object causing a second moving object to follow its trajectory according to that curvature, which can be a circle or elliptical orbit. That approach solves some shortcomings in Newton's theory, but it also does not yet explain what gravity really is.

In 2009, a Dutch physicist Erik Verlinde advanced the hypothesis that gravitational force may well have something to do with communication. Thus, he was able to derive Newton's law of gravitation based on differences in information density in space. Thus, like Einstein, he arrives at something that also suggests the existence of an all-pervading ether, and that gravity can be considered an effect of something and not something fundamentally. That would both put the theoretical idea of dark matter in a different light and make the idea of the Big Bang obsolete. It is probably too big a leap but, when an information-bearing ether comes into the picture, the idea that information qualifies as thoughts or words (‘dia-logoi’) comes to mind. In other words, when we look at this dialectically (as in Hegel’s scientific system) could force be the synthesis or unity within the threefold of matter-being/ non-matter-essence/ force- concept? Like energy is the synthesis of visible matter and invisible light? Or even one step further, could we also experience such a connection spiritually/religiously with the word of creation that in ’in the beginning there was...’. Sprouts for a holistic or con-science practiced by scientists who in continuation to their empirical experiences take spiritual experiences seriously and are willing to further ‘ex- and/or investigate’ (in Dutch ‘onder- en bovenzoeken’) these hypotheses from an open basic attitude, standing between mind and matter.

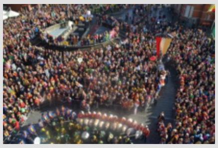
Mathematics as part of formal-mind sciences Spirituality is about the personal handling of the unknowable. The unknowable, or unknowable part of our reality, is the part to which reason and logic have no access. Spirituality is about that which transcends everyday life: not living from a system or a set of rules but from an experience-based vision of man and life. ’Certainty’ is hardly for sale in our world, and that is not an annoying side effect but rather a meaning of the first order. The nature of uncertainty in the world is fertile ground for philosophical contemplation. We might ask ourselves the question, do coincidences exist or not? Or is this uncertainty question irrelevant? When rolling a die, we simply postulate that the probability of each outcome is 1/6 and that seems to work perfectly well despite the fact that the movements of a dice could also be perfectly well described by very complicated deterministic mechanical laws. In other words we choose to use a probability model because it suits our intuition. This model provides an explanation in terms we find acceptable and a working with ”not knowing for sure” from a paradigm chosen by the scientist. For some phenomena it is obvious to use a probability model, for other phenomena there seems to be more freedom of choice.

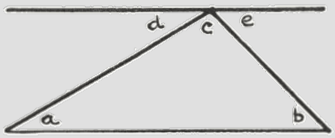
Spiritual life could be described as living in connection with all that is happening In the world around you. A sudden insight into the world is ’spiritually’ charged for this very reason because it brings the one who undergoes it deeper into connection with the reality of the world around us. When this insight is (for now) only to be followed by yourself, we quickly speak of faith. We could ask ourselves the question of what is the difference between faith and insight (quite a difficult question, by the way)? If we all shout things we think we know based on what scientists say then in a sense our ”knowledge” is also a belief. Think of regular scientific insights like ’diseases are hereditary’, ’viruses exist’, and ’particles collide in an accelerator’. These I have to believe on the basis of statements made by scientists who have studied them. Actually then it does not make much sense to think about faith and insight in this way because a lot of what we would say in life is based on faith in this way. Perhaps then the question of how we relate to the source of (spiritual) insight is more essential?

Incitement 2.4 Self-observation of mind vs. Empirics-observation of matter

Facts, such as the Eifel Tower stands in Paris, can be ascertained by outer experience and through the empiric system. A fact that 'salt dissolves in water' in a certain place, with a certain composition can also be ascertained empirically, but cannot be ratified as a universal truth all-encompassing law: i.e., an outer experience. However, no one can say that they find the mathematical truths through outer experience; but one finds them because everything is realised inwardly: 'an act of the mind'. Logic arises in the inner and not from perception. If one wants to show that the three angles of a triangle add up to 180 degrees, one does so by drawing a parallel line with the base line through the top angle and putting the three angles together in a plane; then angle a = d, b = e, c equals itself; and so the three angles equal a stretched angle, equal to 180 degrees. Whoever has once realised this, knows that it must be so for all triangles, just as one knows, once one has realised it, that three times three is nine.
These most trivial and universal truths of all, the arithmetic, the geometric, are found in the inner world, and yet people do not argue about them. There is absolute agreement about them, because today man is so far along to see these things. There is no agreement only so long as pure truth is clouded by the passions, by sympathy and antipathy? Could it then sometimes be a great truth, a great law, that the most individual truths, found in the most inner and pure way, would at the same time be the most universally valid ones? And could it be that when design, which is also an act of the mind', is emptied of passion, manipulation and power, and gone through in a pure and inner way (if possible supported by pure open source mathematical models derived from the mind), leads to a truth of and for all concerned? Or is design actually a part of the spirit-sciences or humanities (just as mathematics is part of mind sciences)? And, is it an empirical fact or an inner experience that the most beautiful Carnaval is celebrated in Oeteldonk, and for whom is this a (universal) truth? What do you see and/or perceive when you look at a man in a farmer's keel in the middle of the summer at a certain spot in a certain city, and what do you see and/or perceive when you look at this same man with the same farmer's keel at the same spot in the same city six months later during Carnaval? What can this tell you about your produced 'thought-content' and your observation with the 'naked eye of the beholder'?

Note: mathematics, which takes place in the inner mind, can, for example, prove that the surface area of two figures is equal, but it cannot, and need not, answer the question of what identity means. Indeed, this inner concept transcends mathematics, because it occurs elsewhere, namely in everything that is.



Next we might ask if mathematics itself is to be practiced in a spiritual way, or is mathematics spiritual by nature and not just logically rational? Many people will want to speak against this and argue that mathematics is simply just practiced with axiomatic and deductive logic, proving one theorem after another. When we look at it that way, there is no spirituality. But that is actually quite a flat view of mathematics in which mathematics is completely reduced to logic. Namely, no mathematician is able to derive his or her results via only logical steps from basic axioms. Logic is necessary but is not the core of mathematics. Indeed, surely no one wants to maintain that mathematics consists merely of algorithmic reasoning that a computer could also generate? If that were the core of mathematics who would want to do it? No, the core of mathematics consists of the unpredictable non-conformist and/or non-conventional ways found for problems and the way we communicate these solutions. Mathematics therefore stands above all for creativity. In communicating mathematics, we are always in need of a creative leap. There is no mathematical language that can replace understanding and insight, no formula that can express everything. What exactly happens the moment one thinks one understands what another is trying to explain to me? What does it mean that a particular result is understood by only a few people in the world? Mathematics viewed in this way is in itself spiritual because it allows people to connect with the world with each other's thoughts and with the question of what everything in mathematics now represents in the world around us: the principle of reflection (see Chapter 5 and onwards for this principle within the Odesys context).

Intermediate note: if we apply complex contour integration to solve differential equations representing a wave radiation problem within a moving object system, we can obtain poles that lie on the real axis (with an imaginary part equal to zero). This leads to meaningless results, although the mathematical operations can be performed well. Therefore, we have to apply the principle of reflection and assume here that in reality there will always be viscosity in a real-life system and that radiated waves always go from the source to the outer environment. Therefore, these poles will actually move into the complex plane and thus contribute in a physical way to the resulting mathematical outcome, see Wolfert (1999).

We argue that according to the definition in this section, this is a spiritual (mind) act, because we are connecting abstract mathematical theory with a living world around us. The truly meaningful moments are those in which you recognize why we must find a certain proposition or assertion to be true: logical verification is then nothing but a process after the fact although necessary but not really the core of mathematics. The moments of truth finding are often very spiritual moments in which the mathematical scientist connects with what is real. Such event transcends the everyday and one really does not have to be spiritual in any sense to see and feel the extraordinary power of this and the authenticity of such moments. Mathematics develops in the moments when things are problematic and at times when more is required than technical skills alone. These skills are necessary but ultimately they are not what matters. You could therefore make a comparison with art and speech. Human speech formation or music does not come about through technique alone, but it is the whole symbiosis of tones, rhythm, timbre through which music and speech 'emerge'. It is true that a good (speech) technique is necessary to be able to speak or play music. Technique is a means and not an end in itself. Art cannot be reduced to technique. To claim that mathematics is only logic is the same as claiming that art consists only of technical use of inner and outer instruments.

Phenomology (Goetheanian science) Regular materialistic-mechanical science has brought us tremendous natural scientific and technical knowledge. With this form of empirical science using the physical-sensory, it often becomes possible to satisfy human needs and (physical) desires in an easier way than before. However, it is not convenient to employ this form of science when the object of desire: (1) cannot be reached at all (or because it is only an instinct-driven object), (2) brings adverse consequences for man and environment, or (3) leads to loss of the actual human in man. Then this outward form of science will lead to disastrous events and crises which we have recently experienced.

For these reasons, it is good that other types of research also exist. That is the inward research, the research into and/or through our consciousness. An extremely successful example of this is the following. Around the year 1800 the physical theory about colours was that they are one-dimensional phenomenon. Light comes from different wavelengths and one of them determines the colour of light. The artist and (spiritual) scientist Goethe who was also interested in observation phenomena came up with another hypothesis in 1810. He stated that colours are a three-dimensional phenomenon for the following reasons: if we have 1,000 cubes that are plain but differently coloured, it is not possible to line them up in such a way that the colours flow evenly. Nor is this possible in the flat plane. However, in a larger cube of 10 times 10 times 10 it is possible to arrange the colours in such a way that the colours flow evenly in all directions. We call this observation phenomenological as it relies on direct observation independent of thought. The physicist insist that colours are a one-dimensional phenomenon. In the 19th century, the physician Young and later the physicist Helmholtz tried to unify Goethe's observations with those from physics. They hypothesized that the eye has three different receptors for colour perception. If this is so, then a single wavelength transmits three impulses to vision. Colours are then one-dimensional in their formation but three-dimensional in their perception. Thus was born the Young-Helmholtz theory, also known as the trichromatic theory, which is a theory of trichromatic colour vision - the manner in which the visual system gives rise to the phenomenological experience of colour. This hypothesis and associated theory was finally demonstrated for the first time by Svaetichin in 1956, which was some 150 years after Goethe's phenomenological observation. Our contemporary spin-off is that there has been a multi-billion dollar industry of colour photography, colour monitors, flat screens, and projectors based on the fact that we have three receptors for colour perception. Finally, we might wonder if we can 'read' back the human threefold using the self-similarity principle (as Husemann phenomenologically showed in his gut study, see Chapter 3)?

This way of Goethean science requires a certain degree of open-mindedness and courage. Actually, following this path, we want to understand something without a preconceived paradigm or a specific hypothesis, certainly not that of 'the sum of the parts constitutes the whole: integration of pieces'. Goethe, on the contrary 'differentiated from the whole' and looked from this whole the other way round, trying to perceive the primal phenomenon and trying to figure out what metamorphosis in development this phenomenon shows, see also Bortroft (1996); Heusser (2016); Husemann (1994); Selg (2022); Zajonc (2008).

Scope & span of science, the extended 4-Quadrant model

Mainstream (empirical) science has retreated into a part of reality and declared itself unfit to judge spiritual observations and theories. This situation is shown schematically in the new extended 4-Quadrant model presented below, as developed by Wolfert, see Figure 2.8. This Figure presents a broader and holistic definition of science, compared to strictly empirical science from the previous section. We call this the extended 'con-scientific' 4-Quadrant model (compared to the empirical 4-Quadrant model of section 2.2). The vertical axis of this Figure addresses the polarity between the spiritual and the material, the polarity between *mind* and *matter*, or between outer mechanistic-matter sense perception and the inner spiritual-mind (psychological) experience. The horizontal axis shows the opposition between one's own *subjective* experience and the universal *objective* reality. Between these two pairs of opposites, which span four quadrants, man must hold his ground and must acquire reliable knowledge of the world within him and around him, i.e. conduct science, see Figure 2.8. This Figure is 'a best fit for purpose' classification/ordering within the context of this book and we will interpret and elucidate it further using the following definitions (so it is a classification amongst others). Note that these definitions are ultra-short definitions of concepts that entire studies are about.

Empiricism places emphasis on observational evidence via sensory experience as the source of knowledge. Empiricism is associated with a-posteriori knowledge, which is obtained through observation and experience. The empiricists consider that knowledge can only be gained through studying or observing the physical world outside the mind, namely through sensory experiences.

Rationalism places emphasis on reason as a source of knowledge. Rationalism is associated with a-priori knowledge, which can be independent of real-life experiences. More formally, rationalism is defined as a methodology or a theory "in which the criterion of truth is not sensory but intellectual (intuitive from the mind) and deductive".The rationalists consider that knowledge is in-born and the intellect, the inner world of the mind, can therefore directly grasp logical truths. Rationalists argue that there are certain principles in logic, mathematics, ethics, and metaphysics that are so universally true that denying them causes a contradiction.

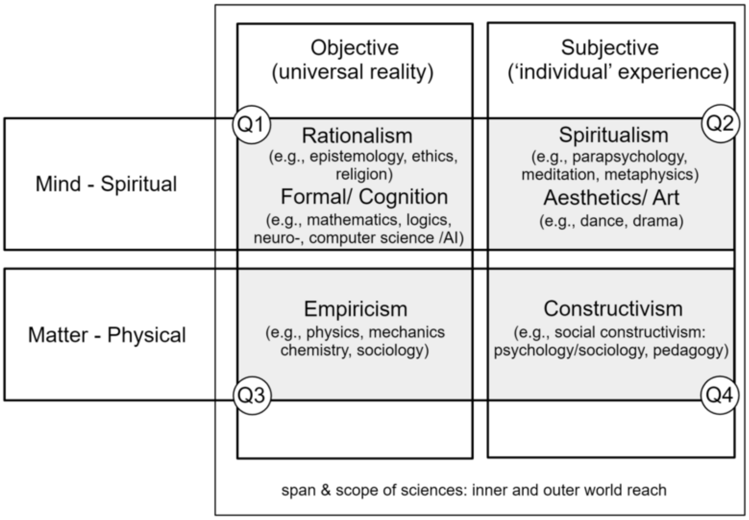


Figure 2.8: Four types of con-science domains, the extended 4-Quadrant model developed by Wolfert and broadening the empirical 4Q model from Section 2.2.

Constructivism opposes the philosophy of objectivism (the 'sum of' rationalism and empiricism), embracing the belief that a human can come to know the truth about the (natural) world not mediated by scientific approximations with different degrees of validity and accuracy. According to constructivists, the world is independent of human minds but knowledge of the world is always a human and social construction. The 'truth' is thus a social construction and can therefore take different forms every time (just as a single design question can also lead to different artifacts). According to constructivists, there is no single valid methodology in science but rather a diversity of useful methods. Social constructivism contends that categories of knowledge and reality are actively created by social relationships and interactions. These interactions also alter the way in which scientific episteme is organized.

Spiritualism is the metaphysical school of thought opposing physicalism and also is the category of all spiritual consciousness, awareness, and/or inner experiences, which can in part be objectified. The generation of knowledge here is therefore subjective and of a spiritual ("ideological") nature. Art is a good example of this,

both from the point of view of the artist and the beholder or spectator. It was for example Steiner, who again connected with Plato, who saw reality as a 're-union' of spirit (inner experience) and matter (outer observation). It is a 'unifying' theory that can be used to explain a much larger part of the world than purely from the material point of view. Even spiritual consciousness persists after death and can be contacted by the living, as seen by some spiritualists; and the afterlife, or the "spirit world", is not a static place but a place in which spirits continue to evolve. We add the following 'definition' notes to the four quadrants from Figure 2.8:
(#1) Sociology and psychology have a place in multiple quadrants because it depends on which research method/ viewpoint one uses to arrive at knowledge and how the results are verifiable (objectively or subjectively). The position of ethics and religion in quadrant Q1 may also shift in to quadrant Q2 depending on the view followed (axiomatically deduced or mindfully obtained). It may even be the case that ethics has no position within this diagram, since there is no separate 'science of good action' (see Steiner's incitement from the previous section)?
(#2) The sub-fields in quadrants Q1 and Q2 (mind/spirit) together belong to the branch of philosophy (sciences). Philosophy is the systematic study of general and fundamental questions, such as those about existence, reason, knowledge, values, mind, and language. Humanities are academic disciplines that study aspects of human society and culture. Today, the humanities are more frequently defined as any fields of study outside of natural sciences, social sciences, formal sciences (like mathematics), and applied sciences. The humanities include the studies of parts of philosophy such as language and all forms of arts, is interdisciplinary, and may be considered both a humanity and a science.
(#3) Actually, mathematics and ethics could also both have a place in Q2. As for applied mathematics, we argued in the previous section that this also has a spiritual component as soon as you connect pure mathematics with the true world (it requires the principle of reflection). It then requires a reflective dialogue to connect the mathematics via your individual thoughts/experiences (meditative aha-erlebnis); the difference between computer logics and applied mathematical modeling or between AI and art. The same goes for ethics, which can also be partly placed in Q2 (see Incitement 2.2, and the previous note (#1)). For metaphysics, this could go the other way. This is now pictured in Q2 but could also be a universal truth in Q1 according to some people (see e.g. Steiner's phenomenology of mind/spirit, in one of the following sub-sections).
(#4) Various approaches in pedagogy derive from constructivist theory. They usually suggest that learning is accomplished best using a hands-on approach. Learners learn by experimentation, not by being told what will happen, and are left to make their own inferences, discoveries, and conclusions. So, learners do not acquire knowledge and understanding by passively perceiving it within a direct process of knowledge transmission, rather they construct new understandings

and knowledge through experience and social discourse (later we will get back in Chapter 9 with respect to the constructivist ODL education method).

Now (after these definition notes), let us continue our scope & span of science 'pathway'. Contemporary mainstream (empirical) science has retreated in the lower left quadrant Q3, where it deals with universal truths and a materialistic view of reality. This restriction to this one quadrant is a choice made by science itself. While the advantage of that choice is the stimulation of technical progress, the disadvantage is that science has little or nothing more to say about the figure as a whole and thus about the total greater reality in and around man. In itself, of course, that need not be an objection. In itself, of course, this need not be an objection, but it becomes a problem when that self-selected limitation to the quadrant Q3 is overlooked an erroneous statements are made about the entire figure about the real world and humankind. Moreover, we argue that the retreat of science in the objective materialist quadrant Q3 is not problem-free either. While the accompanying development of technology has brought much social progress, its one-sided bias has been so great that nature and the physical environment (earth) are now in danger of collapsing under it. Apart from this one-sided technological approach, man's orientation has also become one-sided so that he seeks his meaning and satisfaction of needs solely in the material. This keeps failing to work because man seems to be more than the material bottom of the figure. In short, we should not define and/or limit science and its scope too narrowly.

What then might actually be the broader (philosophical) definition of science? What actually is science and what actually makes it possible to say: this is science and that might not be science. We argue in this section that science in particular is determined by the approach and/or attitude you take as a scientist towards the phenomena you want to investigate. The phenomena you are confronted with can be in all areas: in dead or in living nature, in matter or mind. So in science, it is all about demonstrating a certain objectivity and being able to look at these phenomena in such a way that you don't incorporate your own opinion and your own wishes about the outcomes beforehand and that you therefore consider them this way. In short, an objective scientific basic attitude means that you do not put your own subjectivity into something beforehand. This requires a reverent attitude and strict discipline. When we devise a scientific theory from this basic attitude on the basis of observed phenomena, it has scientific value if we can verify it. Observations need not be limited only to an outer sense perception but also through an inner sense perception, experience, and/or introspective methods (meditative/metaphysical/supernatural).

Intermediate note: There is currently a growing interest worldwide in meditation and research into its effects. One of the first and leading researchers to engage in this is the late Francisco Varela. At the end of the 1980s, he was one of the initiators of the Mind and Life Institute which brings together meditators and brain researchers (see: mindandlife.org). Many more results are expected to follow. Among others, Varela (2017) and Zajonc (2016) speak of a second renaissance: this time reaching back not only to the western ancient Greek tradition, but also to the still living eastern meditation tradition. Thus, despite the serious threats to present man and earth today, there is hope for the future.

Since in all cases in all four quadrants the reliability of knowledge acquisition (i.e., verification) is paramount, it must be demanded that also the subjective knowledge experience of the right sided quadrants Q2/Q4, especially the upper right side, is also verifiable. Even for many para-psychological events, for example, this is practically quite possible. However, when it comes to one's own verified experiences, the usual confidence in human perception often (and perhaps wrongly) takes on a strange connotation. Hence, we will take a closer look at the concept of verifying. In the regular mainstream science (research), the chosen research method and new knowledge results should be reproducible. For engineering design (development) this is different, namely the newly constructed artefact should be reproducible, but the experience and/or value is user specific and these are not reproducible because they say something about the inner (unique) experience of human beings. So, in short, we could say that the way of verification depends on how you solve problems and what domain of science you are in.

Actually, this distinction in verifiability applies not only between engineering and science, but also to different strands within empirical science. Namely, if we dissolve salt in water, the salt dissolves in it and if we do it again, it happens again independent of place and time. But if, for example, we give a cat a candy and then spray it with the plant sprayer immediately when it wants to grab it, we will see that if we do this experiment again that the cat will then naturally anticipate this in one way or another. From this we can conclude that the repeatability/reproducibility of an experiment that we can see so beautifully in dead nature (resulting from its randomness) is already much less clearly achievable in living nature. In fact, we should always look in this way at the domain of science in which we are working: what are the laws there, how can we do an experiment there at all? If we want to do research in the field of spiritual reality, we need to take a much more radical step, because the idea of experimentation is something we have developed in the physical sensory world in a certain way so that we can say yes, we can take salt and water at random and throw them together and then see that the same thing happens every time and in every place. You cannot bring this randomness into the spiritual world of man. Namely, the spiritual world does not allow itself to be controlled in that way by human randomness, because you have to transform yourself into a kind of 'bowl' in which something can emerge that wants to disclose itself in it (see also Odesys' paradigms & views on world and man in Section 1.6). This is actually quite similar to when you are dealing with other people. When people conduct an experiment together, the interconnection, the specific setting, and the interspace will determine what interaction and/or dialogue emerges in the now: presencing. Of course, it is possible to repeat human experiments to a small extent, but at the same time it is immoral to manipulate other people for a scientific setting (and its verifiability). So with people themselves, where that form of experiment is not really an option, you must look for the appropriate verification method. Similarly, in regular psychological and sociological research there is a search for how you can do a form of verifiable research that at the same time produces something for us as human beings.

This problem (not being able to easily and directly verify) plays a significant role in psychic-spiritual research all the more. Indeed, there we cannot do an experiment in the traditional way and this requires a deep personal development of a new way of thinking for acquiring knowledge. We argue here that in that case the way to acquire knowledge and insight is through Goethean phenomenology, which uses thinking to find only the objective lawful ordering of the real (primal) phenomena given as observation. This way of thinking and acquiring knowledge has been extensively investigated and described by Steiner in his works so that those who engage in con-science, with the thoughts/concepts contained therein, offer a form of thought training. They should be for the reader of his works a psychic-spiritual means of self-education, a path of schooling in the proper sense, a spiritual path of knowledge acquisition especially for the scientist and the engineer. One might call this the phenomenology of the mind as already proposed by Hegel. Steiner's most important work (partly inspired by and building on Goethe, Hegel and Aristotle) in this context for training spiritual thinking is the book Philosophy of Freedom, see Steiner (1995). Note that on can find more contemporary literature in this same area of phenomenology of mind, see e.g., Gallagher (2013); Varela (2017); Velmans (2017).

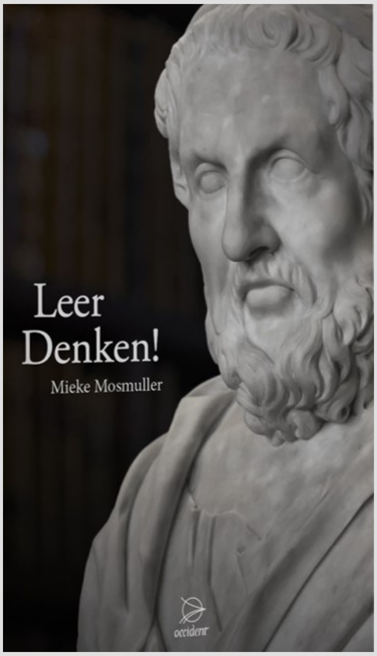
Phenomenology of mind/spirit

The following is an attempt to capture the essence of the book Philosophy of Freedom (originally written at the end of the 19th century: here see Steiner, 1995) as a first incentive to every scientist and engineer who deals with the integration of the inner world of man (subject) and the outer world of things (object) around him. It should be noted at the same time that this book is not actually a book in the traditional sense, as it is much more of a practice book than a reading book. Therefore it is not easy to summarize. Steiner himself says the following about this, particularly addressed to university academics and students: "... this book is meant so that, page by page, we must directly activate our own thinking that, in a certain sense, the book itself is only a kind of 'score' and we must read this score with inner active thinking in order to continually proceed from our own self from thought to thought..."

Let us start by considering the following question: What might phenomenology (looking at primal phenomena, as described in the previous section) mean if one employs and applies it to observe one's own thinking, and can thinking observe itself? In Philosophy of Freedom, he calls us to try this and, in doing so, to have a unique experience: the experience of thinking activity becoming observation content and observing becoming pure thinking. The observation content is now not given but produced, and observing is not the finding of something existing but the production of an observation content. The thinking activity that observes itself is the observation content that produces itself. This self-knowing thinking is the foundation that he declares absolute.

Incitement 2.5 Learn to think

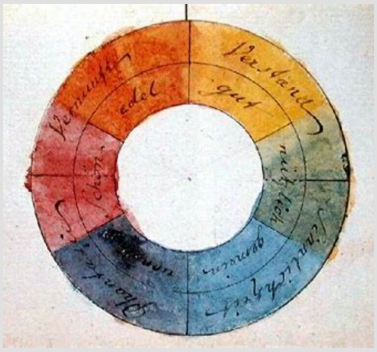
(Dr. Mieke Mosmuller, philosopher/ physician / writer)



Some reflections to put our thinking into perspective.

"...You do think you think, and you do have a lot of thoughts, but that is something different from actually performing thinking as an inner activity. We think that we think because we have thoughts and because we can learn. You can absorb a lot and you can put that into your memory and you can perhaps reproduce that, so you think?"

"...The human being is not only constantly developing in outer appearance, but also in his inner being. A crisis, which literally means 'judgement' (separation), offers a special opportunity to look at this developing inner self. Questions about what is good or right, what is truth, what is truthfulness, what is the value of human beings and what is morality are questions that are particularly among people. One of the overarching questions is that of freedom and unfreedom."



"...When you say: man is a higher animal, you actually exclude what that very specifically human is - but that also gives certain possibilities, because when you no longer want to see that in human thought there is a, let's say primal being of freedom, and you abolish that, you say: man is a higher animal, you have thereby at the same time created the possibility of treating that man as an animal as well."

What might this mean for the open design system within the con-science context? For more inspirations, see: miekemosmuller.com.

He explains that there are primarily two kinds of activities and therefore two kinds of objects to be distinguished. What determines that distinction is whether your own activity is or is not necessary for the object to occur. Let us consider the following example. When you are handed a bunch of tulips and look at them, you recognize the flowers and are happy. While you are actively "present," neither the tulips nor the recognition nor the joy are brought about by your own activity. Any object you encounter without needing your full activity to be there, he calls, 'observation', and the activity needed to have an observation, he calls 'observing'. Distinguished from this is an activity that not only gets to know its object, but also makes it be. Normally, we can only 'make' something by combining already existing things. Steiner, however, discovers one exception. Suppose someone wonders what an "organism" actually is, he can look at a tree or a cat. He can compare those to a clock and reflect on the difference between a "mechanism" and an 'organism'. For example, he may come to the following insight: 'In the organs that are the parts of a living whole, the same, lawfully evolving unity manifests itself all the time.' If you really think and understand this thought complex independently, something special has happened. For understanding occurs only as soon as you bring the thoughts to appearance in your consciousness and place them in their interrelationship. You do this based on the content of the thoughts. However, the connection of content is not observed like the tree or cat, but is produced. He calls this the 'pure thinking' that produces thoughts. With this, a fundamental contradiction is found: observing contents (objects) that are already there, and thinking as the activity that produces and connects understanding contents. This contradiction of observing and thinking is crucial for the whole book. Moreover, it allows you to unite empirics/science and introspection. The 'observation content' has become all-encompassing because of this contradiction. There is no longer any principled difference between sensory, inner or mental phenomena. They all stand as 'given' observation contents against the concepts produced by your thinking. What occurs in the observation without you producing it, can be connected to the thought-content (concepts and ideas) that you produce yourself. This is how knowledge (and insight) arises. This way of producing knowledge is in some way similar to and builds on the dialectical thinking developed by Hegel (2018, 2021), resulting in pure knowledge (epistime) generation (compare Hegel's 'highest' dialectical threefold categories: being/'sein'-essence/'wesen'-concept/'begriff' or thesis-antithesis- synthesis). Note: in Chapter 3, we will see this principle reflected in the concept of the inner dialogue within the U model (purpose and presencing).

This introspective method excludes any metaphysics in advance (or using Hegel's words, "logic coincides with metaphysics"). There are only two kinds of content: observation content and thought content, both connected with and experienced by a human subject. The only thing the experiencing subject can add to both kinds of contents is the knowing process: the unification of both. Beyond that, nothing can exist. The question then is whether this form of thinking is a purely subjective or a super-sensible (universal) activity, and whether the knowing process, i.e. the unification of observation/perception and thoughts/understanding, brings us to reality? First, the common philosophical criticism of this approach is that it enters an infinite regression. Does Steiner's approach escape this infinite series? Can this instrument play itself? According to Steiner, yes, because in thinking the content and the activity coincide. The thought contents (concepts and ideas) are produced and this produced content, when thinking observes itself, is produced by itself (i.e., thinking observed, or using Hegel's words "the mind comes to consciousness of itself").

Another criticism comes from the natural sciences. Even if it were true that thought has access to itself, it is in reality a brain activity that needs to be examined by neurophysiology. After all, our consciousness relying on brain processes is the general 'consensus', and introspective self-reflection is in fact an illusion. This materialistic view of consciousness has become commonplace in our time. At the time of Steiner, brain research was already in full swing. Based on empirical research, people were already linking psychological functions to parts of the brain. Broca's speech centre, for example, had already been discovered. Since then, people have penetrated further and further into the workings of the brain. For many, it is an obvious assumption that processes of consciousness are nothing more than neuronal brain processes. However, Steiner rejects this explanation in principle because it is not based on empiricism. Our thinking is primarily a phenomenon of consciousness, which we learn introspectively. This experienced thinking should be the starting point, not the brain that cognitive science investigates. He was one of the first to analyse the unsolvable problem of any cognitive science with razor-sharp clarity. In The Philosophy of Freedom, he demonstrates the unbridgeable gap between brain research and introspection. Those who examine brains find no consciousness, no feelings, no thoughts. Those who contemplate and observe their own thinking and/or their feelings do not find brains. All attempts at explanation (such as the analogy with hardware and software) notwithstanding, there is no escaping this problem. Doubt also occasionally surfaces in modern science itself. The cognitive scientists Chalmers (2022), Gallagher (2013) or Velmans (2017) amongst others, for example, argue that the 'hard problem' of how consciousness can arise from physical processes is fundamentally unsolvable (cannot be reached at all, which legitimizes the inner phenomenological approach, as described in the Philosophy of Freedom, actually even more).

Last but not least, fearful adherence to old paradigms has too often in history stood in the way of the renewal of thought. The root of the problem seems to lie in not allowing a speculative hypothesis. Its mere formulation is seen as a threat to its own paradigm-based 'authority'. A hypothesis nowadays seems to be able to be stated only if the evidence is directly provided with it. Facts and observations are only accepted as such if they can be directly explained. We particularly recommend this work by Steiner to scientists for today who are open to con-science as a whole, and who do not want and dare to see science only as empirics. This can be seen as a begin of an end, a period of 'Idealismus-Romantik' (Goethe, Hegel, Fichte) or as an end of the beginning, a period of anthroposophy (Steiner). We end this sction with the following notes:

(#1): Philosophy of Freedom (Steiner) - We become free by realising that we are fully determined (apparent paradox). Or stated differently, according to a threefold dialectical categories, the unity of fully determined complete randomness could be freedom. Human beings are conditioned, goal-oriented, and their behaviour pushes them in a certain direction. A person's sense of 'self', with the associated scheming and possessing up to and including self-centeredness and greediness, constitutes a powerful way of survival. People suffer when they cannot get what they desire (or even when they have to give up concepts and ideas they already knew for new truths). Much human suffering is caused by this. Indeed, that desire intended for good survival can even turn against man. Man lives between desire (aspiration), which is 'determined' by the past, and freedom which opens designs towards the future (purpose). This requires faith in yourself and the world around you (inner and outer world), so that you can deal with the unknown (randomness).

(#2): Hegel's scientific system (as a metamorphosis from Aristotle) - Hegel strove to develop one overall concept, in which he wanted to unite science, aesthetics, religion, and philosophy. He did not see reality as static, but as the outcome of a continuous ongoing process, in which new contradictions are lifted each time. The key word here is 'to lift' as well as to abolish and preserve (in Dutch 'opheffen', in German 'aufheben'). During the so-called dialectical (thinking) process, something (e.g. a moment) is first stated, then denied, to finally arrive at a higher truth. Earlier, Fichte used the similar concepts of thesis, antithesis, and synthesis for this purpose. This dialectical system, in which the so-called 'spirit' is the nature of all things and arrives at a new synthesis through the confrontation of thesis and antithesis, should eventually lead to the 'Absolute Idea' in which all the individual elements of spirit merge and transcend themselves. There is no real truth, but there is a truth that grows deeper and more mature. Yet in his famous book The phenomenology of Spirit, Hegel saw his own philosophy as the synthesis of the work of all his predecessors. Hegel thereby elaborates in part on the conception of logic by Aristotle among others. According to Hegel, the dialectical process also applies to individuals: first there is only the consciousness of external truth, then a self-consciousness arises, which gradually reconciles with consciousness. Hegel's system comprises three major parts that are in dialectical relationship to each other: the philosophy of logic, the philosophy of nature, and the philosophy of mind: i.e, thesis, antithesis, and synthesis, respectively. According to Hegel's philosophy, the development of all that exists was the development of 'the Spirit' itself. 'Everything that is a step in the development of the absolute 'Idea" and 'Reason can do nothing without reality; and reality nothing without reason'. The use of this dialectical thinking will be further utilized in Chapter 3 from a general people and management perspective and later in Chapter 4 from a design perspective.

Figure 2.9: A viewpoint on a grain of wheat.

(#3): Steiner's Q&As - Steiner gave many lectures also at Technical Universities (e.g., in Delft or Stuttgart etc.). Students and professors had the opportunity to dialogue with him. Notes were also made of these. Very worthwhile to investigate these further see Steiner & Mulder (2022). Here we do not want to withhold at least one of his answers from the reader:
"... imagine: the grain of wheat (see Figure 2.9) or the ear of wheat grows from the roots and the culm. Then the plant-forming force manifests itself which from the seed can produce a new plant which also seeds z and so on. We see that what works as a formative force In the plant according to an inner law produces one form after another, or as Goethe puts it, goes from metamorphosis to metamorphosis. Thus, we try to follow In humanities rethinking that manifests In man as a formative force. And we then come to the conclusion this thinking that In man is a formgiving force also has a side effect and That is actually our normal core process. But If I want to characterise the nature of thinking by virtue of that side effect I am doing exactly the same as when I say Why should I concern myself with what shoots up In the plant as a formgiving force through the root the culm to the nature. That does not interest me. In fact, I take a nutritional approach and examine what appears In the nature as nutrients. Of course, that is also a legitimate approach to the grain of wheat. We can choose that view too. But If I do that, I am renouncing what actually migrates through the plant as a continuous stream of development. So it is with the core process. What is usually thought by practitioners of the theory of knowledge by philosophers and all those who want to provide a foundation for natural science with their reflections that are in fact processes that occur when the thinking that actually wants to shape ourselves manifests outwardly in their side-effects. That is the same as when we see what grows up in their wheat plant alone as the basis for feeding another being. But it is not right to examine that

wheat Only from that point of view. That has nothing to do with the essence of the grain of wheat. In doing so, we are bringing in another point of view…"

2.5. Open-ended Odesys research questions

With the following research questions (RQs), as developed by Wolfert , we encourage the reader to engage in a process of self-schooling and, in particular, to investigate where Odesys stands within the context of the previous science and engineering context, as explained within the different 4-Quadrant models questions. One could therefore see this as an open-ended self-learning process.

(RQ #1) Is it a true statement when the smell of curry, an egg, and mayonnaise relates to the flat of your grandmother? And if yes, how does this relate to verification and reproducibility ? And if no, why is this statement not true or is this a subjective? Is objectivity always something of retrospective verification, or does objectivity mean that you don't put biased subjectivity into it beforehand? And don't you automatically do that by starting from some paradigm? What is actually the Odesys paradigm and is this 'objective'? And what might be the objective and subjective components of the Odesys methodology?

(RQ #2) What is the difference between belief and insight? An what is it for you (belief or insight) when another scientist tells you that the Majorana particle does exist? And what is it for you (belief or insight) when another scientist tells you that the proper aggregation of preferences is a goal-seeking algorithm rather than arithmetic calculation, see Barzilai (2022), or tells you that you should use the D-decomposition method for complex root analysis to determine stability zones, see Neimark (1978) or Wolfert (1998, 1999)? Having heard from scientists that something works in a certain way, and 'believing' that so far, does not really make much sense to talk about beliefs and science that way: would it not be much more important to explore how do we relate ourselves to the source of that beliefs/ insights? And what does this mean to consider designing in the Odesys way?

(RQ #3) Is thinking a mental and invisible process? And if so, aren't the devised laws of nature actually in themselves also spiritual laws? Are these order laws or are they prompted by something physical (e.g. think of gravity)? And do these only become physical laws of nature when they become operative and visible in the world? And what does this mean for the position of design 'laws' as part of mind and matter sciences?

(RQ #4) When one says that a physicist is a good scientist one assumes that he/she has been educated long enough and thus has acquired knowledge and developed skills to deal with physical matter What does this mean for a good scientist of the mind and their particular education-path? And what would this mean for (integrative) Odesys education?

(RQ #5) Suppose you are sitting on a bench with a friend and see a person passing by. You observe this person X and identify all kinds of physical characteristics (since you do not have no other characteristics or experience with this person. You get no further. Next, a professor familiar to both of you passes by, who taught you both. Now you (and your friend) identify both physical, but also non-physical experience characteristics. You use your outer and inner senses and experiences. Next, another friend of yours comes along and the three of you repeat these experiments/observations by letting person X and the professor pass by again. What can you establish about the replicability (verification) of your experiments and the 'truth' of your results (verification)? How does this then translate to verifying within an Odesys context?

(RQ #6) Could we admit and/or work with speculative hypotheses/paradigms/ axioma's? And if no, what would this mean for the hypotheses as part of Millennium Prize Problem, which are seven well-known complex mathematical problems selected by the Clay Mathematics Institute in 2000 (e.g. the Riemann hypothesis or the Poincare conjecture)? Even within the empirical sciences, we work for a long time with predetermined hypotheses that are proven afterwards and thus by definition. We also know that these are later overturned by a new theory (think of gravitation force, for example). Could we also establish a new theory without a presuppositional hypothesis? Within Odesys, do we establish hypotheses or goals at the beginning of the design process, or is there just an idealized design to which the designer is deeply committed?

(RQ #7) Can someone get a PhD and become a doctor without fully understanding one of the basic algorithms that underpins his theory? Or is belief in this algorithm based on trust in the person who developed it fine and sufficient?

(RQ #8) We now know that a living worm cannot arise from nothing. Or in other words, one could say life arises from life. What could this mean for the life of a human being?

(RQ #9) Is the materialistic worldview a result of science or is today's mainstream science founded on a materialistic human and worldview?

(RQ #10) A dice behaves statistically? A pencil you can sharpen? Could you call human's behaviour statistically and to what extent can you influence or model his behaviour (randomly)?

(RQ #11) Can you observe only outwardly or also inner beholding? And if inner beholding involves a form of phenomenological thinking what is then the difference between introspection and an inner experience?

The last overarching Odesys RQ is: what is the position of design in this present discussion and where is it located in the quadrant figure? What is verification in the design context. Is the concept of design sciences a paradox design philosophy. Would introspection be not necessary and is inner experiences or are the inner senses sufficient for Odesys?

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Chapter 3

Managing the service provider organization

This Chapter decomposes into two main parts with corresponding purposes: 1) describing organisation ordering principles of a service provider, that is a living and dynamically enabling an ongoing quality of service through their engineering assets and other organizational subsystems; 2) a prelude to the basic principles for design and design making within an engineering asset management (EAM) context.

For the first part, the purpose is threefold: (1) to provide a socio-eco perspective on EAM within the context of a service provider, (2) to provide models through which the social identity of such service organisations can be determined, analysed, and/or improved; (3) to introduce a state-of-the-art U-model based management system, through which fit-for-purpose open loops management and (re)design can be completed (making well known management models obsolete).

For the second part, the purpose is also threefold: (1) to provide a prelude/preview to the design and decision systems for the engineering assets within an embedding EAM context (these systems will eventually be developed from Chapter 4 onwards), (2) to provide the basic underlying social theory for collective well-being design/decision making (3) to introduce the Odesys' U-model from a socio-technical best fit for common purpose perspective. To this end, we will first establish a vision based on different human and worldview paradigms. This vision builds upon the principles of (1) human experience and a study of man, (2) social threefolding, and (3) the theory-U and decision science. We argue that the proper study of humankind within its living societal and organisational context is the science of design and management. For us, the works of Brüll (2019; Endenburg (1998); Glasl (1998, 2016); Kahneman (2013); Lievegoed (1991); Senge (2006); Scharmer (2016); Simon (2019); Steiner (1995, 1996), are the key starting points here (otherwise, other relevant literature will be widely cited where necessary).

We make the following notions:
(#1) The reader who is less interested in the socio-eco organisation and asset management concepts offered here and/or in the fundamental basic principles underlying human design and decision science, including the basic background of the U-model, can continue with Chapters 4 and 5 respectively, as far as the Odesys design approach and social identity are concerned;
(#2) This Chapter proposes a new system-oriented service provider organisation model, including a human-centred EAM approach. This model is a quasi-static organisation model at its core. For the reader who is also interested in dynamic organisational development in this context, reference is made to Glasl & Lievegoed (2016) and/or to Van Gunsteren & Vlas (2022) from a different perspective;
(#3) The socio-eco purpose threefold organization model, the Odesys' U-models, corporate social identity and group's well-being design synthesis are all new models and concepts as developed by Wolfert.

From Chapter 1, we will apply the concepts, viewpoints, and/or paradigms to first structure an EAM service provider organisation and then to consider its organisational development via open loop management (i.e., the learning & development organisation). For the first organisational part, the principle of reflection with the tripartite physical body is important. For the management and development part, we will use the insights from the M-threefold of motive-momentum-management, which forms the underlying human mechanism, to arrive at 'actions of response' (see Section 1.6). The following sections will be increasingly summative in nature, as they continuously build on what has been explained within Chapters 1 and 2.

3.1. Socio-eco purpose, the quality of service concept

This section summarizes the key aspects of a service provider organization, which is an entity that enables a certain ongoing quality of service (QoS) through their engineering assets and other subsystems. It will look at this organization from a holistic systems-thinking-based perspective with the aim of modeling, diagnosing (qualitatively and quantitatively), and improving and/or further developing it. The content of this section is a reflection of Wolfert's years of real-life service provider practitioner experience, which he has integrated with scientific research and insights from different backgrounds (social, engineering, organizational, biological etc.). Wolfert has also lectured and elaborated on this topic with MSc students at TU Delft over the last decade. The direct (practical) experience of Wolfert within this field is what makes it a unique state-of-the-art socio-technical synthesis, which builds upon the organizational dynamics works of the aforementioned authors. This section is founded on the fundamental humanistic threefold principles described in Chapter 1 while concurrently integrating a systems thinking design and engineering approach. It constitutes a qualitative prelude that we can use and model quantitatively in the subsequent chapters. The aim of this section is to provide the reader with insight into the overarching principles and concepts, and invite them to apply them independently to improve the social identity of any organization. Finally, this section has a summative character that can also be seen as a portal to relevant reference material. An overarching starting point is that an organization is a living organism which is not simply a sum of the individual subsystems, but a synergetic organization emerging from a certain social quality fit for purpose.

Before moving on to the innovative service provider organizational model, we will first outline the context in which we will apply it. We will then briefly discuss what the current state-of-the-art literature covers about Engineering Asset Management (EAM) within the context of a service provider. The context in which we will consider our service provider organization from now on is that of infrastructure and real estate assets within the built environment, see Figure 3.1.

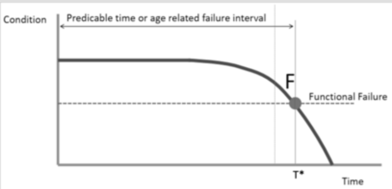
Figure 3.1: Different service providers (infrastructure and real estate in the build environment) and their engineering assets .

Typical physical, technical, or engineering assets in this context are thus rails, roads, surge barriers, dams, water reservoirs, dams, stations, and/or government buildings etc. These assets provide and ensure QoS, together with other relevant subsystems of the service organisation, of the functional performance users or customers experience when using this type of infrastructure or buildings. To guarantee this QoS, a service provider provides both design, build, maintenance, and operations activities (rather than just 'painting and holding the handrail'). This guarantee of QoS is what a systems thinking EAM approach requires. For example, within a telecom service provider, we can think of a QoS that is the ability to provide different priorities to different applications, or to guarantee a certain level of performance to a data flow (e.g., max and min bitrate speed and/or up and downtime etc.). To do so, a telecom service provider makes use of and operates engineering assets such as antennas, routers, switching centres, facilities etc. However, a telecom or internet service is not only provided by these assets, but also by other realms of the organisation such as customer services, marketing and sales, financial and billing support entities etc. Only through dynamic interplay will a certain quality of service (QoS) be possible.

Incitement 3.1 Design and systems thinking

Consider the Dutch A15MaVa transport road infrastructure systems which comprises of the Botlek and Thomassen tunnels, the movable Botlek bridge, and several other superstructures and engineering assets. This road infrastructure is crossing the river which is an important waterway as part of the Rotterdam harbor network. The MaVa Service provider, and in particular the maintenance services contractor, have recently invested in detailed monitoring per asset and can thus closely monitor degradation behavior (see for example Figure 5.3). Because they can now monitor all sub-systems well, this contractor is sure to be able to make an optimal service intervention plan. But is that really the case?

Are other drivers, such as given tunnel possessions, traffic hindrance, availability, and accessibility, much more important as they directly impact the Quality of Service (QoS) for different stakeholders and/or users? Has this contractor integrated these QoS preferences within the service operations plan together with the global engineering asset performance? What would happen if the contractor dared to look beyond the MaVa road system boundaries and, together with the key stakeholders of the waterway system, arrived at a best fit for common purpose service intervention plan in which all interests of different stakeholders are optimised for effective and efficient decision making at multi-system QoS levels?



The overarching questions remain: how can we design an optimal service operations plan that fits for common purpose, and what is the retained relevance of detailed asset degradation curves per asset within such an multi-systems thinking approach? In other words, what is the most effective approach; purely zooming in on system elements or zooming out on the system as a whole?

Much has been written about EAM in literature, see e.g. Balzer(2016); Dhillon (2006); Hastings (2015); Haynes (2017); Uddin (2013); Slack (2010). Although all these authors provide tools, processes, and other facilitating concepts to support EAM in certain sub aspects, none of them act from a holistic point of view. Existing literature therefore fails to enable the integration of socio-technical systems, lacking to provide real solutions for the real context of the service provider. In short, these books offer some basic theoretical concepts to analyze parts of asset management processes, but cannot solve future problems despite their claim to work with meta-models, which is a misleading term because they do not follow a meta or integration approach at all. Instead, they follow a one-sided technology approach that mostly ignores the real socio-technical behavior of a service provisioning system and its engineering assets. Since the principle of human reflection is very often missing, many of the proposed models are instrumental in nature and lose connection with the social context, identity, and purpose of the service provider. We will not elaborate on these instrumental concepts here, but assume the reader is familiar with the relevant EAM concepts or will become acquainted with them through the references mentioned above. In conclusion, we can say that something is needed to diagnose a socio-technical organization and make it "healthy" in case of so-called "disease".

To make this well-needed translation into a new and pure socio-technical organizational systems integration, we start from the important tripartite/threefold principles and paradigms from the previous section. We have seen that human beings (and thus a living organization) consist of three important subsystems: (1) the empiric subsystem which reflects the 'eyes and ears' of the organization, (2) the metabolic subsystem which reflects the 'organs' ('engines') of the organization, and (3) the rhythmic system which reflects the (social) heart of the organization. Let us take a closer look at these three subsystems. Firstly, the empiric system perceives from inside to outside, looking into the world of customers, users, and other stakeholders, and taking care of the 'external housekeeping' from a fair service trading fraternity principle. We therefore call this system the *economic* subsystem, with its purpose being 'association to satisfy'. Secondly, the metabolic system operates from within, providing monitors and cares for the life cycle of the engineering assets ('capital'), and taking care of 'the internal household' from the principle that these continue to function and/or be sustained in a free and logically sound manner. We therefore call this system the *ecologic* subsystem, with its purpose being 'freedom to manifest'. Thirdly, the rhythmic subsystem accommodates the internal dynamic balance and supports the other two subsystems continuously from the principle of equality. We therefore call this system the *isonomic* subsystem with its purpose being 'equality to accommodate'. The other qualitative characteristics of these three enabling subsystems are shown in Figure 3.2. Last but not least, the symbiosis/synergy of these three subsystems will result in the so-called *socio-eco* quality of service, or socio-eco fit for purpose service (in short socio-eco purpose), and expresses the *social* identity of a service provider or corporate social identity (CSI), as developed by Wolfert (including the newly conceived terminology).

ECO-NOMIC / Demand (commercial-customer-empiric)	ISO-NOMIC / Enable (business-support-rhythmic)	ECO-LOGIC / Supply (technological-assets-metabolic)
'Association to satisfy'	'Equality to accommodate'	'Freedom to manifest'
qualitative characteristics of era/life/realm		
Clients Demands (marketing, customer services & sales operations)	Business Enabling (financial means, human resources, ICT and legal support for business operations)	Engineering Assets Supply (deployment, maintenance, operations)
Products & Service functionality (utility, needs)	Organizational functionality (starting points/ policies)	Capital functionality (technical, human, natural assets)
Desireabilities (render individual market/stakeholder wishes for the organisation)	Feasibilities (collective frame of pre-conditions/resource/means where the other two realms can operate from)	Capabilities (individual asset planning development & service operation)
Satisfying & trading (customer care)	Accommodating & facilitating (intermediary economic ecologic)	Manifesting/ learning & developing (foster capital)
Relations (co-maker practices and stakeholders)	Contracts, rights & duties (laws, policies, agreements)	Ideas (new development plans)
Associative – fraternal connects (joint working)	Collective considerations – common requirements (conciliation)	Individual – cyclical developing
Quality experience (perception)	Human Dignity (reasonable-equitable-ethical)	Idealized Design (cultivate identity)
True & fair pricing (supply chain)	Equitable conditions (fitness for common interest)	Initiatives (creative commons, neutralize)
Co-operate, sell and observe/re-act	Mediate, assess and distribute/ integrate conditions-constraints	Sustain, create and deliver/operate
Senses/observe inwards (discontinuous)	Rhythmic/ circulate internal (perpetual)	Metabolic/ deliver outwards ('continuous')
properties when 'working' in era/life/realm		
Purchase money (fair deal: value for money)	Loan money (mutual agreement: reasonable conditions)	Gift money (unconditional)
Customer Service and marketing data	Business data	Engineering assets performance data
Customer service people (shared care)	Treating /secure people equally (dignity)	Invest to develop people (manifestation)
Good Products (associative quality)	Equal distribution (conditions)	Returning to nature / compensating (care)

Figure 3.2: Qualitative characteristics of the different organisational realms.

Note that socio-eco is a concept amalgamation by putting together a number of letters from the concepts economic, ecologic, isonomic, and social to form socio-eco. It thus expresses the symbiosis of these four concepts. More specifically, these three autonomous areas, economy, isonomy, and ecology, which each live and work together from their individuality. This synergy leads (via the primal social phenomenon) to a social force as a resultant. In the case of a service provider organization, the social force is the resulting quality of service (QoS) that is delivered. This is the real service quality that a customer of this organisation experiences, see also Van Gunsteren (2013). Ultimately, this resultant is also an expression of the social identity of the organisation, i.e., the inherent value or identification of the organization's way of working. In other words, it expresses the purpose of the organisation and is thus a measure of well-being. We call this concept from now on the socio-eco purpose: i.e., corporate social identity (CSI), which characterises the well-being of an organisation. In Chapter 5, we will look at how we can not only express this qualitatively, but also quantitatively using preference function modeling/measurement and MCDA techniques (see Section 5.1, Example 4). This CSI value of an organisation is a pure indicator that amongst at least two other organizations will have to be determined, using the integrative socio-eco characteristics as proposed here. This identity is an expression of the emergent quality of service which a service provider is able to deliver. This is the fundamental difference with the traditional corporate social responsibility (CSR), which is determined only from the own single view of organisation. This is fundamentally wrong and leaves a large gap between their espoused theory and their theory in action. In short, determining the CSI quantitatively requires a relative solver and preference-based modeling approach between at least three different organizations. In this way, we can make a real relative comparison and thus determine a CSI (note: within MCDA, 'one is none' applies, see Chapter 5). We have summarized the above in a completely new representation of a socio-eco systems service provider organizational system model, as depicted below in Figure 3.3 and Figure 3.4. We make a few extra notions:

(#1) Within the terminology used, eco stands for 'household' (derived from the Greek oikos), iso(s) for equivalent, nomos for laws and rules, socio(s) for companion/company, and logos for word, idea, logic (isos, socios, nomos, and logos can be traced directly from Greek).

(#2) These three subsystems can also be referred to as the commercial, the technological, and the staff support parts of the organization. In other words, these are the commercial & customer service department, the technological & operations department, and/or the corporate support staff departments of the service provider.

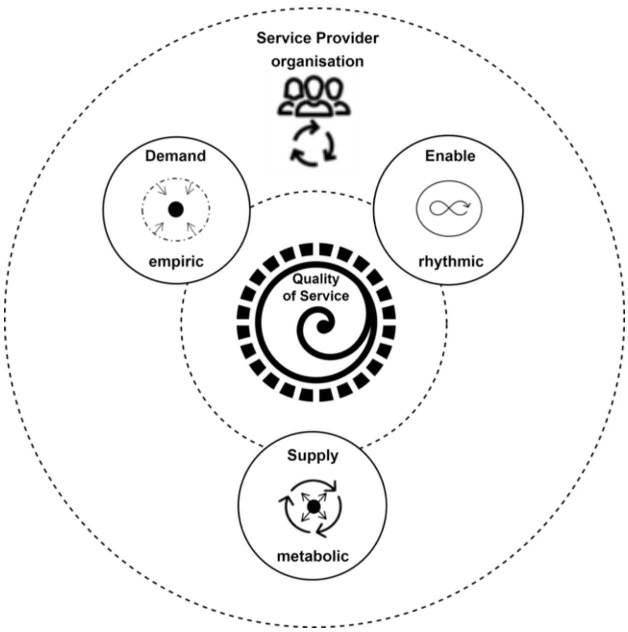


Figure 3.3: Part 1: Socio-eco service provider organizational model and its threefolding social identity (well-being), as developed by Wolfert (including the related models derived from this below).

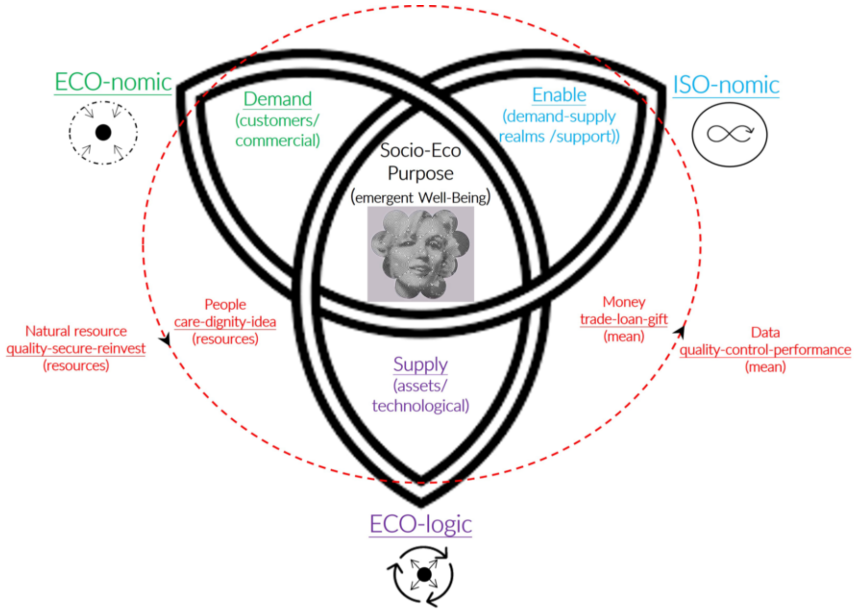


Figure 3.4: Part 2: Socio-eco service provider organizational model and its threefolding social identity (well-being), as developed by Wolfert (including the related models derived from this below).

(#3) People and the possible natural resources, money, and data occupy a specific role within the organization. You could characterize them as the blood (people/resources, sort of continuous circulation) and/or the water and air (money/ data, sort of in-out flow) of the organization because they spread throughout the organization, so to speak, via the rhythmic heart-lung system. They then also take on the characteristics of the part where they are located, and can thus take on multiple qualities. For example, we have already seen that money can take on a gift- (ecological), a loan- (isonomical), and a buying form (economic), independent of the organization, thus showing itself in the three different parts of the organization.

(#4) The isonomic system is actually the true and enabling system from within. It is the continuous enabling system of the other two subsystems which together deliver the resulting QoS. You could say that the social fit for purpose service emerges from the three synergetic enablers. The remarkable thing is that when there is no longer a need to provide service, the isonomic heart stops 'beating' just as the economic system closes its 'shutters'. The ecological system stops only when the assets are 'exhausted' or no longer receive a 'supply of blood'.... Note: this qualitative 'view of the organization' is mainly to be used as a 'mirror' from which one can look to diagnose cause-and-effect relationships in the case of an 'energy-less' non-functioning organization (don't take the comparison too literally, but as a supportive appraisal point of view).

(#5) All the aforementioned principles and the corresponding organizational model which breaks down into the economic, isonomic, and ecological trinity can not only be used for the service provider organization but is a generic organizational system model which can also be used for other organizations outside this specific EAM context.

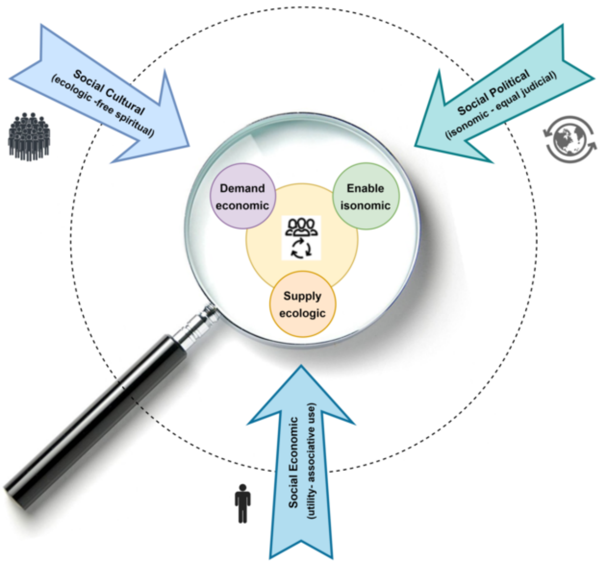


Figure 3.5: Part 1: Zooming out, the service provider and its embedding social threefold dimensions.

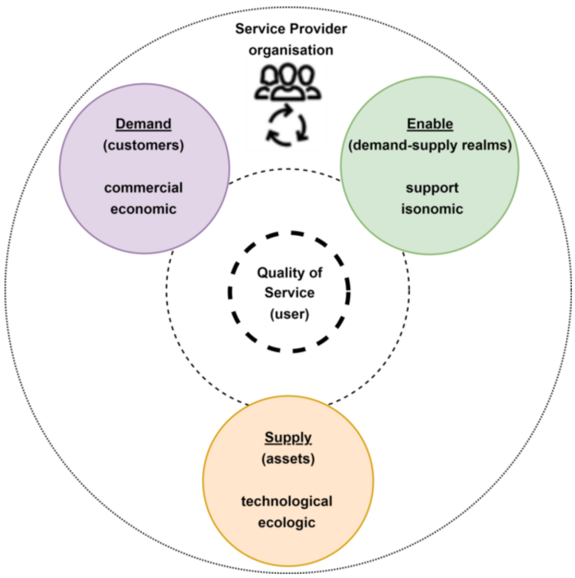


Figure 3.6: Part 2: Zooming out, the service provider and its embedding social threefold dimensions.

Let us continue with the socio-eco service provider organizational model. For this, we zoom out and can see that the service provider organization, like any other organization, is also embedded within a 'social-societal' context. We saw earlier that, according to social threefolding, this context can be divided into three types of embedding system dimensions: the social-economic, social-political, and social-cultural dimensions (see Chapter 1). The result of zooming out further is shown in Figure 3.5 and Figure 3.6. Note: we clearly see here the self-similarity principle of the service provider organization within its embedding system context.

We are now making one final step in the development of the socio-eco purpose organization model, for which we will zoom in again. We then actually observe two further points. First, we can see via the similarity principle that the technological engineering asset management (EAM) organization, the 'supply' part of the service provider, can be broken down into 'internal' subsystems as shown in the picture below. We recognize again the familiar tripartite division: (1) a 'demand' interface to the commercial department (via service level agreements), (2) an 'enabling' part in which so-called functional control takes place, interfaced with the corporate business support organization, and (3) the 'supply' part, reflecting the EAM organization in which both project development plan (PDP) activities and service operations plan (SOP) activities take place, see Figure 3.7.

Figure 3.7: Cyclical Service Operations Plan (SOP) and linear Project Development Plan (PDP), which are both part of open EAM loops.

The PDP activities, including construction project management, together with the SOP activities, including maintenance service management, form the so-called SAMP (strategic asset management plan). Note the following hierarchy here: EAM incorporates both project & construction management as well as operations & maintenance management (in addition to preparative design management). All of the SAMP activities directly contribute to safeguarding and/or expanding the quality of service of the service provider's engineering assets. Secondly, by zooming in closer, we can see that this EAM organization operates from an ecological *control* and *care* viewpoint, sustaining and/or renewing the engineering assets over their entire life-cycles. 'Control' here implies the linear (one-off) process of project development (PDP) by which we renew the assets or add new assets to the asset base. 'Care' here implies the cyclic process of service operations (SOP) supported by effective and efficient maintenance management. These two processes of control and care are recurring in itself and will be effected by both internal and external (seen and unforeseen) changes.

To cope with these changes the EAM organisation has to (re)act in a resilient open loops management approach, reflected by the open loops in Figure 3.8 and Figure 3.9. Obviously, the other two parts of the organisation, the commercial department and the corporate business support department, must also operate according to an open loops management approach to jointly deliver the required quality of service levels given these internal and external changes (typical disturbances). In Section 3.4 we will elaborate on the concept of open loops management and what this means for the developing organisation to deal with changes. We will show that this requires a state of the art approach which goes beyond standard management and organizational learning approaches (such as the PDCA and/or MI/II single and double loop learning). Using the principles of theory-U, we will introduce an innovative approach to open loops management within an organisation (and in the next Chapter to open designing of engineering assets).

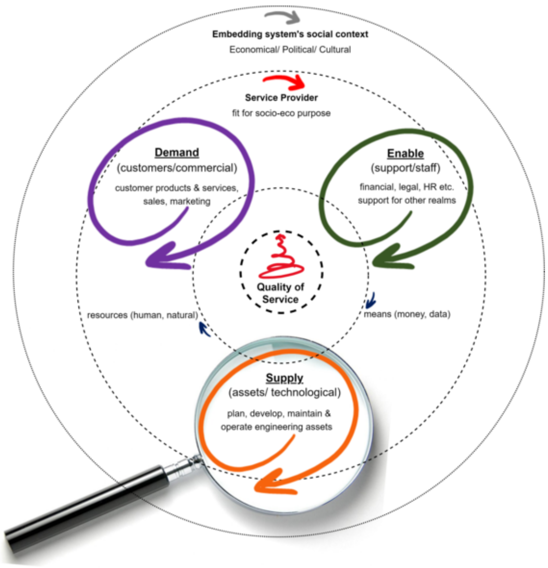


Figure 3.8: Part 1: Zooming in, the open loops socio-eco service provider organizational model and its EAM organizational threefold.

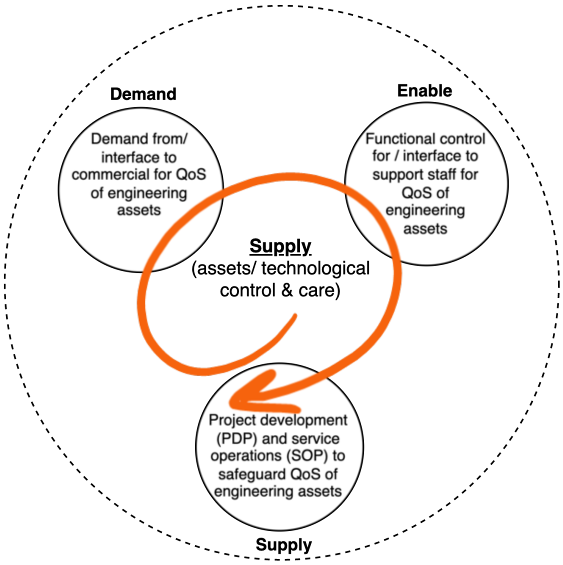


Figure 3.9: Part 2: Zooming in, the open loops socio-eco service provider organizational model and its EAM organizational threefold.

Before we move on to open loops management, we will first extend the socio-eco characteristics of the threefold organization with different ”social” laws that apply to each part (social laws just like natural laws). We do this partially to better understand the social identity of the company, but primarily to see how we can improve or support collective decision-making processes, which is an essential part of open loops management.

Incitement 3.2 Social sciences and design

(Dr. Rudolf Steiner, philosopher/ humanities scientist)

A radical viewpoint on social sciences and pedagogy, which could be used for socially responsible designing and learning?

”... When human beings meet together seeking the spirit with unity of purpose then they will also find their way to each other.”

“... A healthy social life is found only, when in the mirror of each soul the whole community finds its reflection, and when in the whole community the virtue of each one is living.”

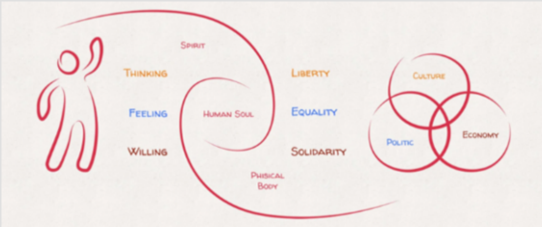
“... In a community of human beings working together, the well-being of the community will be the greater, the less the individual claims for himself the proceeds of the work he has himself done; i.e., the more of these proceeds he makes over to his fellow workers, and the more his own requirements are satisfied, not out of his own work done, but out of work done by the others.”

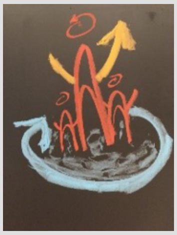
“... When man faces man the one attempts to put the other to sleep and the other continuously wants to maintain his uprightness. But this is, to speak in the Goethean sense, the archetypal phenomenon of social science. This sleeping-into we may call the social principle, the social impulse of the new era: we have to live over into the other; we have to dissolve with our soul into the other."

"... Our task is to educate the human being in such a way that he or she can bring to expression in the right way that which is living in the whole human being, and on the other side that which puts him/her into the world in the right way."

"... If humanity is to live in the future in a socially responsible way, humanity must educate its children in a socially responsible way."

What might this mean for Odesys (and later for ODL)? At least let it be food-for-thoughts during the conspection of socio-technical design synthesis solutions and the ODL concept implementations....





3.2. Social laws & principles, a basis for Odesys

In addition to the qualitative *characteristics* of the threefold socio-technical (service provisioning) organisation as described above, specific *laws and principles* apply to each of the three organisational areas. These so-called social laws are (like physical laws) generalities determined after a long study of man's interaction with his environment. Here, these laws and associated principles are derived on the one hand from Steiner's social/sociological laws, see Brüll (2019); Large (2010); Selg (2011); Steiner (2013), and on the other hand from some philosophical principles of Aristotle: i.e. man is by nature a social being and can find his perfection and bliss only in a community, and the 'golden mean' is the key here. These laws again (like the aforementioned qualitative aspects per realm) are meant to establish the social identity or socio-eco purpose of an organisation, and/or come up with suggestions for improvement. For an overview of the laws and principles as used here, see Table 3.10. We make a few extra notions:

(#1) Social main law / Economic area - The well-being of a group of people working/designing together is greater the less the individual claims the outcome of their achievements. That is, the more he relinquishes it to his co-workers and/or co-designers, the more of his needs are satisfied not by his own performance but by the performance of others: i.e., a forward-looking development in which a link between altruism and well-being is perceived.

(#2) Sociological basic law / Ecologic Area - The individual well-being of people as part of a social organization is greater when the individual becomes (more) free from the interests of the institutions and is free to develop their future needs and personal abilities. At the beginning of its cultural status, humanity strives for the emergence of social institutions where the interest of the individual is sacrificed temporarily for the interest of the institutions.

ECO-NOMIC (demand)	**ISO-NOMIC (enable)**	**ECO-LOGIC (supply)**
'commercial life – fraternity/associativity'	**'judicial life – humanity/equality'**	**'cultural life – liberty/ability'**
laws and or principles within era/life/realm		
Social main law The well-being of a group of people working together is greater the less the individual claims the outcome of their achievements	Solidarity principle Individual well-being of people is greater when individuals are recognizing that defending or encouraging the interests of others is ultimately in their own best interests. Sociocratic principle Individual well-being of people is greater when they are early involved in decision making, when their individual preferences are taken into account and when any principled and reasoned objection is removed. (*Preferendum, consent principle*). Common-natural law Inherent dignity of all members of the human family and their equal and inalienable rights is the foundation of freedom, justice and peace in the world.	Sociological basic law The individual well-being of people as part of a social organization is greater when the individual becomes (more) free from the interests of the institutions and is free to develop his future needs and his personal abilities.

Figure 3.10: The different social laws/principles related to different organisational realms, as developed by Wolfert from Brüll (2019); Endenburg (1998); Steiner (2013).

(#3) Different laws & principles / Isonomic area - Within this area, the following laws and principles play an important role:

1. Solidarity principle - solidarity is the awareness that although individuals have different roles, interests, and values, the order and coherence of society depends on their being able to trust each other to carry out those specific roles. It involves individuals recognizing that defending or encouraging the interests of others is ultimately in their own best interests.
2. Sociocratic principle - sociocracy is a system of governance that seeks to create socially safe environments and productive organizations. It draws on the use of the consent principle or the preferendum, rather than majority voting, in discussion and decision-making by people who have a shared goals or work processes. It has been based on equal human dignity without stating that all people are exactly equal or fulfil an equal function. These are elaborated within the sociocratic circle-organization method, as developed by Endenburg (1998). Within this, two concepts play an important role.
   - Consent principle - decisions are made when there are no remaining "paramount objections", that is, when there is informed consent from all participants. Objections must be reasoned and argued and based on the ability of the objector to work productively toward the goals of the organization.
   - Preferendum – a preferendum is a form of a-priori public decision-making in which the gathering of information, consultation, and ex-

change of arguments and/or potential solutions are central (as opposed to an a-posteriori vote for or against, e.g. referendum).

3. Common-natural laws - these laws arises from the normal interaction of people with one another according to their nature and customs, which maintain peace and equity between themselves. This Common Law is the human manifestation of the universal Natural Law, and creates no hierarchy or dominating force over people with their human rights: e.g.,
   - Recognition of the inherent dignity and equal and inalienable rights of all members of the human family is the foundation of freedom, justice, and peace in the world (Aristotle: "the worst form of inequality is to try to make unequal things equal. Humans are not equal, but they are worth equivalent').
   - All human beings are born free and equal in dignity and rights. They are endowed with reason and conscience and should act towards one another in a spirit of brotherhood.

   Specifically for these common-natural laws, it could be said 'in extreme' that they go back to the 10 commandments (i.e., '10 logoi') given to mankind through Moses. These later became part of the common-natural laws and the preamble to the universal declaration of inherent/inalienable human rights.

Note that to the best of the author's knowledge, we remark that here, for the first time, an integrative link is made between the social threefolding mechanisms, the corresponding qualitative characteristics, and the specific relevant social laws & principles per realm (social main / sociocratic-solidarity-common-natural / sociological). These have been developed by Wolfert and are Odesys' basis for collective and/or participative design and decision making.

Later in this book we will see how we further give substance to the introduction and support of social threefold laws and principles. Or otherwise stated, this set of social laws and principles forms the basis for Odesys' Preferendus. Actually, the Preferendus was inspired by and is a reference to the preferendum concept, and is a composition of the words preferences and preferendum (as a name conceived by Wolfert). The Preferendus was developed to accommodate early and transparent participation within an a-priori group design/decision making process, see Zhilyaev Binnekamp and Wolfert (2022) and/or Van Heukelum, Binnekamp and Wolfert (2023). Through the cyclical running of the so-called social cycle, the participants can eventually give their informed consent without objection (after perhaps many iterations) and with fully transparent insight into the model/design outcome for the *best-fit for common purpose* solution.

Regarding the concept of common purpose, Van den Doel (1993) has already shown through his theory of collectivist utility (well-fare economics, a form of utilitarianism) that the group optimum is greater than when the individual makes less claim to his own individual outcome instead of strive for his own interest. Here we take this (economic) collectivistic utility based decision-making a step further, because we do not only look at utility in the economic sense but consider the aggregated common purpose that is both economically, isonomically, and ecologically determined. This aggregated property defines the group's well-being optimum, where the fundamental laws & principles of all three realms (social/sociological law and sociocratic/solidarity principles) are maximally leveraged. How to retrieve this group's well-being optimum is explained further in Chapters 6 -8, in which the Preferendus (Odesys' software 'engine') is introduced in this book as the ultimate participatory decision instrument to arrive at an optimum on maximising common socio-eco interests and the related aggregated preferences. In other words, the a-priori and equitable (but not necessarily equal) inclusion of all people's preferences in the decision-making process will lead to best synthesis solutions rather than compromises. These synthesis solutions minimise everyone's individual dissatisfaction, however the group outcome turns out to be sub-optimal. Note here the subtle and important difference between the concepts of well-being and well-fare within this context.

3.3. Open loops management, an act of U-ncovering

In this section, we will show an entirely new approach by which you can achieve a redesign of, or within, an organization: i.e., open loops management of change. Most change and learning methods are based on the Kolb Learning Cycle (sometimes also called PDCA), which suggests a version of the following sequence: observe, reflect, plan, act. By grounding the learning process this way, the learning cycles are based on learning from the experiences of the past. Argyris & Schön's distinction between single-loop (model MI) and double-loop learning (model MII) refers (still) to learning from past experiences. Single-loop learning is sufficient where error correction can proceed by changing organisational strategies and assumptions within a constant framework of values and norms for performance. It is concerned with how to achieve existing goals and objectives, keeping organisational performance within the range specified by existing values and norms (it has a so-called self-sealing nature, as opposed to self-opening, see Argyris & Schön (1996). In some cases, however, the correction of error requires an inquiry through which organisational values and norms themselves are modified, which is the essence of double-loop learning (model MII). In summary, one can say that single-loop learning is reflected in the levels of reacting and restructuring, while re-framing is an example of double-loop learning, which includes a reflection of one's deepest assumptions and governing variables).

However, the theory-U with its U-model goes beyond double-loop learning (see Scharmer). It accesses a different stream of time, the future that wants to emerge. It finds its basis in the act of design and decision making as described in section

3.1 (see the 3x3=9-fold of human being diagram and the theory of instinctive versus intuitive thinking). Theory-U is more than just a theory (see e.g., the U-lab and the presencing institute at MIT). It is a process model for renewal and transformation of people, organisations, and systems from a threefold view of human experiences (mind/soul/body). The U-model was originally developed by Glasl and his colleagues Lemson and Lievegoed from the Dutch Institute for Organisational Development (NPI), as an open socio-technical process model to come from an organizational diagnosis of the present state to designs for the future (see Chapter 1). The U-model (literally) goes deeper than the double-loop learning process and gives concrete form to the double loop re-framing part. This is done by consciously uncovering the common or individual open will via a process of dialogue with the blind spot (or your 'silent self'). This U process involves a deep movement, as in the letter U, hence the name (note that the letter U is the most forward vocalisation, especially if one uses the German pronunciation: 'oe', which we also see reflected in the eurythmic movement of the letter U signifying its forward and future orientation, see Steiner(2019). We will see that the U-model will be developed into the ODL-U for education, enabling open design learning from the future, rather than learning from the past .

This section presupposes basic knowledge about the main principles of the U-model and/or theory-U, as described in Sections 1.5 and 1.6. Here in this section, only the innovative tool(s) will be presented as an extension of the U-model for the context of design and management of engineering assets. Moreover, we use the work of Dijksterhuis (2011), Kahneman (2013) and Zajonc (2008) as additional inspiration. This U-innovation emerged from the work of Wolfert and can be seen as a unique complement to the existing theory-U. We will therefore start this section with an interlude describing these basic extensions which can later be used for management, learning, and design. After this interlude, this section will continue with the open loops management within an organisation as a first elucidative application of the renewed U-model by Wolfert. The other applications and associated redeveloped U-models can be found in Chapters 4, 6 and 9: i.e, U-ncovering the best fit for common purpose design or U-nlocking open design learning response respectively. A final introductory note: this section has a summative character covering the models and diagrams for the purpose of this book and, moreover, can also be seen as a portal to relevant reference material.

Interlude 'continuing U-model development'

The U-model was developed by Glasl (1998) and some colleagues (Lemson, Lievegoed) at the Dutch NPI institute for organizational development as an open socio-technical process to come from an organizational diagnosis of the present state to (re)designs or developments for the future. They described a process in a U procedure/formation consisting of three levels: (1) technical/ instrumental subsystem, (2) social subsystem, and (3) cultural subsystem). Note: because design/plan/ management are actions from the mind to the matter, the actor of these activities observes the engineering assets which are outside him. This explains that, according to the inversion principle, in this case the engineering assets are the technical/ empiric system as opposed to the metabolic system as part of the technological service provider organisation (viewed as an independent living organism). In general, the U procedure transforms observations into intuitions (i.e., freely produced 'thought-content', her defined as intuitive ideas) and judgments about the present state and redesign decisions about the future. The three stages represent explicitly recursive reappraisals at progressively advanced levels of reflective, creative, and intuitive insights, thereby enabling more radically open systems intervention and redesign. The stages are a metamorphosis from: a) phenomena - picture (a qualitative metaphoric visual representation), b) idea - purpose (the idealized design or formative principle), and c) creation, judgment - validation (is this design synthesis fit for purpose?). The first three (new idea→ new picture→ new phenomena) then are reflexively replaced by better alternatives (new idea new image new phenomena) to form the final design. In other words, we see that the U procedure goes in two directions uncovering the common will : (1) from the instrumental matter (i.e., technical subsystem) via the organizational context (i.e., social subsystem) to the inner source (i.e., purpose or cultural subsystem) (2) from the new idea working in or towards the new instrumental matter. In other words, you therefore have to go through the process 'twice' in opposite directions to unite the design impulse (internally or externally driven) with its common motive so that social interests can coincide with technical achievability: the essence of the U. Note that this important translation to design and decsion making was first made here, see Section 1.6.

Complementary to that earlier work on the U-model or procedure, which assumes a set of three subsystems in the organization that need to be analysed in a specific sequence, Scharmer's theory-U starts from an epistemological view (i.e., imagination, inspiration, intuition) that is grounded in Varela's approach to neurophenomenology, see Varela (1991), as opposed to the more ontological approach of Glasl's U-procedure (i.e., picture, purpose prototype). It focuses on the process of becoming aware and applies to all levels of systems change. Theory-U contributed to advancing organizational learning and systems thinking tools towards an awareness-based view of systems change that blends systems thinking with systems sensing. On the left-hand side of the U the process is going through the three main "gestures" of becoming aware that Varela spelled out in his work (suspension, redirection, letting-go). On the right-hand side of the U this process extends towards actualizing the future that is wanting to emerge (letting come, enacting, embodying). Scharmer expresses the theory-U as a process or journey, which is also described as 'presencing', as indicated in the diagram below (where presencing integrates the words sensing + presence). Presencing (later seen as dialoguing in the now) is connecting to the deepest source, from which the field of the future begins to arise—viewing from source. Presencing is part of a U-journey with three main movements: We move down one side of the U-'connecting us to the world that is outside of our institutional bubble', to the presencing bottom of the U-'connecting us to the world that emerges from within', and up the other side of the U-'bringing forth the new into the world'. The sources of theory-U include interviews with many innovators and thought leaders on organizational management and change. Particularly the work of Brian Arthur, Francisco Varela, Peter Senge, Ed Schein, Joseph Jaworski, Friedrich Glasl, Martin Buber, Rudolf Steiner and Johan W. Goethe have been crucial for Scharmer, see Scharmer (2016).

For Odesys' purpose, we will from now on adapt, extend, and convert these basic U-diagrams (again Scharmer and Glasl were our starting point) in at least three major directions: i.e., (1) an extension and particularisation to enable open design systems and participatory decision making, including open source modeling support, (2) the introduction of the concept of the living dialogue to give 'hands and feet' to the purpose subsystem, and (3) a specific extension to an application for the innovative ODL education concept. Note that giving 'hands and feet' (i.e., making it concrete and/or giving it substance) shows an interesting language application which expresses that connecting the limbs to something is apparently an expression of will.

Let us continue, and first present these three fundamentally extended U-diagrams from an Odesys/ ODL purpose in the order of the extensions: i.e., (1) design process, see Figure 3.11, (2) living dialogue, see Figure 3.12 and (3) learning process, see Figure 3.13. These have been developed by Wolfert. We will later specialize these basic schemes in the Chapters 4, 6 and 9, where the U-models are expanded in more detail specifically for Odesys and ODL. After this interlude, we will elaborate, detail, and link the design basis diagram to intuitive thinking (slow thinking) and appropriate for open loops management as well. The common thread of these diagrams is that when the actors goes through the U-model, they actually go through an awareness process of consciously disclosing/unlocking their common purpose or uncovering their common will (thinking slow combined with thinking intuitive). The U-process goes from an open mind (imagination) via an open heart (inspiration) to the open will (intuition), and then in reverse and 'renewed' to an action of response via an inner dialogue. This action comes from the free will where the 'contradiction' or reversal of impulse and motive have coincided.

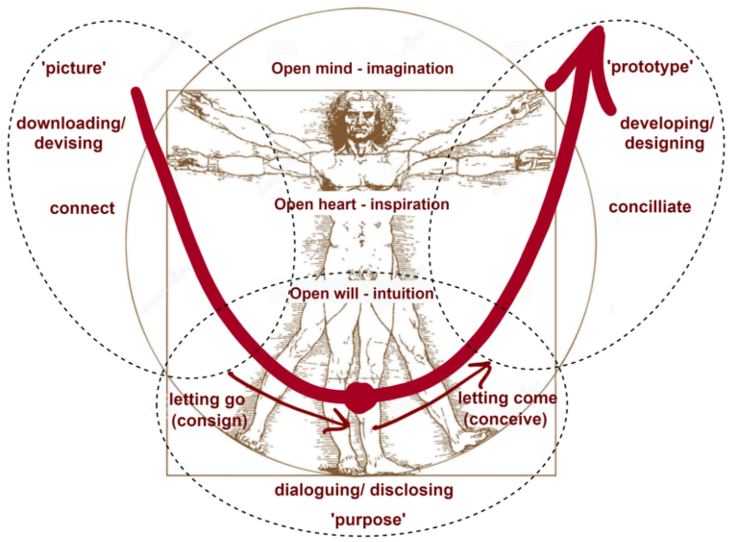


Figure 3.11: The new U-model for (re)designing within Odesys' context, as developed by Wolfert from Glasl (1998) and/or Scharmer (2016).

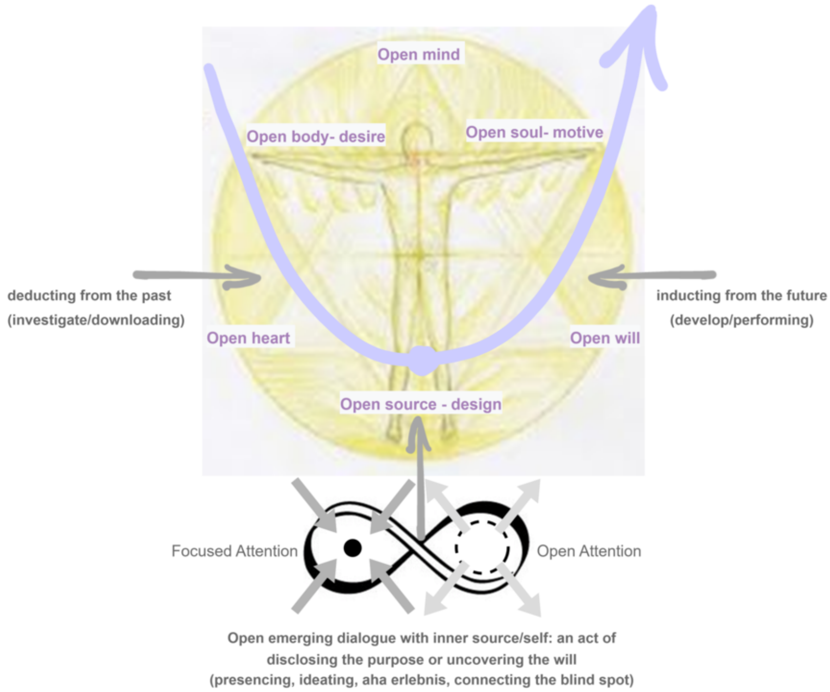


Figure 3.12: The extended U-model linked with the human ninefold and dialoguing with the 'blind spot' (or 'silent self'), as developed by Wolfert from Glasl (1998) and/or Scharmer (2016).

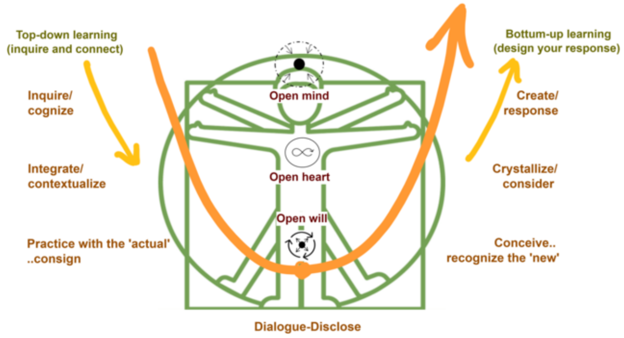


Figure 3.13: The new U-model for open design learning (ODL concept), as developed by Wolfert from Glasl (1998) and/or Scharmer (2016).

We make a few extra notions:

(#1) The design U-model first of all shows three stages (compare Glasl's metamorphosis stages) containing 3 P's, 6 D's, and 4 C's, see Figure 3.11: i.e., (1) 'Picture' - Devise / Download / Connect (2) 'Purpose' - Consign / Dialogue / Disclose / Conceive (3) 'Prototype' - Conciliate / Develop / Design. We will further detail this social-technical-purpose design metamorphosis approach and use it in more detail in the next Chapter 4.

(#2) The individual actor adds something of himself to the world, from outside the 'ego range' (from the inner self), which actually represents the deepest point of the U (a sort of 'aha erlebnis' or 'gut sense/feeling'). To better understand what takes place in this deepest U-point, (which Scharmer calls 'presencing', we will introduce the following two concepts, see Figure 3.12: i.e., (1) the *living (design) dialogue*, see Buber (2004); Bohm (2004), and (2) 'breathing' with *focused & open* attention, see Barendregt (2002); Palmer (2010); Van Lommel et al. (2009); Zajonc (2008). A living (design) dialogue assumes a conversation and a necessity to listen to the other. Its creator/'father' Martin Buber indicated that a real discovery of a true 'I' lies in the encounter with 'You', and 'I' does not exist without a relation with 'You'. According to Buber (2004), a dialogue constitutes the basis of philosophy in general due to the fact that it is the only effective form of communication in contrast to one-sided expressions of opinions. In other words, in the space between one and the other (subject-object and/or subject-subject), a place can be found where new ideas can emerge. From this principle arises the so-called design dialogue as part of the U-model. A design dialogue is a way of 'intuitive thinking' via concentrative inter-sensing-acting on practice that brings together awareness and insights as stepping stones towards the creation of new design. This living design dialogue is an active 'inner' dialogue with yourself and/or an 'outer' dialogue with an open-source model that represents the design problem. To activate this process the first step is consigning (you go as if you would say go to sleep or to bed and you let go), and then continuing to 'breathe' with your full attention.

You could see this as a kind of breathing between focused and open attention. First we are intently focused on the object of design, but then the object is consigned and our open, non-focal, awareness is sustained and a redesign starts to be conceived (note: for further exercises to support this process see Zajonc (2008) and/or the eurythmic movement ‘Ich denke die Rede’. This can be seen as both an introductory exercise and a basic exercise to train the soul, see Steiner (2019). In addition, the movements of the vocals A-O-U are recommended to support the U-metamorphosis from ‘I look around in the present world’ to ‘I contribute to a future world’).

(#3) With regard to the U-model which was developed for the innovative ODL education concept, some special characteristics have been added (see Figure 3.13). First, it can be seen that the U actually consists of two parts in the learning process: a so-called top down learning process and a bottom up learning process. In other words, from top-head cognition to hands-on and from bottom-hands practicing back to head, connected via the heart. This is called pure integrative education (see Ackoff (2008); Biesta (2014); Wiechert (2012) amongst others), a path of knowing (‘kennis’) and being competent (‘kunde’). The emergence resulting from this knowledge/competence synthesis is the art of designing (‘kunst’), see further on in Chapter 9 for the integrative ODL education concept. A second interesting addition/ observation is that the heart means, in our case, the context (reflective practice) of a so called self-chosen system of interest. This context is a stimulus driven learning vehicle (see Chapter 9). The essence is that the student transforms existing concepts via the self-chosen system of interest into a self-created learning response (an appraisal or improvement proposal for its context). Last but not least, the deepest U-point deserves some extra attention. It requires on the one hand letting go but at the same time this letting go needs a kind of counter force to play (practice, test) with the concepts and the new ideas in the self-chosen context (playing like a young child that learns through playing). This ’playing’ or practising will become important when we add open source modeling to the designing U-model (see Chapter 4).

The open loops management U-model

After this interlude we now can (finally) introduce the new Odesys U-model that has been developed for the purpose of open loops management. Open loops management is about redesigning (control and change) the management system of an organization, which is a set of strategies/structures and processes based on which an organisation operates. Traditionally, most organizations focus mainly on their technical or instrumental system (i.e., actual processes and tools), much less on their socio-eco organizational context, and least on their own identity, purpose, or cultural system (with crucial implications for their business performance, think of

Nokia as an imminent example, amongst others). Similarly, when it comes to new solutions resulting from various sources of disturbances, the service provider tends to think and act from its 'familiar and visible instrument'. The service provider thus neglects the context and often ignores its purpose (see Hastings (2015) and/or the NEN-15288/ NEN-15504 process capability system for life cycle management). Therefore, based on the renewed basic U-model as indicated in the previous interlude, we have proposed here an integrated open loops management U-approach. In Figure 3.15 we see this resulting open loops management U-model fully connected with its Open Management System (OMS) diagram. The content and the details of the figure speak for itself, however we make a few extra elucidative notions:

(#1) The OMS diagram contains three subsystems: i.e., the purpose-, the social-, and the instrumental subsystem. Using the principle of reflection from the threefold man and his senses, it is also seen as the open source (will), the open heart (feeling), and the open mind (cognition). We see that the related U-model goes in two directions: (1) from the instrumental processes to the organizational identity/ socio-eco purpose (left U) (2) from the renewed purpose to the adapted or renewed processes and tools. Actually, the OMS diagram is in itself thus only a one-way view but not yet an integrative management approach. Only by going through the U will you arrive at such an approach, at an act of uncovering or unlocking the organisation's common will. To do so, you therefore have to go through the process 'twice' in opposite directions to unite the organizational management impulse (internally or externally driven) with its common motive: the essence of the U (and therefore two opposing arrows have been added to the OMS diagram). In other words, we have integrated the U-model with the MS diagram via a bottom-up and top-down synthesis using the human ninefold of being for open loops decision making. In doing so, the U-model goes beyond the one-sided management approach of 'structure follows strategy'.

(#2) If we zoom in a bit more to the middle axis (the mirror axis) of the U we see the concepts of re-convert, re-concile, re-purpose, and re-generate linked back to the open mind, the open heart, and the open will and the open source of the U. This middle axis of the U expresses that this is a recursive, cyclical, and open-ended process (see Lievegoed). In reality, then, the U will be cyclical and open-ended in order to arrive at new intermediate results and (for then) best fit for purpose solutions. That is why for us open loops management (and we will also show this in Chapter 4 for open design systems) is so intimately connected to the U. To reflect or unite this, the open-ended cyclical approach is depicted in the middle of the U, see Figure 3.14. You could say that this symbolizes a 're-Union' process, since a re-uniting process takes places where a perfect (perhaps temporary) emerge into U-nity or synthesis (note: re-, expresses a "repetition of an action" and unite expresses "join together and make it into one" → re-Unite). As a final detail we have just therefore the open loops that in the previous part rotated clockwise here flipped and directed anticlockwise to even more symbolize its cyclic and open-ended connection with the U (the symbol is actually a ‘U on-the-run’). In the following Chapter 4 (and later in Chapter 9), we will see that these open loops decompose into three cycles: the *technical-cycle* (configuration/concreation), the *social-cycle* (context/conciliation) and the *purpose-cycle* (synthesis consign/conceive) respectively.

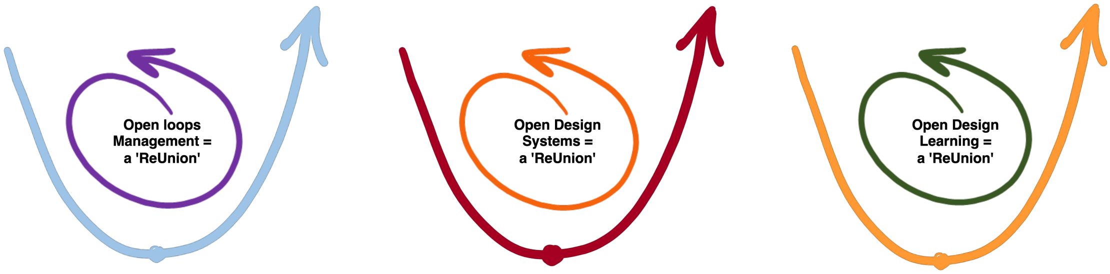


Figure 3.14: Open loops Management and Open design, a re-Uniting approach.

Note that applying the U-model in practice also shows that you can complete a sub-cycle faster on partial aspects than the whole (e.g. a sensitivity or impact check of a single design parameter). You could call this, as it were, ”crossing over” from the left side to the right side, and then continuing the entire U again. In short, a dynamic design and decision-making process.

(#3) Last but not least, the new U-model leaves the possibility of extending this with open-source computer model support. We will see this again in Chapter 4 as far as the elaboration for the open designing U. One could say that the metamorphosis process of ‘picture-purpose-prototype’ in those cases where humans can use a computer system as a management decision support tool given the (too) many combinations of new solutions. This supports the capturing of the properties of the socio-eco organizational context and provides support in the purpose process by realizing, based on logical/mathematical reasoning, a combined inner-outer source which together can arrive at new synthesis solutions. As an example within the open loops management context, we developed the MitC tool, which is a concurrent decision support tool for best fit for common purpose mitigation measures for construction projects on-the-run, see Kammouh et al. (2021). Here we have combined ”slow and intuitive thinking” with an actual representation of how a project manager plans by applying an open design systems’ approach that goes beyond basic PCDA or MI/MII cycles for dynamic planning and control.

In Chapter 4, we will show that this approach can also be made applicable to the design process of physical/engineering assets with a link to an open source decision support model, a mathematical optimisation model for maximising the common purpose.

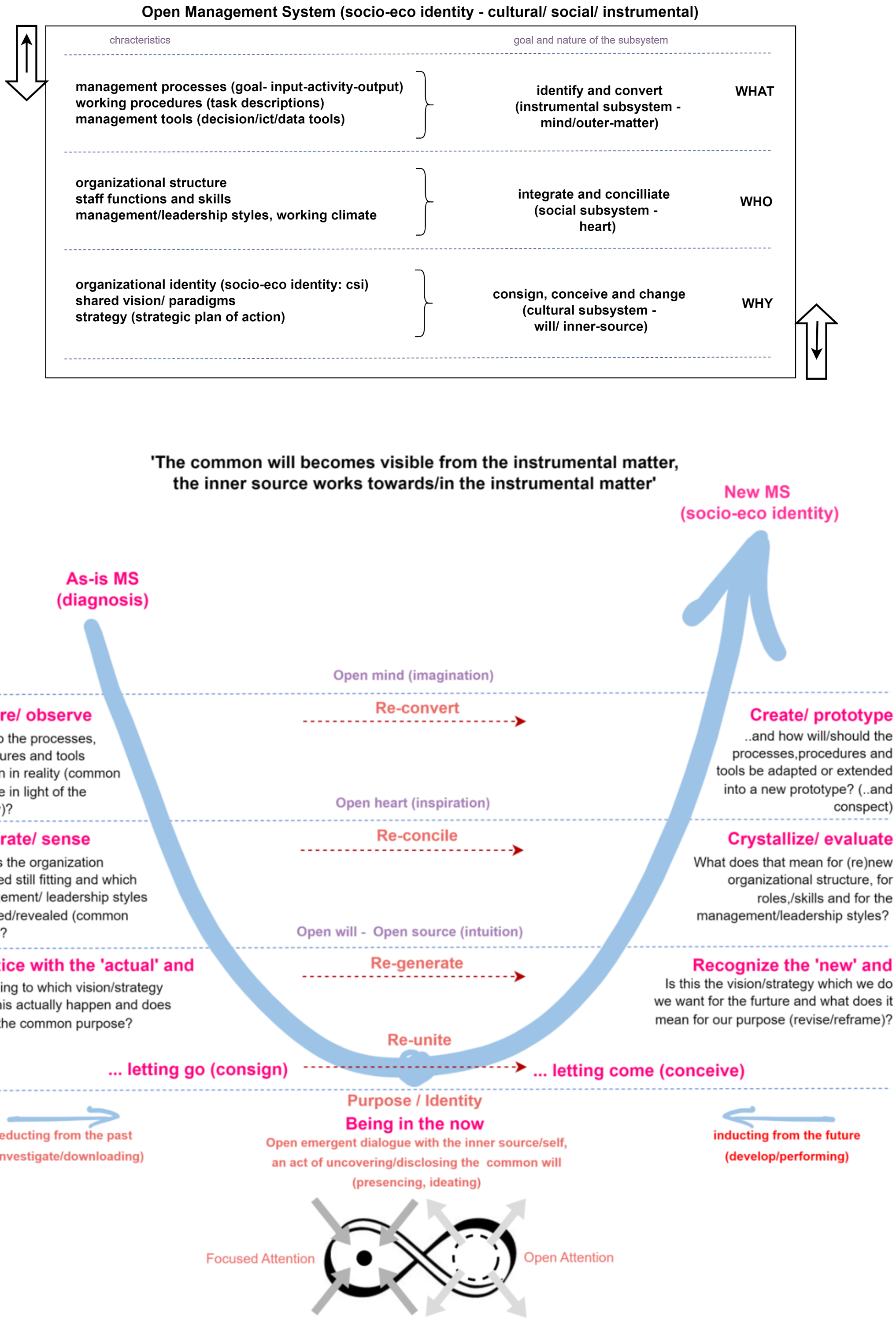


Figure 3.15: The new U-model for open loops management linked with the Open Management System, developed by Wolfert from earlier 'U-work' by Glasl (1998) and Scharmer (2016).

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Chapter 4

Designing to best fit for common purpose

Having zoomed out considerably in the previous Chapter(s) from different perspectives and/or paradigms, other than just the technical and/or empirical sciences, in this Chapter we will again zoom in on that part of the service provider organization that is responsible for the design and/or management of their engineering assets and the related quality of service (QoS) levels. We have seen that these physical assets are one of the 'supply' subsystems through which this resulting QoS is enabled. They are the suppliers thereof and they determine what the system is capable of delivering in terms of performance. They thus give fulfilment to the common 'demand of all' people involved, the common interest of all stakeholders. Ultimately, it is a dynamic interplay between what the engineering assets/objects are capable of, what the people/subjects collectively desire, and how each individual subject's preferences are represented.

The purpose of this Chapter is therefore to establish a perspective on how these common interests can be structured and/or obtained to form the basis for designing (managing and/or renewing) to a best- fit for common purpose engineering asset. Here the new common socio-eco interests diagram, or design tY value framework, holds an important place to reconcile the collective design input (here tY stands for 'design to Y values', where the notion of Y will become clear later). This diagram, as developed by Wolfert, is innovative in the following aspects: (a) it is integrally linked to the socio-eco purpose embedding system dimensions and the organization of which the engineering asset will be part, and (b) it indicates an important clarification with regard to this in contrast to most similar existing diagrams, like those from classical systems engineering (SE) books (see Blanchard & Fabrycky (2011); Dyme (2004); Wasson (2015), amongst others).

Furthermore, we will see that the associated open design system considers three subsystems or open design loops: (1) the *technical-instrumental* ('open config'), (2) the *social-contextual* ('open space'), and (3) the *purpose-idealized design* ('open source') subsystems. This is in contrast to similar engineering design systems which often recognize less than three subsystems (see the aforementioned classical SE books).

Within the second part of this Chapter the threefold open design system is further linked to the U-model for designing, providing a refinement of the open design U model, as developed for open loops management in Chapter 3. This is also innovative in its character, as the U-approach connects the technical and social human design process through a three-layer metamorphosis of picture-purpose and prototype. This perspective culminates in an entirely renewed so-called Odesys U-approach, as developed by Wolfert: i.e., the open config, the open space, and the open source, which is an open-ended spiral design metamorphosis. In doing so, it goes far beyond classical models such as the well-known SE V-model, with best fit for common purpose socio-technical solutions as a result. As a whole, this Chapter forms the basis for the (process) approach of the open design system methodology, which will be further examined by zooming in after this Chapter. From there we will focus on the modeling approach which is integrated into the open design system methodology.

This Chapter assumes that the basic principles and concepts from previous Chapters are known, because we will continue to work with these and zoom in on the main parts from Chapter 3 (social threefold modeling, socio-eco purpose, societal threefolding embedding system dimension, U-model etc.).

4.1. Common socio-eco interests, the design tY model

In view of the systems engineering design terminology that is often found confusing, the logic of the Open Design Systems (Odesys) terminology is first summarised here from the high level split between 'common interests' and 'common purpose' (at the end of this interlude, a note is placed with the subtle terminology differences viewed from their etymological context).

Interlude open design system definitions

Stakeholders often start from vague needs of what is required to fulfill their purpose. Sometimes these needs are already a lot more concrete and the stakeholder is able to formulate more specific requirements. The set which combines the relevant socio-eco concerns within a specific context is 'at stake' between all involved people and is therefore called '*common interests*'. In other words, the stakeholder's common socio-eco interests can generally be translated for a new engineering artifact into design considerations consisting of needs and/or requirements. We will refer regularly to 'design for tY values' as the common interests because they express a common well-being and/or the intrinsic worth of an artifact. It will be seen later that these values are always expressed in words ending in -ty, so design to or for tY (which is a new concept within systems design and engineering context).

These common interests (or design for tY values) can be further translated or converted by the designer into collective objective functions, constraints, individual preference functions (and weights), design performance functions, endogenous and/or exogenous design variables, and their specific bounds. It should be noted here that the design variables are those over which the designer can still exert his influence and which can be directly linked as a property to the object or sub elements hereof (i.e., degrees of freedom). The objective functions are subject-related goal programming functions which can be linked (in)directly to the design performance functions (i.e., an expression of the degrees of capability). These objective functions may be of different importance to each individual stakeholder and therefore should be expressed as a preference function per individual stakeholder with associated weights (i.e., an expression of the degrees of desirability).

In summary, it is the designer's challenge to convert these common interests comprising of design considerations, such as needs/desires (e.g. 'a noise reduction of xx dB must be realised') and/or more concrete requirements (e.g. 'noise barriers must have a minimum height of xx m'), into an integrative open design system articulated through preference-, objective-, and design performance functions that reflect these common interests (i.e., design conciliation input). With this integrative mapping of common interest into these type of functions, the designer can then support the open-ended design process to arrive at a best fit for common purpose design configuration. Note that the following etymologies of the main terms and their subtle differences:

- *interest* - 'from interesse', 'to concern, make a difference, be of importance', literally 'to be between (people)'.
- *value* - 'the intrinsic worth of a thing', 'degree to which something is fit for purpose', 'social principle' (supposedly taken from the art language).
- *desire* - 'express a wish to obtain', 'from Latin de-siderare' and therefore closely related to *consider*.
- *consider* - 'to fix the mind upon for careful examination', from Latin considerare. Probably literally 'to observe the stars and convene/congregate these'.
- *require* - 'repeatedly' (see re-), + quaerere (Latin) 'ask, seek' (see query); 'to need for some end or purpose'.
- *need* - 'be required for some purpose', 'require, have need of' / purpose: 'originates from put forth for consideration', 'a thing proposed for a certain intent/ interest'.

Incitement 4.1 Desires, the parents of thought

Often not only is 'desire the father of thought', but all feelings and habits of thought are actually the 'parents' of thought itself. From experience we know that one can rarely convince someone by using only logical arguments. Something, which lies much ”deeper” in man than logical points of view, often prevails over one's decision or action for response. Could this have something to do with our motives, intentions, and impulses? And, might these in turn arise only from these ’parents' of thought? Or could they also arise from an interplay between with the living (thoughts) world around us? To answer this question, we could first ask ourselves if water can be drunk from a glass without water? In other words, can thoughts be extracted from a world around us where there are no thoughts?
Finally, what would the ”parents of our thoughts” and the ”thoughts around us” mean for our common interests as inputs to the new world to be designed and created around us?

Within the Odesys methodology, we take the more commonly used collectivistic utility based design and decision-making theory/practice a step further because we look not only at utility in the economic sense, but consider the social system's identity that is both economically, isonomically, and ecologically determined. From this aggregated property we can determine the group's well-being optimum. We know that this aggregated property is by definition the group's well-being optimum since the fundamental laws & principles of all three social threefold realms, which are the social/sociological laws and sociocratic/solidarity principles, are maximally leveraged (see Chapter 3). In other words, an a-priori and equitable (but not necessarily equal) inclusion of all people's interests in the design decision-making process will lead to synthesis solutions to best-fit for *common purpose* rather than to compromise solutions, where everyone's individual dissatisfaction is minimised and where the group outcome turns out to be sub-optimal. Later in this book (from Chapter 6 onwards), we will see how to give further content to generating these design synthesis solutions supported by mathematical optimisation modeling. For this, we have developed the Odesys methodology, introducing the Preferendus as the ultimate participatory decision-making tool to arrive at an optimum on maximising common societal goals (inspired by and a reference to the preferendum concept and the word preference, see Incitement 4.2).

Note: (1) the fit/fitness for common purpose concept expresses the intrinsic quality of service (QoS) or real service quality of an artefact which we will refer to as the aggregated social system's identity (see Chapter 3); (2) synthesis is part of Hegel's dialectical threefold categories: thesis- antithesis- synthesis (see Chapter 1). In other words, fit for purpose is the feasible synthesis or unity within the threefold of social-interests-desires/ technical-behavior-capabilities/ purpose-quality-feasibility; (3) With regard to the modeling, we can state that this is seen as a logical act of reasoning to unlock the outer environment ('common will'), also called thinking slow: deliberation. However, intuitive thinking is an act of uncovering the inner will: a dialogue. When the two coincide and are unified, by definition a synthesis solution as a free thinking result is reached (see Chapter 3).

Incitement 4.2 Referendum or Preferendum?

Wouldn't it be great if we lived in a society that decides together, for each other, and with each other? Is a society possible where citizens have equal rights, where the scientist can inform freely, where business takes place associatively with money not as a goal but a means, and where the government acts as a 'true civil servant' (social threefolding). A value-wish dialogue between citizens of all 'sorts and sizes' seems to be the brittle cement of a free society. Or as Lucebert (Dutch artist/poet) famously said, "everything of value is defenseless". The question now is how can we extract desires, wishes, and values from people and society to use them for participatory (deliberative) decision making. A process that starts from these common interests of everyone to design an a-priori synthesis, in which values and wishes are maximised, rather than to appraise an a-posteriori sub-optimal compromise ('after the fact'). Does this mean that we would have to go for a Preferendum, rather than a Referendum? If so, how might we give substance to this and what type of support tools could be of interest covering both the social desirability and the technical capability of a system?

Notes: (a) 'The preferendum brings citizens and politicians closer' according to Dr. David van Reybrouck in De Standaard' on Oct. 30, 2021 (vReybrouck is a Belgian cultural historian, archaeologist and author and also a well-known advocate of the Preferendum); (b) Already in 2007, the WRR indicated that the results of a referendum do not sufficiently reflect the wishes of the citizens. At the same time, it indicated that this would be clearer with a preferendum (WRR is the Scientific Council for Government Policy making, an independent think tank and advisory body to the Dutch government).


Best fit for common interests & purpose

Here, we will describe the best-fit for common interests and purpose design concepts, which are the key elements of Odesys. The aim is to support a design process describing how to get from common socio-eco interests (needs/requirements/ desires) to a design proposition or synthesis that best fits the common purpose. This process can be seen as the search for a dynamic interplay and/or optimal equilibrium between what people want (demand) and what technical assets can offer (supply). Design is thus a process of finding the leeway within the design variables: i.e., the design degrees of freedom, to best achieve this equilibrium between common desirabilities and possible capabilities, given all individual preferences of those involved and all physical constraints or other limitations. We call the results of this the synthesis equilibrium, which is a measure of the degree of satisfaction (for the individuals) and the degree of capability (for assets). When we have obtained such a result, we call it a 'best' feasible design configuration or prototype given all the common interests and purposes.

Let us now introduce the new state of the art open design systems that is explained by the following three parts, shown in Figure 4.1, Figure 4.2, and Figure 4.3 (as developed by Wolfert). The content and the details of the above three figures speak for themselves, however we make a few extra notions:

(#1) Since design is primarily an activity that goes from human being (mind- the inner) towards materialisation (matter- the outer), we must congregate the common interest, the human inner sources of design, as input. We do this by zooming out to the embedding system's context in which the new engineering asset will find its place and to the organisation where it will be managed and/or maintained. Combined with the user needs/wishes/requirements, these form the collective design input of the relevant stakeholders for the new engineering asset. In Chapter 3, we saw a threefold, seen from the inside of the organisation (economic-isonomic-ecologic). Here, seen from the inside of the designer, we see a threefold of a technical subsystems (empiric), a social subsystem (context), and a purpose subsystem (idealised design).

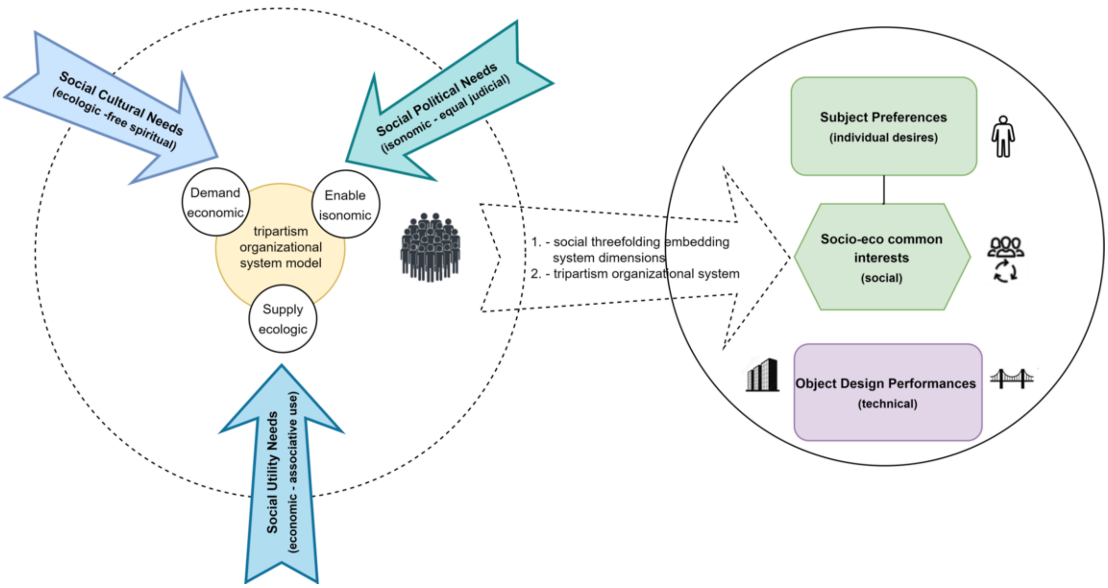

Figure 4.1: Part 1 - The congregate of common interests.

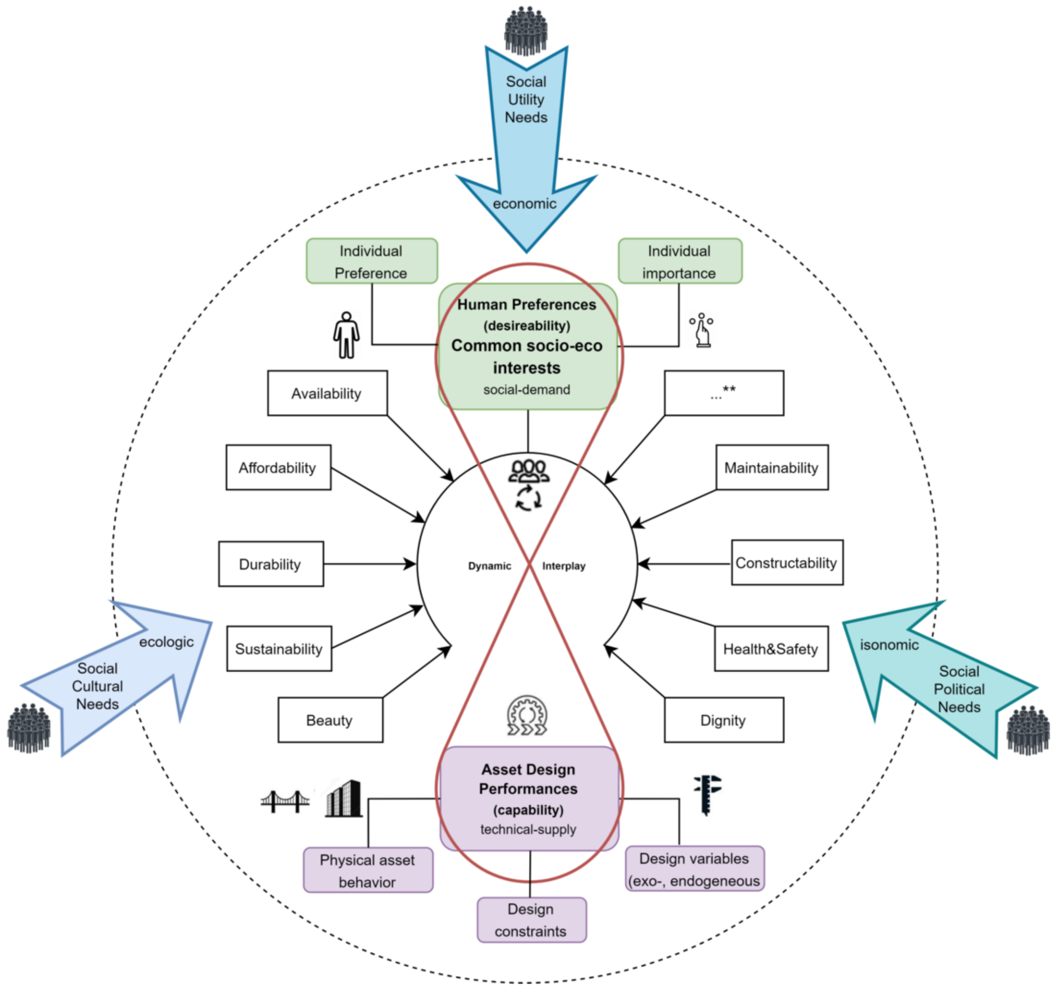

Figure 4.2: Part 2 - Common socio-eco interests diagram, a participatory design tY framework, derived from societal and organizational needs/wishes/requirements. The design tY values, to be translated into preference-, objective-, and performance functions and/or constraints (not limitative). ** Adaptability, Capacity, Comfortability, Connectivity, Creativity, Distributivity, Flexibility, Fraternity, Immunity, Integrability, Integrity, Invest-propensity, Liberty, Liveability, Operatorability, Profitability, Reliability, Resistivity, Reconfigurability, Predictability, Recyclability, Security, Solidarity, Supportability, Simplicity, Servicability, Scarcity, Transportability, Testability, and Vulnerability.

In other words, from the design/decision process that arises from the inner, man will strive to put a technical/physical system in the outer world which tries to find the best match with his/her idealised design, the purpose system, via a collective social system (the system of common interests).
(#2) Depending on the system's context, a multicoloured pallet of interests can be desired by the human stakeholder. We often express these in terms of objectives (goals) such as availability, affordability, dignity, etc., the so-called design to Y (tY) values. All these design tY values are purposive and thus solely linked to

the human/subject and not to the artefact/object. The system can only assume a state because it is connected and/or controlled to these human objectives. There always underlies an (inner) goal-oriented human phenomenon to the final system-state and/or performance behaviour of the (outer)object. This system-state can only be achieved by the input of the designer and after the designer has synthesised and configured the design variables accordingly.

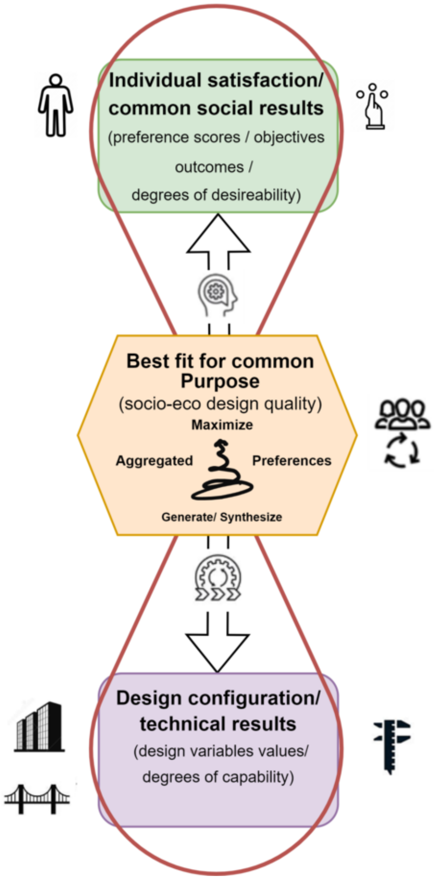

Figure 4.3: Part 3 - The best fit for common purpose model.

(#3) Following from the social laws (see Chapter 3), we argue that a best design is that design which suffices the collective group's well-being that is defined as the maximum of the aggregated individual preferences for the different design objective functions (i.e., for the different design tY values) given the design performance functions and constraints. The 'technical' result is a set of degree of capability values, which describes the prototype configuration and its dimensioning. The 'social' result is a set of degree of capability values (i.e., common objective function values) and set of degree of satisfaction values (i.e., preference functions per individual).

4.2. Open designing, an act of U-ncovering

We take here the starting point of the design U-model showing its three metamorphic stages, comprising 3 Ps, 6 Ds and 4 Cs: (1) 'Picture' - Devise/ Download/ Connect (2) 'Purpose' - Consign/ Dialogue/ Disclose/ Conceive (3) 'Prototype' - Conciliate/ Develop/ Design (see the basic design U-diagram in Chapter 3). To make the basic U-diagram more specific for the open design system (Odesys) approach, in addition to the starting points from the basic diagram, we draw up some important key points for this specific purpose.

Incitement 4.3 Design to consider

Consider the decision making process regarding former military airbase Valkenburg, near Leiden in the Netherlands. The politicians decided that the best thing to do was to close this military airbase to solve Leiden's housing problem. The mayor of Valkenburg was unsure whether this was indeed the best choice. Proper modeling of this multi-criteria decision making problem, taking into account all stakeholders' interest, showed that closing the airbase was far from being the most preferred alternative. Only after removing the criteria of safety, costs, and nature preservation did closing the airbase become the most preferred option. Clearly not all interests were part of this decision making process. Unfortunately, it is common that political manipulation leads to single purpose poor decision making. How can we then ensure open and transparent integration of all stakeholders' interests to be considered when modeling the design/decision problem?

A professor gave a balloon to every student, who had to inflate it, write their name on it, and throw it in the hallway. The professors then mixed all the balloons. The students were given five minutes to find their own balloon. Despite a hectic search, no one found their balloon. At that point the professors told the students to take the first balloon that they found and hand it to the person whose name was written on it. Within 5 minutes everyone had their own balloon. Wouldn't design also be better when considered a participatory process?

The engineer's ideal of Caesar's war chariot is that which never fails but at the end of its lifetime disappears completely into dust. If one bolt would still remain, then that bolt would have been constructed too conservatively and that would have had adverse weight implications. Unnecessary weight impairs the effectiveness of the chariot, which Caesar would never have accepted. How can we then incorporate the right design performance considerations so that it does not lead to over-dimensioning, while satisfying the user needs during the operation phase?

First let us take a closer look at the etymology of the word design ('de-sign, and in Dutch: 'ont-werpen'). The prefix de- (in Dutch ont-) has a special meaning here: (1) spontaneously starting (e.g. decaying, or another Dutch example word 'ont-branding'); (2) removal of something or even put away (e.g., defoliate or decode, or another Dutch example word 'ontcijferen'). Note that especially in Dutch the prefix 'ont-' can also mean 'uit' (out of someone/ out of something, think of the word 'ontvangen'). In short, and if we combine these etymologic starting points, the word design can mean both the starting process 'signing' and/or the opposite (direction) of 'signing', which can mean not signing but read and gather (as an act of gathering towards your mind: 'intel-ligence'). Clearly, the latter also means an opposite movement towards itself (from 'another'), expressed with the word conceive (or in Dutch 'ont-vangen'). In short, these notions play a role (perhaps mirrored) in the process of designing. This would allow us to see that the U, and in particular its deepest point, encompasses actually two opposing movements, which meet interactively withing a living 'dialogue'. From Chapter 3 we know that these two movements of 'the common will' become visible from the technical matter. The inner source then works towards/ in the 'technical matter' to unite the design impulse (internally or externally driven) with its motive.

A living design dialogue is an active 'inner' dialogue with yourself. To activate this process the first thing to do is consigning (you go as if you would say to sleep, allowing yourself to let go), and then continuing to 'breathe' with your full attention. You could even see this as a kind of breathing between focused and open attention. Actually, a supportive open-source model exists within the Odesys approach. This is a second source that represents the design problem reflecting both the human desirability and the engineering artefact's capability. The designer can therefore have a second support tool within the dialogue which is the 'outer' dialogue via or with this model. To activate this process the first thing to do is just to play and practice a bit with the model, and then reflect on the 'proposed' high level design synthesis outcome (let it be generated and try to recognize). In other words, the consigning process requires on the one hand letting go but at the same time this letting go needs a kind of counterforce to 'play' with the model (practice, test, appraise) within the design context (playing like a young child that learns through playing).

With all the aforementioned designing specifics we can convert the basic U-diagram from Chapter 3 into the fundamental Odesys U-model that will be the basis for the open designing process, see Figure 4.4. The central thread of this U-process-diagram is that when the designer goes through the U-model, he actually go through an awareness process of consciously disclosing the common purpose or unlocking (i.e., uncovering) the common will which is a form of thinking slow and intuitive thinking. The 'thinking slow part' here can be fulfilled by a supporting computer model. This action comes from the free will where the 'contradiction' or reversal of impulse and motive have coincided (here common interests and desires, see Chapter 3). The U-process moves from an open configuration (mind-imagination) through an open space (heart-inspiration) to the open source (will-intuition), and then through an inner dialogue proceeds in the opposite and 'renewed' direction to an action of response. This action of response is the realisation of a prototype configuration. This unification covers a new and extended Odesys' U which provides the foundation for a socio-technical design process with a best fit for common purpose result (it will be made even more specific for mathematical modeling in Chapter 6).

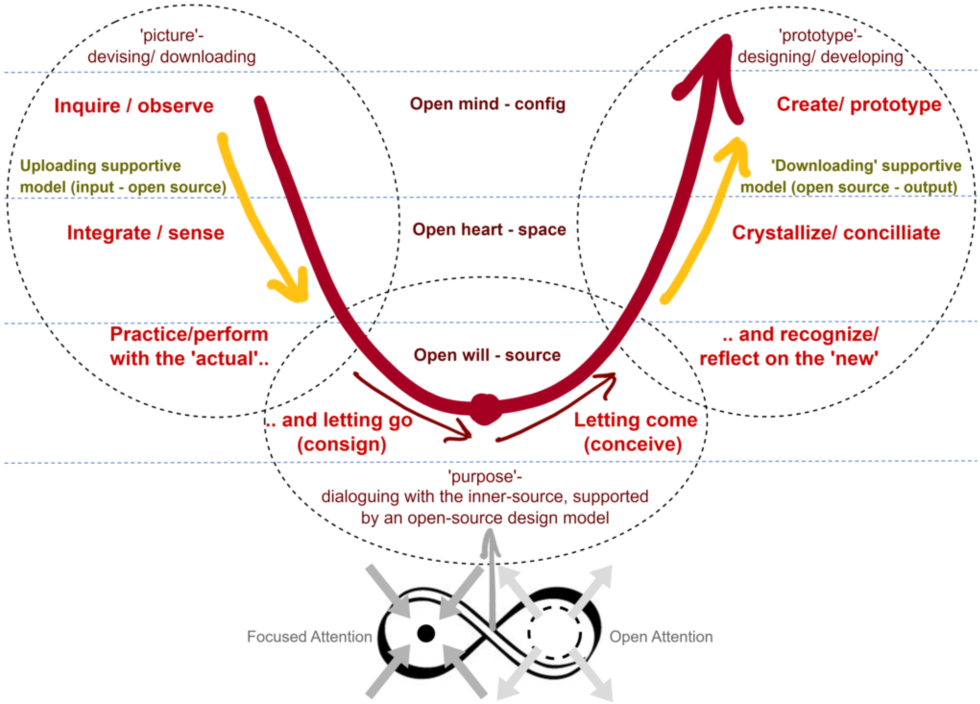

Figure 4.4: Odesys' basic U-model, as developed by Wolfert from Glasl (1998) and/or Scharmer (2016) (extended from the starting U-models in Chapter 3).

We make a few extra notions:
(#1) The model under discussion here is a mathematical optimisation model, supportive to the integrative unlocking process (note, this model neither descriptive nor predictive in character). It is a mathematical representation of the design process, where all human-oriented preference and objective functions and all object performance functions and constraints are brought together to find the maximum aggregated preference of all stakeholders involved (i.e., a re-purpose process). Because this re-purpose involves a complex set of relationships and possibilities, a

search algorithm is called in to find this best fit for common purpose. The best fit for common purpose is the synthesis or golden mean, a design point which unites all the open source input (system capability and human desirability) the best. We will elaborate on this in Chapter 6 and beyond, zooming in one step further (from embedding systems dimension Chapter 3, to the threefold of preference, objective and performance functions as of Chapter 6). Note that here another form of unification takes places as the logical act of reasoning (outer deliberation and open source input) coincides with intuitive an act of intuitive thinking (inner dialogue and open source output) resulting in a synthesis solution as a free design modeling result.

(#2) It is also important here to put the new open design U-model next to the more common SE V-model. First of all, we see that both models fit together seamlessly. The U-model is used when there is still substantial design freedom and has a human-driven focus with a new prototype configuration as its response. The V-model is used when a prototype is being engineered into a lower level of detail for subsequent construction with a new artifact as its response. What is further noticeable is that both models form a 'mirror image' of each other in every tone. In the case of the U-model, there is even a particular 'crossover' visible (devise vs. 'envise'/envisage, consign vs. design), see Figure 4.5. All of this gives the new Odesys' U high added value in designing what people want and the engineering artifact can deliver, reflecting a pure socio-technical modeling approach. Once the most desired socio-technical solution has been configured, the Odesys designer can pass on his response to a structural engineer to further detail this response and realize it according to the engineering development V-model. Note that the U- and V-model go hand in hand, with the U-model in the lead, representing a joint W-model approach (see also Chapter 9 for the 'double-U' principle).

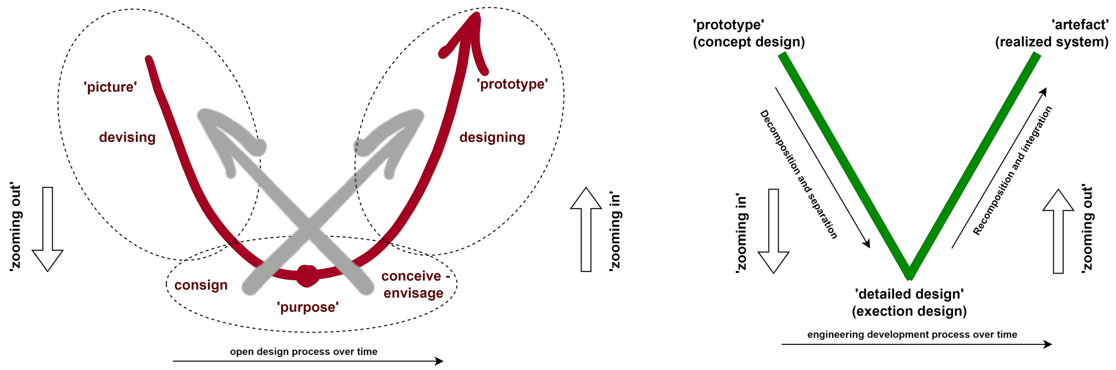

Figure 4.5: The mirror image and connection of the U (open design) and V (engineering development) model.

We can now (finally) introduce the full new Odesys' U-model that has been developed for the purpose of open design systems, see Figure 4.7. 'The common will becomes visible from the technical matter, the inner source and the open source work towards/ in the technical matter' via a threefold of open config re-converting, open space re-validating and open source re-purposing/ re-synthesizing. Traditionally, most designers (or engineers especially) focus mainly on their technical design configuration by parametric engineering, much less on the socio-eco organizational context, and least on an idealized design or purpose system. This is why, so often, we build what no one wants. Moreover, this is why, so often, engineers optimise their solution only for the technical subsystem properties, disregarding stakeholder's preferences (i.e., only a technical driven parametric design approach). Therefore, based on the fundamental basic design U-model as indicated above (see Figure 4.4), we have proposed here the integrated new Odesys's U-approach. In Figure 4.7 we see this resulting Odesys' U-model fully connected with its open design system diagram. The content and the details of the figure speak for itself, however we make a few extra and final notions:
(#1) The Odesys U-diagram consists of three subsystems: i.e., the purpose (idealized or best-fitting design), the social (common socio-eco interests) (the social context), and the technical (design performance configuration) subsystem. Using the principle of reflection from the threefold man and his senses, it is also seen as the open will/*open source*, the open heart/*open space*, and the open mind/ *open config* subsystems. Here, we see that the related U-model goes in two directions: (1) from the technical system (in light of a high level 'picture', e.g. a bridge instead of a tunnel as a fit for a connection) to its intended purpose, which is the left of the U, and (2) from a renewed purpose to the adapted or renewed (engineering) configuration, which is the right of the U. Actually, the Odesys U-diagram is in itself a top-down view only, but not yet an integrative approach. Only by going through the U will you arrive at such an approach, at an act of unlocking the stakeholders common will. To do so, you must therefore go through the process 'twice' in opposite directions to unite the design impulse (in- or externally driven) with its common motive, so that social interests can coincide with technical achievability : the essence of the Odesys-U (and therefore two opposing arrows have been added to the Odesys' U). In other words, we have integrated the U-model with the Odesys' U via a bottom-up and top-down synthesis using the human nine-fold of being for open designing (see for the U-basics Chapter 3). In doing so, the Odesys U-model goes beyond the one-sided design approach of 'detailed implementation design follows strategic sketch design'.
(#2) If we zoom in a bit more on the middle axis (the mirror axis) of the U, we see the concepts of re-convert, re-validate, re-purpose, and re-generate/re-synthesize linked back to the open mind, the open heart, and the open will and the open source of the U. This middle axis of the U expresses that this is a recursive,

cyclical, and open-ended process (see e.g., Lievegoed). In reality, then, the U will be cyclical and open-ended to arrive at new intermediate results and (for then) best fit for purpose solutions. That is why for us open design loops are so intimately connected to the Odesys U. To reflect or unite this, the open-ended approach is depicted in the middle of the U, see Figure 4.6. You could say that this symbolizes a 're-Union' process, since a re-uniting process occurs where a perfect solution (perhaps temporary) emerges in unity or synthesis (note: re-, expresses a "repetition of an action" and unite expresses "join together and make it into one" re-Unite). Here we then see the unique in its sort and state of the art threefold Odesys U-model incorporating three open-ended design loops: i.e., a spiral of: (1) Open config – technical cycle, (2) Open space -social cycle, and (3) Open source - the purpose cycle (in contrast to similar classical engineering design systems which often recognize only less than three subsystems loops). More generally formulated so that these three cycles also apply to open loops management (see Chapter3) and to open design learning (see Chapter 9), we can describe the three cycles as: i.e., (1) the technical - configuration/concept, (2) the social - conciliation/context, and (3) the purpose - consign/conceive cycle respectively.
(#3) Lastly, we make the following open-ended note (see Simon, 2019): 'A paradoxical, but perhaps realistic, view of design goals is that their function is to motivate activity which in turn will generate new goals.'

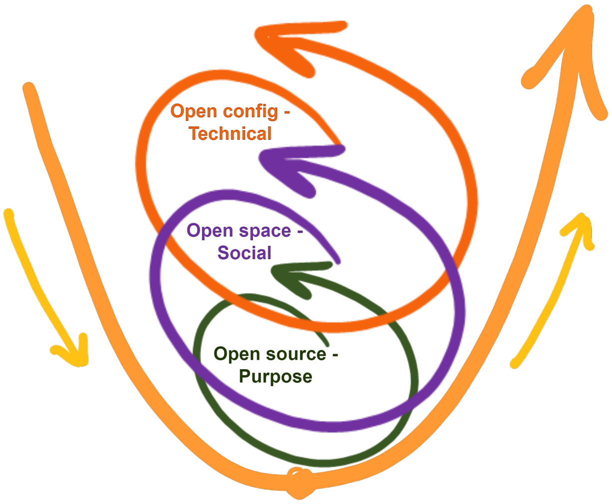

Figure 4.6: The three open-ended U-cycles (open design loops): purpose, social and technical: an open-ended spiral design metamorphosis, as developed by Wolfert.

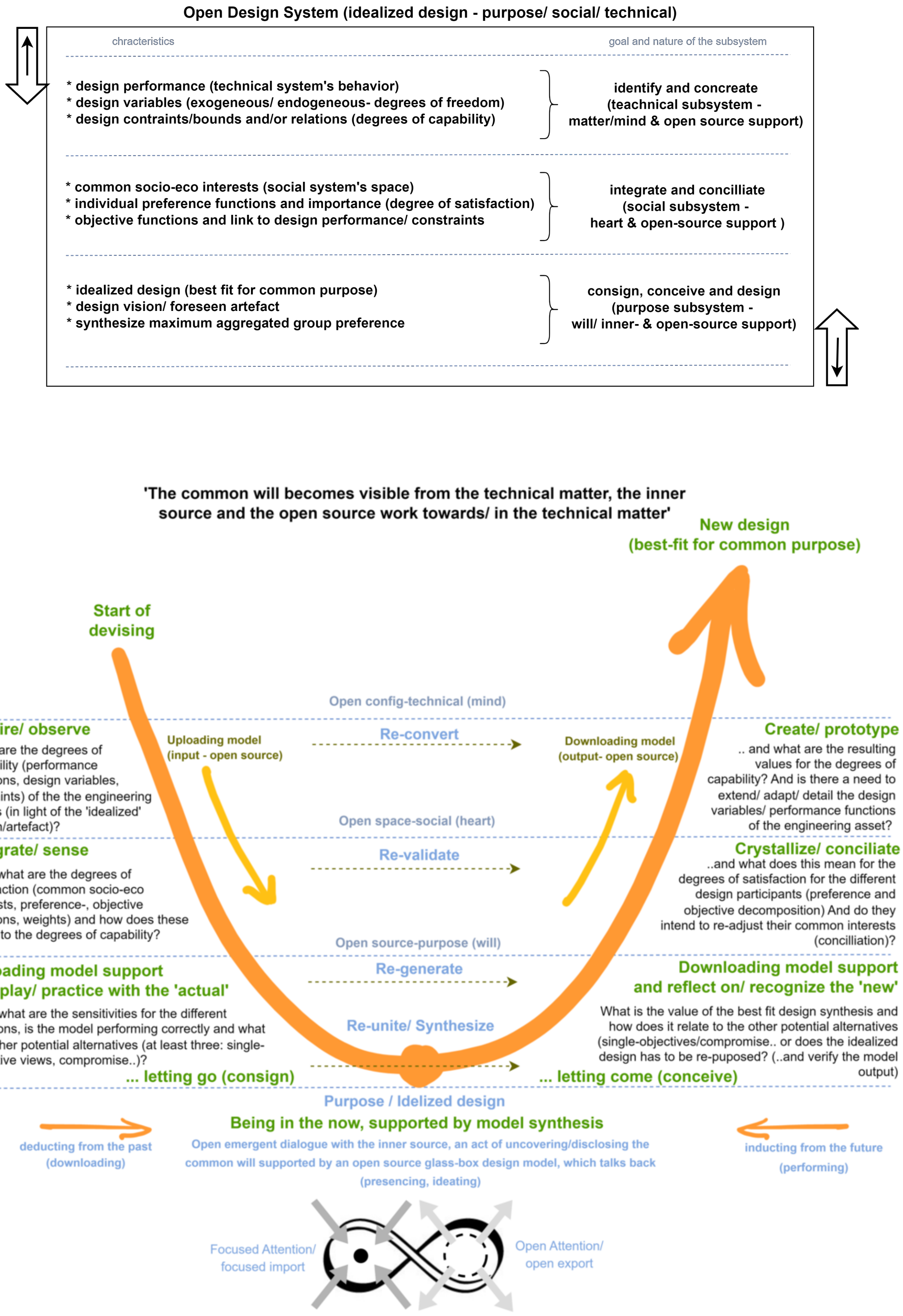

Figure 4.7: The full new Odesys U-model with the Open Design System, developed by Wolfert from earlier ‘U-work’ by Glasl (1998) and Scharmer (2016).

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Chapter 5

Mathematical modeling design & decision problems

Engineers commonly use optimisation and decision making models to select/choose between design alternatives or to generate/configure design solutions: i.e., decision analysis/evaluation versus design optimisation models. The novel Odesys methodology described in this book (see Chapter 6 and onwards) combines these models into one overarching design and decision making methodology. Before combining these models we need to formally define both and uncover the limitations of each. We distinguish a-posteriori decision analysis models and a-priori design optimisation models. In the case of a-posteriori decision models the alternatives to choose from are known and can be evaluated by means of a Multi Criteria Decision Analysis (MCDA) evaluation. Conversely, in the case of a-priori design optimisation models the alternatives are not yet known up front and need to be generated by means of Single and/or Multi Objective Design Optimisation (SODO/MODO) search.

Note that as mentioned prior, for elucidation purposes, the MCDA and MODO are discussed separately in Sections 5.1 and 5.2 respectively. In practice, this 'separate use' may also be the case when we work from 'coarse to fine' during a planning and design process. An MCDA-approach can then first be applied during a variants study (see e.g. Example 2 in Section 5.1) to determine a best variant. A MODO-approach (see Section 5.2) can then be used to come to a best-fit configuration within the chosen variant, given the design constraints, the different stakeholder objectives, and given the design degrees of freedom (this rather than just 'out-engineering' a variant as is often done without true conflict of interest dissolution, resulting in an artifact no one wants).

We now show how to apply these MCDA and MODO approaches in a mathematically correct way using preference function modeling (PFM).

Incitement 5.1 The principle of reflection

Q(1): An event took place in 2005 and another one in 2007. What's wrong with 2005 + 2007 = 4012?
Answer:
The sum of two times, as opposed to time differences, is undefined because time scales are affine scales and the operation of addition is undefined for points on an affine straight line.

Q(2): 3:00 p.m. is 15:00 and 2:00 p.m. is 14:00. Is their ratio 3/2=1.5 or 15/14=1.071428571?
Answer:
The ratio of two times is undefined because time scales are affine scales. The operation of division is undefined for points on an affine straight line. In this context the number 1.071428571 has no meaning despite its scientific appearance. For the same reason, the ratio of two potential energies is undefined.

The literature of classical decision theory and measurement theory offers neither insight as to why "2005+2007=4012" nor these aforementioned ratios are meaningless. For more inspiring incitements visit: scientificmetrics.com.

5.1. Multi-criteria decision analysis & preference function modeling

Multi-criteria decision analysis (MCDA) is integral to engineering design and management processes and is an important element in nearly all of their phases. Viewing engineering design and management as a decision making processes recognizes the substantial role that decision theory can play in their activities. Decision theory articulates the three key elements of decision-making processes as:

1. Identification of options or choices.
2. Development of expectations on the outcomes of each choice.
3. Formulation of an evaluation system of values for rating outcomes to provide an effective ranking to obtain the preferred choice.

The foundations of decision and measurement theory, however require major corrections. Below we show, based on a new PFM theory developed by Barzilai, that von Neumann and Morgenstern's utility theory, which is at the basis of decision theory, contains fundamental mathematical flaws with regards to modeling the measurement and aggregation of preferences. We introduce this new theory of measurement which provides mathematically well founded scales for the measurement of preference.

Incitement 5.2 When being good is not good enough

Consider a reputable construction company that used to address their customers with a yearly survey to measure their perception of delivered service quality. Respondents were requested to give a grade on the following criteria: Communication; Reliability; Delivery times; Eye for customer's interests; Quality control; Image. On all criteria the company scored well above seven, so everything seemed to be in order. Until, that is, someone raised the question: What do these seven actually represent and what is the best and what is the worst you can score? And above all and more importantly, how do you know that your major competitors don't score an eight and what is the scale of? After all, to be selected in a bidding procedure, to be 'good' is not good enough. One has to be perceived as better than the competing candidates.

So the question remains: how can we properly measure the firm's performance on all criteria that reflects the firm's relative position using properly defined scales?

The issues with classical preference measurement theories

Classical measurement and evaluation theories, including utility theory, cannot serve as the mathematical foundation of decision theory, game theory, economics, or other scientific disciplines because their models do not satisfy the conditions that must be satisfied to enable the application of the mathematical operations of linear algebra and calculus. For modeling psychological variables, where the existence of an absolute zero is not established, the only possibility for addition, multiplication, order, and limits to be applicable is the model where the measured objects correspond to points in a one-dimensional affine space over the ordered real numbers. In such a space the ratio of two points is undefined while their difference is a vector and the ratio of two vectors is a scalar. Note: psychological variables relate to a human subject as opposed to physical variables that relate to a physical object. For instance, the room that you are sitting in has a temperature that can be objectively determined, whether or not you find the room to be warm or cold is up to you to determine.

Ratios of variables for which the existence of an absolute zero has not been established are undefined. For example, ratios T_1/T_2 of temperature have been undefined until it was established that temperature has an absolute zero, see e.g. Von Neumann et al. (1955). In the case of time, the ratio t_1/t_2, where t_1 and t_2 are two points in time, is undefined while the ratio $\Delta t_1/\Delta t_2$ of two time differences, i.e. time periods or time intervals, is well-defined. It follows that the ratio is undefined for any psychological variable since the existence of an absolute zero has not been established for psychological variables.

Incitement 5.3 Job decision

Consider a person having to decide between two job positions with characteristics as shown in first the Table below. Using the arithmetic mean (weighted sum) to determine the overall rating of each position shows that position 1 is preferred over position 2.

	Criterion		
	Opportunities	Salary ($/Yr)	Weighted sum
Position 1	15	50 000	20 009
Position 2	20	45 000	18 012
Weight	0.6	0.4	

However, if we change the unit, which the weighted sum allows, for the salary criterion from $/Yr$ to k/Yr the order is reversed and position 2 is preferred over position 1, see the following Table below.

	Criterion		
	Opportunities	Salary ($k/Yr)	Weighted sum
Position 1	15	50	29
Position 2	20	45	30
Weight	0.6	0.4	

How should this person now come to a well-supported job decision? Seemingly the weighed sum produces an infinite number of non-equivalent 'absolute' outcomes which should be relative... So the question remains: how can we mathematically correct determine and aggregate scores on different criteria.?

Proper preference measurement scales

The expression $\frac{a-b}{c-d} = k$ where a, b, c and d are points on an affine straight line and k is a scalar is used in the construction of proper scales. The number of points in the left hand side of this expression can be reduced from four to three (e.g. if $b = d$), but it cannot be reduced to two and this implies that pairwise comparisons cannot be used to construct preference scales where the operations of addition and multiplication are enabled.

A scale s is a mapping of the objects in an empirical system E into the objects in a mathematical model of that system M that reflects the structure of E into M, see Figure 5.1. The construction of measurement scales requires that the property-specific empirical operations be identified and reflected in the mathematical model. Moreover, the operations should be chosen so as to achieve the goal of this construction which is the application of mathematical operations in the mathematical model. Note that the property (length, mass, etc.) of the objects must be specified in order for the mathematical operations to be applicable and that addition and multiplication are applied on lengths and masses of objects. It is not possible to "add objects" without knowing whether what is being added is their mass, length, temperature, etc. In this context, preference is the only property of relevance in the context of the mathematical foundations of game theory.

In conclusion, to create preference scales that enable the mathematical operations of addition and multiplication we need to map at least three alternatives within the empirical system E to three objects in the mathematical system E. Of these three alternatives the worst and best performing alternatives are used to define the scale on which the third alternative is scored.

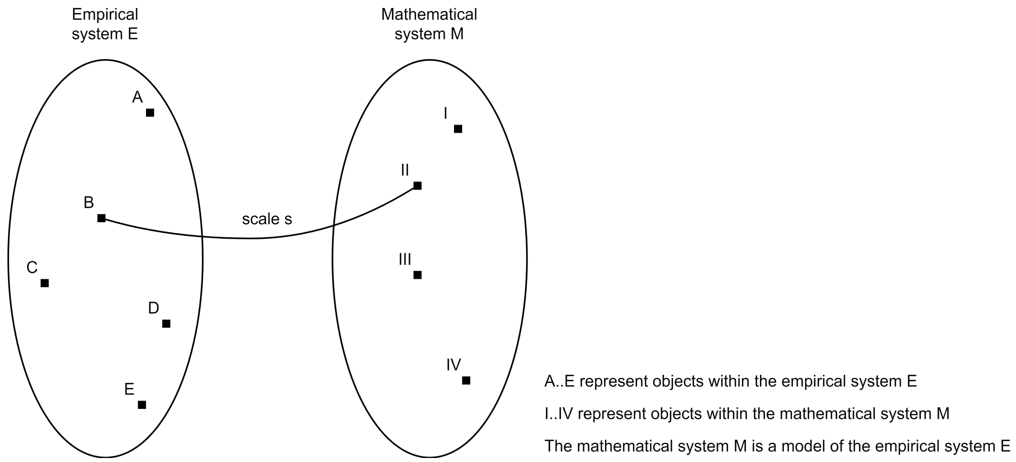


Figure 5.1: A scale is a mapping of the object in an empirical system into the objects in a mathematical model of that system.

Aggregating preferences

Having determined how to create proper preference scales we also need to aggregate preference scores on different criteria given a set of weights. The weighted arithmetic mean is commonly used to yield an overall preference scale:

$$V(a) = \sum_{i=1}^{m} w_i v_i(a) \tag{5.1}$$

Where $V(a)$ is the overall value, performance or preference score of alternative a, v_i the value or preference score reflecting alternative a's performance on criterion i and w_i the weight assigned to reflect the importance of criterion i. Employing the weighted arithmetic mean to yield an overall preference scale is, however, a mathematical modeling error for the following three reasons:

1. It produces an infinite number of non-equivalent outcomes.
2. Mathematical operations are applied where they are not defined.
3. It produces absolute outcomes without regard to other alternatives being considered.

Ad. 1 - The output of this procedure depends on the units by which the scales are measured. As a consequence, we can produce an infinite number of non-equivalent outcomes, just by changing the units. This is an unacceptable property of any mapping used to aggregate scales. Note that the definition of the weighted arithmetic mean does not prerequisite having only normalized numbers.
Ad. 2 - The overall performance of an alternative is determined by multiplying preference scores by weights assigned to criteria. As explained above, the mathematical operations of division and its inverse are undefined for any psychological variable since the existence of an absolute zero has not been established for psychological variables. Applying multiplication implies that the empirical system is modeled by a vector space where addition and multiplication are defined. This is however the incorrect mathematical model for representing psychological variables.
Ad. 3 - The weighted arithmetic mean is a mathematical formula that does not take into account how other alternatives under consideration score. Instead we need an algorithm for finding the aggregated preference score: i.e., the 'best' fit of all weighted (relative) scores for all the stakeholders' criteria, of an alternative that minimises the least-squares difference between this overall preference score and each of the normalized individual scores of this alternative on all criteria in the affine space, by computing its closest counterpart, see Barzilai (2022).

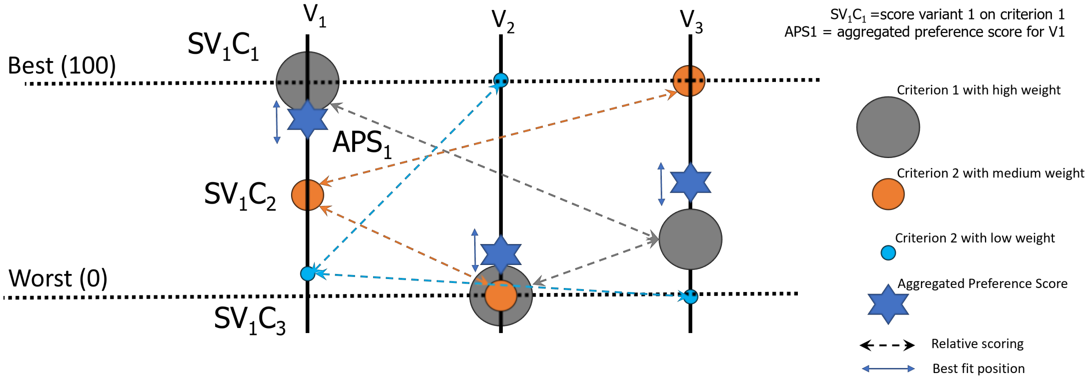


Figure 5.2: Visualisation of PFM-based preference aggregation.

Figure 5.2 can be used to illustrate how preference scores can be properly aggregated. The first variant scores highest on the criterion with the highest weight attached to it, scores average on a less important criterion and scores low on the least important criterion. As a result the aggregated preference score ends up close to the score on the criterion with the highest weight. The opposite holds for the second variant which scores lowest on the criterion with the highest weight attached to it, scores also low on the less important criterion and highest on the least important criterion. As a result the aggregated preference score ends up close to the score on the criterion with the highest weight. Finally, the third variant scores low on the criterion with the highest weight attached to it, scores highest on the less important criterion and lowest on the least important criterion. As an overall result the first variant has the highest overall preference score in relation to the remaining variants. The second variant has the lowest overall preference score and the third variant ends up in between both other variants. Note that scores of variants are not 'isolated' but always relative to the other variants. This is highlighted by the dashed lines.

To determine the (overall) aggregated preference score we use a software package called Tetra which is a solver rather than a 'calculator', and is based on the aforementioned algorithm. For more information on the Tetra solver, see: scientificmetrics.com or choicerobot.com. Those that want to know more about the mathematical modeling errors of classical measurement theories are referred to the book "Pure Economics" by Barzilai (2022). A more detailed description of the errors relating to preference modeling in engineering design can be found in Barzilai (2006).

To explain the previous PFM-based preference aggregation and to show how to apply these for multi-criteria evaluation purposes, four illustrative MCDA examples will be given below.

Example 1: Phone selection (MCDA)

We illustrate proper preference measurement and aggregation into one overall preference scale using two examples of two decision makers A and B facing a multi-criteria phone selection problem. The first decision maker has a different set of criteria, weights and ratings compared to the second decision maker. This underlines the subjective nature of preference measurement where 'beauty is in the eye of the beholder'.

We note that choice is synonymous to preference as we choose those objects that we prefer. This is why in the following tables physical properties like screen size and weight are translated into preference scores by means of linear interpolation (i.e., to arrive at a common denominator which is preference). Recall that preference is the only property of relevance in the context of utility theory and game theory. Note that 'unit price' is not a physical property of an object but rather relating to economics which is part of the social sciences (demand versus supply as driving factors for the pricing of goods). In other words, price is not related to the object but to affordability as determined by the human subject. Also note that by linear interpolation we assume a linear relationship between an object's physical properties and relating preference scores. It is up to the decision maker to decide whether or not this is a valid assumption or needs adjustment. Tables 5.1 and 5.2 show the input for decision maker A and B respectively and the output obtained by the Tetra solver. Decision maker B is not interested in brand but is interested in privacy instead and also has a different set of weights and ratings. Not surprisingly the output is different for decision maker A and B.

Table 5.1: Criteria, scores and weights for different phones (decision maker A).

Criterion weight	Looks 40%	Price 5%	Brand 45%	Size 5%	Mass 5%	Overall score
Iphone	100	0 (€900)	100	50 (6.1")	50 (175g)	100
Samsung	70	15 (€80)	30	100 (6.2")	100 (160g)	56
Pinephone	0	100 (€200)	0	0 (5.95")	0 (190g)	0

Table 5.2: Criteria, scores and weights for different phones (decision maker B).

Criterion weight	Looks 5 %	Cost 40%	Privacy 45%	Size 5%	Mass 5%	Overall score
Iphone	100	0 (€900)	20	50 (6.1")	50 (175g)	0
Samsung	70	15 (€80)	0	100 (6.2")	100 (160g)	1
Pinephone	0	100 (€200)	100	0 (5.95")	0 (190g)	100

Example 2: Parking garage (MCDA single-stakeholder)

We can illustrate the problems with aggregation of preference ratings using a simple engineering decision making problem concerning four design variants of a parking garage:

- Variant 1: two level, where the parking spaces are at a 45°angle.
- Variant 2: two level, where the parking spaces are at a 70°angle.
- Variant 3: three level, where the parking spaces are at a 45°angle.
- Variant 4: three level, where the parking spaces are at a 70°angle.

The decision maker takes three criteria into consideration: 1) functionality, 2) environmental impact, and 3) cost. The scores for each alternative and the weights attached to the criteria are shown in Table 5.3 including the overall preference score according to Tetra and the weighted arithmetic mean. Note that on each criterion the worst (0) and best (100) alternatives have been determined to define the scale on which the remaining alternatives are scored and that the scores obtained by the arithmetic mean are also re-scaled to the range 0-100 to make them comparable to the Tetra outcomes.

As can be seen the aggregated scores according to the weighted arithmetic mean are different from the scores obtained by the Tetra solver. We now remove variant 4 to illustrate the problem with the arithmetic mean. As this variant has the

Table 5.3: Scores and weights for the parking garage decision making problem.

	Variant 1	Variant 2	Variant 3	Variant 4	Weight
Functionality	100	0	20	85	40%
Environmental impact	0	100	45	60	10%
Cost	90	100	55	0	50%
Overall rating Tetra	100	52	4	0	
Overall rating arithmetic mean	85	60	40	40	
Overall rating re-scaled	100	44	0	0	

same score as variant 3 according to the use of the arithmetic mean the scores obtained by the arithmetic mean will remain unchanged. The removal of variant 4 does, however, have an effect on the overall preference ratings of the alternatives according to the Tetra solver as can be seen in the revised Table 5.4. This is because Tetra takes into account the relative position of each alternative to find the aggregated preference score that reflects this new position.

Table 5.4: Scores and weights for the parking garage decision making problem.

	Variant 1	Variant 2	Variant 3	Weight
Functionality	100	0	20	40%
Environmental impact	0	100	45	10%
Cost	90	100	55	50%
Overall rating Tetra	100	73	0	
Overall rating arithmetic mean	85	60	40	
Overall rating re-scaled	100	44	0	

Example 3: Parking garage (MCDA multi-stakeholder)

In the previous example we considered a single decision maker taking three criteria in consideration when making their decision. A rudimentary way of solving multi-stakeholder problems is by considering each of the main criteria to belong to a single stakeholder. In the case of the parking garage it could be that we have three stakeholders where one is interested in the functionality, another in the environmental impact and the third one in the cost. Note that the weight distribution now expresses the power of each stakeholder. A more elegant way of defining multi-stakeholder decision making problems is by using the top level criteria for representing decision maker weights. The sub-criteria can then be used by each decision maker to express their individual set of criteria (and sub-criteria). This also allows for multiple decision makers expressing their preference for the same criterion. We converted the parking garage problem to a multi-stakeholder decision problem as shown in Table 5.5. For the sake of simplicity we use the same set of criteria for each stakeholder and set the criteria weight to zero for those criteria that a given stakeholder is not interested in.

Table 5.5: Scores and weights for the parking garage multi-stakeholder decision making problem.

Decision maker weight	Criterion weight	Variant 1	Variant 2	Variant 3
Stakeholder A (50%)	Functionality (20%)	100	0	20
	Env. impact (0%)	0	0	0
	Cost (80%)	0	100	45
Stakeholder B (50%)	Functionality (15%)	100	0	55
	Env. impact (80%)	100	90	0
	Cost (5%)	0	10	100
Overall rating Tetra		58	100	0

Example 4: Supermarket's CSI (MCDA)

Multi-criteria decision making tools can also be used for determining an organization's socio-eco identity: i.e., corporate social identity (CSI) as an expression for the socially responsible quality of service delivery that is perceived by a user/client (see also Chapters 3 and 4). According to PFM principles, to mathematically correctly determine the CSI indicator of an organization mathematically correctly, we must consider at least three organizations (see PFM principles in Section 5.1). Moreover, these three organisations should be experienced through the eyes of at least one and the same customer. Note that the traditional Corporate Social Responsibility (CSR) indicator is in most cases only viewed from the perspective of one's own organisation which is fundamentally flawed and thus these results are meaningless showing no reliable results at all. It results in a large delta between espoused theory and theory in action. The CSI indicator and its quantitative approach, has been developed by Binnekamp and Wolfert (see Chapter 3 for the qualitative origin of the CSI indicator).

As an CSI example, consider a customer that wants to identify the identity of three Dutch 'brands' of supermarkets: Odin, Jumbo and Ekoplaza. The client distinguishes the overall socio-eco purpose threefold main criteria: economic, isonomic and ecological performance indicators which are weighted equally. Each criterion is subdivided into further sub-criteria which are also weighted equally. Finally each supermarket is scored on each sub-criterion. For the process of scoring the client visited each supermarket to sample the products & services on offer and also assessed how each organization operates in a broader societal perspective. All in- and output scores are summarized in Tables 5.6 and 5.7, which also shows the overall score of each brand of supermarket (as a result from Tetra). Note that both the sub-criteria, the values and the weights are indicative, generic and static to show only the operation of the method here (in reality, a more thorough customer study is needed as input accompanied by a dynamic sensitivity analysis).

Table 5.6: Supermarket socio-eco purpose input

Main criteria	Weights	Sub-criteria	Weights	Scores		
				Odin	Jumbo	Ekoplaza
Economic	33%	Quality experience by customer / customer satisfaction	25%	80	0	100
		Associative / co-maker relations that share pain and gain	25%	100	0	50
		Future proof / fair pricing	25%	100	0	70
		Lowest market price	25%	0	100	20
Isonomic	33%	Collective decision making / involvement employees and/or clients	25%	100	0	50
		Contracts from equality instead of self-interest	25%	100	0	60
		Equitable / fair working conditions	25%	100	0	100
		Vulnerability due to market / contract changes	25%	0	100	50
Ecological	33%	Liberty / free development potential employees	25%	100	0	10
		Unconditional re-investments / neutralize capital	25%	100	0	50
		True care for earth / (social) environment	25%	100	0	90
		Relieving nature by using artificial organisms / ways of farming	25%	0	100	0

Table 5.7: Relative CSI ranking outcome for the supermarket's CSI.

Alternative	Solution
Odin	100
Jumbo	0
Ekoplaza	60

5.2. Single- & multi-objective design optimisation

In the previous section we viewed engineering design and management as an a-posteriori decision-making processes to show that decision theory can play an important role in their activities. Engineering design and management can also be viewed as a process of a-priori modeling a single or multi-objective design or plan resulting in a mapping from the design variant space to the design performance attribute space. Note that a design is defined as a plan or scheme in the mind. Subsequently, a utility function is constructed that reflects the designer's (acting on behalf of the decision maker) preference while considering trade-offs among system attributes. As such the design process is goal-oriented aimed at maximising utility: i.e., aggregated preference.

Where in the previous section a selection needed to be made between a set of given (a-posteriori) design alternatives, the goal here is to generate these alternatives (a-priori) and to be able to select the most optimal one. For the generation of alternatives the utility function is used. Think of a designer going for the most sustainable (minimise raw material use) or most profitable (maximise yield) design. Note that the utility is inversely proportional to the material use (the less material use, the higher the utility).

While a designer can manually (or sometimes 'intuitively') search for an optimal design, optimisation techniques could be used to make this search process more efficient and effective. Mathematical single- or multi-objective design optimisation (SODO/MODO) models can be used for representing engineering design problems because such problems can be modeled using goal-oriented systems. We first introduce the general formulation of mathematical optimisation models, which can be stated as follows:

$$U = f(X, Y) \tag{5.2}$$

The utility or value (U) is a function of two types of variables: controlled (endogenous) (X) and uncontrolled (exogenous) variables (Y). An optimisation algorithm is used to select the configuration of controllable (design) variables X that yields the highest utility U whilst not violating the constraints. The system's utility U is defined by an objective function which needs to be maximised. This model can be solved using different mathematical optimisation techniques. A gentle introduction into the application of the above optimisation framework for solving generic making problems can be found in the work of Ackoff (1999).

The technique of linear programming, among other techniques, can be used for solving mathematical optimisation problems. For the description of the general mathematical model of linear programming, we will use the nomenclature and the standard form adopted in the Operations Research (OR) textbook of Hillier, Lieberman et al. (2006). This model is to select the values for the (design) variables

$x_1, x_2, \ldots, x_n$, so as to:

$$Maximise\ U = c_1x_1 + c_2x_2 + \ldots + c_nx_n \tag{5.3}$$

Subject to the inequality constraints:

$$a_{1,1}x_1 + a_{1,2}x_2 + \& \ldots + a_{1,n}x_n \leq b_1 \ldots a_{m,1}x_1 + a_{m,2}x_2 + \& \ldots + a_{m,n}x_n \leq b_m \tag{5.4}$$

$$x_1 \geq 0;\ x_2 \geq 0;\ \ldots x_n \geq 0 \tag{5.5}$$

In this model the variables $x_1, x_2, \ldots, x_n$ represent the controlled variables. Together with coefficients $c_1, c_2, \ldots, c_n$ they represent the objective function. Coefficients $a_{1,1}, \ldots, a_{m,n}$ and $b_1, b_2, \ldots, b_m$ represent the uncontrolled variables. Variables $x_1, x_2, \ldots, x_n$, coefficients $a_{1,1}, \ldots, a_{m,n}$ and $b_1, b_2, \ldots, b_m$ together represent the different constraints. Note that this is a linear problem setup since both the objective and the constraint functions are linear. For an overview of how to apply (non)-linear programming to other types of managerial optimisation problems we suggest the work of Balakrishnan et al. (2017).

To explain the previous general mathematical formulation for a design problem and show how to solve it, four illustrative example problems will be given below, which can also be found on the Odesys Github, using the different standard Python based solver types as explained in Appendix E. The first example is still a single-objective managerial optimisation problem (SODO). However, the second problem is a multi-objective design optimisation problem (MODO). The third example is again a multi-objective design optimisation problem (MODO), but then applied to a planning problem. For illustrative purposes, these first three problems have been kept linear. Finally, the fourth problem is a non-linear multi-objective design optimisation example.

Example 1: Computer production (SODO linear)

We start with a simple example of a company that produces two types of computers, a basic computer and a more advanced computer. The basic computer type requires one hard drive, the advanced type requires two hard drives. Each produced basic computer type has a profit of \$300 whereas an advanced computer has a profit of \$500. There are 60 cases in stock for the basic computer and 50 cases in stock for the advanced computer type. Finally there are 120 hard drives in stock. The company wants to know how many computers of each type it should produce to maximise profit (a typical managerial decision making problem).

The controllable variables $x_1, x_2, \ldots, x_n$ are the numbers of computers produced of each type. The profit needs to be maximised so the single objective function becomes:

$$Maximise\ U = 300x_1 + 500x_2 \tag{5.6}$$

The constraints relate to the number of cases and hard drives in stock:

$$x_1 \leq 60;\ x_2 \leq 50;\ x_1 + 2x_2 \leq 120 \tag{5.7}$$

Solving this single objective optimisation problem shows that producing 60 basic computers and 30 advanced computers results in the highest profit of $33 000. Note that within Python one can use the 'Minimise' algorithm to solve this type of optimisation problems (both for linear and non-linear continuous objective/constraint functions, where the Mixed Integer Linear Programming (MILP) algorithm can be used for mixed integer and linear objective/constraint functions extended with a Genetic Algorithm (GA) modification for non-linear mixed integer cases).

We can also solve simple linear optimisation problems graphically. Figure 5.3 shows how the computer production problem can be solved in this way.

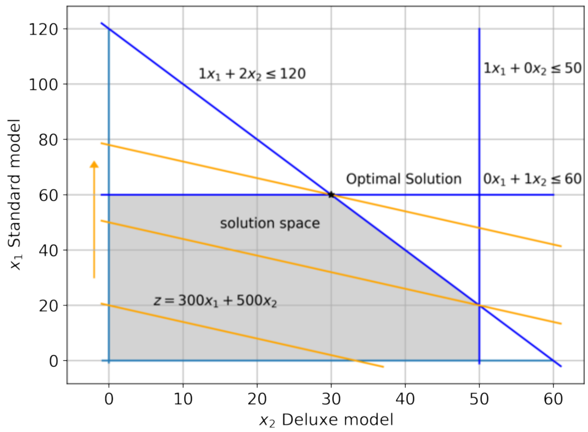


Figure 5.3: Graphical representation of the computer production problem.

Blue lines represent the constraints relating to the amount of cases and hard drives in stock. All constraints determine the solution (or design) space which is the gray area in the figure. If the constraints indeed define a solution space (no conflicting constraints) the objective function is used to find the optimum. The lower orange line shows the of the objective function. Its slope is determined by the coefficients of the objective function (300/500). Depending on the nature of the problem the objective function can be either maximised (e.g. profit) or minimised (e.g. costs). In this case the profit needs to be maximised which means that the orange line needs to be shifted up along the Y axis. The optimum is reached when the objective function can no longer be shifted upwards without violating the constraints (leaving the solution space). The optimal solution is the coordinate i.e. combination of controllable variables found which is in this case 60 basic computers and 30 advanced computers. Note that a problem having three controllable variables (x_1, x_2, x_3) can still be represented graphically. In that case the constraints are represented by planes that in turn define a 3-dimensional solution space. The objective function is also represented as a plane that needs to be shifted towards one of the solution space's corner points. A problem having more than three controllable variables can no longer be represented and solved graphically but still can be solved mathematically.

This simple example shows how a managerial decision problem can be modeled and solved using mathematical optimisation techniques. Mathematical optimisation models thus allow searching for the optimal solution to a decision making problem. It relies on defining the controllable variables, the objective function and the constraints that define the solution space. Should the solution space be empty, then no solution can be found. All solutions within the solution space are feasible, however, given the objective function, the most desirable solution can be identified. The main question is whether the technique of mathematical optimisation using linear programming is also applicable to solving real life (engineering) design problems.

Example 2: Bridge design (MODO linear & PDP)

Consider a bridge design where we limit the design problem to the determination of the optimal span and the clearance height of the bridge. Assume that there are two decision makers (stakeholders) that have conflicting interests: 1) the municipality interested in the costs of the bridge, and 2) the waterway users interested in the waiting time when the bridge is closed for waterway users. This can thus be transformed in a so-called 2x2 MODO problem statement (i.e., 2 design variables and 2 objectives). It serves as a base for a project delivery plan (PDP).

For this problem we have two controllable design variables, the bridge span x_1 and the clearance height of the bridge x_2. The municipality wants the cost to be minimised which becomes the first objective function. The costs are a function of the material use which in turn is a function of both the span and clearance height. We assume a linear relationship between costs O_1 and material use F_1 defined by coefficient $c_1 = 3$.

$$O_1 = c_1 F_1 \tag{5.8}$$

We also assume a linear relationship between material use and both span and clearance height defined by coefficients $c_2 = 4$ and $c_3 = 7$ respectively.

$$F_1 = c_2 x_1 + c_3 x_2 \tag{5.9}$$

The first objective to be minimised then becomes:

$$O_1 = c_1 F_1 = c_1 c_2 x_1 + c_1 c_3 x_2 \tag{5.10}$$

The waterway users want the waiting time to be minimised which becomes the second objective function. The waiting time is a function of the traffic flow which in turn is a function of both the span and clearance height. We again assume a linear relationship between waiting time O_2 and traffic flow F_2, and reads as:

$$O_2 = -c_4 F_2 + w_0; \; F_2 = c_5 x_1 + c_6 x_2 \tag{5.11}$$

where $w_0 > 0$. We also assume: (a) the coefficient $c_4 = 1.2$ (b) a maximal waiting time of $w_0 = 100$ (for a traffic flow that is 'nearly' zero); (c) a linear relationship between traffic flow and both span and clearance height defined by coefficients $c_5 = 1.7$ and $c_6 = 1.9$ respectively. The second objective to be minimised then becomes:

$$O_2 = -c_4 F_2 + w_0 = -c_4 c_5 x_1 - c_4 c_6 x_2 + w_0 \tag{5.12}$$

The constraints relate to the minimum and maximum span and the minimum and and maximum clearance height:

$$1 \leq x_1 \leq 5; \; 3 \leq x_2 \leq 8 \tag{5.13}$$

An overall conceptual model of this linear 2x2 problem is shown in Figure 5.5. The graphical representation of this problem and both optimal solutions are shown in Figure 5.4. The SODO design points are $(x_1, x_2) = (1, 3)$ and $(5, 8)$ for costs and waiting time respectively. Note the difference with the previous example where we now have two objective functions and two optima.

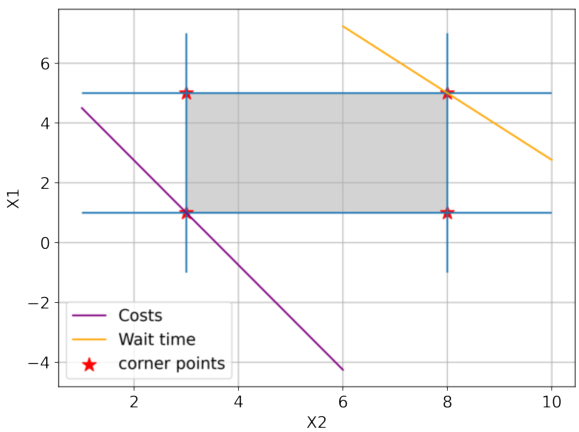


Figure 5.4: Graphical representation of the bridge design problem.

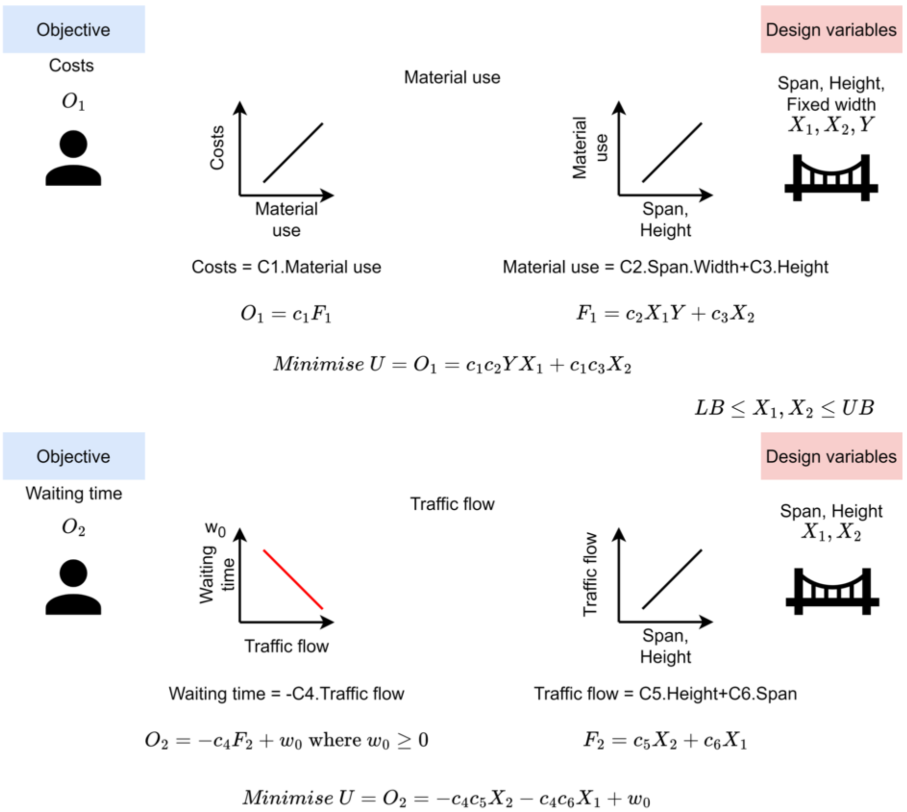


Figure 5.5: Conceptual model of the bridge design problem.

Example 3: Railroad maintenance plan (MODO linear & SOP)

Consider a level crossing railroad maintenance problem where regular tamping activities need to be carried out . We limit the problem to the determination of the optimal number of tamping activities per service interval and the tamping length (measured from the crossing). Assume that there are two decision makers (stakeholders) that have conflicting interests: 1) the railroad user interested in travel comfort when passing the crossing, i.e., the smoothness of the railroad track, and 2) the railroad operator interested in the crossing's availability, i.e., the railroad's operational service time. This can thus be transformed in a so-called 2x2 MODO problem statement (i.e., 2 design variables and 2 objectives). It serves as a base for a service operations plan (SOP)

For this problem we have two controllable design variables, the number of tamping activities x_1 and the tamping length x_2. The railroad user wants the comfort to be maximised which becomes the first objective function. The comfort

is a function of the number of tamping activities per service interval and the tamping length. We assume a linear relationship between travel comfort O_1 and both the number of tamping activities and tamping length defined by coefficients $c_1 = \frac{50}{21}$ and $c_2 = \frac{-5}{21}$ respectively.
The first objective to be maximised then becomes:

$$O_1 = c_1 x_1 + c_2 x_2 \tag{5.14}$$

The railroad operator wants the availability to be maximised which becomes the second objective function. The availability is also a function of the number of tamping activities per service interval and tamping length. We again assume a linear relationship between availability O_2 and both the number of tamping activities and tamping length defined by coefficients c_3 and c_4. We also assume a maximal availability of $a_0 = 80$ (in case there are no tamping activities or disturbances). The second objective to be maximised then becomes:

$$O_2 = a_0 - c_3 x_1 - c_4 x_2 \tag{5.15}$$

The constraints relate to the minimal safety level $t_c = 70$ and minimal availability level $a_v = 100$:

$$O_1 \geq t_c; \; O_2 \geq a_v \tag{5.16}$$

An overall conceptual model of this linear 2x2 problem is shown in Figure 5.7. The graphical representation of this problem and both optimal solutions (for comfort and availability) are shown as cornerpoint solutions in Figure 5.6.

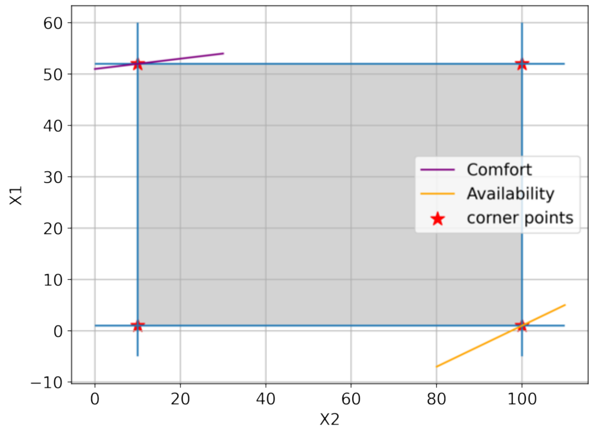


Figure 5.6: Graphical representation of the railroad maintenance problem.

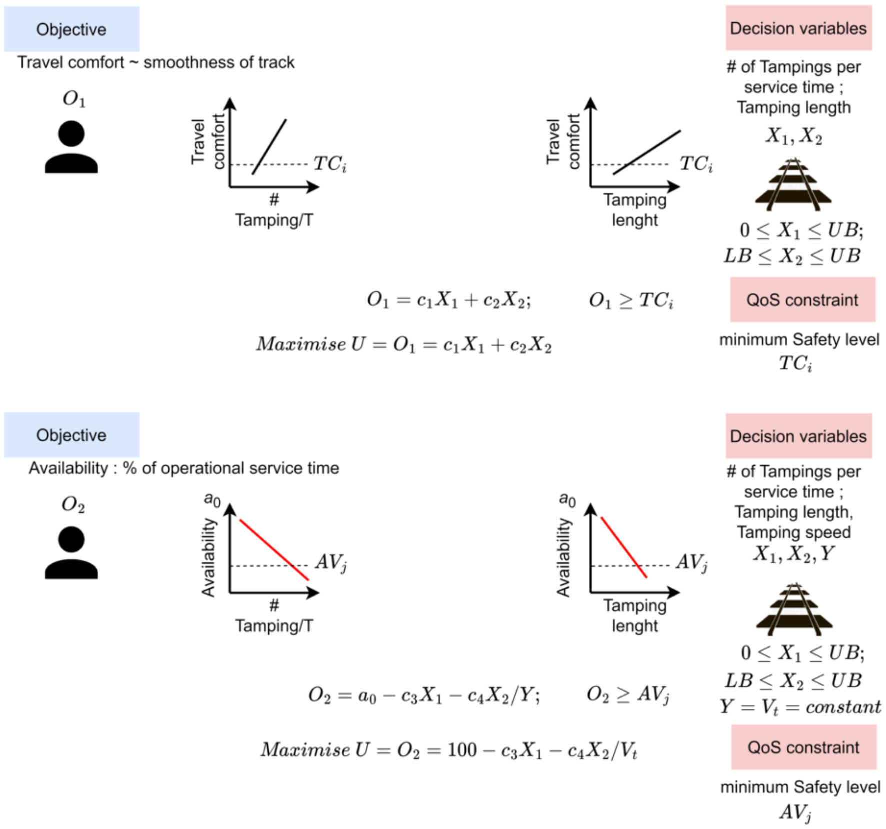


Figure 5.7: Conceptual model of the railroad maintenance problem.

The previous three examples contained only linear equations. In reality also non-linear equations will apply. In the following example we show how to solve problems containing non-linear equations.

Example 4: Building design (MODO non-linear)

Consider the design problem for a new building. We limit the problem to the determination of the optimal dimensions of the building (length, breadth, height). Let us assume that there are two decision makers (stakeholders) that have conflicting interests: 1) the project developer interested in the project's profit, and 2) the user interested in the building's energy use. This project development problem can thus be transformed in a so-called 3x2 MODO problem statement (i.e., 3 design variables and 2 objectives). For this problem we have three controllable design variables, the building's length x_1, breadth x_2 and height x_3. The project developer wants the profit to be maximised which becomes the first objective function O_1. The profit is defined as the difference between the revenues and the construction costs. The revenues are a function of the floor area while the costs are

a function of both the floor area and facade area. We assume a linear relationship between revenues and floor area defined by a coefficient $c_1 = 55$. We also assume a linear relationship between facade area and costs defined by coefficient $c_2 = 3.5$. Finally we assume a linear relationship between floor area and costs defined by coefficient $c_3 = 1.5$. We assume the floor height to be 3 meter.
The first non-linear objective to be maximised then becomes:

$$O_1 = c_1 x_1 x_2 - 2c_2(x_1 + x_2)x_3 - c_3 x_1 x_2 \tag{5.17}$$

The user wants the energy use to be minimised which becomes the second objective function O_2. The energy use is a function of the building's volume. We assume a linear relationship between the volume and energy use defined by a coefficient $c_4 = 0.32$.
The second non-linear objective to be minimised then becomes:

$$O_2 = c_4 x_1 x_2 x_3 \tag{5.18}$$

The building's footprint cannot exceed 35 000 square meters (constraint):

$$x_1 x_2 \leq 35000 \tag{5.19}$$

The profit needs to be no less than 30 000 Euros (constraint):

$$c_1 x_1 x_2 - 2c_2(x_1 + x_2)x_3 - c_3 x_1 x_2 \geq 30000 \tag{5.20}$$

Solving this model shows that the design configuration $x_1 = 176.52$, $x_2 = 198.27$ and $x_3 = 3$ yields the highest profit. Conversely, the design configuration $x_1 = 80.0$, $x_2 = 75.0$ and $x_3 = 3.0$ yields the lowest energy use. Note that by definition non-linear optimisation can only arrive at a local optimum where linear optimisation will arrive at a global optimum.

5.3. Conspection & curiosity

These MODO examples illustrate how mathematical optimisation techniques can be used to solve engineering design problems. There are major limitations, however, that prevent optimisation to be used for solving group design optimisation problems.

An important feature of optimisation models is that there is only one objective function. In other words: it can only produce solutions optimised on one objective to fully satisfy no more than one of only a single decision maker's interests. Therefore, this technique does not extend naturally to group decision making. When there are multiple objectives or multiple decision-makers, each objective or decision maker is associated with its own objective function. In that case, there are as many optimisation models as there are objective functions. So, although this technique helps decision-makers to find feasible design solutions, it does not help them to select the most preferred solution from these. For this decision-makers have to rely on negotiation. In other words, the math is lost. Moreover, the negotiations will only involve compromise solutions as each solution fully satisfies only one objective of one decision-maker (multiple single-criterion design solutions). An approach to overcome this problem is to use the so-called constraint method which operates by optimising one objective while all of the others are constrained to some value. The use of the constraint method, however, is completely arbitrary and still relies on unstructured negotiation.

Another common approach to address this problem is employ methods from the domain of decision theory as described in the previous section to select from the different design solutions the most preferred one. To elucidate this, we return to the MODO example 2, the bridge design problem. In this case we now perform an Multi Criteria Decision Analysis (MCDA) using the different single-objective design optima (corner point solutions) as alternatives. Looking at Figure 5.4 we can distinguish four corner points that represent different design configurations. Each has its own properties and again using linear interpolation as used in the phone selection problem we can determine preference scores for each. Using this information we can use Tetra to determine the overall preference rating of each corner point design solution. We assume that both objectives are equally weighted. The resulting information is summarized in Table 5.8. As can be seen the corner point solutions found by optimising on costs (corner point A) and the one found by optimising on waiting time (corner point D) are outperformed by the design configuration represented by corner point C. This makes sense as this design configuration performs reasonably well on both costs and waiting time. Figure 5.4 also supports this conclusion as it graphically 'meets both stakeholders somewhere in the middle'.

Table 5.8: Design configurations (corner points), objectives and overall scores for the bridge design problem.

	x_1	x_2	O_1	O_2	Overall score
Corner point A	1	3	100 (€75k)	0 (91 seconds)	37
Corner point B	1	8	31 (€180k)	58 (80 seconds)	0
Corner point C	5	3	69 (€123k)	42 (83 seconds)	100
Corner point D	5	8	0 (€228k)	100 (72 seconds)	63

We can conclude that multi-criteria decision making can be performed mathematically correct using the new Preference Function Modeling (PFM) theory of Barzilai. This is, however, limited to a-posteriori evaluation of defined (engineering design) alternatives. For supporting the a-priori multi-objective design process we can make use of optimisation models that are, however, limited to producing only compromise solutions that fully satisfy no more than one objective of one stakeholder (limitations as seen in the examples of the previous sections). What is needed is an a-priori methodology for finding the most preferred and feasible design solution that represents the synthesis of all stakeholders' interests instead of having to choose between compromise solutions a-posteriori. This is the key topic of the next Chapter where we construct this new Open Design Systems methodology which we call Odesys and a new integrative maximisation of aggregated preferences (IMAP) method, implemented in the Preferendus tool.

Part II

Odesys methodology and applications

Chapter 6

Socio-technical systems design & integration

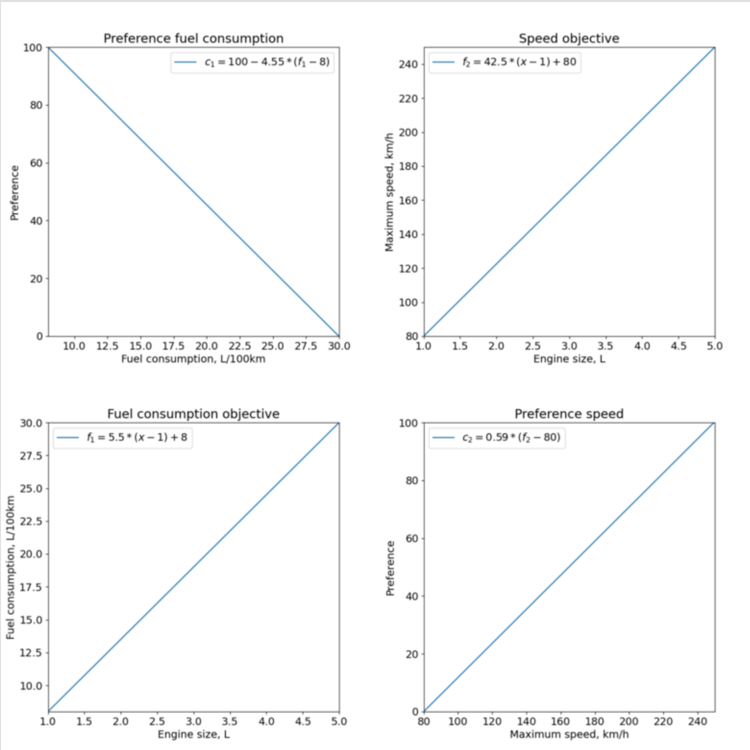
Current systems design optimisation methodologies are one-sided, as these ignore the dynamic interplay between people's preferences (demand) and engineering assets' physical performance (supply). Moreover, classical multi-objective optimisation methods contain fundamental (aggregation) modeling errors and are not able to reflect various socio-eco interests in one common preference domain. Therefore, we introduce a new and state of the art open design systems (Odesys) methodology in this Chapter. First, a sharp motivation for the need, or development gap, for such a new integrative socio-technical design methodology will be described. This will be followed by the Odesys' development statement, its mathematical description, and a new threefold modeling framework linked with the open-ended Odesys U-diagram.

As part of this Odesys methodology, a new IMAP (Integrative Maximised Aggregated Preference) optimisation method is introduced for maximising aggregated preferences. This IMAP method forms the basis of a software tool called the Preferendus and combines the state-of-the-art PFM principles with an inter-generational genetic algorithm (GA) solver developed specifically for this purpose. Odesys' added value and use are demonstrated in Chapters hereafter (Chapters 7 and 8), both for specific components within formative examples and for summative exemplars of real infrastructure design applications, showing how to achieve "best fit" for common design points. To make a comparison between Preferendus/IMAP results and a conventional optimisation method which is among the few that does not violate PFM principles, the Min-max goal attainment method is introduced here as a comparative mathematical formulation.

The state-of-the art Odesys methodology and the new IMAP multi-objective optimisation method, implemented in the Preferendus tool, have been developed by Binnekamp, Van Heukelum, and Wolfert. Parts of the text are taken verbatim from the scientific paper Van Heukelum, Binnekamp and Wolfert (2023). It is noted that the Preferendus in its primary form was published in Zhilyaev, Binnekamp and Wolfert (2022).

Incitement 6.1 The impossible car design

Consider a person that wants to design: i.e., configure using existing knowledge, a new car and is interested in the car's fuel consumption and top speed. The person has stated their (added) value or preference for two typical car design variables: i.e., their preference criteria for fuel consumption and top speed of their future car. The person was asked to determine the relation between these variables as depicted in the figure below.



This means that a car having a fuel consumption of 6 l/100km and a top speed of 250 km/h is most preferred by this person (subject). Although such a car design is most desirable, in real-life such a car is simply infeasible/incapable if one takes into account the physical engineering properties of the car (object). This is because the laws of nature (natural sciences) dictate that the fuel consumption and top speed are related to the engine size, see the next figure.

The question now remains: how can this person arrive at a feasible design solution while maximising their individual preferences? In this book we will show how such design/decision problems can be solved using mathematical optimisation modeling where capability (physical object behavior) and desirability (human subject values) are interconnected into an overarching design/decision support system to find the best fit for common purpose design/decision solution.

6.1. Odesys' methodology & significance

Why, so often, do we build what nobody wants? Why, so often, do engineers optimise their solutions based only on physical capabilities and fail to consider the stakeholders' desires? Why, so often, do policy makers and/ or infrastructure managers so often keep the design/decision-making process non-transparent and non-participatory? Why, so often, do conflicts stem from failed attempts to constructively design? The answer to these questions is that engineering design and decision-making are often solved from a one-sided point of view, without considering the fact that the problem is complex and multifaceted. Therefore, a participatory process that does justice to both the 'hard' technical and 'soft' social aspects of infrastructure systems development is needed. It is thus crucial to truly connect and bridge the gap between human preference interests and the engineering assets performances using transparent models for complex systems design and integration. The goal of such an Open Design Systems (Odesys) approach is to promote the use of the civil infrastructures that surround us every day through a multi-system level socio-technical approach, supported by sound mathematical open-glass box models as means for observation and perception during collaborative decision-making.

Above all, zooming in on the design challenge of our contemporary (civil) infrastructures, it can be noted that this challenge is becoming increasingly complex due to the environmental demands, new transport modes, and other transitions. This rapidly changing infrastructure context requires an optimal life-cycle value design within the framework of infrastructure asset management (see e.g. Balzer (2016), Hastings (2015) and/or the NEN/ISO 15288 systems life-cycle standard). Multi-objective optimisation is key to supporting informed decisions in infrastructure asset management (for an extensive literature review and overview of optimisation methods, see Chen & Bai (2019)). Increasing stakeholder involvement, combined with the multidisciplinary nature of infrastructure design challenges, further necessitates a more effective and efficient participatory and supportive decision-making process (see also Van Heukelum et al. (2023) for more references). In this context of asset management decision-making, the focus of this book is therefore on socio-technical design optimisation, where both the various stakeholder preference interests (or societal values) and the technical system life-cycle capabilities are unified in a best-fit for common purpose design configuration. To this end, a new so-called Odesys methodology is introduced, with a new preference-based multi-objective design optimisation method. This is required because the current design optimisation methods have intrinsic problems and/or shortcomings that make them unsuitable to provide the required unique and best-fit design solutions.

In the following sub-section we will summarise these in five *fundamental problems* and *shortcomings* which together constitute the Odesys' development gap.

Development gaps

The first problem with the current multi-objective design optimisation methodologies is the disconnect between the domain of human preferences (subject desirability) and the domain of the physical performance behaviour of the engineering asset (object capability). Moreover, when applied in the classical systems engineering context, design optimisation is usually limited to a single objective design approach and/or to an *a-posteriori* evaluation of design alternatives Dym (2004), Blanchard (2011) and/or Cross (2021). However, in *a-posteriori* evaluation, there is no guarantee that the optimal design point has been found and a choice has to be made between sub-optimal compromise solutions (even when optimisation and *a-posteriori* evaluation are combined, see Mueller and Ochsendorf (2015)). Especially in complex engineering projects, the number of possible design alternatives is too large to evaluate them all and the optimal solution may thus be ignored.

Secondly, most multi-objective optimisation methodologies introduce fundamental mathematical operation and aggregation flaws because they: 1) use undefined measurement scales and apply mathematical operations where these are not defined (e.g. for variables that have neither an absolute zero nor one, such as time/potential energy/preference, the mathematical operations of addition and multiplication are not defined in the corresponding mathematical model which is the one-dimensional affine space); 2) produce an infinite number of non-equivalent 'optimal' outcomes (e.g. the definition of the aggregation algorithm does not prerequisite having only normalised numbers); 3) outcomes do not take into account the relative scoring impact of other design alternatives (e.g. in reality, the score of one alternative depends on the performance of all the other alternatives; the score is obtained by finding the best balance between the normalised and weighted scores for all sub-criteria given the set of alternatives). As a result, the outcomes of decision-making in engineering design may lead to sub-optimal design configurations. The foundations of this second shortcoming are found from the principles of Barziali's Preference Function Modeling (PFM) and its associated preference measurement theory, see Barzilai (2022, 2006 and/or 2005).

A third problem with many of the classical multi-objective design optimisation methods is that they do not have a consistent way of translating the different objective functions into a common domain to find a best-fitting aggregated optimum. To get around this problem, these multi-objective design methods often use monetisation. In other words, all objective functions are expressed in terms of money. However, according to classical decision/utility theory, decisions are not based on money, but on value or preference (where minimising expenditure or maximising profit can be one of the objectives). Here, preference is an expression of the degree of 'satisfaction', and it describes the utility or value that something provides. Although some researchers have incorporated preference modeling into their multi-objective optimisation frameworks (see, for example, Lee et al. (2011) or Messac (1996)), none of them use strong (preference) measurement scales or individually weighted preference functions (i.e., continuous functions linking an individually weighted preference to a specific objective). In addition, these approaches do not lead to a single optimal design point and also contain the aggregation modeling errors mentioned above.

A fourth shortcoming of classical multi-objective design optimisation methods is that many of them consider the so-called Pareto front as a valid outcome Marler (2004). Apart from the fact that the Pareto front is often obtained in a mathematically incorrect way (see the aforementioned second point), it also generates an infinite set of possible, and supposedly equally desirable, design points, see e.g. Farran (2015), Furuta et al. (2006) and Saad et al. (2018). However, this is inconsistent with the fundamental basis of an engineering design process, where each design point is (subjectively) interpreted by people in terms of preference (i.e., a statement of their individual interest) and where a search is performed to find a single optimal design solution. These Pareto shortcomings are also noted by e.g. Kim et al. (2022), Lee et al. (2011), Bai et al. (2015), Golany et al. (2006) and Bakhshipour et al. (2021), amongst others. However, their proposed (hybrid) solutions still rely on the Pareto front (with its mathematical flaws) and some form of *a-posteriori* evaluation. Their modeling approaches therefore fail to provide a pure integrative design approach and are not able to obtain *a-priori* a single best configuration.

A fifth shortcoming is that current multi-objective optimisation processes are rather disconnected from systems design practices, as they lack deep involvement of decision-making stakeholders, see e.g. Guo (2022). In addition, the dynamic nature and the socio-technical interaction between stakeholder preferences ('what a human wants') and the performance of technical assets ('what a system can') are often not considered in service life design.

Development statement

To overcome the aforementioned shortcomings and problems, and to enable pure human preference and asset performance systems design integration, the socio-technical Open Design Systems (Odesys) design methodology is introduced in this Chapter. In other words, the above summarizes the development gap that motivates Odesys' development statement which reads as follows:

"There is a need for an open design methodology enabling socio-technical systems integration on all relevant levels using a human centered preference based design performance approach supported by a pure mathematical optimisation modeling."

As part of this development statement, we formulate the following Odesys principles which follow from the perspective Chapters within Part I 'Setting the scene':
(#1) The maximum aggregate preference reflects the *group's well-being optimum*, since the fundamental laws & principles of all three social threefold realms are maximally leveraged, and where aggregation is a solver algorithm rather than an arithmetic operator (see Section 3.5);
(#2) Best fit for common purpose: i.e., the group's well-being optimum, is the best feasible *synthesis* or unity within the threefold of social-interests-desires/ technical-behavior-capabilities/ purpose-well-being-feasibility (see Section 2.4);
(#3) The *design synthesis* solution that is best uniting system capability and human desirability is to be obtained by a supporting preference function based model (PFM) searching for the group's well-being optimum, involving a complex set of relationships and feasible solutions, and (see Chapters 4 and 5);
(#4) *Synthesize* is a unification of re-generate and re-purpose, which is an integration of a logical act of reasoning/modeling to unlock the outer environment ('thinking slow', deliberation), and intuitive thinking (dialogue) is an act of uncovering the inner will (see Chapters 3 and 4);
(#5) *Design* is an open-ended systems integrating U-model based approach where the technical, social and purpose cycles are incorporated (see Chapter 4).

Note: using typical expressions (at least following from the Dutch language), these points can be summarized as a movement from "every man for himself and God bless the grip" towards "common interest for the greater good based on individual commitment and support for dynamic and social design".

Methodology

Continuing, Odesys builds further on the multi-stakeholder design optimisation methodology proposed by Zhilyaev, Binnekamp and Wolfert (2022), who showed that the unambiguous solution to a multi-objective engineering design/decision problem is to translate each of the objective functions, as a function of the design variables, into an overarching preference domain. This can be done using stakeholder preference functions: i.e., the relationship between an individual preference and a specific objective, which then allow for the maximisation of the aggregated group preference, leveraging Barzilai's PFM theory (see Binnekamp (2010) where this concept originated in its initial form, and Arkesteijn et al. (2017) for its early social validation). However, all these aforementioned developments in the field of preference-based design, which so far only were applied in the context of real estate planning, still have three methodological *deficiencies*, and lack the following:
(#a) a generalised mathematical framework for multi-objective socio-technical design optimisation: i.e., a threefold modeling framework of integrative performance, objective and preference functions;

(#b) a connection between common socio-eco interests and the related subject preferences, and the physical/mechanical object behaviour: i.e., a pure integration of technical design performance, social objective and preference functions;
(#c) a PFM-based solver: i.e., a search algorithm to find the optimal solution with the maximum aggregated preference;
(#d) an open-ended socio-technical process model that reflects a human centered best fit for common purpose design: i.e., an open-ended spiral design system with different open loops/cycles, expanding the U-model to achieve a design metamorphosis from picture via purpose to prototype.

Finally, the Odesys methodology will allow for the full integration between subject (un)desirability: 'what a stakeholder wants/does not want', expressed via preference functions, and object (in)capability: 'what a system can/can not', expressed via design performance functions. This integration is schematically depicted in Figure 6.1. It is being achieved by constructing preference functions that are a direct function of both the stakeholder objective and the engineering asset design performance functions, which depend on the design and physical variables and their constraints. In other words, this unified set of preference functions, which at the lowest level is a function of the engineering design variables and the physical constraints, is a translation (a mapping) of the socio-technical system under consideration. Next, an automated algorithm is needed that searches for a feasible and optimal design synthesis solution where the aggregated group preference score is maximal. In reality, this search is an open-ended approach. This means that an iterative process of technical-, social-, and purpose-cycles will have to take place. This implies that a best-fit for common purpose design configuration can only be achieved through an iterative socio-technical process given the final 'idealised' desires, objectives, interests, and requirements of the stakeholders.

This makes Odesys a pure socio-technical systems integration methodology where human preference-based design and engineering physics/mechanics converge, offering a wide range of potential applications within the context of (infra)structure systems engineering design. As part of this Odesys methodology, a new Integrative Maximised Aggregated Preference (IMAP) optimisation method for maximising aggregated preferences is introduced. This IMAP method forms the basis of a new software tool called the Preferendus and combines the state-of-the-art PFM principles with an inter-generational Genetic Algorithm (GA) solver developed specifically for this purpose. Note: the Preferendus (inspired by and a reference to the preferendum concept, a composition of the words preferences and preferendum, and conceived by Wolfert) was developed to accommodate early and transparent participation within an a-priori group design/decision making process, see Zhilyaev et al. (2022) or Van Heukelum et al. (2023). The basis for group decision making according to fundamental laws and principles of social threefolding theory is found in Chapter 3.

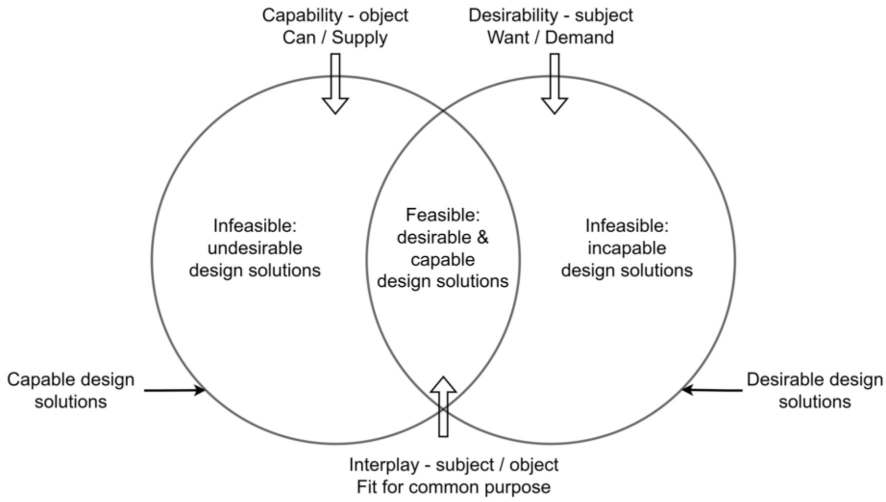


Figure 6.1: Socio-technical interplay between (un)desirability and (in)capability

Now we can continue to formulate a general mathematical statement of the open design systems integration methodology. Next, a flow chart (or concept diagram) of the Preferendus software tool is described in which the Odesys methodology is implemented. Finally, the use and added value of the Odesys methodology, the IMAP optimisation method, and the Preferendus tool are demonstrated in Chapters 7 and 8.

6.2. Odesys' mathematical formulation

As described in the motivation, there is currently no optimisation framework that allows for pure integration of the human preference domain (subject desirability) and the engineering asset physical performance behavior domain (object capability). This disconnection will limit optimisation to sub-optimal results, as the interaction between these two levels is not considered. To overcome this, the following mathematical statement is introduced, which integrates subject desirability and object capability and searches for a feasible solution with the maximised aggregated group preference which is the core of the Odesys methodology:

$$\underset{\mathbf{x}}{Maximise}\ U = T\left[P_{k,i}\left(O_i\left(F_1(\mathbf{x},\mathbf{y}), F_2(\mathbf{x},\mathbf{y}), ..., F_J(\mathbf{x},\mathbf{y})\right)\right), w'_{k,i}\right] \tag{6.1}$$

for:

$$\begin{aligned} k &= 1, 2, ..., K \\ i &= 1, 2, ..., I \end{aligned} \tag{6.2}$$

and subject to:

$$g_p(O_i(F_{1,2,...,J}(\mathbf{x}, \mathbf{y})), F_{1,2,...,J}(\mathbf{x}, \mathbf{y})) \leq 0 \text{ for } p = 1, 2, ..., P \tag{6.3}$$

$$h_q(O_i(F_{1,2,...,J}(\mathbf{x}, \mathbf{y})), F_{1,2,...,J}(\mathbf{x}, \mathbf{y})) = 0 \text{ for } q = 1, 2, ..., Q \tag{6.4}$$

and with:

- T: The aggregated preference score determined using the PFM theory principles (see Barzilai (2022)).
- $P_{k,i}(O_i(F_{1,2,...,J}(\mathbf{x}, \mathbf{y})))$: Preference functions that describe the preference stakeholder k has towards objective functions, which are functions of different design performance functions and dependent on design and physical variables.
- $O_i(F_{1,2,...,J}(\mathbf{x}, \mathbf{y}))$: Objective functions that describes the objective i, functions of different design performance functions and dependent on design and physical variables.
- $F_{1,2,...,J}(\mathbf{x}, \mathbf{y})$: Design performance functions that describe the object, depending on one or multiple design variables x (i.e., controllable endogenous variables) and one or multiple physical variables y (i.e., uncontrollable exogenous variables).
- $\mathbf{x}$: A vector containing the (controllable) design variables $x_1, x_2, ..., x_N$. These variables are bounded such that $lb_n \leq x_n \leq ub_n$, where lb_n is the lower bound, ub_n is the upper bound, and $n = 1, 2, ..., N$.
- $\mathbf{y}$: A vector containing the (uncontrollable) physical variables $y_1, y_2, ..., y_M$.
- $w'_{k,i}$: Weights for each of the preference functions. These weights can be broken down into weights for the stakeholders and weights for the objectives:
  - w_k: weights for stakeholders $k = 1, 2, ..., K$. These weights represent the relative importance of stakeholders.
  - $w_{k,i}$: these weights represent the weight stakeholder k gives to objective i.

  The final weights $w'_{k,i}$ can be constructed via $w'_{k,i} = w_k * w_{k,i}$, given that $\sum w'_{k,i} = \sum w_{k,i} = \sum w_k = 1$
- $g_p(O_i(F_{1,2,...,J}(\mathbf{x}, \mathbf{y})), F_{1,2,...,J}(\mathbf{x}, \mathbf{y}))$: Inequality constraint functions, which can be either objective function and/or design performance function constraints.
- $h_q(O_i(F_{1,2,...,J}(\mathbf{x}, \mathbf{y})), F_{1,2,...,J}(\mathbf{x}, \mathbf{y}))$: Equality constraint functions, which can be either objective function and/or design performance function constraints.

To further elaborate on this formulation, several important remarks are made which are discussed below.

Remark 1: preference aggregation

Here, the aggregated preference scores are determined based on the principles of PFM, expressed by the mathematical operator T. This operator is a solving algorithm that is based on finding/synthesising the aggregated preference score (i.e., the 'best' fit of all weighted (relative) scores for all the decision-making stakeholders' objectives) that minimises the least-squares difference between this overall preference score and each of the normalised individual scores (on all criteria) by computing its closest counterpart, see Barzilai (2022) and/or Van Heukelum et al. (2023). In this, preference is a statement of an individual stakeholder's interest and a measure of satisfaction, which is a score that is expressed as a real number (scalar or bare quantity) on a defined scale, e.g. 0 to 100, where 0 corresponds to the 'worst' performing alternative and 100 to the 'best' performing alternative. For the applications shown in this book (Chapters 5-8), Tetra is used as this preference aggregation solver (i.e., operator T). For more information on the Tetra solver, see: scientificmetrics.com or choicerobot.com.

Remark 2: preference functions

Preference functions describe the relationship between an individual stakeholder's preference and a specific objective (where a stakeholder is defined as one of the participants in the design/decision-making process). The theory of preference functions (often also called utility functions) for *a-posteriori* multi-criteria decision evaluation is a branch of the social science in itself. However, the preference functions are needed as input to the design/decision system to enable *a-priori* multi-objective design optimisation. Here, the elicitation of the preference functions and associated weights is handled pragmatically using 'static' expert judgement, whereas in practice this is inherently a dynamic and iterative process that helps stakeholders better understand the impact of their input on the optimisation outcome (see see Arkesteijn et al. (2017) for the specifics of this elicitation as part of the design cycle). Finally, note that an objective O_i can be associated with multiple stakeholder preference functions $P_{k,i}$ (as $k \geq i$). However, it is not required that a stakeholder expresses a preference for all objectives. This is modelled by giving a stakeholder's objective a weight of zero, which means that some elements of the $w_{k,i}$ matrix can be zero.

Remark 3: bound preference scores

Here, a preference score is bounded by $0 \leq P_{k,i} \leq 100$. A constraint can be added to the objective functions to prevent preference scores which lay outside these bounds.

Remark 4: design variables in objective functions

A design variable x can be directly linked to an objective function O. In this case, the design performance function F is just equal to the design variable x. Moreover, these design performance functions F can also only relate to an exogenous physical variable y.

Remark 5: rewrite equality constraints

Equality constraints are quite common in the object behaviour domain. However, as the Preferendus uses a genetic algorithm (GA), equality constraints can complicate the convergence of the optimisation, as especially the simpler constraint handlers for GAs have problems with handling equality constraints, see e.g. Homaifar et al. (1994). Therefore, when modeling a system of interest, the equality constraints can be rewritten as inequality constraints, as is often done in literature, see e.g. Coello (2002) and/or Kramer (2017). This is often done in the form of Equation (6.5). For the proposed Odesys methodology, it is possible to rewrite most equality constraints directly into inequality constraints, as the methodology aims to reduce 'waste' in the result. For example, the length of a beam supporting a floor will usually have a fixed length: the length of the span. Since a length greater than the length of the span will result in more costs, material consumption, carbon emissions, etc., this equality constraint can safely be rewritten as an inequality constraint. This makes modeling easier, since the tolerance ϵ does not have to be set and tuned for each problem.

$$|h_{1,2,\ldots,M}(O_{1,2,\ldots,I}(F_{1,2,\ldots,J}(\mathbf{x})), F_{1,2,\ldots,J}(\mathbf{x}))| - \epsilon \leq 0 \tag{6.5}$$

Remark 6: soft and hard constraints

Finally, a distinction can be made between soft and hard constraints. The former result from the sociological aspect of a design process and are negotiable. They can be adapted during the process based on discussions with other stakeholders or new insights. The latter are fixed and non-negotiable. They are given by, among others, laws of nature, material composition, environmental conditions, etc.

6.3. Threefold modeling framework & the Odesys' U

The mathematical statement with the aforementioned remarks provides a general framework in which it is possible to connect the subject desirability level (preference functions) with the object capability level (design performance functions) via the integrative subject-object conciliation level (objective functions). Note that there will be three types of functional values and/or outcomes of interest: (1) degrees of capability – design performances (technical) (2) degrees of freedom – design variables (technical) (3) degrees of satisfaction – preferences and objectives (social).

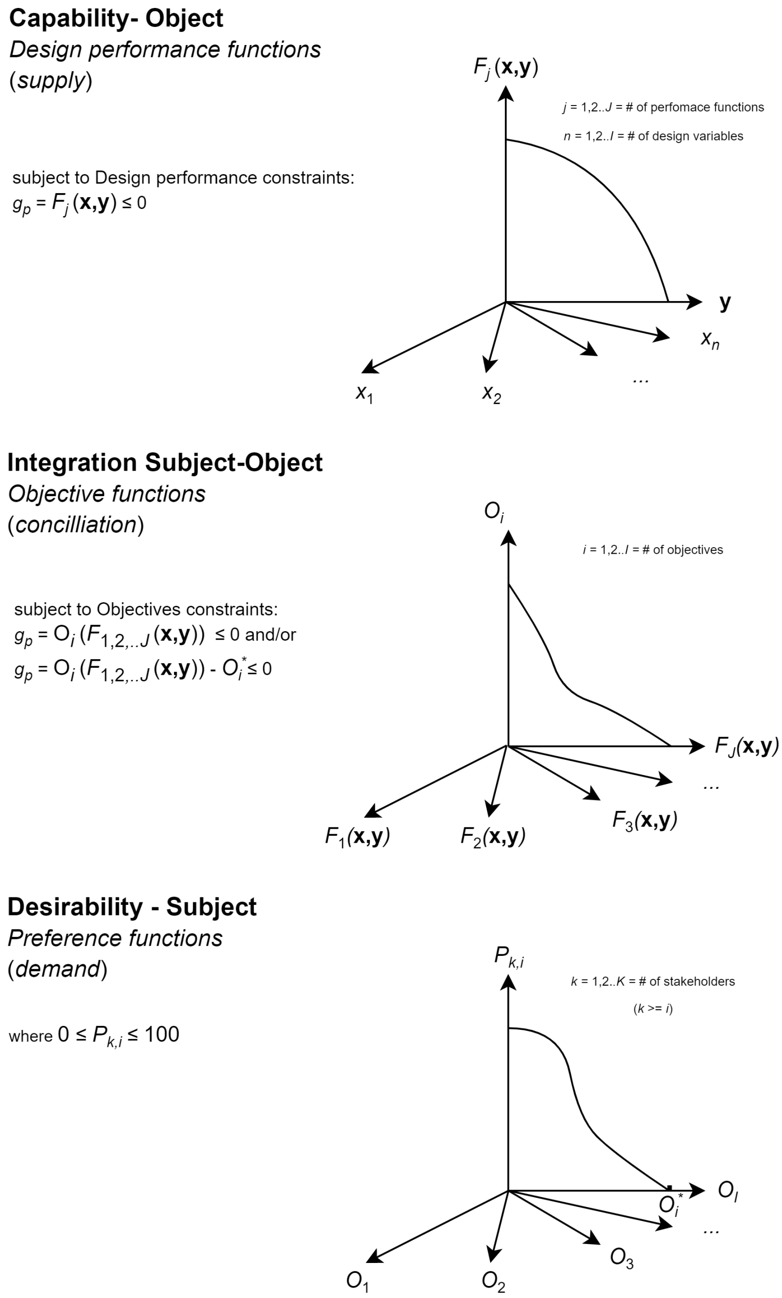


Figure 6.2: Conceptual threefold modeling framework of the Odesys mathematical statement, where desirability-subject (preference functions) and the capability-object (design performance functions) are integrated subject-object (objective functions).

To better understand and further detail this specific social-technical systems integration, the different functions as part of the mathematical formulation are conceptualised in a threefold modeling framework, as shown in Figure 6.2. Note that the different functions are linked (an ordering principle) and that maximisation is not yet part of this threefold.

Now that we know the relationships between the different functions (preference, objective and performance functions), we can set up the complete design problem statement using the U-approach. The U-approach connects the technical and social human design process, through a three-layer metamorphosis of picture-purpose and prototype, see Chapter 4. In other words, the mathematical problem formulation, including the maximisation of aggregated group preference, is now translated into the U model, see Figure 6.3. Note that the cyclical activities re-convert/re-validate/re-purpose are not present here (see Chapter 4 for the entire Odesys U).

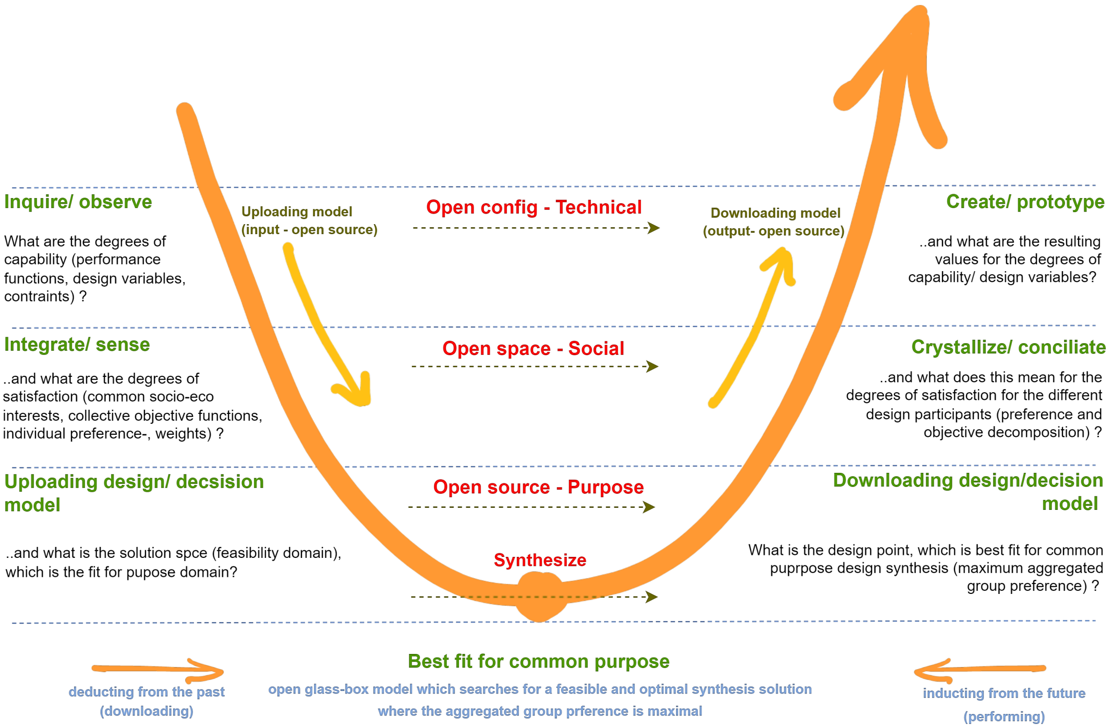


Figure 6.3: Odesys U-model representing the mathematical design/decision support modeling (as a simplification of the U-model of Chapter 4, developed by Wolfert).

So here we then see the unique in its sort and state of the art threefold Odesys U-model for the incorporating three open-ended design loops: (1) Open config – *technical* cycle, (2) Open space - *social* cycle and (3) Open source - the *purpose* cycle (in contrast to similar classical engineering design systems, such as the V-model, which often recognize only less than three subsystems without open loops). Finally, using the full Odesys U and the open-ended spiral diagram from Chapter 4, the three open design loops can be run cyclically to achieve a design metamorphosis from picture via purpose to prototype. Note here the combination of both the epistemological and the ontological origins of the U-modeling theory (see Chapter 1 and/or 3).

6.4. IMAP & the Preferendus

In this section, the so-called Preferendus tool and its optimization method, named IMAP (Integrative Maximised Aggregated Preferences), are described as part of the Odesys methodology. This IMAP method forms the basis of a software tool Preferendus and combines the state-of-the-art PFM principles with an inter-generational genetic algorithm (GA) solver developed specifically for this purpose. Here the conceptual functioning of the Preferendus will be introduced, as an extension and further advancement of the Preferendus as first described by Zhilyaev, Binnekamp and Wolfert (2022). As part of this Preferendus, a new IMAP optimization method is introduced for maximising aggregated preferences within a socio-technical system, as schematically depicted in Figure 4.3 in Chapter 4. The Preferendus combines proper preference aggregation with preference maximisation, as described by the mathematical formulation of the Odesys problem statement of the previous section. The state-of-the-art Preferendus applications will be demonstrated using formative and summative design applications in the Chapters 7, 8.

Preference aggregation (IMAP part 1)

Following the Odesys methodology, it is argued that the overarching goal of multi-objective design optimisation is to find the highest overall group preference score that represents the design synthesis. However, for these design syntheses to be possible, the individual preference scores first need to be aggregated.

Since preference scores are defined in an affine space, aggregation should also take place in this space. This means that, according to the basic principles of PFM theory, the correct way of aggregating preference scores is to find the aggregated preference score that provides the 'best' fit to all the weighted (relative) scores of the different preference functions ($P_{k,i}$). Here, the preference functions are the integration of objective functions and design performance functions. The final preference score aggregation is performed by the aforementioned PFM-based solving approach (see remark 1 of the previous section), as an integral part of the overall design optimisation algorithm.

Preference maximisation (IMAP part 2)

To finally find the design configuration that reflects the maximum group preference aggregation, it is also necessary to use a maximisation algorithm. To do this, a GA is used that is specifically adapted to work with Tetra. This is necessary because it is not possible to directly compare one generation of the GA with another, as the aggregated preference scores contain only information about the alternatives of a single generation. To overcome this, a GA is developed that combines widely available elements and is extended with a so-called inter-generational solver. The details and the operation of this GA solver are given in Appendix C.

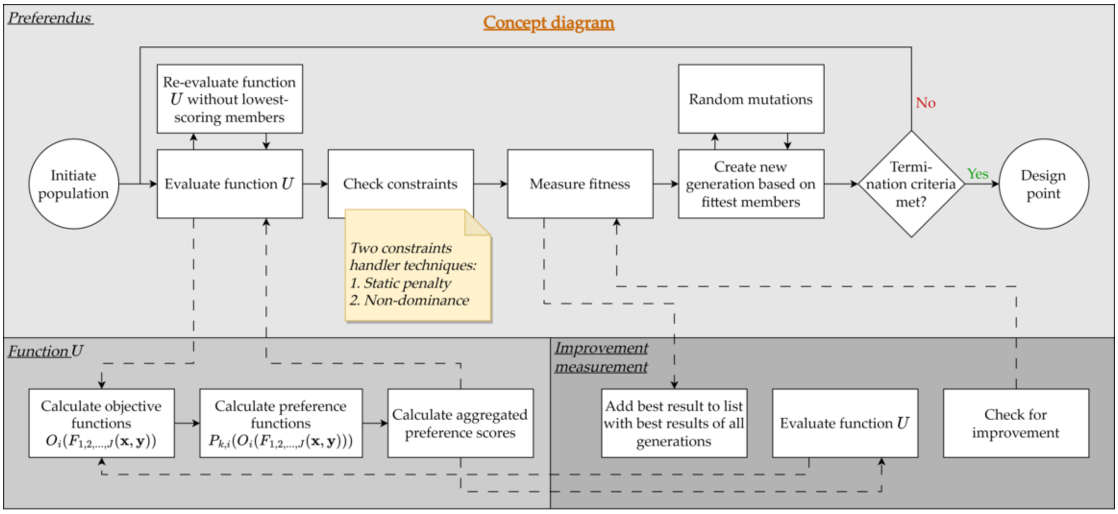


Figure 6.4: The workflow of the Preferendus, presented as a concept diagram.

The final result is an Odesys-based design optimisation tool, the Preferendus, which incorporates the IMAP method. The concept diagram of the Preferendus is shown in Figure 6.4. This is an open-source tool available via GitHub (see data availability statement).

IMAP validation (Min-max goal attainment and SODO)

To compare and validate the results and added value of the IMAP multi-objective optimisation method, the following section first compares the results with those of the single-objective optimisation. In addition, a comparison is made with the classical Min-max goal attainment multi-objective optimisation method (Marler and Arora (2004)). This method does not generate group results based on overall aggregation, but rather optimises: i.e., equalises, each individual result so that it is as close as possible to a 'utopian' design point. In other words, the Min-max method tries to minimise the maximum dissatisfaction for all individual scores (expressed by the distance to this utopia point). The result of this method, which does not conflict with the fundamental PFM principles, is a solution that gratifies each stakeholder equally.

In order to make a like-for-like comparison between IMAP and Min-max, the mathematical formulation of the Odesys problem statement needs to be modified (i.e., Equation (6.1) needs to be changed). First, this means that in this case the Min-max method will try to minimise the distance to a score of 100 for all different preference scores $P_{k,i}$ (i.e., the best-scoring utopian point has been defined as 100). Then, the preference score $P_{k,i}$ with the greatest (weighted) dissatisfaction must be found and minimised, which mathematically can be read as Equation (6.6).

$$\underset{\mathbf{x}}{Minimise}\ U = \max_{k,i} \left[w'_{k,i} \times \{100 - P_{k,i} \left(O_i \left(F_1(\mathbf{x}, \mathbf{y}), F_2(\mathbf{x}, \mathbf{y}), ..., F_J(\mathbf{x}, \mathbf{y}) \right) \right) \} \right] \tag{6.6}$$

for:

$$\begin{aligned} k &= 1, 2, ..., K \\ i &= 1, 2, ..., I \end{aligned} \tag{6.7}$$

It should be noted that the Min-max goal attainment method, as part of a larger group of multi-objective optimisation methods, does not violate the PFM principles. However, this method treats the scores of all design alternatives as absolute values, ignoring the dynamic interplay between them. In other words, this method focuses on making each stakeholder as 'happy' as possible, even though this may not be beneficial for the group as a whole. This is why this optimisation is called a compromise method, because it finds a design configuration based on a compromise between stakeholders rather than a synthesis.

Chapter 7

Formative Odesys examples

In this Chapter, by means of a number of examples, the reader will be introduced into the basic working Odesys methodology, the IMAP optimisation method, and the Preferendus. These examples highlight the limitations of classical design/decision making approaches that use mathematical optimisation models. The examples show the novelty of the Odesys methodology and its possibilities versus the limitations of the more traditional multi-objective approach from Chapter 5. We will therefore start with a "rerun" of one of the problems from Chapter 5, namely the bridge design problem (revisited). Now, the integral IMAP/Preferendus is used to show that it can arrive at the same solution, but a-priori and all at once. The other examples, a shopping mall and a supermarket design, zoom in on the use of different types of preference functions (non-linear and non-monotonic), showing that the design points are able to move away from the corner points and can even lie within the design space. The latter is new, especially compared to the classical methods that search the edges (and/or Pareto front) of the design space for the best design point. In some of the examples a comparison with the Min-max MODO (multi-objective design optimisation) or SODO (single-objective design optimisation) methods, the corner point solutions of Chapter 5, is also made. In Chapter 8, we will consistently make the comparison between SODO, Min-max, and IMAP MODO methods. This Chapter however focuses on the location of the optimal design point and the use of the preference functions.

The examples used in this chapter are educational in nature rather than an actual representation of real-life design problems. We therefore call them *formative* examples. However, the design applications in the following Chapter 8 demonstrate the real-life value of the Odesys design/decision methodology and its application in systems engineering design and management. Therefore, we call these *summative* design applications. All of these can also be found on the Odesys Github.

7.1. Bridge design (revisited)

The first example is the bridge design problem, which we already have seen in Section 5.2, see Example 2 (MODO). This problem showed that the corner point solution found by optimising on costs-only and the one found by optimising on waiting time-only were outperformed by the design configuration represented by another 'intermediate' corner point, see the conspection section 5.3 and Table 5.8. This made sense as this design configuration performs reasonably well on both costs and waiting time. When we use the Odesys methodology we expect to find this most preferred and feasible design solution without the need for a-posterior evaluation of corner point solutions (as done in Chapter 5).

As discussed in the previous Chapter 6, for proper a-priori optimisation, all objectives should be translated to the preference (functions) domain. This allows it to connect an outcome of the objective function (e.g. Objective costs of €5) to a preference function score (e.g. 60). Let us first recall the objective functions for this example:

$$O_1 = c_1 F_1 = c_1 c_2 x_1 + c_1 c_3 x_2 \tag{7.1}$$

$$O_2 = -c_4 F_2 + w_0 = -c_4 c_5 x_1 - c_4 c_6 x_2 + w_0 \tag{7.2}$$

where $1 \leq x1 \leq 5$; $3 \leq x_2 \leq 8$; $c_1 = 3$; $c_2 = 4$; $c_3 = 7$; $c_4 = 1.2$; $c_5 = 1.7$; $c_6 = 1.9$.

For now, we limit ourselves to the construction of linear preference curves. This means, the outcome of the objective that is most favourable will get a preference score of 100, and the outcome of the objective that is least favourable will get a preference score of 0. In between, the preference score will linear increase or decrease.

Table 7.1: Minimum and maximum values for the two objectives from the bridge example.

Objective	Minimum	Maximum
Objective 1	75	228
Objective 2	71.5	108.9

Given the objective functions, we can find the minimum and maximum of them by using a simple minimisation and maximisation algorithm (see Appendix E for an overview of these algorithms). This will result in the outcomes as shown in Table 7.1. For the construction of linear functions, one can use the equation as shown in Equation 7.3. Here x_1 and x_2 are the minimum and maximum outcome of the objective, and y_1 and y_2 are the corresponding preference scores. Now we can construct the preference functions resulting in Equations 7.4 and 7.5.

$$y = y_1 + \frac{y_2 - y_1}{x_2 - x_1}(x - x_1) \tag{7.3}$$

$$P_1 = 100 + \frac{0 - 100}{228 - 75}(x - 75) = \frac{7600}{51} - \frac{100O_1}{153} \qquad (7.4)$$

$$P_2 = 100 + \frac{0 - 100}{108.88 - 71.56}(x - 71.56) = 465.849 - 5.11247O_2 \qquad (7.5)$$

These preference functions are also plotted in Figure 7.1.

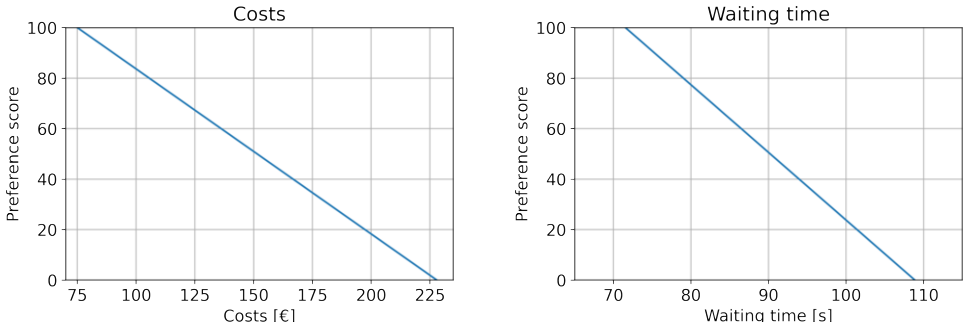


Figure 7.1: Preference functions for the bridge example.

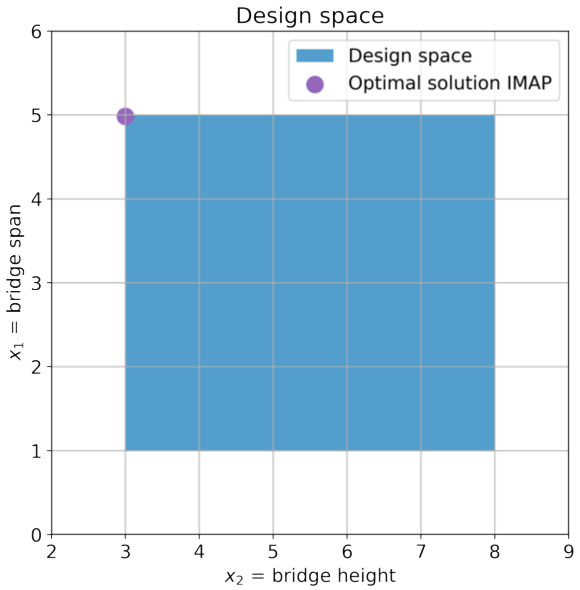


Figure 7.2: Design space of the bridge problem, including IMAP design point

Finally, the new multi-objective optimisation method IMAP that uses the Preferendus algorithm (instead of the minimise algorithm as in Chapter 5) indeed also finds this best solution ('corner point C') and in one time without the need for a-posteriori evaluation. The result is shown in Figure 7.2 (here is the MODO design point again equals point C: (x1,x2)=(5,3)). Note that we assume both objectives equally weighted.

7.2. Shopping mall (linear & non-linear)

Consider a design/decision making problem for a new shopping mall. An investor and municipality can choose between two types of shops with different properties with respect to the profit, CO_2 emissions and shopping potential (attractiveness), see Table 7.2.

Table 7.2: Types of shops and their characteristics.

	Shop type x_1	Shop type x_2
Profit [euro/m2]	160	80
CO2 emission [kg/m2]	120	30
Shopping potential [ppl/m2]	15	45

The total shopping area is limited by the municipality to 10 000 square meters. No more than 5 000 square meters of shop type A are allowed and no more than 7 000 square meters of shop type B are allowed. Finally, the total amount of shops needs to be at least 3 000 square meters. The investor wants to make as much profit as possible whereas the municipality wants to minimise the CO_2 emissions. The existing shop owners want to make sure that the potential of the shopping mall is maximised.

Design performance functions

In this case, the performance functions relate to the amount of shops type A (variable x_1) and type B (variable x_2). Note that there are no physical performance functions in this case, but only the design variables x_1 and x_2 (which are directly related to the objectives). From consistency point of view we always set the design performance functions first, then the objective functions and finally the preference functions (see Chapter 8 for this rationale).

Objective functions

For the investor, the objective function is defined by the total profit given the amount of shops type A and B. The investor wants the profit to be maximised. The objective function for profit reads as:

$$O_1 = 160x_1 + 80x_2 \tag{7.6}$$

For the municipality, the objective function is defined by the total CO_2 emission given the amount of shops type A and B. The municipality wants the CO_2 emissions to be minimised. The objective function for CO_2 emission reads as:

$$O_2 = 120x_1 + 30x_2 \tag{7.7}$$

For the existing shop owners, the objective function is defined by the total attractiveness (i.e., shopping potential) given the amount of shops type A and B. The shop owners want the shopping potential to be maximised. The objective function for shopping potential reads as:

$$O_3 = 15x_1 + 45x_2 \tag{7.8}$$

The *constraints* are the restrictions given by the municipality:

$$x_1 \leq 5\,000; x_2 \leq 7\,000; x_1 \ + x_2 \ \leq 10\,000; x_1 \ + x_2 \ \geq 3\,000 \tag{7.9}$$

Preference functions (linear)

As explained in Chapter 6 and shown in the previous example, we need to translate the objective functions into the preference domain. For this example, we will limit ourselves to linear preference curves. To construct these, we first determine the minimum and maximum outcomes of each objective. These can be found in Table 7.3. By utilizing the linearisation Equation 7.3, we can construct the preference functions, resulting in the following equations (which are also visualized in Figure 7.4):

$$P_1 = \frac{O_1 - 240\,000}{9\,600} \tag{7.10}$$

$$P_2 = 100 - \frac{O_2 - 90\,000}{6\,600} \tag{7.11}$$

$$P_3 = \frac{O_3 - 45\,000}{3\,150} \tag{7.12}$$

Table 7.3: Minimum and maximum values for the three objectives from the shopping mall example.

Objective	Minimum	Maximum
Objective 1	240 000	1 200 000
Objective 2	90 000	750 000
Objective 3	45 000	360 000

IMAP optimisation and design results (linear)

Now that we have the preference functions, we can optimise the shopping mall problem a-priori using the methodology introduced in Chapter 6. This is done here with both the MODO IMAP and the MODO Min-max methods. To properly evaluate and compare the results of these two MODO methods, a third design point should be added (as explained in Chapter 5). Therefore, a corner point is added as a third (trivial) design option. Note that we calculated the relative aggregated preference scores, which were used to determine the overall relative ranking, via the PFM-based MCDA tool Tetra, and where the resulting aggregated preference scores are re-scaled between scores of 0 and 100 (where 0 reflects the 'worst' scoring configuration/alternative and 100 the 'best', see Appendix C for further details).

Table 7.4: Evaluation of design points and their relative ranking (based on aggregated preferences).

Method	Variable 1	Variable 2	Relative preference score
IMAP	3 000	7 000	100
Min-max	1 400	7 000	55
Corner point (5 000, 5 000)	5 000	5 000	0

The relative ranking of the design points (the optimisation and/or corner point results) are shown in the Table 7.4. The last column contains the relative preference scores of the three alternatives, showing that the IMAP method gives the solution with the highest overall preference score, followed by the Min-max method, and finally the selected corner point. The results of the optimisations are also shown in the Figures 7.3 and 7.4. Note that the weights of the three preference functions are all equal (i.e., $w_i = 1/3$).

The IMAP design point moves toward the corner point (3 000, 7 000) due to the linearity of the preference curves. Especially since both P_1 and P_3 (with a combined weight of 2/3) prefer larger x_1 and x_2, it is likely that the overall best-fit solution lies at one of the corners of the solution space, since here the values for x_1 and x_2 are often highest. This is what we observe here. This is in contrast to the Min-max design point. By its nature, the Min-max method searches for the design point where each stakeholder's dissatisfaction is minimal. When two preferences are in conflict, as is the case here for the profit and CO_2 preferences, this will lead to sub-optimal results for both preferences, rather than preferring one over the other (where the IMAP method will prefer one over the other if it is better for the group).

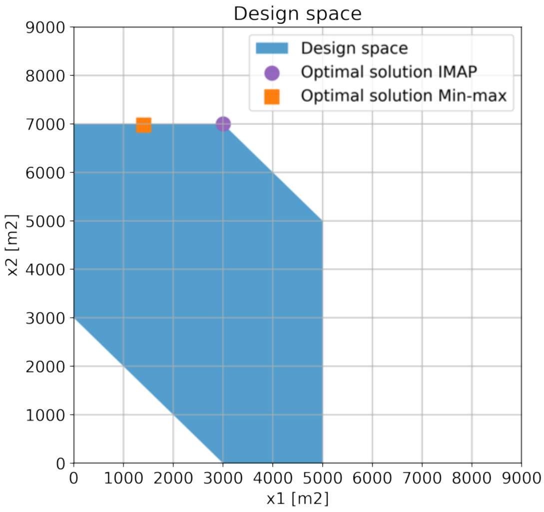


Figure 7.3: Design space for the linear shopping mall example, showing the MODO design points.

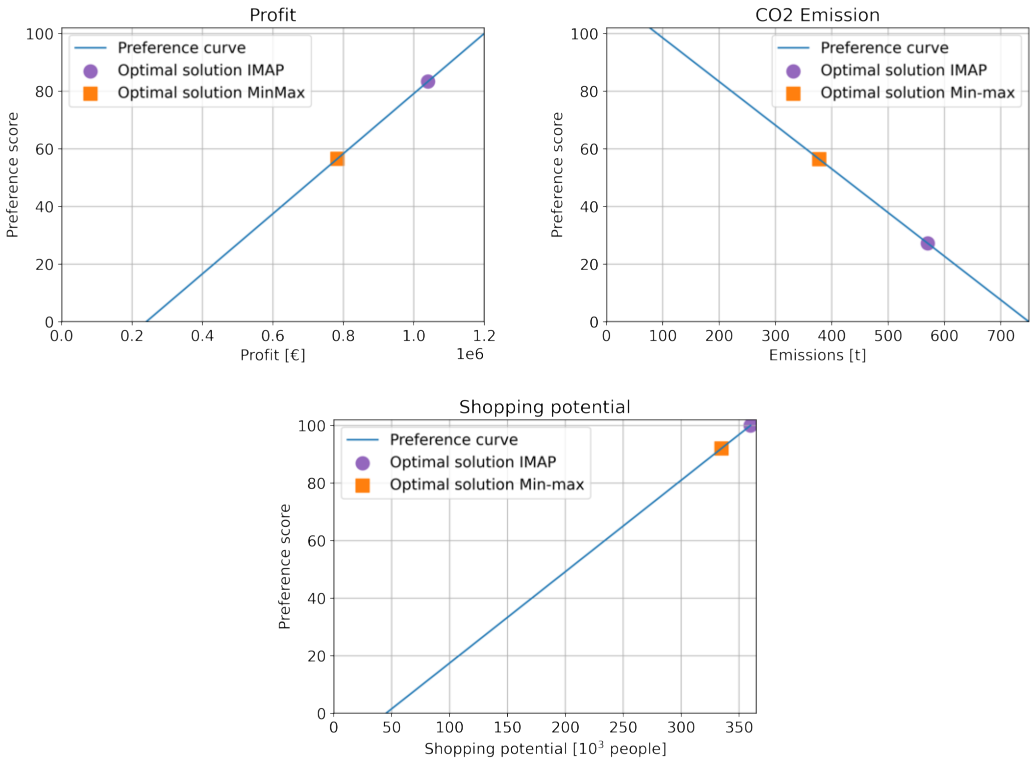


Figure 7.4: Preference curves for the lienar shopping mall example, including the MODO results.

Preference functions (non-linear)

To show the difference between linear and nonlinear preference functions, we can transform the functions of the previous section into nonlinear functions. It is possible to do this transformation by hand, but to make it easier and more user-friendly, we will use an interpolation function here (more specifically, we will use the common PCHIP interpolation method). We can feed this function the combinations of preference scores and objective function outcomes, and it will generate all the intermediate points itself. The input for the interpolation function for the shopping mall example is shown in Table 7.5. The resulting preference curves are shown in Figure 7.6.

Table 7.5: Objective outcomes and there preference scores, as input for the interpolation function.

Objective 1		Objective 2		Objective 3	
Outcome O_1	Related P_1	Outcome O_2	Related P_2	Outcome O_3	Related P_3
240 000	0	90 000	100	45 000	0
450 000	65	200 000	30	200 000	80
1 200 000	100	750 000	0	360 000	100

IMAP optimisation and design results (non-linear)

The results of the nonlinear preference curve optimisation are shown in the Figures 7.5 and 7.6. The weights of the preference functions were $w_1 = 0.25$, $w_2 = 0.5$, and $w_3 = 0.25$. When the preference curves are no longer linear and/or conflicting objectives are more balanced in the weight distribution, it is no longer guaranteed that the best-fit design solution lies at a corner point. This can be seen in this example where the design point moved from a corner solution in the linear example to a solution on the edge of the design space in the nonlinear example. Since the preference functions are still monotonically decreasing or increasing, it is expected that the solution will still be on one of the edges of the design space (as is the case here). To move into the design space, non-monotonic preference curves are needed. This will be shown in the next example.

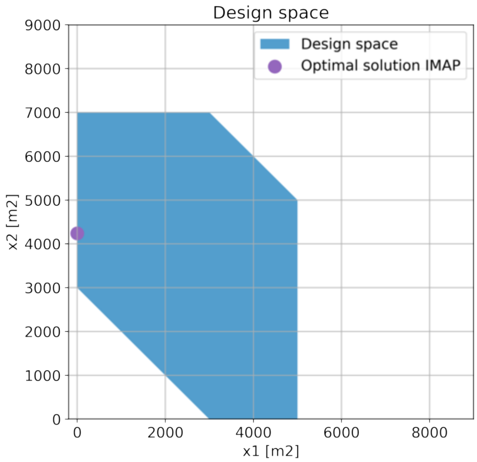


Figure 7.5: Design space for the non-linear shopping mall example, showing the MODO IMAP design point.

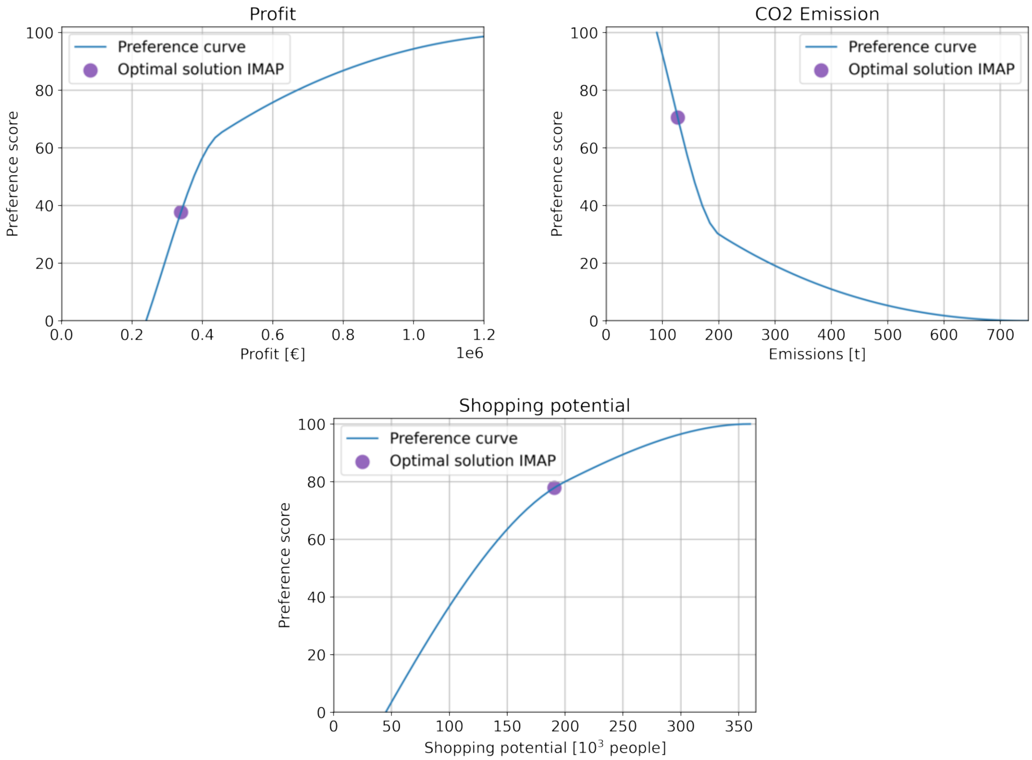


Figure 7.6: Preference curves for the non-linear shopping mall example, showing the MODO IMAP result.

7.3. Supermarket (non-linear & non-monotonic)

As shown in Chapter 5, the solution to a linear optimisation problem can be found graphically. The objective function is a straight line and if you move this line through the solution space, it will eventually reach a corner point where the value for the objective function is at the highest point. For non-linear objective functions, this is not that straight forward anymore. Here, the best possible outcome is not necessary in a corner of the solution space but could even lay somewhere within the solution space.

So far we only used monotonic preference functions. In real-life also 'U' and inverted 'U' shapes might be a representation of the stakeholder's preferences, which are typical non-monotonic curves. Design/decision problems that only contain monotonic preference curves are quite certain to result in optimal solution points that are on one of the edges of the solution space. However, as soon as non-monotonic functions are part of the problem this is no longer a certainty. As we will see in this example, the introduction of inverted 'U' shapes indeed results in solution points within the solution space.

Design performance functions

In this example, we investigate the configuration of a new supermarket. This supermarket is located at a distance from the center of a neighborhood (design variable x_1) and has a certain size of the assortment (design variable x_2). The optimal distance and size of the assortment must be determined. Note that there are no physical performance functions in this case, but only the design variables x_1 and x_2 (which are directly related to the objectives). Based on a questionnaire, the minimal distance to the supermarket must be 100 meters (to prevent noise hindrance) but cannot be higher than 1 000 meters. The size of the assortment of a supermarket can range from 800 different items for a very small and local supermarket to 30 000 for a very large supermarket.

Objective functions

For this example, we consider two objective functions: shopping added value and sustainability. The former is of interest of the owner of the supermarket, as it will give an insight in the number of customers he can expect. The latter is of interest for the municipality. The two objective functions are discussed separately below.

Shopping added value (location vs. assortment size) The first objective is the shopping potential of the supermarket. This is depending on the relative effort people must do to reach the supermarket in relation to the assortment size. For this we first normalize the distance and assortment size:

$$x_{1,norm} = 1 - \frac{x_1 - 100}{1\,000 - 100} \tag{7.13}$$

$$x_{2,norm} = \frac{x_2 - 800}{30\,000 - 800} \tag{7.14}$$

For these normalized values we can construct a function that represents the incentive that people have to go to the shop. This incentive will not increase linearly with the normalized scores, because there is an interaction between the two. To reflect this, the normalized scores are combined via the root sum squared:

$$O_{SP} = \sqrt{x_{1,norm}^2 + x_{2,norm}^2} \tag{7.15}$$

Transport sustainability and waste There is an increasing demand for sustainable shopping facilities. Sustainability relates to transportation, waste and emission issues as follows:

1. The assortment is supplied by trucks. The higher the size, the more efficient this transport can be, the lower the emissions are per item.
2. A high number of items in the assortment can cause waste. More items will be thrown away and people buy stuff they might not need.
3. The larger the distance, the more interesting it is to take the car or scooter instead of walking or cycling. This also contributes to emissions.

Based on this, we can construct an index function to express the relative sustainability:

$$O_S = \frac{x_2}{20\,000 - \frac{x_1}{400}} \tag{7.16}$$

Here, the assumption is that an assortment size of 20,000 items is most favorable. This number is however influenced by the distance, as discussed above.

Preference functions

To find the proper balance for the shopping added value, the extreme outcomes must be 'constrained' (i.e. high and low $x_{1,norm}$ and low $x_{2,norm}$ respectively), because they have little incentive. For this, the interpolation function is used with the values as displayed in Table 7.6.

For the second objective, we again use the interpolation function to get to the preference curve (see Table 7.6). Note that for both functions the resulting curves are non-monotonic inverted 'U' functions.

Table 7.6: Objective outcomes and their preference scores, as input for the interpolation function.

Objective Added value		Objective Sustainability	
Outcome O_{SP}	Related P_{SP}	Outcome O_S	Related P_S
0	0	0	0
1	100	4	100
$\sqrt{2}$	60	6	60

Plots of the resulting preference functions are shown in Figure 7.8.

IMAP optimisation and design results

For this decision-making problem, the weights are given in Table 7.7. We have chosen to make shopping potential more important than sustainability. This is because without shopping sustainability matters not at all. The ratio is an arbitrary one in this case.

Table 7.7: Weights per stakeholder for the supermarket example.

Stakeholder	Weight
Shopping added value	0.65
Transport sustainability & wasted	0.35

Using the Preferendus and its a-priori IMAP optimisation method, the shop configuration has a distance of 147 meters and an assortment size of around 11 370. In Figure 7.7, this result is plotted in the solution space. For comparison, both optimal solutions via the IMAP and via the Min-max methods are plotted. Figure 7.8 shows the preference curves including the results. As can be seen, the solution lies neither in a corner point nor on any of the edges of the design (solution) space. This emphasizes the need for the application of non-linear solver algorithms, which not only searches the edges but also within the design space.
Now we will evaluate the results of the different MODO methods, following the same steps as in the previous shopping mall example (see Section 7.2). To properly evaluate and compare the results the number of design alternatives must be increased to ≥ 3, and thus we added two corner point solutions for the relative ranked design evaluation (again we use the PFM-based MCDA tool Tetra, where 100 and 0 reflect 'best' and 'worst' respectively). The additionally chosen corner

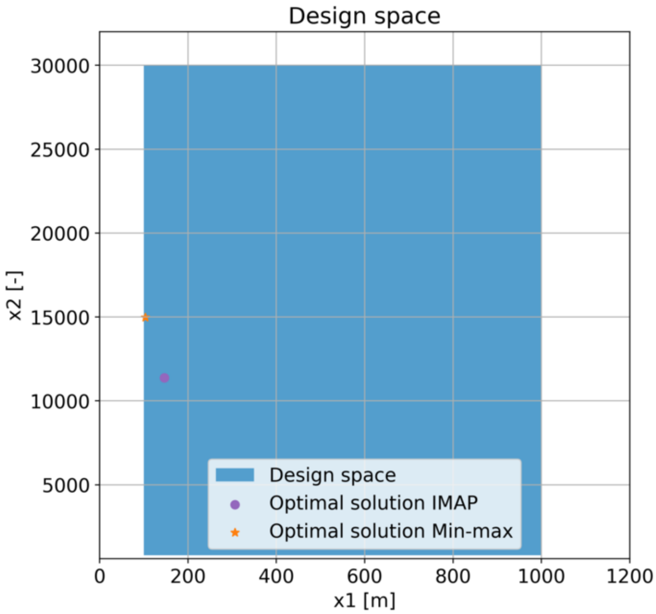


Figure 7.7: Design space for the supermarket example, showing the design points for the two MODO methods.

Table 7.8: Evaluation of design points and their relative ranking (based on aggregated preferences).

Method	x_1	x_2	Relative preference score
IMAP	147	11 370	100
Min-max	104	14 972	0
Corner point (100, 800)	100	800	51
Corner point (1 000, 30 000)	1 000	30 000	70

points are promising design configurations since they will result at least in a 'single' preference score of 100 for P_1.

The final evaluation is shown in Table 7.8. We see that the IMAP method gives the solution with the highest overall preference score, followed by the corner point solutions. The Min-max design point gives the lowest overall preference score. We conclude that the IMAP method gives the best-fit for common purpose design point, which in this case lies *within* the design space (as also Min-max lies within this space, but close to the edge).

Note that the results may differ for specific other preference curve and/or weights distributions. This may result in an optimal design point that lies even further within the design space (on a 'line' between the 'best' corner points). For an example where both the Min-max and IMAP design points are both 'well' within the design space, see the design application in Section 8.4.

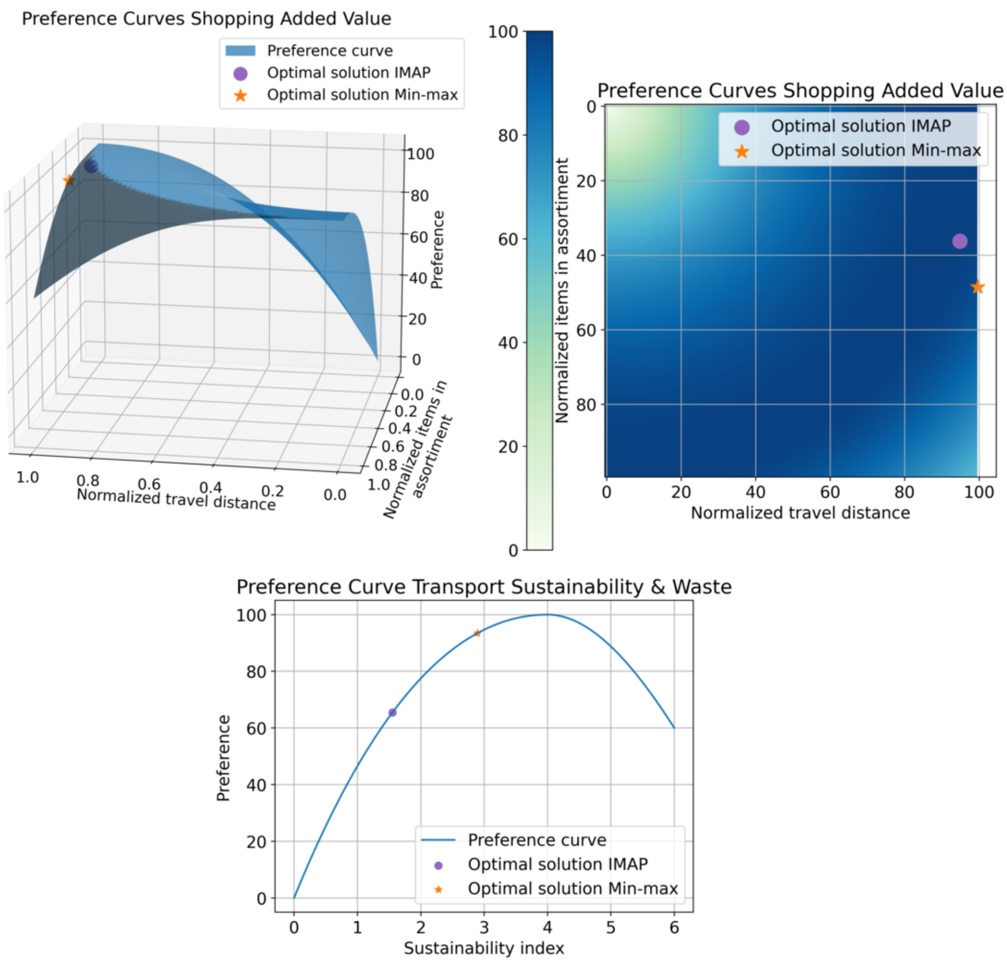


Figure 7.8: The preference curves for the supermarket example, including the results of the two MODO methods.

Chapter 8

Summative Odesys applications

This chapter builds upon the Odesys methodology (see Chapter 6) from an engineering asset management (EAM) viewpoint within a multi-stakeholder context. In other words, this chapter deals with typical problems in which an engineering asset manager has either needed to add new functionality or capacity to the engineering asset base (to extend existing systems), or to operate his in-service engineering assets including small/large maintenance, upgrades/renovations, and/or renewals.

These types of design applications are part of the so-called strategic asset management plan (SAMP) of a service provider, an organization that must ensure that the quality of service (QoS) is continuously guaranteed (see also Chapter 3). It does this by developing new assets: i.e.,, new one-off service delivery, and by maintaining and/or upgrading existing ones: i.e., ongoing service operations on-the-run. The 'rolling' SAMP for a certain planning horizon therefore consists of a so-called project development plan (PDP) and a service operations plan (SOP) (see also Chapter 5 for a basic PDP bridge design problem and a SOP rail maintenance problem). Within these plans, either optimal development or best operational strategies are determined. The design applications that we examine in this chapter will provide EAM examples for both existing and yet to be developed assets.

These SAMP activities require optimal decision-making, taking into account the different interests of various stakeholders (e.g. project manager, maintenance manager, environmental manager, user/client, etc.). These so-called design tY aspects, such as availability, maintainability, comfort, etc. (see Chapter 4), form the basis of such multi-objective design optimisation applications (MODO, see Chapter 5) and necessitate a pure socio-technical design methodology where subject desirability ('what a stakeholder wants') and object capability ('what a system can do') will meet. The Odesys methodology can be used to arrive at these best fit for common purpose strategies while making use of the application potential of the IMAP/Preferendus.

To exemplify all of the aforementioned in an integral manner, four different *summative* design applications (in contrast to the formative examples from Chapter 7) will be demonstrated on the basis of the following real-life (civil) engineering systems of interest:

DA-1	A capacity extension of a Norwegian light rail system.
DA-2	A new German high voltage power line.
DA-3	A service-life renewal of a Dutch rail level crossing.
DA-4	A new South Korean offshore floating wind farm.

All of these design applications (DAs) can be found on the Odesys Github. Before we start dealing with these DAs in Sections 8.2-8.5, we first make some introductory notes here.

(# DA-1) Note that the first light rail application/system of interest is still without integrating physical/mechanical design performance behavior (as opposed to the other three examples, here only design variables and constraints are considered). However, the focus is on a project management application in which some of the stakeholder preference functions are non-monotonic. Therefore, a traditional corner point method is not sufficient and the IMAP/Preferendus is applied. A comparison is made with the as-built configuration and a classic corner point solution, showing that the Preferendus solution is best fit for common purpose.
(# DA-2) Note that the design configuration for this power line application/ system of interest is initially determined using the a-posteriori corner points method. The integral IMAP/Preferendus is then used to show that it can arrive at the same solution, but a-priori and all at once. This is also demonstrated within the framework using a special type of design space which is discontinuous (i.e., lines instead of a plane). The MODO Preferendus results are compared with both SODO- and MODO Min-max methods and show that all methods arrive at the same best fit for common purpose design.
(# DA-3) Note that the service life design model of the rail level crossing application is an integral Odesys model in which the physical/mechanical performance functions are directly linked to the preference functions. A comparison of the results of the IMAP/Preferendus with classical SODO and MODO Min-max methods shows primarily that the Preferendus best fits a common purpose design. This comparison is shown both graphically in the design space (two-dimensional) as well as numerically using the preference scores. In addition, this example shows that using the so-called Pareto front does not automatically lead to an optimal socio-technical design.
(# DA-4) Note that the design planning model of the offshore wind farm application is an integral Odesys model in which the physical/mechanical performance functions are linked to the preference functions via, amongst others, a technical

design constraint. A comparison of the results of the IMAP/Preferendus with classical SODO and MODO Min-max methods shows that the Preferendus best fits a common purpose design. This comparison can not be shown graphically anymore since the design space is multi-dimensional. For this design application, moving towards even better real-life modeling by zooming in further on the design performance functions is the closest step compared to DA1-3 (see Van Heukelum et al., 2023).

(# DA-1..4) We will structure the problem for all DAs by 'running' the Odesys threefold diagram integrally. This will be achieved by constructing preference functions that are a direct function of both the stakeholder objective and the engineering asset design performance functions, which depend on the design and physical variables and their constraints. In other words, this unified set of preference functions, which at the lowest level is a function of the engineering design variables and the physical constraints, is a translation (a mapping) of the socio-technical system under consideration. Next, an automated algorithm is needed that searches for a feasible and optimal design synthesis solution where the aggregated group preference score is maximal. Last but not least, to show the true potential of Odesys, the IMAP/ Preferendus results are conspected within a broader design context.

Finally, for all DAs in this chapter, we only do this run for one social technical cycle to arrive at a best fit for the common purpose solution. In real-life design practices, as well as even within the educational context (see the ODL response in Chapter 9), this quest is an open-ended approach (see Chapter 4). This means that an iterative process of technical-, social-, and purpose-cycles will have to take place, implying that a best fit for common purpose design configuration can only be achieved through an iterative socio-technical process given the final 'idealised' desires, objectives, interests, and requirements of the participating stakeholders. This culminates in the so-called Odesys U-modeling, as developed by Wolfert: i.e., the open config, open space, and open source design metamorphosis (see Chapters 4 and 6). We will therefore first describe this U-modeling approach and its open design loops in general terms in the following Section 8.1, before showing only one such cycle/loop for each DA in Sections 8.2-8.6. In this way, we will refer back to and/or integrally connect to the main elementary principles from the previous Chapters 3-6. We invite the reader to convert the current one-off DA solutions in Sections 8.2-8.5 to an open-ended U-modeling approach.

A final note: parts of the text (i.e., design applications 3 and 4 in sections 8.4 and 8.5) are taken verbatim from the scientific paper Van Heukelum, Binnekamp and Wolfert (2023).

8.1. Open-ended Odesys' U

The Odesys methodology, the associated IMAP optimisation method and the use of the Preferendus are demonstrated in four real-life infrastructure design applications (DA): (1) a railway level-crossing life-cycle design and (2) a floating wind turbine installation design. Both of these design cases were conducted within a real-life infrastructure design context. Alle of these have been developed in collaboration with reflective practitioners and relevant stakeholders from (1) Skyss, a Bergen light rail operator, (2) Tennet, a German transmission system operator (TSO), (3) ProRail, a Dutch railway infrastructure service provider, and (4) Boskalis, an internationally operating maritime contractor. Especially within Boskalis, several socio-technical cycles were carried out to validate the Odesys' best fit for common purpose results and the added value of the Preferendus with various stakeholders involved. In addition, here the Preferendus has also been validated for dredging applications with promising validation results (but beyond the scope of the current edition of this book).

Although all DAs are a somewhat simplified for illustrative purposes, they still provide insight into the added value and principles of the Odesys methodology, the IMAP method and the use of the Preferendus tool. For further substantial extensions of two of the four design applications, as presented here, see Shang et. al. (2023) and/or Van Heukelum et al. (2023). For all the DAs, the mathematical threefold diagram of design performance, objective, and preference functions is presented using the Odesys diagram. Here are the preference functions ultimately a direct function of both stakeholder objective and engineering asset design performance functions, which in turn are related to the design variables and their constraints. These functions are derived from an idealised design configuration (i.e., a tangible design representation) and from the common preference interests of the stakeholders involved. The goal is then to find, within the feasibility space, the candidate solution with the highest aggregated group preference score. In reality, this quest for optimisation is actually open-ended.

This means that within an actual design there is an iterative process of technical, social and purpose cycles: i.e., from an idealized design, a best configuration can be achieved through an iterative socio-technical process, given the final idealised desires, goals, interests and requirements of the stakeholders, and given the technical or physical constraints of the system. This is reflected in the form of the open-ended Odesys' U, incorporating three open-ended design loops: i.e., a spiral design metamorphosis that contains three cycles: (1) *Open config* - technical concept/concreation, (2) *Open space* -social context/conciliation and (3) *Open source* - common purpose/synthesis. In this book, for demonstration purposes, only one socio-technical best fit for purpose cycle per DA is included. It should be noted that in the real-life DA-4 ('floating wind installation'), as carried out within Boskalis, the stakeholders were asked to re-adjust both their open-config and open-space parameters (from the social context) to achieve a better result. This open-ended process was repeated several times for 'idealised' purposes. The Preferendus has shown its added value here to arrive at the best-fit-for-common-purpose design configuration, especially within multi-objective dredging and off-shore planning applications, in combination with discrete event simulation (DES). The Odesys combination of intuitive 'U-thinking' and deliberative 'thinking-slow' made the Preferendus an effective and transparent design/decision support tool within Boskalis. Note that applying the U model in practice also shows that you can complete a sub-cycle faster on partial aspects than the whole (e.g. a sensitivity or impact check of a single design parameter). You could call this, as it were, "crossing over" from the left side to the right side, and then continuing the entire U again. In short, a dynamic design and decision-making process.

Moreover, the social-technical cycle was also gone through and validated in a real-life design application called Waelpolder, an area development project in NL where the Preferndus was used. Together with the municipality of Naaldwijk, the urban planning consultancy firm Planmaat and students from TU Delft, this project was carried out (see van Eijck & Nannes TU Delft repository, 2022 , and section 8.6). With regards to the goal the stakeholders expressed that they preferred the design obtained using the Preferendus method. The Min-nmax method optimisation results were deemed less satisfactory for the group as a whole. Although there was a differentiation in stakeholder satisfaction when using the Preferendus, the optimisation result was more diverse and attractive.

The open-ended Odesys methodology and modeling approach described above is summarized below with the help of four essential diagrams, all described and explained in more detail in the previous Chapters 4-6: (1) the full Odesys U-model Figure 4.7, (2) the open design cycles/loops Figure 4.6, (3) the Odesys threefold mathematical framework Figure 6.2, and (4) the mathematical design support U-model Figure 6.3. We will use these four auxiliary diagrams to structure, model and work through the DAs in the following sections.

8.2. Norwegian light rail

'Technical' context: The Norwegian city Bergen wants to add a new section to its light rail network. The hope is that the extension of the light rail will facilitate more jobs and houses, making it an interesting investment for the municipality. We assume that the decision for exact design of the route is not made yet and that we want to model the design process. The route actually selected by the municipality is shown in Figure 8.1. As a preliminary design exercise, a simplified decision making problem was formulated first in which performance functions are not included for the time being since the objective functions are directly linked to

the design/decision variables (compare the supermarket/ shopping mall examples from Chapter 7). This type of design problems are sometimes called managerial decision making problem because technology and/or physics are not really included (that is why it is actually social design rather than socio-technical one). However, it is an interesting real-world application for a typical engineering asset management (EAM) department. We will see the potential of IMAP multi-objective design optimisation as preparation for the project development plan (PDP).

Social context: In this design application, a MODO approach for the decision on the number of stations along the route and the number of trains per hour is demonstrated based on different conflicting interests from multiple stakeholders: i.e., the municipality is interested in the project's development potential, the users and inhabitants are interested in the travel time, the light rail operator is interested in the operational costs and the project development organization is interested in the construction time. These potentially conflicting interests, make this problem a multi-stakeholder design problem containing, for example, the number of train stops and the number of trains as important design variables.

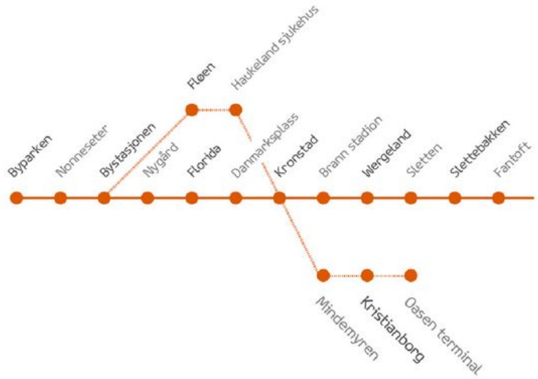


Figure 8.1: Light Rail trace as realized.

We will first describe the integral problem by constructing the design performance, objective, and preference functions (we follow this order as motivated in the previous section 8.1.)

Design performance functions

There are two main design/decision variables: the number of stops/stations along the route (design variable x_1) and the number of trains per hour (design variable x_2). Note that there are no physical performance functions in this application, but only the design variables x_1 and x_2, which are directly related to the objectives.

Objective functions

We start by formally defining (conflicting) objectives, bounds and constraints for each relevant stakeholder. The objective functions read as follows.

Development potential is a key driver for the municipality which it wants to maximise. This potential can be expressed in two ways:

1. The value of a property increases if it lies in the vicinity of a station. The increase in value also means an increase in tax incomes for the municipality. Secondly, this will lead to an increase in economic activity. Both will lead to an assumed added value of €500 000 per station.
2. The number of trains per hour will influence the economic activity in the surroundings. Less than 10 trains per hour will influence this negatively, and more than 10 will be positive.

Both objectives are captured in the following objective:

$$O_M = 500\,000x_1 - 25\,000(-x_2 + 10) \tag{8.1}$$

Besides this, the municipality demands that the number of stops is at least 1, excluding the beginning and end stops. This stop is at Haukeland Hospital. Secondly, to assert a minimal level of economic activity, the number of trains per hour should be at least 2.

$$G_1 = x_1 \geq 1;\ G_2 = x_2 \geq 2 \tag{8.2}$$

Travel time is a key value parameter for the light rail users. The shorter the travel time is the better. The travel time is depending on a lot of variables (distance between stops, acceleration length, deceleration length, minimal wait time), but for simplicity, we assume here an average 1.5-minute travel time between stops. The average travel time will secondly decrease fast by adding more trains on the route.

$$O_U = 1.5x_1 + 60\frac{1}{x_2} \tag{8.3}$$

To assert good accessibility of the line, the minimal number of stations should be 3 according to the users. However, there must be no more than 10 stations, to prevent excessive disturbance due to noise and vibrations.

$$G_3 = 3 \leq x_1 \leq 10 \tag{8.4}$$

Maintenance costs will be the determining objective for the light rail operator. From reflective practice, we can extract the costs per station, which are around 120 000 euros per year. This value is influenced by the number of trains per hour since the track will wear more with an increased number of movements. The 120 000 euros is for 10 trains per hour and expected is that this number will decrease by a maximum of 10% for a decreasing number of trains per hour, and *vice versa.*

$$O_O = 120\,000 x_1 + 0.1 \times 120\,000 \frac{x_2 - 10}{10} \tag{8.5}$$

For profitability, the minimum number of stops must be 2. Otherwise, the line will attract too few users. The number of trains cannot be higher than 20 per hour, to allow for safe operation.

$$G_4 = x_1 \geq 2;\; G_5 = x_2 \leq 20 \tag{8.6}$$

Construction time is the leading objective for the project organization. From reflective practice, we can make a reasonable assumption for the time needed to construct one station which is around half a year.

$$O_P = 0.5 x_1 \tag{8.7}$$

Since the route needs to be finished within 5 years, the number of stops cannot exceed 10, assuming no parallel construction can take place.

$$G_6 = x_1 \leq 10 \tag{8.8}$$

Note that all constraints given in this section are determining the bounds of the solution space:

$$3 \leq x_1 \leq 10;\; 2 \leq x_2 \leq 20 \tag{8.9}$$

Preference functions

As discussed in Chapters 5 and 7, we distinguish two approaches for determining preference functions. The first approach searches for the range of decision variable values for each objective by means of maximisation and minimisation. Within the second approach each stakeholder is asked for this range, regardless of the feasibility of attaining this range. In this design application, we apply the latter approach combined with curve fitting. The values used for this curve fitting are given in Table 8.1. The resulting functions (i.e., relations between different values $P_{1..4,1..4}$ and $O_{1..4}$) are shown as blue curves in Figure 8.2.

Note that the preference function for the income of the municipality is non-monotonic. The municipality's objective is not to profit on a project, but to facilitate new projects. Making money is still important, but not the highest goal, hence this preference function shape.

Similarly, the preference for the operational costs is non-monotonic. The given objective function is a simplification, but in the underlying functions, quality of material must be considered. The lower the quality, the higher the risk of sudden breakdowns; i.e., low costs of replacement if failure is foreseen, but a large risk of when breakages are not foreseen. Hence the lowest operational cost does not have the highest preference.

Table 8.1: Preference points Bergen Light Rail.

Dev. potential		Travel Time	
P = 60	€5.25 × 10^6	P = 100	7.5 min
P = 100	€4.00 x 10^6	P = 80	20 min
P = 0	€1.30 x 10^6	P = 10	35 min
		P = 0	40 min
Operational Costs		**Construction Time**	
P = 60	€350,400	P = 100	1.5 years
P = 100	€750,000	P = 95	2 years
P = 0	€1.212,000	P = 0	5 years

Design optimisation results & conspection

For this decision-making problem, and to generate the design points (i.e., design configuration results) for this multi-objective optimisation problem, the weights for each objective must first be determined. For this decision-making problem, the weights are taken as $w_{1,M} = 0.2$, $w_{2,U} = 0.4$, $w_{3,O} = 0.3$, $w_{4,P} = 0.1$. Note that for this example the weight distribution represents each decision maker's power in the design/decision making process.

We now first perform a-posteriori evaluation to determine what is the best relative solution of the corner points using the Tetra software. If we evaluate these alternatives, we get the outcome as displayed in Table 8.2.

Table 8.2: Alternatives for evaluation.

Alternative	$P_{1,M}$	$P_{2,U}$	$P_{3,O}$	$P_{4,P}$	Score	Rank
x_1 = 3; x_2= 2	0.00	11.00	60.00	60.00	21	3
x_1 = 3; x_2= 20	33.73	100.00	65.00	65.00	100	1
x_1 = 10; x_2= 2	81.74	0.00	8.00	8.00	0	4
x_1 = 10; x_2= 20	60.00	85.00	0.00	0.00	40	2

The multi-objective design optimisation problem can also be solved via the a-priori IMAP optimisation method, using the Preferendus. The result of this optimisation, i.e., the best fitting design point for this decision-making problem, is 6 stations and 20 trains per hour. To evaluate this outcome and see how it compares to other design points, we include both the real-life as-built solution (9 stations and 12 trains per hour) and the a-posteriori corner point solutions. Note that, in general, one needs at least three alternatives for such an overall evaluation.

The outcomes of the different design points/configurations are first of all plotted on the different preference functions showing the different objective function values ($O_{1..4}$) and their corresponding individual preference function values

Table 8.3: Results of the objective functions ($O_{1..4}$) and the corresponding preference functions ($P_{1..4,1..4}$) of the light rail design application.

Optimisation methods	O_M [€$x10^6$]	$P_{1,M}$	O_U [min]	$P_{2,U}$	O_O [€$x10^6$]	$P_{3,O}$	O_P [years]	$P_{4,P}$
x_1 = 3; x_2= 2	1.3	0	34.5	11	0.35	60	1.5	100
x_1 = 3; x_2= 20	1.75	34	7.5	100	0.37	60	1.5	100
x_1 = 10; x_2= 2	4.80	82	45	0	1.19	8	5	0
x_1 = 10; x_2= 20	5.25	60	18	85	1.21	0	5	0
As-built	4.55	91	18.5	83	1.08	45	4.5	24
MODO IMAP	3.25	94	12	96	0.73	100	3	76

Table 8.4: Evaluation of different design configurations per optimisation method and their relative ranking (based on aggregated preference scores) for the sued-link design application.

Optimisation methods	x_1 [m]	x_2	Aggregated preference score
x_1 = 3; x_2= 2	3	2	15
x_1 = 3; x_2= 20	3	20	72
x_1 = 10; x_2= 2	10	2	0
x_1 = 10; x_2= 20	10	20	32
As-built	9	12	63
MODO IMAP	6	20	100

($P_{1..4,1..4}$), see Figure 8.2 and Table 8.3. Secondly, the numerical results of the different design points/configurations per optimisation method (SODO and/or MODO) can be read from Table 8.4. In this table one can also find the aggregated preference score, which was used to determine the overall score/ranking via the PFM-based MCDA tool Tetra, where the resulting aggregated preference scores are re-scaled between scores of 0 and 100 (0 reflects the 'worst' scoring configuration/alternative and 100 the 'best', see Appendix C for further details).

Finally, as there are only two design variables in this design application, the two-dimensional design space (sometimes called solution space, see Dym & Little (2004)) containing the different design points/configurations can be plotted, see Figure 8.3. Note that the optimal outcome is not a corner point solution, because some of the preference functions are non-linear/ non-monotonic. This illustrates the pure added value of the a-priori optimisation Odesys methodology and its IMAP/Preferendus method as illustrated in this book.

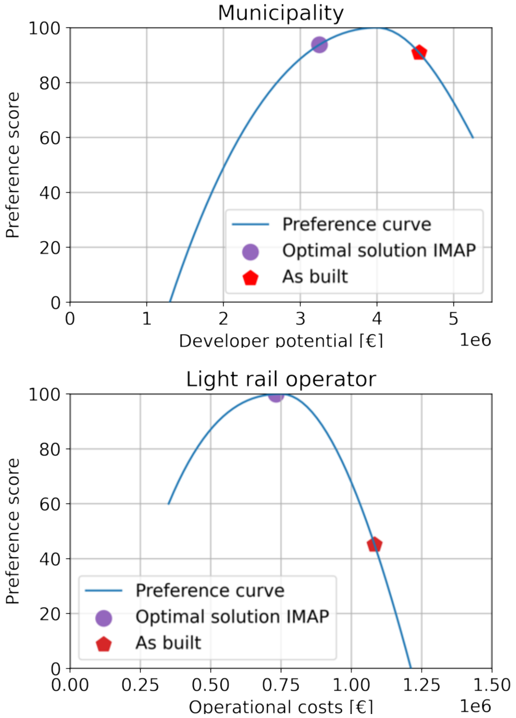


Figure 8.2: The four stakeholder preference functions ($P_{1..4,1..4}$) for different objectives ($O_{1..4}$) for the light rail design application, including the results of the different optimisations. The numerical results can be found in Table 8.3.

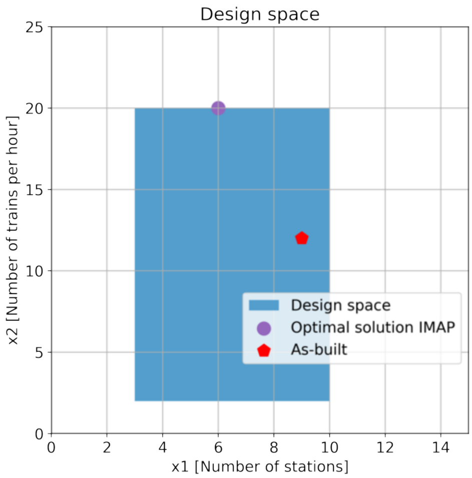


Figure 8.3: The design space of the light rail design application and the design configuration/points for the different optimisation methods. The numerical results can be found in Table 8.4.

The preference functions show that the objective of the municipality is in conflict with the other objectives. In light of optimising for the best fit for common purpose design point, it is then logical that the final outcome favor the stakeholders other than the municipality, given that the weight (power) of the municipality is not the highest of all the stakeholders. This is also what is expected in the real case. A municipality's goal is not to make the highest profit on a project, rather to financially facilitate the new project so that societal goals can be achieved. The as-built solution favors the municipality, where the IMAP/Preferendus solution favours the common purpose for all stakeholders involved.

8.3. German power transmission line

Technical context: SuedLink is set to connect the offshore wind farms of the German North Sea and Norway with the industrialized area of South Germany (see Figure 8.4), enabling Germany to be closer to its goal to utilize 80% power from renewable sources by 2050. In the project, HVDC was chosen over HVAC. DC transmission lines have gained popularity for long distance transmission, however, the technology is not as mature as AC which leads uncertainties and thus to higher risks. Although in reality SuedLink will be built fully underground, in this example we assume that the choice for AC/DC and the lengths of over/underground cables has not been decided upon yet.

Social context: This application demonstrates a multi-objective design optimisation (MODO) approach for the decision on type of current (direct or alternating) and the length of the underground cable is demonstrated based on different (conflicting) interests from the project organization's view: i.e., the installation costs, use of area and project duration. Take the German branch of Tennet, for example, with a project delivery department. Both installation costs and project duration objectives are primarily linked to this stakeholder organisation. The permitting department with its objective of minimising area usage is presented as a second stakeholder.

We will first describe the integrative design problem by running through the Odesys threefold mathematical statement framework (Chapter 6), resulting in design performance-, objective-, and preference functions.

Design performance functions

For this example we will use two design variables:

1. x_1: the type of current (DC or AC)
2. x_2: the length of underground cable (ACU or DCU).

Figure 8.4: SuedLink route.

With x_2 and the overall length of 700km, we can also determine the length of over ground cable. From these two design variables and the given overall length, we can thus construct four different lengths as functions of both design variables:

1. Direct Current Underground, DCU
2. Alternating Current Underground, ACU
3. Direct Current Overground, DCO
4. Alternating Current Overground, ACO

These four variables thus indirectly represent the design variables and are used in the objective functions. The route will pass some cities and waterways. At cities it will need to pass underground, and at waterways it will mostly have to pass over ground. These limitations constrain the problem:

$$300 \leq x_2 \leq 600 \tag{8.10}$$

Objective functions

As mentioned before, three (conflicting) objectives are investigated in this design application: the installation costs, use of area and project duration.The objective functions read as follows.

Installation costs for this project depend on the fixed cost of transformers, etc., and the cost per kilometer. Literature (e.g. Meah ,2007) shows that the fixed installation cost is lower for a HVAC line, but the cost per kilometer is higher. Second, the cost for underground cable is higher because insulation is required (with overhead cable, insulation is created by air). Next, the costs objective function can be structured as follows:

$$O_C = \begin{cases} 0.475ACO + 0.580ACU + 375 \\ 0.120DCO + 0.190DCU + 430 \end{cases} \tag{8.11}$$

where the installation costs are in €×10^6.

Local area for overhead high-voltage power lines is needed to place the large masts in which the cables are suspended. This takes up much more space or local area than an underground route where the cables can be laid virtually side by side. To determine how much area we need, the number of conductors (i.e., individual high-voltage lines) must be determined. These depend on the type of current and the line voltage. For this system, the details are given in Table 8.5.

Table 8.5: Configuration of power lines.

Current type	Line voltage [kV]	# of conductors
AC	800	12
DC	525	8

Only the area directly below or above power lines is required. However, power lines emit noise and magnetic flux, making the area unusable for buildings etc. In this example, we will consider the noise component. The magnetic component is perhaps even more important, but also quite extensive, making it difficult for this design application. For describing the noise we use the principle assumptions from Chartier (1981). In the case of AC, this results in the following equations:

$$\text{noise}_{\text{AC}} = 10log\left(\sum_{i=1}^{3} 10^{(\text{PW}L_i - 11.4log(R_i))/10}\right) \tag{8.12}$$

$$\text{PWL}_i = -164.6 + 120log(e) + 55log(69.4) \tag{8.13}$$

$$\text{noise}_{\text{DC}} = -133.4 + 86 * log(e) + 40log(109.71) - 11.4log(R) \tag{8.14}$$

where: e is the voltage gradient in kV/cm, and R is the radial distance between the observer and the power lines in m.

The following numeric values are used: i.e., for (a) DC: $e = 22kV/\text{cm}$; (b) the outer phase of AC: $e = 13.66kV/\text{cm}$; (c) the inner phase of AC: $e = 14.58kV/\text{cm}$.

For this example the AC and DC lines are located 12 meters above the ground and the distance between the three phases in the AC case is 20 meters. The maximal sound level is assumed to be 45 dB(A). With the equations above, we can calculate the distance from the power lines where this sound level is reached.

For AC this is 287 meters, for DC 42 meters. These values need to be added to the already needed clearance right below the power lines. This results in the following objective function:

$$O_A = \begin{cases} (0.170 + 0.287)ACO + 0.018ACU \\ (0.120 + 0.042)DCO + 0.015DCU \end{cases} \tag{8.15}$$

Project duration is especially of importance for the transmission system operator (TSO)/Tennet). The installation of underground cables is more intensive than over ground cables. More groundwork is needed, and these cables also come in shorter pieces at once. Secondly, there is a difference in conductors for the different current types, resulting in different construction times. Since the preparation duration is considered equal for all type of currents and lengths of cables, only the duration of installation is considered. This results in the following project duration objective function (in days):

$$O_D = \begin{cases} 2.5ACO + 2.6ACU \\ 1.8DCO + 2.2DCU \end{cases} \tag{8.16}$$

Preference functions

To construct the preference curves, we define our preference for given a range of decision variable values as inputted by each stakeholder. The outcome of this process is shown in Table 8.6. The resulting functions (i.e., relations between different values $P_{1,1..3}$ and $O_{1..3}$) are shown as blue curves in Figure 8.6. Note that the preference function elicitation was performed using the fundamentals of relevant preference functions research by Arkesteijn et al. (2017).

Costs		Area use		Project Duration	
P = 100	€500 × 10^6	P = 100	20 km^2	P = 100	1,300 days
P = 50	€600 × 10^6	P = 50	130 km^2	P = 40	1,450 days
P = 0	€800 × 10^6	P = 0	200 km^2	P = 0	1,700 days

Table 8.6: Preference points SuedLink.

Finally, the problem statement of the systems design integration is conceptualised with the threefold diagram as shown in Figure 8.5.

Design optimisation results & conspection

For this decision-making problem, and to generate the design points (i.e., design configuration results) for the different multi-objective optimisation methods (MODO Min-max and IMAP), the weights for each objective must first be determined. Here

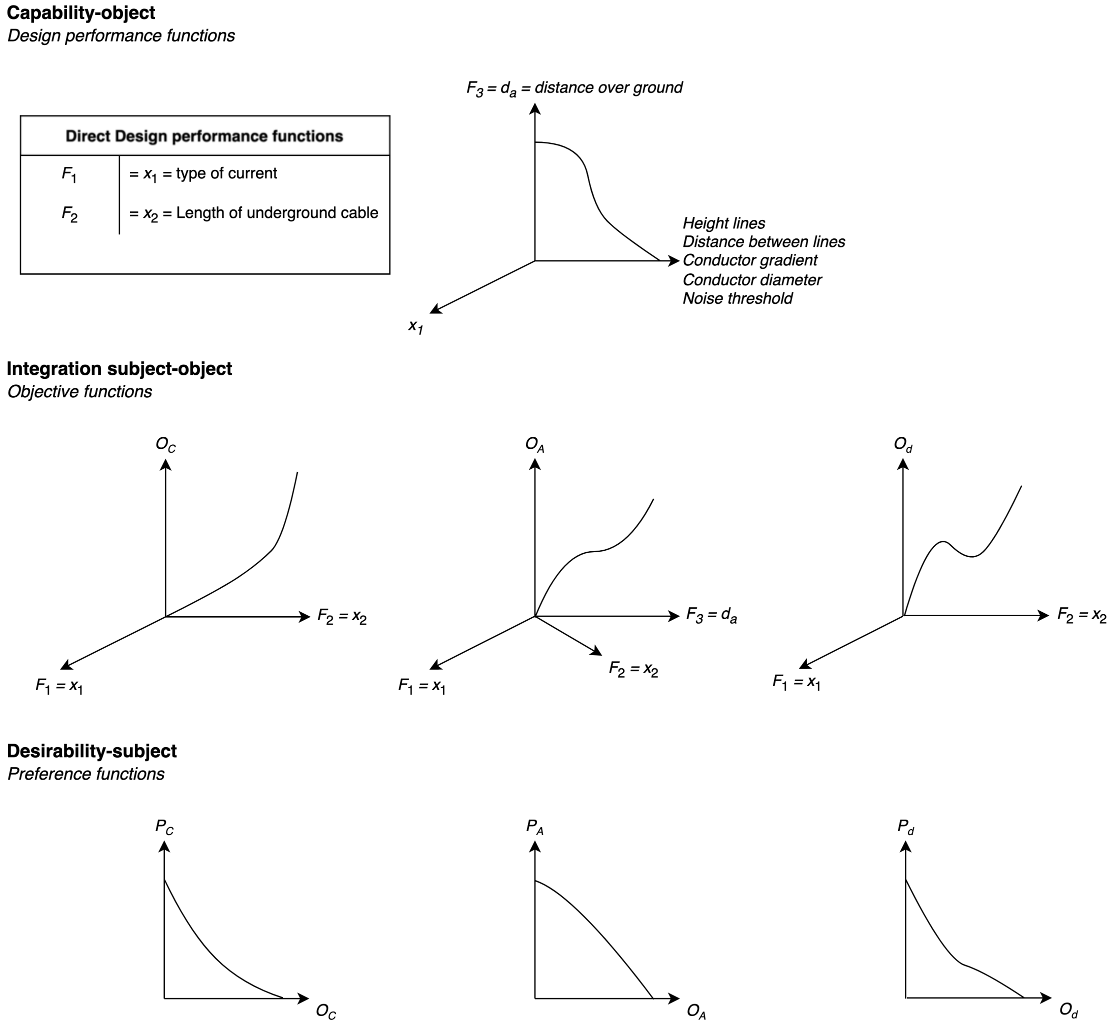


Figure 8.5: Conceptual threefold diagram, describing the systems design integration for the sued-link design application. Note: the aim of this figure is to illustrate the relationship between the different functions and some curves may not represent the actual function.

the weights are taken as $w_{1,C} = 0.4$, $w_{1,A} = 0.2$, and $w_{1,D} = 0.4$. Both costs and time are taken as important. Time is given this relative high priority due to the incentive to move faster to renewable energy and the reduce the use of fossil fuels. Note that we assume that for this case the objectives relate to one stakeholder.

We can construct a design space for the problem and evaluate the corner points as a first optimisation strategy (a-posteriori evaluation). If we evaluate these design alternatives using Tetra, we get the outcomes for the relative ranking as shown in Table 8.7. Alternatively we can now use the IMAP/Preferendus as part of the Odesys methodology. The result of this optimisation, i.e., the best fitting design point for this decision-making problem, is HVDC an length of the underground cable of 300km.

Alternative	$P_{1,C}$	$P_{1,A}$	$P_{1,D}$	Score	Rank
AC – 400 ACO – 300 ACU	9	9	6	0	4
AC – 100 ACO – 600 ACU	3	87	11	22	3
DC – 400 DCO – 300 DCU	80	81	52	100	1
DC – 100 DCO – 600 DCU	69	98	16	63	2

Table 8.7: Alternatives, scores and ranking.

To evaluate this outcome and see how it compares to other design points, we include both the design point as obtained by the Min-max method (see Chapter 6) and the a-posteriori corner point solutions. Note that, in general, one needs at least three alternatives for such an overall relative evaluation.

Table 8.8: Results of the objective functions ($O_{1..3}$) and the corresponding preference functions ($P_{1,1..3}$) of the sued-link design application.

Optimisation methods	O_C [€]	$P_{1,C}$	O_A [km^2]	$P_{1,A}$	O_D [days]	$P_{1,D}$
AC – 400 ACO – 300 ACU	739	9	188.21	9	1780	6
AC – 100 ACO – 600 ACU	770	3	56.50	87	1810	11
DC – 400 DCO – 300 DCU	535	80	69.15	81	1410	52
DC – 100 DCO – 600 DCU	556	69	25.16	98	1560	16
MODO Min-max	535	80	69.15	81	1410	52
MODO IMAP	535	80	69.15	81	1410	52

The outcomes of the different design points/configurations are first of all plotted on the different preference functions showing the different objective function values ($O_{1..3}$) and their corresponding individual preference function values ($P_{1,1..3}$), see Figure 8.6 and Table 8.8. Secondly, the numerical results of the different design points/configurations can be read from Table 8.9. In this table one can also find the aggregated preference score, which was used to determine the overall score/ranking via the PFM-based MCDA tool Tetra, where the resulting aggregated preference scores are re-scaled between scores of 0 and 100 (0 reflects the 'worst' scoring configuration/alternative and 100 the 'best', see Appendix C for further details). Note that, in general, one needs at least three alternatives for such an overall evaluation.

Table 8.9: Evaluation of different design configurations per optimisation method and their relative ranking (based on aggregated preference scores) for the sued-link design application.

Optimisation methods	x_1 [m]	x_2	Aggregated preference score
AC – 400 ACO – 300 ACU	1	300	0
AC – 100 ACO – 600 ACU	1	600	26
DC – 400 DCO – 300 DCU	0	300	100
DC – 100 DCO – 600 DCU	0	600	68
MODO Min-max	0	300	100
MODO IMAP	0	300	100

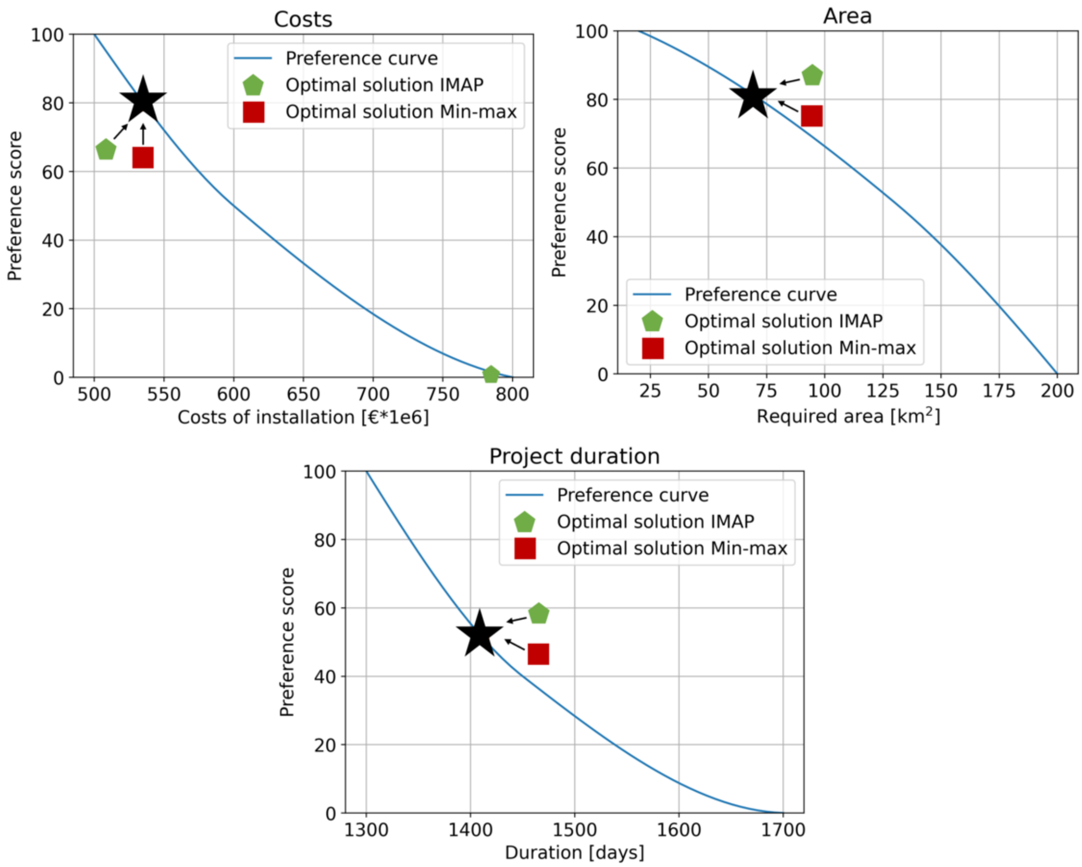


Figure 8.6: The three stakeholder preference functions ($P_{1..3,1..3}$) for different objectives ($O_{1..3}$) for the sued-link design application, including the results of the different optimisations. The numerical results can be found in Table 8.8.

As there are only two design variables in this design application, the two-dimensional design space containing the different design points/configurations per optimisation method can be plotted, see Figure 8.7.

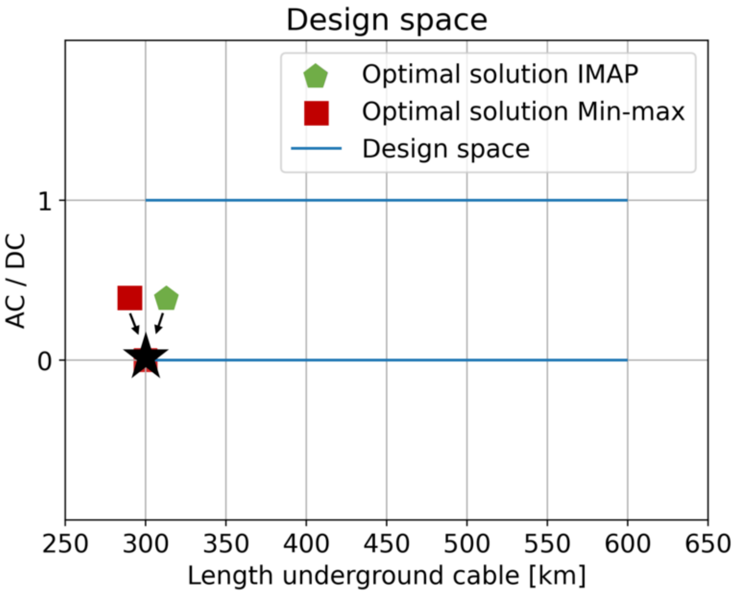


Figure 8.7: The design space of the sued-link design application and the design configuration/points for the different optimisation methods. The numerical results can be found in Table 8.9.

We can thus conclude that the direct evaluation of corner design points gives the same result as via the IMAP/Preferendus approach. This example was therefore chosen to show this, in addition to the peculiarity of a 'design space' which, due to its mixed integer nature, consists of only two lines. Because in a design problem we do not know whether the corner point solutions are the maximum (see also examples Chapter 7 or the light rail design application in section 8.2), the use of the IMAP/Preferendus is essential, which we will see in the following design applications. Finally, we note that the resulting design point via the Min-max method is equal to the IMAP/Preferendus design point. It can also be concluded that the objectives relating to the use of area and the costs of the line are aligned, where the time objective is not. In other words, the area and costs objectives are conflicting with the project duration objective. The time objective has a similar weight as the costs objective, so it would be expected that time and costs would have a similar final preference score. However, this is not the case. This indicates that a decrease in time would not only mean a decrease in preference for the costs, but also a significant decrease in use of area. Since costs and use of area together have a higher weight than the project duration, it explains why time has a lower final preference rating than the costs.

8.4. Dutch rail level crossing

Technical context: Railways and roads often cross each other at level-crossings. Because heavy vehicles must also be able to cross, the railway crossing is often cast in a concrete foundation. The mechanical properties of this concrete foundation are very different from the foundation of the other parts of the railway track. As a result, transitional radiation occurs during the passage of a train, potentially resulting in faster degradation of the local rail system or a negative passenger experience due to vibrational hindrance, see Wolfert et al. (1998) and/or Metrikine et al. (1998). Therefore, a transition zone is created by varying the number of sleepers and the distance between them to contribute to a smoother transition, which should have a positive effect on both operational performance and passenger comfort.

Social context: In this application, a multi-objective design optimisation (MODO) of the transition zone is demonstrated, based on several conflicting interests of multiple stakeholders: i.e., (1) capital investment and (2) operational maintenance expenditures, and (3) travel comfort objective functions. It is assumed that these three objectives are linked to three different stakeholders. Take for instance the Dutch ProRail organisation, where there is both a project delivery and a service operations department. They are linked to the capital and operational expenditure objectives, respectively. The Dutch train passenger is represented as the stakeholder linked to the travel comfort objective.

We will first describe the integrative design problem by going through the Odesys threefold mathematical statement framework (Chapter 6 and Figure 8.8), resulting in design performance, objective, and preference functions.

Design performance functions

In reality, this design depends on a multitude of design variables, but for now, it will be limited to just two of them:

1. $F_1 = x_1 > 0$: the distance between the sleepers. Sleepers are the concrete (or sometimes wooden) beams that support the rails, as part of the ballast bed.
2. $F_2 = x_2 (\geq 1)$: the number of sleepers in the transition zone. The transition zone consists of a different type of sleeper than the rest of the track.

Note that (1) in order to be consistent with the general mathematical statement from section 1, the design performance functions F_1 and F_2 are added here, equal to x_1 and x_2 respectively, and (2) from the practical application context, the design variables are bounded by $0.3 \leq x_1 \leq 0.7$ and $4 \leq x_2 \leq 15$, which defines the design space (i.e., the solution space defined by the design variables). The key design performance functions describing the dynamic behaviour of the track at the level-crossing transition zone are the force $F_3 = F(x_1, x_2)$ and the acceleration $F_4 = a(x_1, x_2)$. These are usually the result of extensive numerical finite element and/or analytical calculations. For this design application, the physical/mechanical relationships between the design variables are simplified by using interpolation of discrete numerical calculations derived from a finite element based structural dynamic model (Shang et al., 2023). These interpolated results are the input to the design performance functions.

Objective functions

As mentioned before, three objective functions are investigated in this design application: maintenance costs, travel comfort and investment costs. Given these three objectives, the optimal design for the level-crossing zone is determined. The objective functions read as follows.

Maintenance costs (OPEX) are the key driver for the design of the level crossing transition zones. Large forces and accelerations will have a negative effect on the degradation of the track and foundations, resulting in increased maintenance costs. Hence, this objective can be written as a function of the force and acceleration. For that purpose, the force and acceleration are normalised and combined via the root sum of the square. The final maintenance costs per year objective reads as:

$$O_M = \sqrt{F_N^2 + a_N^2} \cdot 15\,000 \tag{8.17}$$

where

$$F_N = \frac{F - F_{min}}{F_{max} - F_{min}};\ a_N = \frac{a - a_{min}}{a_{max} - a_{min}} \tag{8.18}$$

and where O_M expresses the OPEX per year in EUR. Note that at the level of design performance functions (i.e., capability-object level), it holds that $F_3 = F$ and $F_4 = a$ respectively.

Passenger travel comfort is an important consideration in railway design. When the dynamic behaviour (due to transition accelerations) during a passage of a level-crossing is substantial, it may lead to a negative travel experience or, in the worst case, to minor mishaps in the train (falling while walking, spilling drinks, etc.). To integrate this into the design problem, an objective is added that describes travel comfort as a function of the normalised acceleration:

$$O_C = 1 - a_N \tag{8.19}$$

with a_N as given in Equation 8.18.

Investment costs (CAPEX) must be considered as a key decision-making parameter. The installation of more sleepers will result in higher investment costs. However, more sleepers spread out over a greater distance will also mean that the investment costs for other parts of the rail will be reduced. Therefore, the investment costs objective can be represented as follows:

$$O_I = 1000x_2 - 350x_1x_2 \tag{8.20}$$

where O_I expresses the CAPEX in EUR.

Preference functions

The preference functions for this design application are constructed based on the input from relevant stakeholders (Shang, 2021, 2023). The three resulting functions, which describe the relations between different values for $P_{1..3,1..3}$ and $O_{1..3}$), are shown as blue curves in Figure 8.9. Note that the preference function elicitation was performed using the fundamentals of PFM research by (see Arkesteijn et.al. (2017).

The systems design integration problem statement is now conceptualised with the threefold diagram shown in Figure 8.8.

Design optimisation results & conspection

To generate the design points (i.e., design configuration results) for the different multi-objective optimisation methods (MODO Min-max and IMAP), the weights for each objective must first be determined. Since traditional (contractor) design offices often give a dominant weight to investment costs alone and less to the quality of service (QoS) oriented interests of maintenance and travel performance, here it is deliberately done 'the other way round', resulting in $w_{1,M} = 0.4$ for maintenance, $w_{2,C} = 0.4$ for travel comfort and $w_{3,I} = 0.2$ for investments. For evaluation purposes, the design points for the different (1...3) Single-Objective Design Optimisations (SODO) are also determined for maintenance-, investment costs and travel comfort respectively. The outcomes of the different design points/configurations per optimisation method are first plotted in the preference functions showing the different objective values ($O_{1..3}$) and their corresponding individual preference values ($P_{1..3,1..3}$), see Figure 8.9 and Table 8.10. Secondly, the numerical results of the different design points/configurations per optimisation method (SODO and/or MODO) can be read from Table 8.11. In this table one can find the aggregated preference score, which was used to determine the overall score/ranking via the PFM-based MCDA tool Tetra (the resulting aggregated preference scores are rescaled between scores of 0 and 100, where 0 reflects the 'worst' scoring configuration/alternative and 100 the 'best', see Appendix C for further details). Note

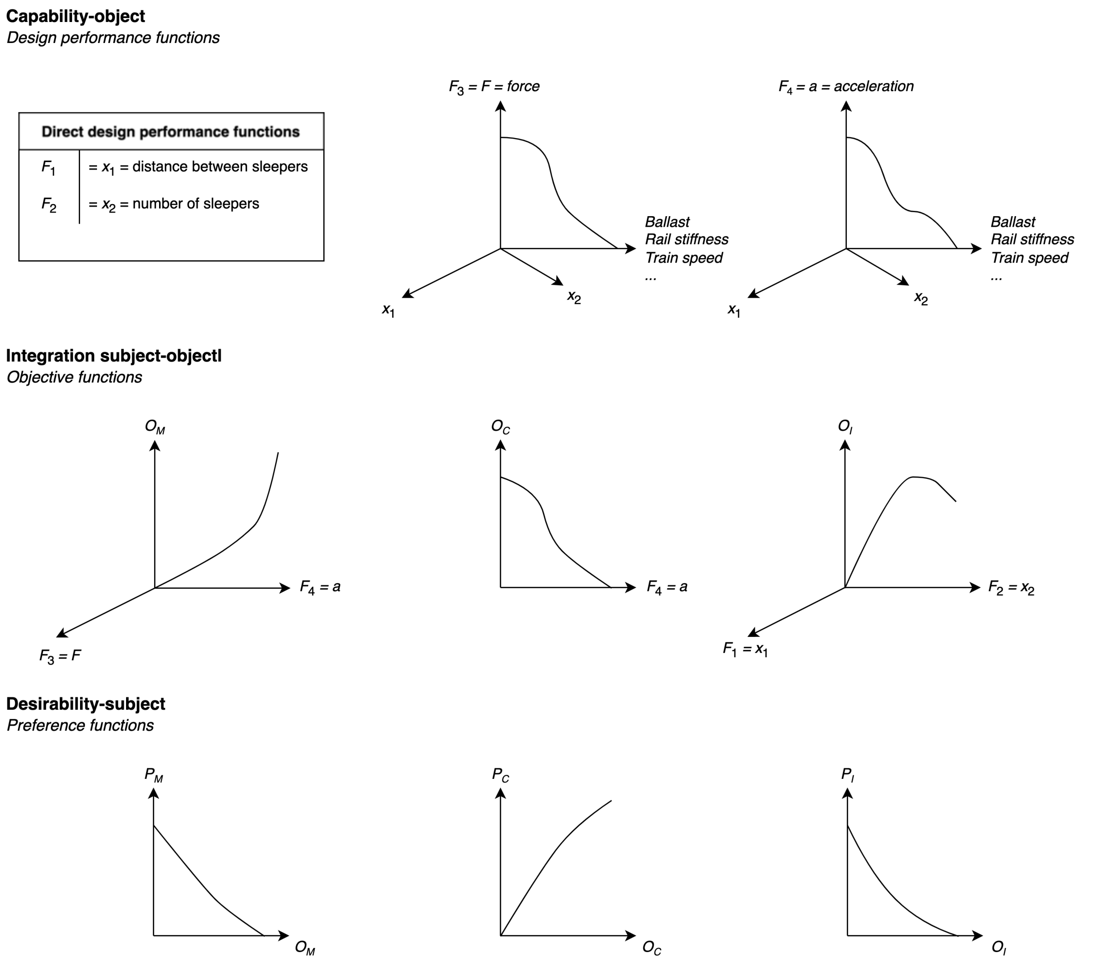


Figure 8.8: Conceptual threefold diagram, describing the systems design integration for the rail level-crossing design application. Note: the aim of this figure is to illustrate the relationship between the different functions and some curves may not represent the actual function.

that at least three alternatives are needed for such an overall evaluation (e.g. one reference configuration and two different MODO configurations).

Since there are only two design variables in this design application, we now plot the two-dimensional design space (sometimes referred to as solution space, see Dym & Little (2004)) containing the design points/configurations per optimisation method, see Figure 8.10.

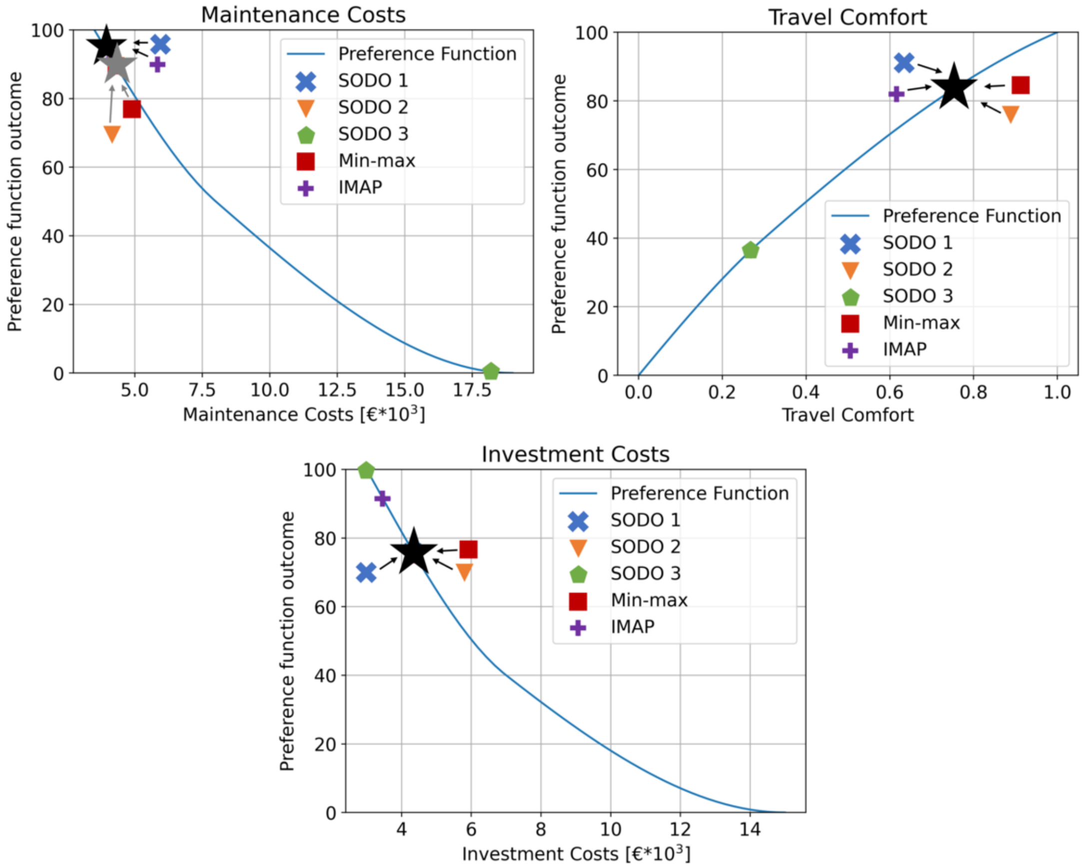


Figure 8.9: The three stakeholder preference functions ($P_{1..3,1..3}$) for different objectives ($O_{1..3}$) for the level-crossing design application, including the results of the different optimisations. The numerical results can be found in Table 8.10.

The following three conclusions can be drawn from these figures and table:

(#1) The IMAP configuration is either equal to or closest to the best result on all single objectives (the SODO configurations). Only for the single-objective investment costs, IMAP is second best, since it also aims to optimise the other two objectives O_M and O_C. For these objectives, a low sleeper spacing (x_1) is expected, while the number of sleepers (x_2) has a relatively small influence on the outcome of these objectives. For this design application in particular, and given the different objectives and associated stakeholder preferences, a low sleeper spacing (x_1) is expected to have a significant impact on objectives O_M and O_C, while the number of sleepers (x_2) will have a smaller impact. However, for objective O_I, the influence of x_2 will be significant, because for lower x_2 the investment costs decreases. Furthermore, the influence of x_1 on O_I is opposite to its influence on the other two objectives. Therefore, the design configuration that is optimised for

Table 8.10: Results of the objective functions ($O_{1..3}$) and the corresponding preference functions ($P_{1..3,1..3}$) of the level-crossing design application.

Optimisation methods	O_M [€]	$P_{1,M}$	O_C	$P_{2,C}$	O_I [€]	$P_{3,I}$
Single objective O_M (SODO1)	3942	94	0.75	83	4319	76
Single objective O_C (SODO2)	4297	90	0.76	84	4381	75
Single objective O_I (SODO3)	18243	0	0.27	36	3020	100
MODO Min-max	4305	90	0.76	84	4382	75
MODO IMAP	3974	94	0.75	83	3466	91

investment costs only is not representative. A MODO optimisation is expected to find the ideal balance for the sleeper spacing (x_1), at lowest investment costs with the number of sleepers on the lower bound (i.e., $x_2 = 4$). The result of the IMAP optimisation does indeed reflect this best fit-for-common-purpose balance. As a result, IMAP may be characterised as a pure synthesis multi-objective design method.
(#2) The IMAP configuration achieves better or equal individual preference function values ($P_{1..3,1..3}$) and, more importantly, much better overall scores than the MODO min-max method result. This is because, according to the Min-max principle, this method will not be able to outperform the one objective score that shows the maximum attainable minimum distance to 100 (i.e., the minimum dissatisfaction). Thus, the min-max method inherently produces a sub-optimal compromise design configuration which, depending on the specific input parameters, can at best perform as well as the synthesis IMAP method. This limits the applicability of the Min-max method as a real multi-objective design optimisation method.
(#3) From the design space figure it is seen that, perhaps counter-intuitively, both the SODO 1 and 2 and the MODO min-max results fall within the design space ($x_1; x_2$ equals 0.35/0.39 and 5 respectively) and that the MODO IMAP and SODO 3 results lie on the edge and in a corner point of the design space respectively. This is because the set of design points that fall within the design space are the result of optimising the 'technical' design performance only. In other words, this means

Table 8.11: Evaluation of different design configurations per optimisation method and their relative ranking (based on aggregated preference scores) for the level-crossing design application.

Optimisation methods	x_1 [m]	x_2	Aggregated preference score
Single objective O_M (SODO1)	0.39	5	84
Single objective O_C (SODO2)	0.35	5	81
Single objective O_I (SODO3)	0.70	4	0
MODO Min-max	0.35	5	81
MODO IMAP	0.38	4	100

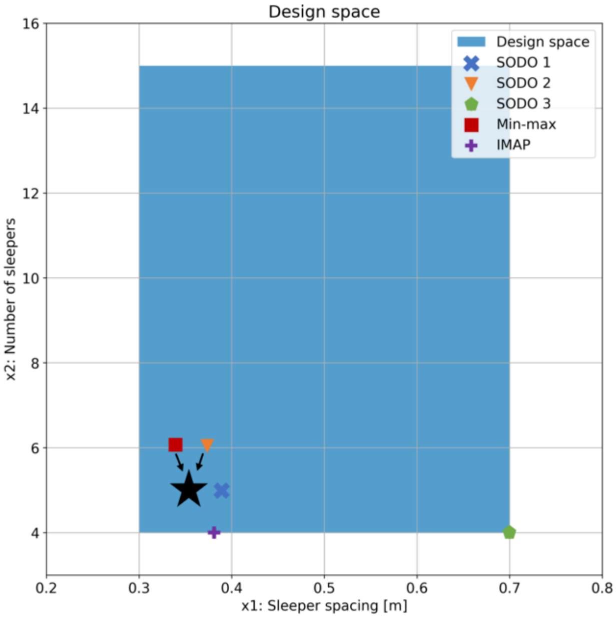


Figure 8.10: The design space of the level-crossing design application and the design configuration/points for the different optimisation methods. The numerical results can be found in Table 8.11.

that these optimal solutions move to an optimum only within the feasibility space (i.e., a solution space defined by the physical engineering variables only, and which is a subset of the design space) and lie on the 'classical' Pareto front. Note that in this case a possible Pareto front, which defines an edge of the feasibility space as a function of F and a, results only from the minimisation of O_M and O_C. Despite the fact that SODO 3 actually does find the edges of the design space (corner point), it still scores low overall because it is by far the lowest on the other two objectives (1 and 2). MODO IMAP gives the overall best design point on the edge of the design space (x_1 and/or x_2 equals 0.38 and/or 4 respectively), and can therefore be considered the pure best fit-for-common-purpose design point.

Note that when the emphasis in the design application is on optimising the integrated socio-technical problem, the overall best configuration will be found within and/or on the edge of the design space. When optimising solely on cost or technics, one can either end up at the classical Pareto front or in a corner point of the design space (see also the next design application in Section 8.5).

8.5. South Korean floating wind farm

Technical context: A promising solution for wind energy production in deep waters (e.g., within the Korea Strait which is a sea passage between South Korea and Japan, connecting the Yellow Sea and the Sea of Japan sea) could be the use of floating wind turbines (FWT). Rather than being placed on a fixed monopile, these turbines are placed on a platform moored to the seabed by anchors. The floating wind farm considered in this design application consists of 36 FWTs and 108 suction anchors (i.e., 3 anchors per FWT).

Social context: This application illustrates a MODO approach for the installation of multiple FWTs, taking into account several conflicting interests of multiple stakeholders: i.e., (1) project duration, (2) installation costs, (3) fleet utilisation, and (4) CO2 emissions. Given these four overall interests, an energy service provider (stakeholder one, e.g. Shell) requires a marine contractor (stakeholder two, e.g. Boskalis) to determine the optimal installation design plan. While cost remains a significant factor in the offshore industry, the energy service provider's primary concern lies in minimising delivery time to expedite resource income generation. Secondly, the energy service provider will have an interest in reducing the CO2 emissions of the project, as this will benefit its carbon footprint and the societal acceptance of the project. The marine contractor's primary focus will be on reducing the costs, as this will make it more competitive. Secondly, the fleet management department may express a preference for optimising fleet utilization to maximise operational efficiency.

We will first describe the integrative design problem by working through the Odesys threefold mathematical statement framework (Chapter 6, and Figure 8.11), resulting in design performance-, objective-, and preference functions.

Design performance functions

Several types of vessels are available for the installation of the FWTs and their suction anchors. The amounts of vessels used in the project are the initial three design variables:

1. $F_1 = x_1$ $(0 \leq x_1 \leq 3)$: small offshore construction vessels (OCV), capable of carrying up to 8 anchors.
2. $F_2 = x_2$ $(0 \leq x_2 \leq 2)$: large offshore construction vessels, capable of carrying up to 12 anchors.
3. $F_3 = x_2$ $(0 \leq x_2 \leq 2)$: self-propelled crane barges, capable of carrying up to 16 anchors.

Note that the lower bound of these three design variables is equal to zero. Therefore, a design performance constraint is required to ensure that the sum of all vessels on the project is greater than one (reflecting that at least one vessel is required):

$$g_1 = -(F_1 + F_2 + F_3) + 1 \leq 0 \tag{8.21}$$

This design application also considers the design of the anchors themselves. To do this, design performance functions are defined that describe: (1) the resistance of the anchor to the forces acting on it, and (2) the amplitude of the forces acting on the anchor. The resistance of the anchors considered in this design application can be estimated using analytical design calculations according to Arany(2018; Houlsby (2005); Randolph (2017). These calculations usually depend on several design variables, only two of which are considered here:

1. $F_4 = x_4(> 0)$: Diameter of the suction anchor in meters.
2. $F_5 = x_5(> 0)$: Penetration length of the suction anchor in meters.

For practical reasons, these variables are bounded by $1.5m \leq x_4 \leq 4m$ and $2m \leq x_5 \leq 8m$. The other design variables are uncontrollable variables $\mathbf{y}$ in this design application, where $\mathbf{y}$ = [working point F_a, mooring configuration, anchor type, soil conditions, mooring line properties]. Consequently, the anchor resistance can be mathematically formulated as $F_6 = R_a(x_4, x_5, \mathrm{y})$. The soil is assumed to be clay with an undrained shear strength of $s_u = 60$ kPa and a submerged weight of $\gamma' = 9\ kN/m^3$. The coefficient of friction between the anchor shaft and the soil is $\alpha = 0.64$. The mooring line consists entirely of a chain with a nominal diameter of 240 mm. This chain is attached to the anchor at a depth of 0.5 times the penetration length. Furthermore, the coefficient of friction between the seabed and the chain is taken as $\mu = 0.25$ and the active bearing area coefficient AWB = 2.5. While anchor resistance can be determined by analytical calculations, the forces acting on the anchor can not be determined in the same manner. This is due to their dependence on various variables such as platform type, mooring line characteristics, pre-tension, and/or anchor radius. To obtain accurate normative forces, numerous numerical time-domain calculations must be performed, as outlined in DNV (2021). These calculations are beyond the scope of this paper. Instead, the relevant design variables are considered as uncontrollable physical variables $\mathbf{y}$, resulting in the following (assumed) force on the anchors: $F_7 = F_a(\mathrm{y}) = 3.8MN$, where $\mathbf{y}$ = [platform type, mooring line characteristics, pre-tension, mooring line length, anchor radius].

The two design performance functions F_6 and F_7 are related through a design performance constraint. This constraint describes (part of) the feasibility space of the 'technical' design by defining the boundary where the resistance of the anchor is larger than or equal to the force on the anchor:

$$g_2 = F_7(\mathbf{y}) - F_6(x_4, x_5, \mathbf{y}) = F_a - R_a \leq 0 \tag{8.22}$$

Objective functions

As mentioned before, four objectives are investigated in this design application: project duration, installation costs, fleet utilisation, and CO_2 emissions. Given these four objectives, the optimal design plan for installing the FWTs is determined. The objective functions read as follows.

Project duration depends on the number of vessels involved in the project, their deck capacity and the speed at which they can install anchors, which is assumed to be one anchor/day/vessel. In addition, after all the anchors on board have been installed, the vessels will have to load new anchors. This process takes 1.5 days for the small OCV, 2 days for the large OCV, and 2.5 days for the barge. To obtain the overall project duration, a discrete event simulation (DES) was incorporated into the model, which depends on the type and number of vessels (i.e., $x_1..x_3$). See the data availability statement for the code of the DES. In conclusion, the objective function for the project duration can be expressed as follows:

$$O_{PD} = f(x_1, x_2, x_3) \tag{8.23}$$

where f is the DES and O_{PD} is expressed in days.

Installation costs of this project depends on two components: (a) the day rates of the vessels, and (b) the cost of the anchors. The following theoretical day rates R are assumed: (1) Small OCV (x_1): R_1 = €47,000/day; (2) Large OCV (x_2): R_2 = €55,000/day; (3) Barge (x_3): R_3 = €35,000/day.
The cost per anchor can be divided into a fixed part (€40,000/anchor) and a variable part, where the variable part depends on the material costs (€815/t). This results in the following objective cost function:

$$O_C = (815M_a + 40,000)n_a + \sum_{i=1}^{3} x_i t_i R_i \tag{8.24}$$

where O_C is expressed in EUR, n_a is the number of anchors (i.e., $n_a = 108$), t_i the time a vessel is needed (result from the DES), and M_a the mass of the anchors, which is defined as:

$$M_a = \left(\pi x_5 x_4 t + \frac{\pi}{4} x_4^2 t\right) W_{steel} \tag{8.25}$$

with W_{steel} is the weight of steel, assumed as 78.5 mt.

Fleet utilisation is a key driver for a maritime contractor and describes the extent to which its vessels are (optimally) utilized. Consequently, this objective focuses on evaluating the probability of a vessel being better utilized in another project (e.g. specialised vessels are preferred to multi-purpose vessels). For this purpose, the following values are assumed::

1. Small OCV (x_1): $p_1 = 0.7$
2. Large OCV (x_2): $p_2 = 0.8$
3. Barge (x_3): $p_3 = 0.5$

The fleet utilisation objective is then defined as:

$$O_F = \prod_{i=1}^{3} p_i^{x_i} \tag{8.26}$$

where O_F is expressed as the combined chance with a value between [0, 1].

CO_2 emissions is one of the sustainability aspects, and is becoming an increasingly important aspect within offshore (wind) project development. Most of the emissions will be generated by the vessels, for which the following theoretical average emission rates are assumed:

1. Small OCV (x_1): $E_1 = 30\ t/day$
2. Large OCV (x_2): $E_2 = 40\ t/day$
3. Barge (x_3): $E_3 = 35\ t/day$

As other sources of emissions are neglected, the emission objective is defined as:

$$O_S = \sum_{i=1}^{3} x_i E_i t_i \tag{8.27}$$

here O_S is expressed in t ('toness') and with t_i the time a vessel is needed (result from the DES).
Note that the Odesys mathematical statement allows for the direct integration of design performance and objective functions. However, in certain cases, design performance functions will not only directly link to the objective functions but can also connect through (in)equality design performance constraints. This indirect linking is common in design problems where, for example, force constraints play an important role. In such cases, these constraints define the feasibility space, and together with directly linked design performance functions, they span the design (solution) space.

Preference functions

The preference functions for this design application were developed with floating wind project experts within Boskalis, based on the input from an energy service provider. The four resulting functions, which describe the relations between different values for $P_{1..2,1..4}$ and $O_{1..4}$), are shown as blue curves in Table 8.12. Note that the preference function elicitation was again (like in the previous design application) performed using the fundamentals of PFM research by Arkesteijn et.al. (2017).

The systems design integration problem statement is now conceptualised with the threefold diagram shown in Figure 8.11.

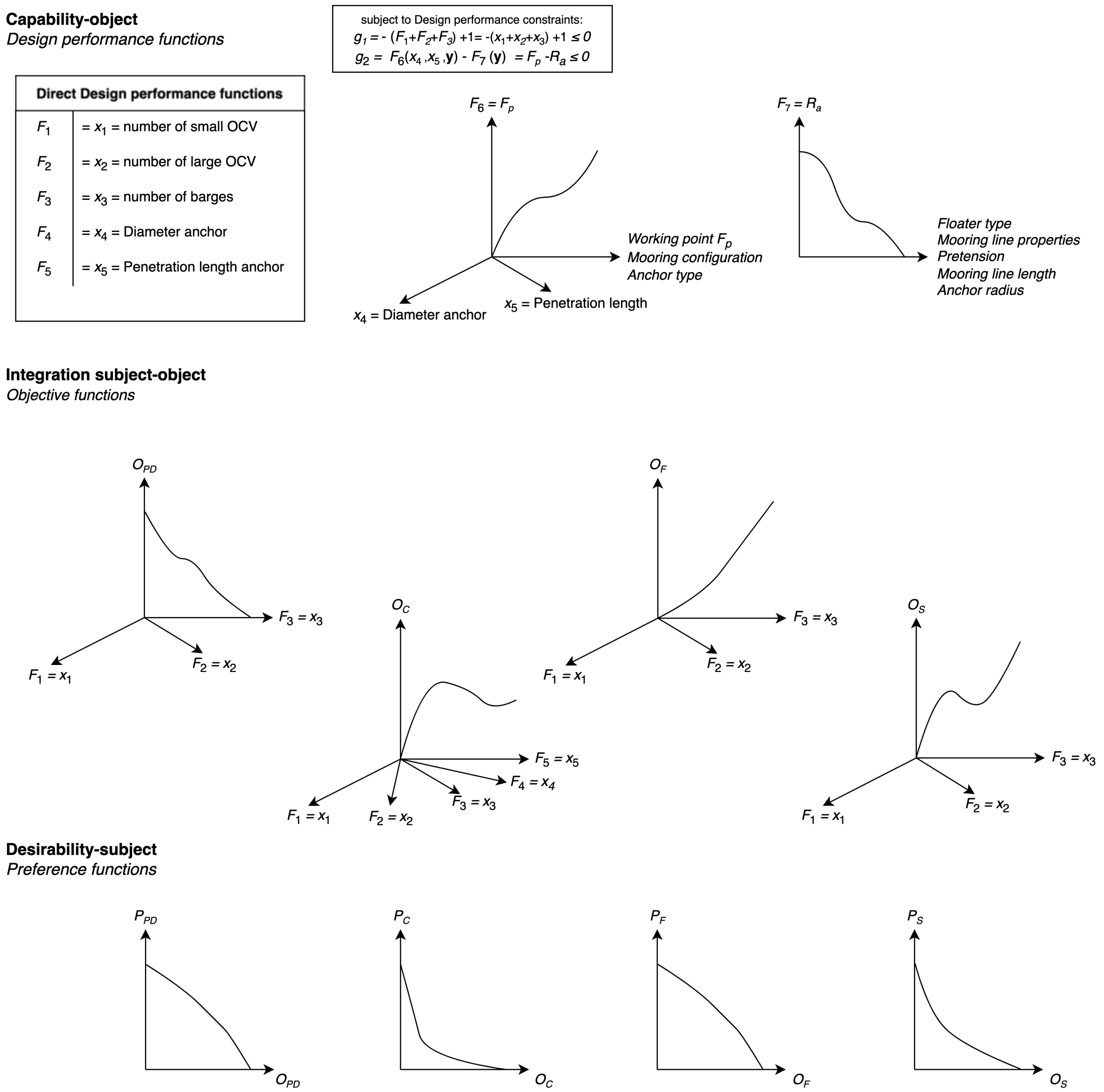


Figure 8.11: Conceptual threefold diagram, describing the systems design integration for the floating wind turbine design application. Note: the aim of this figure is to illustrate the relationship between the different functions and some curves may not represent the actual function.

Design optimisation results & conspection

To generate the design points (i.e., design configuration results) for the different multi-objective optimisation methods (MODO Min-max and IMAP), the weights for each objective must first be determined. Traditionally, installation costs have been the main driver for offshore projects and/or tender bids. However, with the introduction of the Odesys design optimisation methodology, it is now possible to optimise the design considering other relevant objectives that reflect the shared value of the installation plan for both the energy service provider and the contractor. The following weight distributions were chosen to model this joint plan: $w_{1,PD} = 0.30$ for project duration, $w_{1,S} = 0.20$ for sustainability (emissions), $w_{2,C} = 0.35$ for the installation costs, and $w_{2,F} = 0.15$ for fleet utilisation. For evaluation purposes, both the single-objective optimisation of O_C (SODO costs) and the MODO min-max optimisation design points are also determined. Note that the other SODOs (single-objective optimisations on O_{PD}, O_F, and O_S) cannot be included in the integral evaluation as they are not dependent on x_4 and x_5 (but only on $x_1..x_3$).

The outcomes of the different design points/configurations per optimisation method are first plotted in the different preference functions showing the different objective function values ($O_{1..4}$) and their corresponding individual preference function values ($P_{1..2,1..4}$), see Figure 8.12 and Table 8.12. Secondly, the numerical results of the different design points/configurations per optimisation method can be read from Table 8.13. In this table, one can also find the aggregated reference score, which was used to determine the overall score/ranking via the PFM-based MCDA tool Tetra (the resulting aggregated preference scores are re-scaled between scores of 0 and 100, where 0 reflects the 'worst' scoring configuration/alternative and 100 the 'best', see Appendix C for further details).

Table 8.12: Results of the objective functions ($O_{1..4}$) and the corresponding preference functions ($P_{1..4,1..4}$) of the floating wind design application.

Optimisation methods	O_{PD} [days]	$P_{1,PD}$	O_C [€]	$P_{2,C}$	O_F	$P_{2,F}$	O_S [t]	$P_{1,S}$
Single objective O_C (SODO costs)	110.5	5	9.96E6	69	0.50	60	3868	73
MODO Min-max	91	43	10.45E6	38	0.04	97	7135	15
MODO IMAP	72.5	70	10.47E6	37	0.35	74	3722	79

Table 8.13: Evaluation of different design configurations per optimisation method and their relative ranking (based on aggregated preference scores) for the floating wind design application.

Optimisation methods	x_1	x_2	x_3	x_4	x_5	Aggregated preference score
Single objective O_C (SODO costs)	0	0	1	2.2	8.0	69
MODO Min-max	1	0	2	2.2	8.0	0
MODO IMAP	1	0	1	2.2	8.0	100

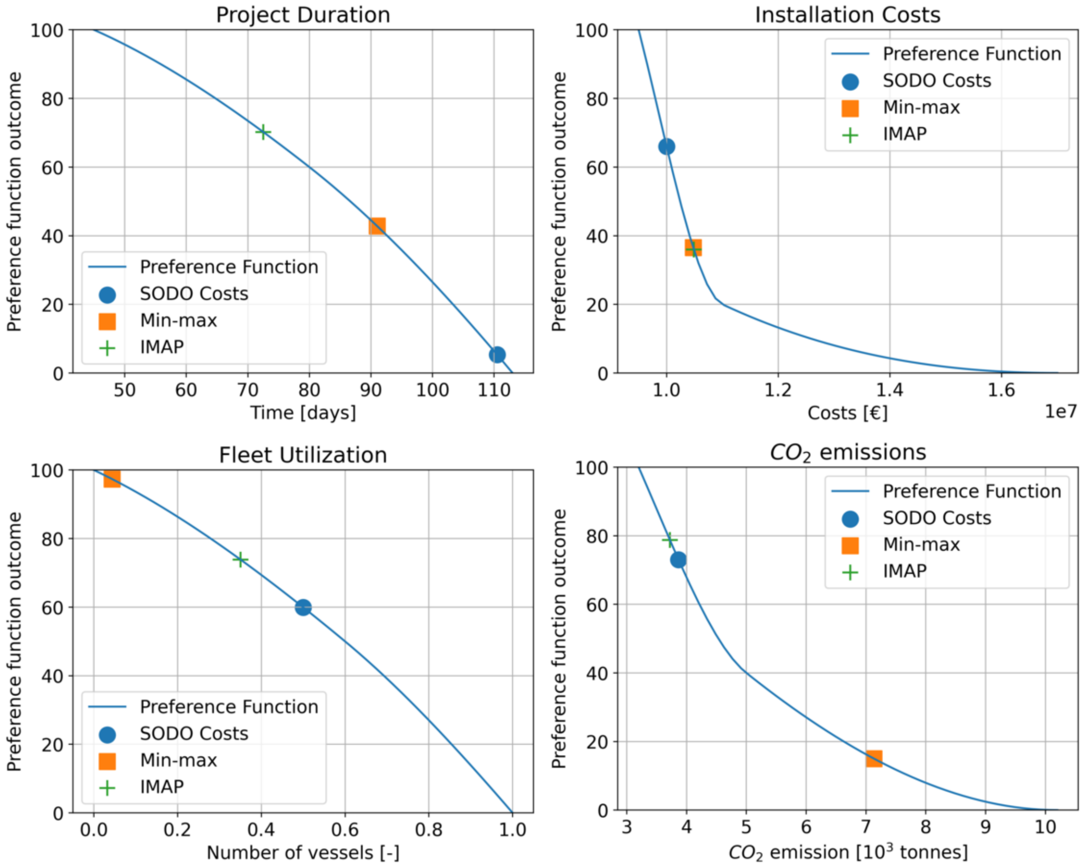


Figure 8.12: The four stakeholder preference functions ($P_{1..4,1..4}$) for different objectives ($O_{1..4}$) for the floating wind design application, including the results of the different optimisations. The numerical results can be found in Table 8.12.

The following three conclusions can be drawn from these figures and table:
(#1) Comparing the IMAP configuration with the SODO design point on installation costs, IMAP outperforms the SODO on three of the four objectives. This difference is most evident when the result of the project duration objective is compared with the result of the installation cost objective. These objectives are opposite by the impact of the number of vessels ($x_{1..3}$) on them. More vessels leads to faster project completion but higher costs. Therefore, a design configuration that scores well on cost will not score well on project duration, as can be seen for the SODO on installation costs. This result illustrates that considering only costs (single stakeholder and single objective approach) is not an accurate representation of real planning challenge. In contrast, IMAP demonstrates a balanced approach by considering multiple objectives, including both the technical design and economics.

(#2) he overall score of the IMAP configuration is substantially higher than that of the min-max method. As the min-max method tries to minimise the distance to a score of 100 for all different preference scores $P_{1..2,1..4}$, it can result in very low preference scores for conflicting objectives. In this design application, this is the case for the project duration (O_{PD}) and installation costs (O_C) objectives. As a result, the min-max solution scores low for these two objectives. This is in contrast with the IMAP design solution, which can find higher preference scores $P_{1..2,1..4}$ for these two objectives. The presence of these conflicting interests thus limits the applicability of the min-max method, as also shown in the first design application. Note that it can still perform well for a 'single' interest, as shown by the positive reflection of the fleet utilisation objective with the use of more barges.
(#3) Table 8.13 shows that all three solutions have the same result for design variables x_4 and x_5. This indicates that this particular combination of x_4 and x_5 yields the lowest anchor cost without violating the design performance constraint g_2. In other words, for all three methods, there would be no difference in the optimisation if limited to a purely technical optimisation within the feasibility space. However, the added value of IMAP is evident from the results for design variables x_1, x_2, and x_3, where IMAP can arrive at an overall better design solution than the other two methods by including both technical and vessel-related installation planning concerns. Note that also the best outcome within the feasibility space for x_4 and x_5 will change if objectives in the managerial (subject desirability) domain favour technical over dimensioning of the suction anchors. In such cases, the solution may be selected from the edge of the feasibility space (i.e., the Pareto front) as it offers greater benefits to the overall planning and design performance.

Part III

Educating the Odesys engineer

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Chapter 9

The art of Open Design Learning

In this chapter, we will first briefly revisit some parts of Chapter 2. We placed design in a broad scientific and technical context in that chapter. Here we add what this means for the real Odesys system integrator, introducing the Zeta (ζ) engineer and explaining their integrative position. From this positioning and from a comprehensive educational incitement following a number of key educators, we show the main founding principles and educational paradigms of the Open Design Learning concept (ODLc). Finally, we conclude this chapter with the open-ended ODL U-diagram. In this, students follow an open-ended design learning approach of three cycles (1) the technical - concept, (2) the social -context, and (3) the purpose - consign/conceive cycle respectively: an open-ended design learning metamorphosis integrating the open mind, heart, and will with an open design impulse as unifying result.

Note that these founding principles and the key elements of ODLc are summarised here in the form of a concise management summary. To place ODL in the current context of other educational concepts, reference is made to the education paper by Binnekamp, Wolfert et al. (2020) and/or the education section from the paper by Wolfert et. al (2022). Finally, it is noted that ODLc is not a method but a learning concept in itself. It is therefore not an instruction, but a concept with constructivist learning principles which you have to live and do yourself. This chapter assumes that the basic principles and concepts from Chapters 1, 2, 3, and 4 are known, as we continue to work with them (such as Odesys' paradigms & views on world and man, theory U and the different U-diagrams, and the (extended) 4-Quadrants models).

Incitement 9.1 Learn to learn and do not be afraid of the future dark

As a recently graduated civil engineer, I had a talk with the CTO on my first working day at Deutsche Telekom (DT), an ICT service provider. Being a promising new DT 'trainee', he had invited me to join him. He explained to me that we needed to develop a new build and roll-out concept in which a new so-called 'network-sharing' concept was a major cost driver for DT. He was confident that we would be able to manage this concept technically. At the moment, however, we did not have approval from the licensing authority OPTA to roll out the network sharing concept. He had just had a meeting with them and the OPTA asked for a reasoned case for the network sharing concept in which not only cost savings were the driver, but also the benefits for the users, the 'civilians', and the living environment. Given my background in civil engineering, this 'civilian' assignment seemed a good fit for me. In addition, he handed me a stack of documents that, coincidentally, I couldn't transport all at once to my workspace. Furthermore, he requested me to create a poster that we could bring to the upcoming OPTA meeting, scheduled to occur within the next week or two.

This was my response: "Although I am a civil engineer, I have never heard of licensing and legal-technical matters." I asked him: "Do you have any 'old' mock exams within DT to qualify me in this field? And, do you perhaps have a sample elaboration of this and or a similar problem that you earlier solved? And lastly, what should the poster look like, what is the format and do you have a list of what should be on that poster?"

The CTO replied: "We actually just hired you to work on this problem, or on other problems that have not yet been solved. I expect you to come and 'educate us' and surprise us with solutions that we just don't know yet ourselves." Moreover, he stated: "It seems that you are being unlearned and that you are afraid to push yourself into new domain and solve unknown problems. In any case, I hope you have confidence to find your way, and you know my door is always open for co-creation. And by the way, don't worry too much yet about the underlying modeling in detail, we can always send these after. It is about the bigger picture first." Finally, he said: "A civil engineer should be able to work especially for and with civilians, not just only from and with civil technics, shouldn't he?" "Think about that again", he advised me and I started my way into the future dark.

9.1. Positioning the Odesys engineer

In Chapter 2 we have distinguished between the natural or Beta (β) domain and the social or Gamma (γ) domain, providing a distinction between scientific research and engineering development. This allowed us to define a research and development framework containing four types of empirical R&D domains, see the 4-Quadrant model in Figure 9.1.

Having made these distinctions, we can now position what we call the Odesys (open design systems) or Zeta (ζ) engineer: a real systems integrator. Note that the Zeta (ζ) is the symbol of integration as it signifies the integration of multiple domains. Here the top part of the symbol signifies the broadening of the management domain and the bottom represents the anchoring in the technical domain ('hook in the ground').

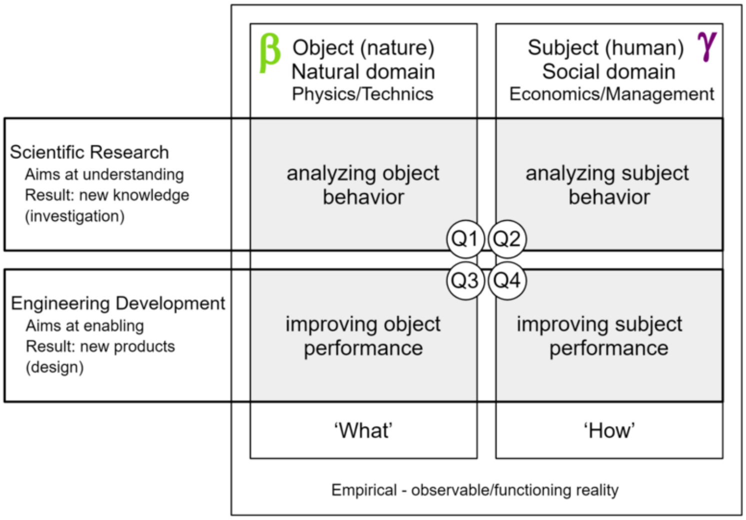


Figure 9.1: The 4-Quadrant model with the distinction of the β and γ domains

Let us now look closer at the activities of the Odesys engineer, a ζ professional within the empirical R&D fields. Although the open design systems engineer operates mainly in Q3 and Q4, there is a need for integrating the other quadrants. Namely, to solve design/decision problems the ζ engineer makes use of the body of knowledge of the natural and social sciences. Think of the laws of physics, the output of (lab) experiments, preference function modeling and measurement theory, the output of the statistical analysis of interviews, etc.. This serves as one of the contextual starting points for the ζ engineer. However, because the ζ engineer at technical universities is also schooled in the engineering domain, they have an advantage over those who are only schooled in business management schools that focus primarily on social science (Q2). Figure 9.2 illustrates how we position the open design ζ engineer within the empirical R&D context.

Let us now zoom out to the activities of the Odesys engineer, a ζ professional within the broader context of the spiritual mind and the physical matter. To do this, we must first recall the essence of design. Design means (in a non-artistic sense) a plan or scheme in the mind (inner) for a potential realisation in the observed world (outer). Design is a process of concretization within the synergetic context of mind, matter, subject, and object that unites the open design impulse (see Chapters 1 and 2). Designing to best fit for common purpose is also a U-process which moves from an open configuration (mind-imagination) through an open space (heart-inspiration) to the open source. The process then moves in the opposite and 'renewed' direction to an action of response, through an inner (will-intuition) and model (will-deliberation) dialogue (see Chapters 4 and 6). This is a process of U-ncovering the common will resulting in a realisation of a prototype configuration (see Chapters 3 and 4).

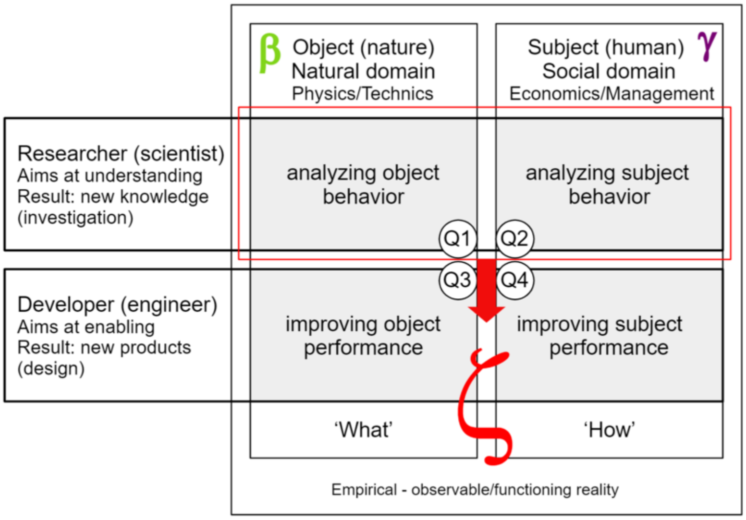


Figure 9.2: The position of the Odesys ζ engineer, mainly positioned in Q3/4, gathering knowledge from Q1/2.

In addition, we have seen that the final outcome of a design is that artefact which, given its specific desirabilities and capabilities, is best-fitting. However, this artefact is certainly not the one and only fitting 'socio-technical construct', which can lead to a possibly different outcome somewhere else in another place in another time (see Chapters 2 and 4). Last but not least, the open designer should at all times realise that his creation of the mind has a moral impact to open 'doors' for the future (see Chapter 2). In summary, this means that the open design ζ engineer is more than just an integral designer, but is a true ζ professional which must be able to 'navigate' integratively ('synergetically') in the con-scientific (holistic) fields of empiricism, spiritualism/art, constructivism, and rationalism/formal logicism. Figure 9.3 illustrates how we position the open design ζ engineer within this extended con-science context (via the extended 4-Quadrant model of Chapter 2). Note that the process of inner dialogue/ meditation makes just that difference between computer logics and applied mathematics, the difference between AI and art (see Chapter 2). The ζ professional needs both logics (computer model) and real-life mathematical modeling (reflective/meditative dialogue) to come from mind toward matter.

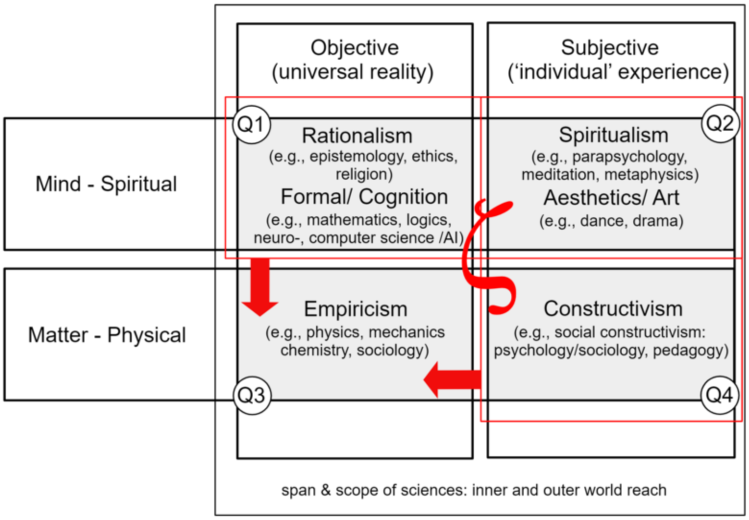


Figure 9.3: The position of the Odesys ζ engineer, integrating subjective Q2/Q4 supported by objective Q1 into the socio-technical design.

Now that we have positioned the Odesys engineer as a genuine ζ systems integrator ('synergeticor'), we must establish a learning concept that ensures that the aforementioned integrations can be achieved as much as possible. Important principles will therefore be constructivist, formal logical, inner-outer dialogical, experiential, and observational characteristics. To lead the way for ζ engineers, we have developed an open design learning concept (ODLc) that supports the Odesys education. Why? Because we observed that today's education is often based on existing static and past (research) knowledge transfer, where teachers instruct what students have to think. Alternative thought pathways are closed and students are funnelled towards using single solutions derived from past problems rather than opening them so that they are prepared to solve future multi-faceted problems. Teachers or 'instructors' mostly do believe that they are empowered to only fill the inner of their students with known facts and procedures to understand existing situations. We believe that education should also work outwards to create solutions from and for our societal challenges and aims. Educators should therefore not simply be teachers, but developers or 'constructors', people who do incite, co-create, and learn to learn by designing within a real-life context. For this purpose we devised the ODL concept (ODLc) that is fully congruent with aforementioned ζ principles. ODLc truly unlocks and integrates/synergizes the inner ego and the outer eco along the U-model, as described in the next sections.

Incitement 9.2 'Steiner Waldorf education in Silicon Valley – a preparation for life?'

"Why Are Silicon Valley Executives Sending Their Kids to a Tech-Free School? Parents employed by Google and Apple are sending their kids to computer-free Steiner Waldorf schools. Are they on the right track?"

You'd think executives at Silicon Valley's top tech firms would be keen to enrol their children in schools chock-full of the latest education technology: one-to-one laptops, iPad programs, digital textbooks, and teachers engaging students using Twitter. But according to The New York Times, some Silicon Valley parents are doing a 180 and sending their kids to the area's decidedly low-tech Steiner Waldorf school. Waldorf's computer-free campuses are a sharp contrast from most schools, where access to technology is seen as key to getting kids college- and career-ready. Instead you'll find plenty of play-based learning and storytelling.

While that may sound out of place at a time when moms brag about their 3-year-olds' abilities to operate iPads, there's an appeal to Waldorf schools' philosophy that students should "experience" literature, math, and science—along with visual and performing arts—in a developmentally appropriate way. The tech-free teaching methods are designed to foster a lifelong love of learning and teach students how to concentrate deeply and master human interaction, critical thinking, creativity, and problem-solving skills. Indeed, through knitting socks, Waldorf students pick up math and patterning skills, and they come out of it with something beyond a standardized test score to show for their effort."

The Steiner Waldorf approach to education is both innovative and insightful (more than 1200 schools in more than 60 countries worldwide). Students are well-balanced as individuals and develop a general enthusiasm for learning, whatever the context might be. With over a hundred years of experience to draw on, the education is well-proven and central themes of innovation and enquiry ensure that it remains at the forefront of contemporary education in a fast-changing world. It enables students to mature in a balanced way; innovative and rigorous academic education is combined with the development of impressive human qualities. These human qualities promote purposeful engagement and, more than anything else, they ensure that our pupils take up meaningful and fulfilling roles that contribute in a positive way to our rapidly-unfolding future. It's all about igniting the flame rather than filling the barrel. The Steiner Waldorf educator addresses the whole child and each lesson integrates academic work with fine arts and practical skills, so that a child is not only intellectually engaged, but also emotionally and aesthetically invested in their learning. By addressing intellectual capacities (thinking), artistic and emotional capacities (feeling), and practical skill-building capacities (willing), the Steiner Waldorf curriculum brings key attributes of the human being into balance. The Steiner Waldorf schools develop analytical, logical and reasoning skills as education has always done, but also fosters social skills, cooperation, imagination, inspiration, intuition, creativity, and flexible systems-thinking.

We conclude with some typical Steiner Waldorf educational quotes:

...'What matters to us is how you learn something to the student, not what you learn to the student.'

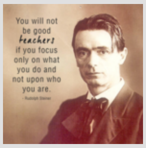
...'You get to know things in their genuine reality only when you can relate to them in the real world.'

...'To come to yourself you must look out into the world together.'

...'It is important that we should discover an educational method where people learn to learn, and go on learning from life their whole life long. There is nothing in life from which

we cannot learn.'
...'Education can be a force for social change.'
...'Knowledge is power, that prescribes (normative). Wisdom is love, that lets free (exploratory).'
...'Not everything that counts can be counted.'
...'Luminosity (clarity) in thinking, engagement (compassion) in feeling and warmth (conductive) in the will, this is how man comes enthusiastic in being.' (compare these with the 'daily' sayings like: shining a light on something; I am warming up to the idea; that's close to my heart; having a warm heart for the matter; that's a real light-bulb moment).'

See also: waldorfeducation.org or waldorftoday.com or amexpas.net/articulos/a-silicon-valley-school-that-doesnt-compute



9.2. Open Design Learning (ODL) concept

The ODLc may actually deserve an independent book given its importance and impact on young people who use education to lay their foundations and build their future ("he who has the youth has the future"). However, that is not the focus of this book (that is the new design methodology Odesys). Nevertheless, to give ODL some place here, we will first summarise the basic founding principles of the ODL concept following from some inspirators and/or educators in the form of an extensive incitement. A conscious decision was made, as in the ODL concept itself, to work from an incitement and let it be a basis for the main components of the ODL concept (rather than an entirely bottom-up narrative). Indeed, the incitements of these great educators and a few of their short quotes: Ackoff (2008); Argyris & Schön (1987, 1996); Aristotle (1985); Biesta (2014); Buber (2004); Hamelink (2015); Heusser (2022); Hoffmann (2020); Katz (2011); Palmer & Zajonc (2010); Robinson (2011); Schieren (2012, 2023); Steiner (1995,1996); Wiechert (2012), and some well-known names without references form the basis for ODL. Note that the order of the incitements is not educator alphabetical, but aims to line up various terms and concepts that are printed in bold and italics in the text. These terms will be used later in the nine basic ODL foundations. Before we start with these nine foundations, we provide a general summary of the concept (followed by the extensive incitement which is partly the design basis for the ODLc).

ODLc is both a constructivist and a design and systems thinking-based learning approach ("learn to design by real-life designing"), where students actively develop new solutions originating from their inner and outer designs. It goes beyond research and inquiry based learning concepts such as experiential and/or organizational learning, see Binnekamp, Wolfert et al. (2020). ODL integrates the human learning & development process, viewed from the general human (threefold) principles. It forms the fundamental basis for creating open, integrative and persistent learners concerned about solving future world problems.

The ODL concept is an innovative educational concept for higher education. It is a reflective, creative, and engaged learning approach that opens human development and U-nlocks new knowledge and solutions. The ODL concept stimulates students' curiosity, clarity, and creativity. ODL constructors 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. 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. We argue that only a living and reflective dialogue with luminosity in the mind, intimacy in the heart, and warmth in the will can conceive openings for the challenges from tomorrow.

ODL students learn and design a self-chosen system of interest (SoI), as opposed to a given and predefined casus that has already been solved by the teachers (such as in most of the traditional experiential education concepts such as PBL/CBL/CDIO). They follow ODL U-model as the basis for the design learning process to arrive at an original ODL response demonstrating their unique individual achievements. In other words, students follow an open-ended design learning approach of three cycles (1) the technical - concept, (2) the social -context, and (3) the purpose – source (consign/conceive) cycle respectively: an open-ended design learning metamorphosis integrating the open mind, heart, and will.

The ODL concept has been developed and applied over the last 10 years. It has found its way into several MSc curricula within TU Delft. The number of the participating students varied between 25 - 350 students per course in different topics (engineering asset management, engineering projects management, construction management systems, information systems, systems engineering design, R&D methodology, and innovation management).

ODLc can be seen as a thorough extension of Steiner Waldorf education for Master students within the age of 21+ (so far this education concept has only been developed for students under 18-21).

Incitement 9.3 'Open Design Learning, the art of education'

Gert Biesta: "We cannot understand education as a powerful, production-like process, but only as a weak, ***existential*** process. He shows that we must set goals in education more broadly than just measurable yields and outcomes, and argues in unsurpassed fashion that if education is to succeed, it cannot be enforced by anyone.. Today, education is mostly knowledge-driven and must effectively and efficiently contribute to the knowledge economy. Two entirely different goals are often overlooked: ***socialization*** and personal development or '***Bildung***'. Education is sinking into 'learnification' and is no longer a free place for ***critical thinking*** about developments in society.. Education is a form of co-creation. Creating what is not yet there. Making yourself ***vulnerable*** by showing that you too do not know everything but dare to explore and create the new: a beautiful ***risk***."

Nigel Hoffmann: "Concern for the world today provides the impetus to ask of ourselves a profound question. how can our way of knowing, the very style of our ***thinking*** which informs our research and our teaching, come to express care, to reveal itself to be a deed and duty of care?' Basing this practical study on the human quality of care for the world around us, Hoffmann takes us to a threshold beyond which lies a true science of living form. ***Care***, he says, springs from the ***whole human being*** - the thinking, heart and will - and is implicit in the scientific method of conscious inner participation in nature that derives from the work of the poet and scientist Goethe. The Goethean approach - a living form that unites science and ***art*** - is not an alternative to contemporary science but complements it."

Peter Heusser: "Thinking is a pure activity of the will and identical to the activity of the ***artist ('designer')***. When thinking wants to be experienced one speaks of artistry ('design'). In reality, thinking is not just "passive" thinking, but actively working ***thinking*** and also ***feeling and willing***. Willing is an activity, activity and productivity Feeling is a connection, devotion and receptivity. And, thinking is the ideal perception of thought-content. Therefore, in thinking the whole person, including the willing (productive) and feeling (receptive) person is present. Consequently, a state of artfulness arises in the thinking man at the same time. ... Only teachers and educators who acquire skills in these fundamentals of artistic (design-based) thinking are able to awaken in their pupils and students the desire to develop such skills themselves. Heusser argues that only in this way can one bring about the necessary transformation in educational (and scientific) culture."

Rudolf Steiner (1): "We must conceive of pedagogy not as a theory, not something that can be learned, but as an ability of the teacher or lecturer to develop by strengthening his living ***artistic ('design'***) mind itself in a living humanity and in ***pure thinking***... Our task in our method of education is always to consider the ***whole human being***. We could not do this if we did not focus our attention on the formation of the artistic (design) sense in human disposition. By doing so we will also make man inclined for later to take an interest in the whole world with his whole being. All educational methodologies must be immersed in the artistic. Educating and teaching must become a true art ('an art of design education'). Knowledge should be only the basis there too... When you look at the ***whole human life***, not just childhood, it becomes clear for the first time what a central significance in the whole human life education actually has, how often happiness/ luck or unhappiness/ unluck in terms of the spiritual, psychological and physical are related to education..When those who want to become teachers or educators are examined today, they mainly look at what they have gained in terms of knowledge, which is actually quite superfluous. After all, what they need for teaching, they can always reread in a suitable book or on an internet site when preparing. After all, what one has learnt for the exam is soon forgotten afterwards anyway. Exams are just a comedy in life. Real education is ***learning to learn*** a life long."

Rudolf Steiner (2): "A ***curriculum*** should be an ***echo*** of ***humanities***. You relate everything you see in the world to what you see in humans . Our highest endeavour must be to develop free human beings who are able of themselves to impart purpose and direction to their lives. The ***need for imagination***, a sense of truth, and a feeling of responsibility—these three forces are the very nerve of education. We are fully human only while playing, and we ***play*** only when we are human in the truest sense of the word... Intuition is for thinking what observation is for perception. ***Intuition and observation*** are the sources of our knowledge... Our highest endeavour must be to ***develop*** individuals who are able out of their own initiative to impart purpose & direction to their lives... ***Reverence***, ***enthusiasm*** and a ***sense of care***, these three are actually the panacea, the magic remedy, in the soul of the educator."

Pablo Picasso: "Everything you can ***imagine*** is real... ***Inspiration*** exists, but it has to find you working... Every child is an ***artist***. The problem is how to remain an artist once he grows up."

Parker Palmer & Arthur Zajonc: "We propose an approach to teaching and learning that honors the ***whole human being*** – mind, heart, and spirit – an essential integration. Whoever may be, whatever the subject we teach, ultimately we teach who we are.Good teaching cannot be reduced to simply a technique, good teaching comes from the ***identity and integrity*** of the teacher... The educator is a person who has the possibility through destiny to know the people, to recognize their capacities, and to bring them to ***bear on the problem***."

Russell Ackoff (1): "Except for practices that incorporate ***design*** as the way they practice, the art of design is not incorporated into students' experiences in schools, despite its superiority in many situations, even to such analytical problem solving as scientists employ. The power of design as an instrument of learning is almost completely overlooked by the educational system. For example, the best way to learn how an automobile works and to gain understanding of why it works the way it does is to design one. Moreover, it is in design that people learn what they want... Reality consists of sets of interacting problems, systems of problems we call 'messes'. As previously noted, problems are abstractions extracted from reality by analysis. Therefore, education for practice should develop and apply methodology for dealing holistically with ***systems of problems***. Because messes are complex, this requires an ability to cope with complexity. It is much easier to deal with complexity through design in practice than in dealing with it academically in a classroom or research facility. The theory of ***complexity*** is not required for dealing with complexity in practice; design can handle it... Those involved in the redesign process must know what they would do if they could do whatever they wanted. Such knowledge is essential if they are to set meaningful goals for the future. The outcome of such a design is idealized in the sense that the resulting system is ***ideal seeking***, not ideal. It should be subject to continuous improvement with further experience and changing environments. The only certainty is that some of whatever we think we will want five or ten years from now will not be wanted then. Such a vision should be inspiring, a ***work of art***... Scientists are searching for a way of dealing effectively with such ***complexity***. Unfortunately, most of them are approaching the subject analytically. The result is identification of such a large number of variables and relationships between them that we are not able to handle them. However, if complexity is approached ***synthetically***, ***by design***, there seems to be no limit to the complexity we can handle effectively."

Russell Ackoff (2): "All through school, we are shown that making a mistake is a bad thing, something for which we are downgraded. This reveals how little conventional schools are interested in learning, because we ***never learn by doing something right***; we already know how to do it. Doing it right does confirm what we already know, and this has some value, but it contributes nothing to learning into the future... ***Exams*** do not assess anything significant to the future of children, because no one knows how to assess or measure the key factors to the future success of any person. They are a ***closed system***; tests exist for their own sake. They measure the ability of the entire school community—children, parents, teachers, administrators—to focus all their efforts on producing good results on ***tests***! Nothing more, nothing less."

Russell Ackoff (3): "The objective of education is ***learning***, not teaching. The ideal school is a school where there is no teaching but a lot of learning...One might wonder how on earth learning came to be seen primarily a result of teaching. Until quite recently, the world's great teachers were understood to be people who had something fresh to say about something to people who were ***interested*** in hearing their message. Moses, Socrates, Aristotle, Plato, Jesus, Steiner etc.—these were people who had original insights, and people came from far and wide to find out what those insights were. One can see most clearly in Plato's ***dialogues*** that people did not come to Socrates to "learn philosophy," but rather to hear Socrates' version of philosophy, just as they went to other philosophers to hear (and learn) their versions. In other words, teaching was understood as public exposure of an individual's perspective, which anyone could take or leave, depending on whether they cared about it. No one in his right mind thought that the only way you could become a philosopher was by taking a course from one of those guys. On the contrary, you were expected to come up with your own original worldview if you aspired to the title of philosopher... The educational environment of students should ***encourage*** them to continue to explore the ***open-ended connections*** between their experiences, and to be receptive to new interconnections and interpretations of theories and explanations that they have either learned or developed."

Ken Robinson: "Our task is to educate our students ***whole being*** so they can face the ***future***. We may not see the future, but they will and our job is to help them make something of it. ***Creativity*** now is as important in education as literacy, and we should treat it with the same status. Imagination is the source of all human achievement. Too many people never ***connect*** with their true talents and therefore don't know what they are capable of achieving..We have to go from what is essentially an industrial model of education, a manufacturing model, which is based on linearity and conformity and batching people. We have to move to a model that is based more on principles of agriculture. We have to recognize that human flourishing is ***not a mechanical*** process; it's an ***organic*** process. And you cannot predict the outcome of human development. All you can do, like a farmer, is ***create the conditions*** under which they will begin to flourish. Learning happens in the minds and souls, not in the databases of multiple-choice tests... Teaching for creativity involves teaching creatively. There are three related tasks in teaching for creativity: encouraging, identifying and fostering..To improve our schools, we have to humanize them and make education personal to every student and teacher in the system. Education is always about ***contextual relationships***. Great teachers are not just instructors and test administrators: They are mentors, constructors, motivators, and lifelong sources of inspiration to their students. Do schools kill creativity? Everyone is born a genius but mainstream education kills ***creativity***."

Chris Argyris & Donald Schön: "Complexity, instability, and uncertainty are not removed or resolved by applying specialized knowledge to well-defined tasks. If anything, the effective use of specialized knowledge depends on a prior restructuring of situations that are complex and uncertain. An ***artful practice*** of the unique case appears anomalous when professional competence is modelled in terms of application of established techniques to recurrent events. Problem setting has no place in a body of professional knowledge concerned exclusively with ***problem solving***... We are in need of inquiry into the epistemology of practice. What is the kind of knowing in which ***competent practitioners*** engage? How is professional knowing like and unlike the kinds of knowledge presented in academic textbooks, scientific papers, and learned journals? In what sense, if any, is there intellectual rigor in professional practice? ***Reflective practice*** is the ability to reflect on one's actions so as to engage in a process of continuous learning from real life experiences.. Most people define learning too narrowly as mere 'problem-solving', so they focus on identifying and correcting errors in the ***external environment only***. Solving problems is important. But if learning is to persist, managers and employees must ***also look inward***. The need to reflect critically on their own behaviour, identify the ways they often inadvertently contribute to the organisation's problems, and then change how they act.. Individual learning is a necessary but insufficient condition for ***contextual*** learning."

Herbert Simon: "We can conclude that, in large part, the ***proper study of mankind*** is the science of design, not only as the professional component of a technical education but as a core discipline for every ***liberally*** educated person."

Jost Schieren: "Steiner Waldorf Education: An all-round, balanced approach to education that is equally concerned with intellectual-cognitive and artistic-creative learning. A practice- and experience-based pedagogy. An alternative education that has been successfully practiced for over a century. Recent scientific inquiry into Steiner Waldorf Education is breaking new ground, casting light on its fascinating ***humanistic ideal and wholistic potential***...Since the beginnings of Western thought, there have been broad discussions in philosophy, psychology, and pedagogy, on the issue of the learning process and its significance for the human being. Within the Steiner Waldorf education concept some core aspects of learning are ***transformation, knowledge & capabilities, holistic orientation, truth, freedom and purpose***. The learning concept of Waldorf education is based in Steiner's epistemology. In his early philosophical writings, Steiner took a basic epistemological position in regard to man's relationship with reality. He distances himself from a naïve-realistic notion of reality that takes the world phenomena as given and attributes ***purely reflective*** mirroring functions to human cognitive processes. It is the human natural constitution (mind and matter) of increased ability in man's encounter, interplay, or dialogue with the world. The learning environment created by arranging an internship, a synergist practice, is an essential determinant of the learning and development process.An essential core of Steiner's thought is the perspective of a capacity for freedom of the human being. He outlines a view of man that leaves development ***open-ended*** and contains the ethos of ***individual freedom***. This is in contrast to contemporary historical-pedagogical anthropology, which rejects any form of an authoritative view of man."

Christof Wiechert & Jacques Meulman: "Teaching is a ***dialogic*** process, where dialogue can be multidimensional. Show the world as image not as an understanding. Learning is ***bottom-up***, we nurture will and action, which they can feel and which awakens the intellect. Learning is also ***top-down***, we incite the intellect, to which they connect and which warms the will... Education is the integration of knowing and being able to... Learning is not linear but ***pulsing*** (a periodic process)... Education must move either from one-sided knowledge ('kennis') or only skills ('kunde') toward arts ('kunst'), and/or design, because arts ***integrate*** knowledge and skill with the "***heart***," the social human context... Light in mind ('sheds new light on the matter'), warmth in the will ('getting warmed up about doing something') and love from the heart ('having a heart for the matter', 'it is contagious', 'enthusiastic and emotion'). Not knowledge is power (past) , but wisdom is love and art (design) is future... Not all that **counts** can be counted... Education should be so ***vivid*** that a test is no longer needed. A final open project instead of a final closed test."

Martin Buber: "Human life and humanity come into being in genuine encounters. The hope for this hour depends upon the renewal of the immediacy of a ***living dialogue*** among human beings. When two people relate to each other authentically and humanly, 'spiritual electricity' surges between them.The real struggle is not between East and West, or capitalism and communism, but between education and normative propaganda. There are ***three principles*** in a man's being and life: the principle of thought, the principle of speech, and the principle of action. The origin of all conflict between me and my fellow-men is that I do not say what I mean or think, and I do not do what I say: a open-minded dialogue with action of response."

Joseph Beuys: "There is an artist (designer) in every person. Every human being is an artist (designer), a freedom being, called to participate in transforming and reshaping the conditions, thinking and structures that shape and inform our lives. To make people free is the aim of art, therefore ***art or design*** for me is the science of freedom..For instance, in places like universities, where everyone speaks so rationally, it is necessary for a kind of ***enchanter*** (magic or spell) to appear."

Cees Hamelink: "He argues for re-enchantment at universities. After all, a scientific theory that gives insight into a wondrous reality is certainly enchanting. By accepting that wondrous reality, however, we should sometimes also ***dare*** to say, "I don't know (yet)." But for that, we often lack ***courage***... To understand the soul of world and solve the complicated problems of today's society, we need enchanters. That is why we need people who encourage us to create art unabashedly and 'chant' in the classrooms, full of ***enchanted stories and incitements***. Even as an educator, you should want to remain continuously enchanted just as, for example, Einstein was. He said, 'I can explain a storm physically very well but a storm was at the same time a religious experience for him because in the storm he had the experience of being part of a much larger universe'...He advocates ***Amor Mundi*** as Hannah Arendt described it earlier: feeling at home in the world and dealing with it and learning from it without hesitation. Dare to love the world. Dare to take responsibility for a world that is bigger than people alone and includes everything that lives in the world, more than a world of passive, producible and inanimate objects... This is what we should already start with in education, teach students to feel at one with the earth, nature and the ***experiential context*** around them... It is important to teaching '***compassionate communication***' to students and others."

Aristotle: "Within universal knowledge, roughly three areas of knowledge can be distinguished: the use of ***reason*** (logic), ***being*** (physics and metaphysics) and man's ***actions*** (ethics and design).. Many observations and the memory of them lead to experience ('empeiria'). Skill or "art" ('technê') comes from much repeated experience of similar situations; Technê is always practical or productive. Many ***practitioners*** do their work without knowing exactly what they are doing, routinely, but the masters do know what they are doing and for this reason are able to impart their professional knowledge. Scientific knowledge ('epistêmê') is not productive, but always theoretical. Epistêmê is knowledge for knowledge's sake and never aimed at practical utility or enjoyment.. The only reliable characteristic of profound knowledge is the ***ability of teaching***. The purpose of art is not to represent the ***outward*** appearance of things, but the ***inward*** that is the real reality... Doubt is the beginning of wisdom."

Let us now summarise the main principles and elements as part of the ODL concept point by point. These principles are only briefly described here to get started and can be seen as the ODL basic foundations ('grondslagen') for further self-development. Although these should not be seen as static elements, but as living ones, some of them can typically be included in a course syllabus. Note that an additional section (9.3) is devoted to the new ODL-U model, as the overarching foundation of the ODL concept.

1 *ODL's human-centered paradigm*

ODL is based first and foremost on the three- and/or nine-fold human image as described in Section 1.6. This view on world and man and its associated general human-centered paradigms form the basis for ODL's educational approach. Here we formulate two extra pedagogical human image paradigms, PIII and PIV, to complement the earlier two paradigms (PI and PII). We focus in this section on Master students aged 21+.

The first additional pedagogical paradigm has to do with the developmental stage of the child/student and it reads:

PIII – 'the curriculum and the teaching approach should match the developmental stage of the student'

Steiner pointed out that human development takes place in periods of about seven years (later confirmed and further examined by Lievegoed (1996, 2013), among others). In each period, the focus of development is on something different. With the alternation of the periods a change occurs, but also halfway through the periods there is a change, which is referred to as I-realisation. This I-realisation is a kind of impact (insert) moment or conscious awakening via the I-sense. An I-realisation is a moment in a phase of life when you begin to experience yourself differently (via your I-sense). You become aware of something. You see yourself differently from the rest of the world. In this section we briefly discuss the development from birth to age 28, to better tailor the educational approach to the specifics of the student's developmental stage (with a focus on the stage of 21-28 years, the age in which the MSc student is usually located). These four periods can be seen from the child's/student's relationship with his environment, see also Figure 9.4: i.e.,

1. In the period from 0 - 7 years, the child's relationship to the environment is that of outside to inside. The small child perceives a lot. However, the perceptions and experiences that are gained do not yet come together in a centre. Everything is simply absorbed and is imitated. Halfway through, at about the age of three, the child begins to refer to itself as "I" instead of its own name. From then on, it distinguishes between itself and all other beings and things (this is the first I-impulse or I-realisation, in Dutch 'ik-inslag').
2. In the second period (7 - 14), the child lives in a world of his own and has become a closed unit. Perceptions no longer penetrate unhindered, but are modified. From a centre, forces work up to the limit of one's own world (an example is the self-conceived and designed imaginative play, where attributes are something other than they are in reality). Around the ninth to tenth year, there is another I-impulse or moment of self realisation. The child withdraws more into themself. It starts to see differences and notices that its neighbours are different. Its own emotional life awakens. Discourses with others follow, with accompanying criticism and opposition.
3. In the third period (14 - 21), the main direction is from inside to outside. The environment must be conquered and is adapted to one's own perceptions and emotions. The I-impulse is around the 19th year. The adolescent starts looking for his ideals and values. With the I-impulse, the I in the will and activity is born (realized). This allows judgment to become more personal and coloured more from one's ideals. With the I-impulse, the spiritual basis for self-education is laid. One starts trying out a lot, experiencing and also traveling into the world alone.
4. After the 21st year, this unilateral movement comes into balance as man strives to explore the environment. The environment again intrudes more inwardly. This period (21 - 28) has the characteristic that the activities

outward interact with the experiences coming from there. By the 21st year, the body has grown. The I organization is born as the fourth part of beings. The personality can appear. The will has matured to act independently and the young person can begin to take responsibility for themself and for others. Part of the powers of the will become available for independent creation and for creative thought. One passes from the imitation to the self phase. The sensing or sentient soul ('gewaarwordingsziel', and see Chapter 1), the part of the soul directed toward perceiving, is developed. Until the 21st year, things are bestowed; after that, the young person must work to develop themself. That has to do with the self that is born. Before 21, you imitate everything, so to speak: mimic ('after-doing'), imitate ('after-feeling') and reflect ('after-thinking'). From 21 you start doing it yourself from the sensing soul (next seven-year focus). Self-education begins, everyone is specifically sensitive to certain impressions and they seek them unconsciously. The educators must work together to realize the ideals. It is this striving that is formative to young people.

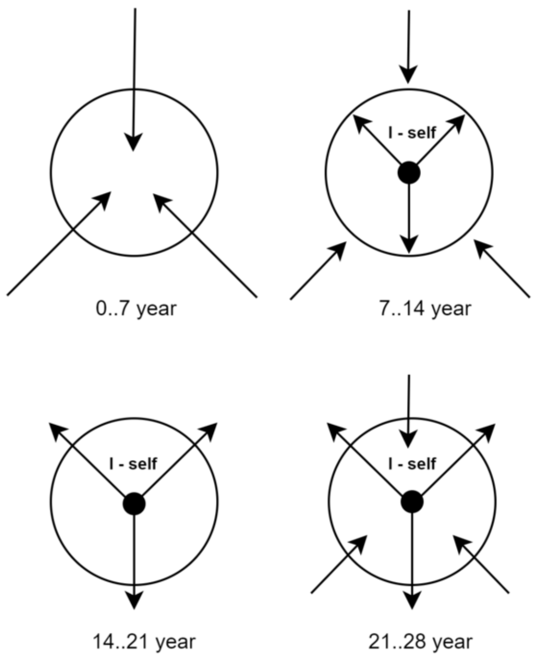


Figure 9.4: The child/student's relationship with their environment, conform Lievegoed (2013).

We can distinguish the following specific I-organization characteristics of the 21+ student (we will use these three later in the ODL U model):

Thinking (open mind) - In thinking, two things stand out. Because the young person must be able to discover where their ideals lie, they must be exposed to and offered many things. They can then notice where their preferences lie. Perception supports the will because perception clarifies will intentions. Thinking also becomes focused on fathoming coherence in the world. The step to self-education can be made so that one takes charge of one's own development, alone or with others.

Feeling (open heart) - In the previous age phase (from 14-21, with focus on the astral body), feelings were strongly experienced and lived out. This continues, the feeling life remains intense. The opinion others have is still important, but slowly shifts through one's own awareness to an independent placement towards, and in, the world.

Willing (open will) - The impulses that emerge from willing must be followed and explored. Practical situations are at least as suitable for this as training situations, because in practice one encounters the world more strongly and sees what one wants to do.

Incitement 9.4 Ecce Homo

(Dr. Rudolf Steiner, philosopher/ artist and educator)

In the heart, feeling weaves
In the head, thinking illuminates
In the limbs, willing strengthens
Weaving illuminating
Strengthening weaving
Illuminating strengthening
That is the human.

The second additional pedagogical paradigm, also called Steiner's pedagogical principal law, has to do with the way an educator should focus their interaction, and it reads:

PIV - 'the educator is acting on the development of the child/student from the adjacent part of being (from a specific realm)'

For example, children in infancy develop their physical body, the educator/teacher works on this with their ether body (see the ninefold figure of man in Chapter 1). That means the educator works on their ether body and perfects it. Precisely the continual work on the ether body is important. It is the same with the successive ages. With children from 7 to 14 one must work on their astral body. With youngsters from 14 - 21 educators work on their I-body and with youngsters from 21 - 28 on their spirit-self (from imagination). That means working together to develop constructively the education. This has a forming effect on the students' self. Note that the I-organization, the body is what makes man an individual, gives him a centre and makes man constructively and creatively active. This paradigm PIV has been schematically summarized in Table 9.1.

Table 9.1: Result of Steiner's pedagogical principal law, see Lievegoed (1996,2013) and Steiner (1996)

Educator operates primarily from their...	Educator interacts primarily with the ... of the child/student	Aged
Ether body	Physical body	0 - 7
Astral body	Ether body	7 - 14
I-organisation	Astral body	14 - 21
Spirit self (imagination)	I-organisation with the sentient soul*	21 - 28

*from 28-35: comprehension soul, and from 35-42: conscious soul, as the predominant focus.

In short, before the 21st year of life, the education goes mainly through the way of demonstrating and imitating, pre-feeling and after-feeling, and pre-thinking and considering. After the 21st year of life, the educator engages in the real-life world together through the path of co-create, co-sense, and co-reflect in order to stimulate the student's sensing soul and enhance flash-forwards instead of flash-backs. To promote this, the educator will be required to have an open mind and/or spirit levelling attitude to the perceptions of their students. They can "feed" their students with enchanting incitements (from practice and/or real experiences) and concept introductions rather than traditional from a to z spelled-out lectures. Making a connection through experiential learning and reflective practitioning to the real-life context is thus now called for and an absolute must. We do not want to move toward a pre-prescribed reality but towards a truly experiential reality. This is the challenge in the 21+ phase and at the same time the risk of dealing with this in an open (and therefore not normative), explorative, and collaborative way to provide condition-creating constructivist education.

#2 Integrative & constructivist U-nlocking

We have already discussed the term (social) constructivism in Chapter 2. This form of knowledge inquiry is always via human and social construction, and is also reflected in the ζ engineering position of the Odesys engineer (see the previous section 9.1). Constructivism can also be used in pedagogy. Within this movement (opposed to instructivism) we see the traditional teacher taking a step aside to a new role as facilitator, connecting students with peers, prompting learning, and reflecting on key moments based on data and observation, while students create

their own knowledge and even their very first designing pathways (”learning to learn and design”), see Figure 9.5.
Constructivist education is human-centered, where educators strive for human manifestation and foster the individual self to liberate (”freewill”), see as Figure 9.6. Instructivist schooling is certainly more focused on teachers and institutions, where policy makers and ”rulers” create processes, resources, and conditions for (their) success.

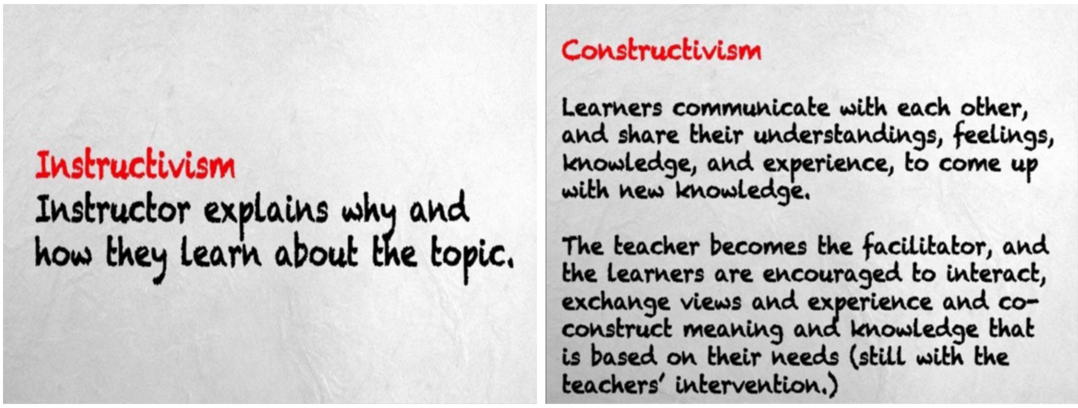


Figure 9.5: Difference instructivism versus constructivism (by Dr. J. Gerstein)

It should be clear from the foregoing that educating a 21+ Odesys engineer via the constructivist approach thus offers the most persistent success for the future. The condition-creating constructivist educator has basically two main facilitating tasks to unite the open design impulse: (1) unlocking the individual's freewill (2) synergyzing integrative design aspects, see Figure 9.6. From this arises the basic principle of the so-called design dialogue as part of the U model (see Chapters 1, 3-4). A design dialogue is a way of ‘intuitive thinking' via concentrative inter-sensing-acting on practice that brings together awareness and insights as stepping stones towards the creation of new design. We argue here that this intuitive thinking can also be complemented by a form of logical thinking. This logical thought is also a formal process of the mind, supported by open glass-box models. The living design dialogue is then an active ‘inner' dialogue with yourself and/or an ‘outer' dialogue with the model representing the open design problem. See the next section devoted separately to the U-model and its dialogue principles within the education context.

As a final 'cautionary' note, most students are used to instructivist education from classical mainstream schools. They think good teaching is the same as easily getting a good grade and passing an exam. Consequently, the grades of the best teachers are usually directly proportional to the degree of instructivism. However, students forget that in this way, good teacher grades are more related to being able to show what you have learned and have been taught, rather than to being able to persistently solve future problems and learning to learn. Would it not be far better to have the student evaluation take place well after the course and then call the award 'educator of your study' instead of 'teacher of the year'?

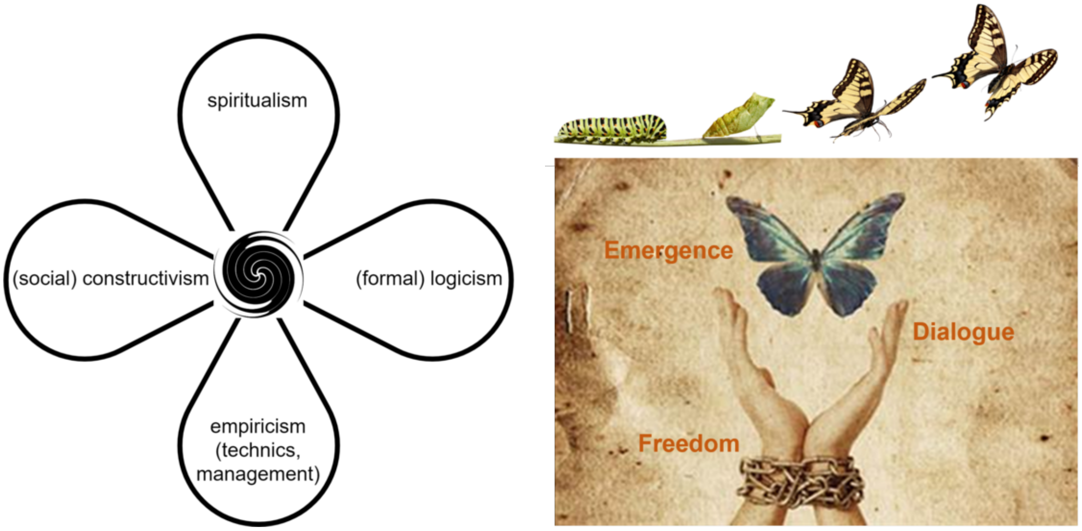


Figure 9.6: Synergizing and unlocking the integrative open design impulse, a process of dialogical transformation.

#3 Self-chosen System of Interest (SoI)

Within ODL it is the main idea that the integration of 'knowledge and skills' should be able to be connected to a self-chosen System of Interest (SoI) from a real-life context. Via this stimulus driven SoI (student's area of interest), 'new knowledge and skills' (R&D) can be transformed by means of this experiential learning vehicle into creative and new conceptions and improvements (within scope of the course context). It is important to note that the SoI is also unknown to the educator/ constructor beforehand (at the start of a course). Thus, the student and the constructor co-develop new open designs. Examples of such a SOI could be a systems service provider, a construction project, a contractor organization, etc. It is important that the student has a certain connection and interest in this SOI, and a desire to always know more about it (e.g. a student chooses a French toll road with a number of large bridges and engineering structures because as a young child he used to go and stay with his grandmother near one of these bridges; he has always been curious to know more about it, not only the technical system, but also the toll service system. It is also important that the student can find a reflective practitioner 'within this system', an experienced and involved professional('buddy') who is able to reflect on real-life contextual matters and on the new design proposals that are made. These open designs or disclosures are things for the student that he did not know or could not do yesterday and will be able to do tomorrow within a systems thinking context. Students transform or design (designs) existing knowledge and/or skills into new insights or improvement conceptions. The self-chosen & experiential SOI vehicle and state of the art course concepts are themselves a prerequisite for the student to learn and develop experientially. The ODL concept forms the bridge between the learning subject and the empirical systems within its context.

The latter aspect in particular makes the ODL education unique in its kind and at the same time resistant to the influence of AI tools like ChatGPT. Indeed, it is through a unique self-selected social context that students transform course concepts and make an individual (through) translation. This from an idealised design and his individual purpose. In short, the SOI makes it possible to make maximum use of the unique and creative human to create a future-oriented design instead of regurgitating existing knowledge from reference material.

#4 Open living dialogue

We know from Buber and Glasl that engaging in dialogue, confronting the conflict, doing what you say, and saying what you think is the way to reach new insights and solutions. Even within education, we can add that what is a question or an issue for you is usually also a question or an issue for the other person. Dare to ask and seek an open dialogue. This is not about 'can you give me the answer to the next question', but rather an open-ended question where in the interspace between people a first draft of a solution can emerge. This is the basis for learning from a free encounter and that is the basis for co-design. This form of dialogical education can return in dialogue sessions in which the educator (constructor) shares experiences and/or reflections based on dialogue questions, meaning open questions with an interest for the whole group. Dialogical education can also be returned in the master class, where the student gets the chance to reflect on their design work with the educator and the class. This requires an open attitude from both student and educator, in which the student comes up with the 'O'-question and the educator moves forward together, not from authority but from authenticity. Finally, it also requires courage from both the student who dares to share his O-question ('what is a question for you is mostly also a question for your neighbour...'), but also from the educator who has to make themself vulnerable and sometimes dares to say "I have to think about it again" without already knowing the answer. In this way, this question becomes a joint development question. Finally, it should be noted that dialogue is not only with another person, but also with the SoI and/or with the open glass box model what this system can be represented by. The student reflects or dialogues with the SoI, the model (the outer), and with themself (the inner) with an open design impulse as a unifying result. We call this dialogical learning, and the modeling component in particular, a form of 'play-based' learning.

#5 ODL's rhythm & sessions

Education is not linear but cyclical. More specifically phrased, education is pulsating, like man's inhalation and exhalation. Education is about repeating, recalling, working through, and living through. In addition, there is another remarkable thing at stake; something that one practises one day is mastered better the next day. Similarly, one can observe that upon waking up, problems from the day before are often solved or one knows what to do. Many of the best impulses ('realisasations') occur immediately after waking up. During the night, something has happened to what one has done or learnt the day before. This means that learning and processing continue during the night (see also Incitement 9.4). We make use of this fact in the rhythm of the ODL course, which has a weekly cycle 'inhalation and exhalation' rhythm within a ten-week cycle as a whole. Every week students are asked to study specific concepts and apply these to their self-chosen System of Interest (SoI) by means of a self-created response and related open-glass-box (computer) models. The teachers incite the course concepts using both reference books and dialogue questions from the students during a weekly **concept and dialogue** sessions. Students can also upload their dialogue questions upfront. Moreover, students have a weekly **practical work** session, which is preferably two days after the concepts and dialogue session. During the co-creative and co-relective work sessions, students can work on their ODL response under supervision of the coach/constructor.

Figure 9.7: A typical conducting masterclass.

In addition, **master class** (MC) sessions are held, where students and constructors co-reflect on a group's concept translation. A masterclass is a short event in which a selection of groups share their work in progress (WiP), followed by feedback from the constructor. It is a moment of co-creation and co-relection rather than an assessment moment. There is no formal evaluation, the goal is only to bring the content further. It is also not a moment of formal presentation, but a moment in which the work in progress can be interactively reflected on by both the constructor and colleague students. It is an art-moment, like when a music masterclass the 'conductor is going to sit in the room and the student is going to conduct' (see Figure 9.7). The goal of a MC is to identify a group's issues, problems, ideas, and opportunities that mostly also apply to other groups. We have experienced that masterclasses are found very useful, both by the students who share their work and by the listening students.

#6 General ODL learning goals

In general, we can summarize the learning objectives of an ODL course as follows so that they can be used for multiple courses. After an ODL course students should be able:

- To understand and be familiarized with the course specific concepts, principles, and practices, through dialogue with the constructors, navigation through the course reference documents, and engagement with a self-chosen real-life System of Interest (SoI).
- To apply, relate, and examine these course concepts, by dialoguing and experiencing the concepts with the SoI and its reflective practice, and by (if relevant) constructing SoI specific (computer) models.
- To (re)work this course knowledge and SoI specific concepts observations, by transforming and linking the SoI-dialogues into new insights and/or developing improvement proposals.
- To form an individual judgement and conspect these new insights/developments.
- To demonstrate the aforementioned learning goals by creating and internalizing the openings/ learning outcomes in an original Open Design Learning (ODL) response.

#7 ODL response

Education should be so vivid that there is no need for a test. A self-designed kind of final work instead of a final test. After all, a test 'seals' something and are closed systems which do not assess anything significant to the future of students, because no one knows how to assess or measure the key factors to the future success of any person. Moreover, doing something right confirms what we already know, which has some value but contributes nothing to future learning. This is why we are working towards an open-ended deliverable, which is the so-called Open

Design Learning response. This ODL response is a group deliverable based on the self-chosen SoI. The ODL response is an original enabler demonstrating both the group and personal learning and development achievements. The ODL response illustrates how the general concepts have been transformed, linked, and evaluated to the self-chosen SoI using logical diagrams/reviews and/or a computer model(s). All of these, including relevant open glass box models, should be presented in a self-chosen format (we stimulate to delivering a self created poster with annexes). This poster can also be presented during the course as a work-in-progress in a kind of atelier setting. It must contain a clear justification of the individual contributions of each group member. Each group member must also write an individual Comment in which they write a collegial review of a specific individual contribution from the other one. Good collegial Comments make use of specific ODL Commendation aspects (see one of the other basic ODL foundations). Finally, everything in the ODL response is intended to be unique, new, and completely proprietary to the SoI and its context. Existing knowledge from reference material therefore has no place in an ODL response.

Figure 9.8: A facilitating U-shaped swimming stick.

To accommodate students somewhat with this rather free ODL form (which they are mostly not used to from classical instructivist 'spoon-feeding' teaching), we typically make an auxiliary table with so-called ODL building blocks, see an engineering asset management course example in Figure 9.9. This is not a prescribed outline of the ODL reponse but serves as a reference point and auxiliary structure for the student (getting them 'water-free' and like an ongoing 'stick to stay above water', see Figure 9.8).

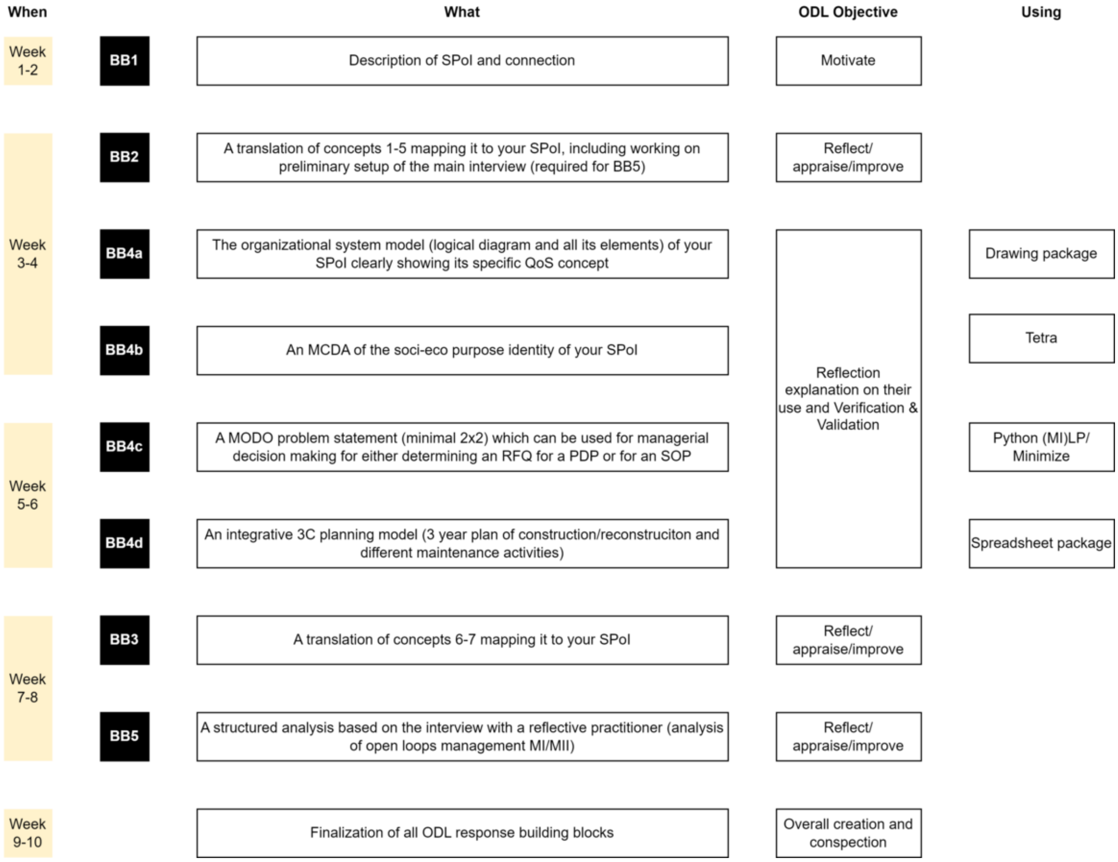


Figure 9.9: ODL response building blocks, an example for an engineering asset management course.

#8 ODL commendation

The Open Design Learning commendation principle will be applied as a sort of 'grading rubric' for the ODL response. Both the SoI content characteristics (sub-products), and the student's learning process are integrated within these commendation principles, as summarized in Table 9.2. We call it 'commendation' because when we grade a response, we start from a grade of 10 and only deduct points if aspects are missing or only partially worked out. The commendation table also serves as a basis for the grading obtained in any subsequent dialogue of the ODL response.

#9 ODL-CC coding language

Actually, this is not really an additional foundation, but a summary of 'coding language' of ODL. We will not present a definition list, but below we list the 'creative-common-terms', see Figure 9.10.

Table 9.2: Commendation table and the C's

Categories	Relates to:	Expressed in (the making of) the ODL response:
Connect	Learning process	Showing *courage*, being *curious* and/or *compassionate*, being a *creative* problem solver: the **commitment** 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: the **compile** factor.
Conclude	Developed results, validation and reflection	Showing a *cyclical* approach, dealing with *completeness*, *critical* and open-end reflection of own work: the **conspection** factor.
Convey	Reporting and presenting the response	Showing a crystal *clear* line of reasoning. Easy to *comprehend*. Being *concise* (signal to noise ratio). Not copying reference material: the **cognoscible** factor.
Convince	Response speaking to / arousing the imagination	Being *cogent* and demonstrating a *critical* attitude: the **compelling** factor.

Note that the list is not limiting as, for example, essential non-.. (e.g. non-conventional, non-conformist etc.) and/or co-... (e.g. co-creation, co-reflection etc.) are not included. These CC terms are used in several places in the text of this chapter and the reader can find them there. These CCs form the common ground of ODLc and are meant to be guiding and not prescriptive (as definitions or norms). We encourage the interested educator/student to use this coding language to 'write your personal program'.

Ultimately, with a (coding) language usually belongs an alphabet. This is also the case for ODL's language. Namely, within ODL we know the expression "U,V,W,X,Y,Z these are the letters of the ODLc alphabet." These capital letters symbolize a number of important elements of ODLc (and Odesys) and are summarized in Table 9.3.

9.3. ODL, an act of U-nlocking

In this section, we zoom in one more time on the second foundation of ODL from the previous section. There we have shown the importance of achieving a real unlocking of the open design impulse through an integrative and constructivist

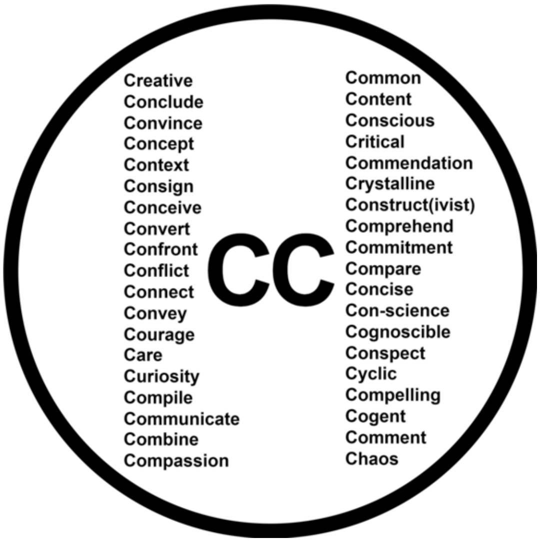


Figure 9.10: ODL's coding language and its creative common terms.

Table 9.3: ODLc alphabet: U,V,W,X,Y,Z

U	U-model; Utility; $U = f(x, y)$ inner ('ego') development	**X**	X-factor, don't be afraid of the dark; Design variables $U = f(X, y)$
V	V-model; systems engineering outer ('eco') development	**Y**	tY, design to Y (common socio-eco interests); Design constraints $U = f(x, Y)$
W	Double-U (ODL & Odesys) Double loop $W = U + V$; $W = \wedge + \vee$; Double diamonds	**Z**	Zeta (capital of *zeta*) professional; dialectical synthesis; symbol for integration

approach. We saw that for the individual student this involves an integrative process of the mind, heart, and will. We also noticed that it is important for MSc students that the educator engages them in the real life world through a collaborative and integrative path of co-create, co-sense, and co-reflect to maximally stimulate the student's sensing soul and enhance flash-forward open designs. A fitting process model which unifies these issues is the U-model we described in Chapter 3. Here we assume that the reader is familiar with theory U as described in Chapter 1 and the further developed for Odesys U diagrams from Chapters 3 and 4. The starting point for ODL is the conceptual Figure 3.13.

Incitement 9.5 'Dream-education'

We very easily forget that very important processes take place at night, even if 'sleeping on something' or 'I'll have to sleep on that' is widely practised. In the night, problems are 'digested', as it were, by consciously 'taking them into the night'. It proves extremely fruitful to 'letting go' of something that at first seemed difficult to solve without judgement or decision and leave it until the next day. The solution presents itself more easily, often with great obviousness. After a night's sleep, you also often feel a lot better. Logical, after all, the physical life body has had a rest despite the organs 'working through' the night. In this 'breathing-out' pause or release pause, a human can 'dialogue' with his healthy primal image and can then reorient himself accordingly.

In the earlier healing mysteries, the so-called temple sleep (incubation) made use of this idea. The mystery leader guided the patient to behold his healthy primal image. With this recorded new imprint all the realms of the human being then returned to awakening. This imprinting or recording does not only happen upon awakening, it takes place several times during the night. In the electroencephalogram of the brain, this shows itself in the short-lived periods of REM sleep (REM = rapid eye movement). After this, the human awakens or simply sleeps on. This imprinting is at least as important for health as the resting of his physical body.

We might now ask whether we could not also make active use of this knowledge in learning and development processes? Could it be that actively 'letting go' could also lead to openings and 'letting come'? Or in other words, could we not 'actively' involve the night 're-generation' principle (breathing in and out) in which organs do go full steam ahead and cognition rests completely into the learning and development process? What could this 'night-conceiving' mean for the design process? Could there possibly be such a thing as a 'mind-fullness' process as contemplative learning and design ('dream-education')? And finally, would this principle also play a role in actively enhancing the generation of a so-called 'aha-erlebnis', a situation in which a person suddenly gains a new open 'in-sight' (a 'gut intuition')?

The common thread of these U-diagrams is that when the actor, in our case the designer or learner, goes through the U, they actually go through an awareness process of consciously disclosing/unlocking their purpose or uncovering their will (thinking slow combined with thinking intuitive). We refer to the left side of the U as top-down learning, and the right side as bottom-up learning. The U-process goes from an open mind (imagination) via an open heart (inspiration) to the open will (intuition), and then is 'renewed' in reverse to an action of response via an inner dialogue. This action comes from the free will where the 'contradiction' or reversal of impulse and motive have coincided. For the ODL U, this involves a metamorphosis or transformation from various course concepts to an ODL response in which these concepts are converted to the real-life contextual system of interest

(SoI). We will now make only some notes in addition to Chapters 3 and 4 which are specific to ODL, followed by the new ODL model and the corresponding ODL system diagram at the end of this section:
(#1) To the left of the U-model we see cognize instead of observe and contextualize instead of sense, compared to the Odesys U. To the right of the U-model we see externalize instead of conciliate and response instead of prototype, again compared to the Odesys U. The ODL U-model thus reflects a design-based learning metamorphosis from concept cognition via contextualize/externalize of the concepts within the self-chosen SoI towards the self-creation of an ODL response. This ODL metamorphosis can be supported by the Odesys open glass box modeling approach and the corresponding Odesys U (see Chapter 6). Note that in that case we are actually dealing with a 'double-U', which we then refer to as the W- model.
(#2) The ODL threefold system diagram comprises of the sub-systems: (a) conceptual, (b) contextual, and (c) purpose. Design-based learning, like design, is cyclical. Therefore, the ODL U incorporates three open-ended design learning loops, a spiral of: (1) Open concept– technical cycle, (2) Open context -social cycle, and (3) Open source - purpose cycle. In other words, students follow an open-ended design learning approach integrating the open mind, heart, and will.
(#3) We have already recognized that the ODL U actually consists of two parts in the learning process: a so-called top down learning process and a bottom up learning process. In other words from top-head cognition to hands-on and from bottom-hands practicing back to head, connected via the heart. This is called pure integrative education, a path of knowing ('kennis') and being competent ('kunde'). The emergence resulting from this knowledge/competence synthesis is the art of designing ('kunst'). A second interesting addition/ observation is that the heart in the ODL case means the social context represented by a so called self-chosen system of interest (SoI), which is a stimulus driven learning vehicle and can be used as reflective practice. The essence is that the student transforms existing course concepts through this self-chosen SoI into a self-created ODL response, which consists of an appraisal or improvement proposal for that specific context.
(#4) The deepest U point also deserves some extra attention. It requires on the one hand letting go but at the same time this letting go needs a kind of counterforce to play (practice, test) with the concepts and new ideas in the self chosen context (playing like a young child that learns through playing). This play-based learning or practice becomes more natural when we add open source/ Odesys modeling to the ODL U model (see chapters 4 and 6). Dialoguing in the now, which we do in the depth point of the U with the glass box model, with the SoI, with the inner self (partly through the night), with the reflective practitioner and/or the constructor, and finally playing with the concepts, can bring the real transformation. Thus the 'depth-point' of the U can culminate into an aha-erlebnis, a 'high-point', a pure living design dialogue impulse disclosing a

new response ('eureka-effect'). This depth-point is also characterized by a state of chaos or confusion; in a state of being in the storm and at the same time in the eye of the storm. Note here the intertwined definitions of chaos and/or confusion: chaos is the confused unorganized state of primordial matter before the creation of distinct forms. This means that the student (design-based learner) must have the courage to inhabit this 'dialogical chaos' from the confidence that this is the very condition necessary for creation; a state of being in the now with focused and open attention. After these additional ODL U notes, we now can introduce the full new U-model that has been developed for the purpose of open design learning (ODL). 'The individual will become visible from the concepts, connected with the SoI, and both the inner and open sources work towards/ in the concepts' via a threefold of re-converting the open concepts, re-validating the open context, and re-uniting and/or re-purposing the open source, see Figure 9.11. And then all the way to the open-end, we make the following art of ODL note.

We argue that according to the definition in this book (see also Chapter 2), complex problem solving is a spiritual (mind) act of design, because we are connecting design systems with the living world around us. The truly meaningful moments are those in which one recognizes why a certain solution is found to be true. Verification is then nothing but a process after the fact, although necessary it does not represent the core of problem solving. The moments of solution finding are often very spiritual moments in which an individual connects with what is real. Such an event transcends the everyday and one really does not have to be spiritual in any sense to see and feel the extraordinary power and authenticity of such moments. Design develops in the moments when things are problematic and at times when more is required than technical knowledge and skills alone. While both are necessary, they are ultimately not what matters most. A comparison can be made with art and speech. Both human speech formation and music cannot be created through technique alone, but it is the whole symbiosis of tones, rhythm, and timbre through which music and speech 'emerge'. It is true that good technique is necessary to be able to speak or play music, however technique is only a means and not an end. Art cannot be reduced to technique. To claim that design is only technique is the same as claiming that art consists only of technical use of inner and outer instruments. Similarly, students will experience that ODL is an art to really internalize problem-solving potential which, from the sensing soul, can be carried along on the personal development journey. Integrating knowing and doing through a living idealized design dialogue, linked with the inner self and the social real-life context, allows them to incorporate these experiences into their body-soul system (genuine 'memory'). This capacity may then be 'retrieved' in the future to solve a new problem with courage and confidence (like you can forever invoke your ability to swim because you have made it through and are never afraid to swim again).

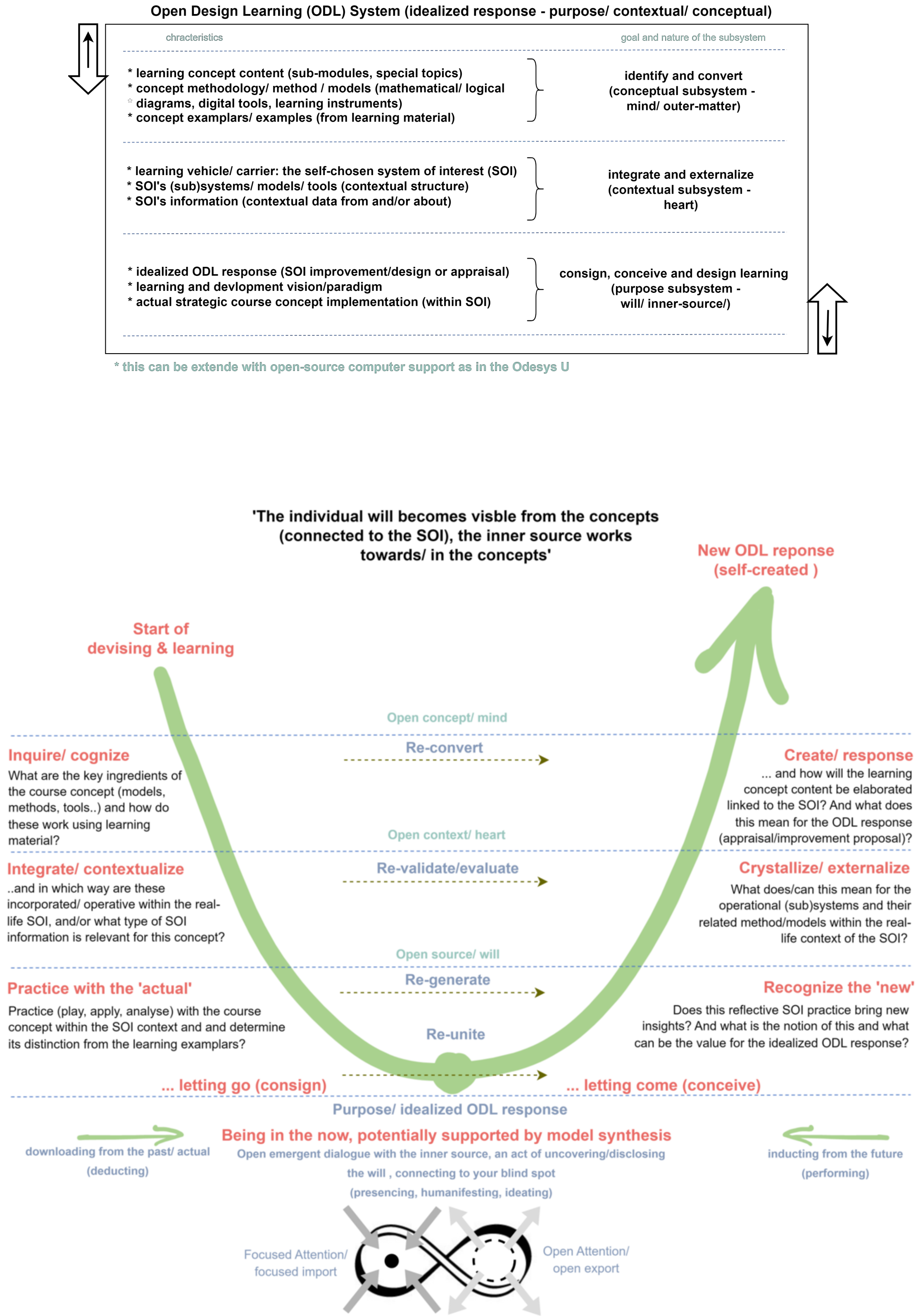


Figure 9.11: The new ODL U-model with the ODL system diagram, as developed by Wolfert from earlier 'U-work' by Glasl (1998) and Scharmer (2016).

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Open end

Conspection & outreach

'Odesys & ODL join forces for social change. Odesys is the key to unlocking conflicts and is capable of delivering socially responsible 'getting into yes' solutions. ODL is a pure act of design-based learning to confront the emerging future and to become open and persistent problem solvers. Everyone has a designer within themselves; it is the art of Odesys & ODL to awaken this inner designer.'

If we distinguish feasible and infeasible design solutions, then we can make a distinction between three types of design solutions: (1) capable but undesirable design solutions which we call bridges to no-where; (2) incapable but desirable design solutions which we call 'bridges to no-land'; (3) capable and desirable design solutions which we call 'bridges to anywhere'. It is clear that only the last type of 'bridges' are feasible as these bridge the socio-technical gap and are best fit for common purpose.

In this book we introduced the Odesys methodology for transparent design/decision support models which are crucial to offer unprecedented opportunities and 'bridges for anywhere' solutions. The aim of Odesys is to promote the adoption of engineering artefacts in our future society by following an open config/space/source design and systems integration approach supported by sound mathematical open glass box optimisation models. This as a means to achieve well informed decision-making leading to the best-fitting socio-technical solutions. This requires systems thinking and a stakeholder-oriented focus to explore different solutions within an open-ended optimisation process, uniting both capability (technological) derived from the engineering asset's performance and desirability (sociological) derived from each stakeholder's preferences.

Odesys results in an open dialogue and a co-design approach that enables a-priori best fit-for-common-purpose design synthesis dissolutions rather than a-posteriori design compromise absolutions. The Odesys combination of intuitive 'U-thinking' and deliberative 'thinking-slow' made the IMAP/Preferendus method and tool an effective and transparent design/decision support tool. It offers an open-ended U-modeling approach for a spiral design metamorphosis of technical, social and purpose cycles, incorporating three open-ended design loops: (1) Open config - technical concept/concreation, (2) Open space -social context/conciliation and (3) Open source - common purpose/synthesis.

Within this book we presented a pure and a-priori socio-technical systems design integration methodology, together with a new Integrative Maximised Aggregated Preference (IMAP) synthesizing method. Furthermore, IMAP has been integrated into the Preferendus tool, which combines state-of-the-art principles of PFM with a specifically developed inter-generational GA synthesizing solver. Four specific engineering systems design and planning applications have been worked out by first using the threefold diagram to formulate the mathematical problem statement. The resulting outcomes of these applications clearly demonstrate the added value of IMAP/Preferendus.

Firstly, IMAP/Preferendus provides a single best fit-for-common design point, unlike a Pareto front where a systems designer still has to choose the final design because the front does not define a single optimal design point. This solves an important modeling error, in addition to the fact that classical design synthesizing methods leading to these Pareto fronts contain fundamental aggregation errors, namely that design configurations lying on the Pareto front cannot all have the same preference scores.

Secondly, IMAP/Preferendus returns the best design configuration in all design applications compared to a set of single-objective design configurations and a design configuration obtained by the classical multi-objective min-max method. This allows IMAP to be synthesizing as a pure synthesis, multi-objective design method that ensures a best fit-for-common-purpose point within the design space, rather than a sub-optimal, one-sided corner point and/or best point in the feasibility space only.

Finally, IMAP/Preferendus truly unites design performance functions (supply), via the level of inter-play objective functions, with stakeholder's preference functions (demand), synthesizing for the best fit-for-common-purpose solution and outperforming one-sided design approaches that focus only on the technical domain. This means that the IMAP/Preferendus is either equal to other design methodologies in the technical domain, but outperforms methodologies within the management domain (see design application DA-4: a floating wind turbine installation) or outperforms other design methodologies in both the technical and the management domains (see design application DA-1: a rail level-crossing service life design).

Further developments

Although the design applications are simplified for methodological illustration puposes, they already demonstrate the added value of the Preferendus/IMAP in the field of multi-objective design optimisation. However, at the time of publishing this first edition of this book, it is also being applied and further validated in the following real-life projects: (1) the primary dredging and offshore design and construction/production management processes of the marine contractor Boskalis (e.g., Van Heukelum et al. (2023)); (2) the EU NRG-Storage research project (Zhilyaev et al., (2022)); (3) several PhD/MSc thesis project applications (Shang et al. (2021, 2023); van Eijck & Nannes, on TU Delft's repository (2022)). In all projects, the decision-making stakeholders (both on the project developer side and on the contractor side) are predominantly positive about the unexpected design solutions that they would not have been able to achieve without the use of this computer-aided decision support system, the Preferendus, as part of the Odesys methodology.

For the two design applications DA-3,4 (rail level-crossing and floating wind turbine), a major extension of the models is currently underway to better fit the design/decision problem in practice, so that more realistic design performance and better preference functions will be included. For the floating wind application, this means that Open- FAST, an open-source wind turbine simulation tool, is linked via a surrogate model and integrated at the level of design performance functions. For the level-crossing application, the modeling input will be refined at all levels (focus on the preference and objective functions). In addition, for the floating wind application, but also for a dredging application, validation sessions will be carried out to refine the modeling inputs (especially the performance functions) and to evaluate the results, especially of the new IMAP and the existing min-max methods. This is done in the form of a serious game, using the Preferendus as a design support 'engine', with the aim of increasing the internal acceptance and the link with the iterative group design engineering process. Based on these current developments, we can formulate at least three main focuses for further development of the Preferendus:

(#1) The output depends not only on the best possible design performance functions, but also on a good reflection of human objectives and preferences. Especially for the latter, further preference elicitation research is needed to arrive at balanced preference functions with corresponding individual preferences as input. Finally, further research is also required to determine stakeholder weight distributions in an efficient and effective way where the sociocratic principles (consent principle and preferendum) are leading.

(#2) The result of the optimisation may also be an empty design solution space: i.e. a so-called stalemate situation. In this case, additional decision support functionality will be required to support stakeholders to achieve the best possible negotiation and arrive at an acceptable design solution space.

(#3) The design performance functions are currently deterministic. However, for more realistic applications, probabilistic design modeling techniques will need to be

integrated, e.g. for the offshore design application, uncertainty in working hours or operational weather slots. Improvements to the current Discrete Event Simulator (DES) may be required, particularly for repetitive production and installation operations.
(#4) Finally, the Odesys methodology has already been taught, and further tested and validated in several MSc courses in Systems Engineering Design at the Faculty of Civil Engineering & Geosciences at Delft University of Technology this year. The purpose is to further explore the added value and potential improvements of the Preferendus as soon as possible. Within these courses, MSc students develop a Preferendus/IMAP-based model of a self-selected real-life system of interest as part of the so-called Open Design Learning (ODL) response (see Wolfert et al. (2022) and Chapter 9). Some findings from these courses have already been incorporated into the current Preferendus code, see the Odesys Github for further details

Future applications

The Preferendus and the IMAP method will be applied in future systems design and management applications, including (1) dynamic preference and performance based mitigation control (MitC) of large construction project, in combination with discrete event simulation (DES), (2) optimal socio-technical planning of flood defence system reinforcements, and (3) a far-reaching improvement on playing a Preferendus-based serious game, incorporating improved preference elicitation techniques and or expert judgment and the application of a stalemate solver (see e.g. Kammouh et al. (2022) and Klerk et al. (2021) for the actual state of the art planning and control solutions without an IMAP/Preferendus application).

Furthermore, the added value within the so-called concurrent engineering and design developments in the field of 'Early Contractor Involvement' is also investigated. In particular, the Preferendus will be used to support and evaluate the new so-called two-phase contract for infrastructure projects, in which the activities of the Dutch national infrastructure service provider (RWS) and its contractors are further intertwined, to avoid major contract changes that are the result of the classic serial, non-participative design and engineering process.

The future developments described above are, at the time of publishing this first edition of this book, envisaged to materialize in at least the following three projects.

Preferendus based Mitigation Controller (MitC) "Construction projects management require dynamic mitigation control ensuring the project's timely completion by a best fit for common purpose strategy for all stakeholders. Current mitigation approaches are usually performed by an iterative Monte Carlo (MC) analysis focusing on lowest cost strategies which do not reflect (1) the project manager's goal-oriented behavior (2) automated network restructuring potential (3) multi-dimensional optimisation criteria for best fitting mitigation strategies. Therefore the development statement within this paper is to design a method and implementation tool that properly dissolves all of the aforementioned shortcomings ensuring the project's completion date by finding the most effective and efficient mitigation strategy. For this purpose, the Mitigation Controller (MitC) has been developed using an integrative approach of non-linear optimisation techniques, probabilistic Monte Carlo simulation, and preference function modeling. MitC's applicability is demonstrated using a recent tunnel construction within one of the largest Dutch infrastructure construction projects showing its added value for multi-criteria decision making on-the-run. It is shown that the MitC is a state-of-the-art decision support tool that a-priori automates and optimises the search for the best set of mitigation strategies for common purpose rather than a-posteriori evaluating the potentially sub-optimal and over-designed mitigation strategies (as commonly done with modern scheduling software such as Primavera P6). The extended MitC has proven its added value within a real-life project context."

This text is part of a key publications on dynamic project control, in which the MitC is implemented, see Kammouh et. al. (2021, 2022). Within the current MitC (see github.com/tudelft-odesys/mitc), the focus is primarily single objective optimisation strategies (time or costs) on-the-run where different preferences and multi-projects optimisation have not been incorporated yet. Currently this is being developed within state-of-the-art R&D projects of the EAM group of the author, and in particular within the project Logiquay: Adaptive Multi-Actor Multi-Modal Closed- Loop Planning and Logistics for Renewal and Renovation of Urban Bridges and Quay Walls (# NWA.1431.20.005). This project is continuing to integrate the IMAP/Preferendus to enhance systems engineering optimisation with the best-fit for common purpose methodology. Moreover, within several Boskalis project the MitC will also be extended both with IMAP/Preferendus and DES simulation techniques to improve multi-objective optimisation and control especially given the dynamic workable weather windows.

Preferendus based 3C-planner "The well-being of modern societies is dependent upon the functioning of their infrastructure networks. This paper introduces the 3C concept, an integrative multi-system and multi-stakeholder optimisation approach for managing infrastructure interventions (e.g., maintenance, renovation, etc.). The proposed approach takes advantage of the benefits achieved by grouping (i.e., optimising) intervention activities. Intervention optimisation leads to substantial savings on both direct intervention costs (operator) and indirect unavailability costs (society) by reducing the number of system interruptions. The proposed optimisation approach is formalized into a structured mathematical model that can account for the interactions between multiple infrastructure networks and the impact on multiple stakeholders (e.g., society and infrastructure operators), and it can accommodate different types of intervention, such as maintenance, removal, and upgrading. The different types of inter-dependencies, within and across infrastructures, are modeled using a proposed Interaction Matrix (IM). The IM allows integrating the interventions of different infrastructure networks whose interventions are normally planned independently. Moreover, the introduced 3C concept accounts for central interventions, which are those that must occur at a pre-established moment, where neither delay nor advance is permitted. To demonstrate the applicability of the proposed approach, an illustrative example of a multi-system and multi-actor intervention planning is introduced. Results show a substantial reduction in the operator and societal costs. In addition, the optimal intervention program obtained in the analysis shows no predictable patterns, which indicates it is a useful managerial decision support tool."

This text is part of a key publication on engineering systems design/decision making, in which the 3C-planner method is implemented to accommodate for multi-system intervention optimisation of interdependent infrastructure (see Kammouh et al., (2021b) and/or github.com/tudelft- odesys/3c- planner). It is noted that for an optimal service operations plan a system thinking approach is required to arrive at a best-fit for common purpose plan. The so-called 3C-planner method has been develop to accommodate for multi-system intervention optimisation of (interdependent) infrastructures, using traditional optimisation techniques that are not preference based. Within the current 3C-Planner the focus will be on multi-system service intervention planning and IMAP/Preferendus based optimisation, where both the mechanical behavior and trade-offs based on individual preferences will be incorporated. Currently this is being developed within state-of-the-art R&D projects of the EAM group of the author of this book, in particular within the Dutch NWO perspective program Future FRM Tech: Future Flood Risk Management Technologies for Rivers and Coasts.

Preferendus, confronting the urban planning conflict... "Waelpolder is an area development project between 's-Gravenzande and Naaldwijk in the municipality of Westland. The area will be a residential neighbourhood with a focus on greenery. Waelpolder, together with other sub projects, is part of the Waelpark area development. The first goal of the IMAP/Preferendus application to Waelpolder was to investigate which design methodology, Preferendus or the Minmax goal attainment, is best suited to support the urban design/decision making process. The second goal for Waelpolder was to test the acceptance of the Preferendus. Investigating the acceptance is linked to the entire process of the Preferendus, starting with the input and ending with a design. The approach is accepted if the stakeholders endorse the added value in the use of the Preferendus. With regards to the second goal, the stakeholders expressed that they preferred the design obtained using the Preferendus method. The Min-max method optimisation results were deemed less satisfactory for the group as a whole. Although there was a differentiation in stakeholder satisfaction when using the Preferendus, the optimisation result was more diverse and attractive."

This text is part of a MSc students thesis project (for details on this project application the reader is referred to the work of van Eijck &, Nannes (2022) on TU Delft's repository). As an example, where the Preferendus result showed a pronounced housing differentiation, the Min-max result showed very little housing differentiation making it a rather bland end result. With regards to the second goal, the stakeholders showed great interest in this new approach for solving urban design problems. The stakeholders appreciated that the model can give insights into the consequences of certain requirements. Stakeholders did not expect that the stated requirement would still allow for as many houses as the optimisation results showed. The representative of the municipality wants to use the Preferendus within the organization to show the effects of adjusting certain constraints and coefficients (e.g. parking norms).

Overall, this project has shown promising results that make traditional Linear Programming (LP) and/or single-objective optimisation techniques things of the past. The Preferendus here proved itself as an ultimate conflict dissolver, where the compromise solution was outperformed. For a next step, an improvement in the social cycle is proposed along with a stalemate solver. The latter can ensure that at least a transparent and objective start (perhaps as a 'start-compromise') in the social cycle can be made with a possible solution space in which all conflicting interests are secured.

Outreach

The Preferendus as a decision support tool for the Open Design Systems (Odesys) methodology introduced in this book is what Kahneman would call a 'thinking slow' as opposed to 'thinking fast' decision system. As we saw in Chapters 1,3 and/or 4, Kahneman distinguishes between two systems that drive the way we decide. System 1 is fast, instinctive, and emotional; System 2 is slower, more deliberative, and more logical. The logical aspect relates to the unbiased modeling output that cannot be any other than a pure reflection of all stakeholders' preferences. It is not uncommon that the model output surprises stakeholders in the sense that it defies instinctive preconceptions about possibilities and impossibilities. In other words, applying Open Design Systems methodology allows the creation of a design and decision model that 'talks back'. Odesys and its Preferendus is therefore congruent with the negotiation principles based on the Harvard Negotiation Project, advocated by Fisher & Ury in their book "Getting to Yes", see Fisher (1997). These negotiation principles aim for reaching mutually satisfying solutions by focusing on stakeholder interests, rather than positions, working together to find creative and fair solutions. In addition, Glasl's book "Confronting Conflict" describes a model of conflict escalation that aids in conflict analysis, see Glasl (1999). Appropriate reactions can be derived from this analysis. Within this conflict model, so-called non-values and/or no-go areas also play a role. The Odesys methodology proposed in this book can be considered as the implementation of these negotiation and confronting conflict principles within a participatory design framework, using the Preferendus to search for the maximum of aggregated preferences (values) within a given and constrained solution space. Even if the confronting conflict calls for a compromise solution rather than a synthesis, the Preferendus via the Min-max method can also provide relief.

Moreover, we learned that the use of the Odesys open glass box mathematical models greatly helps to resolve such situations to pinpoint the exact reason why the design or decision process got stuck. Most commonly the reason for such a stalemate situation can be traced back to a few conflicting constraints. The Preferendus is used to find these constraints and related stakeholders. A check is then performed on whether these individual stakeholders are willing to relax their constraints. If constraints can be relaxed then the design process can proceed, if constraints cannot be relaxed then the project can be considered infeasible. In the near future, similar project applications will be used to build a stalemate solver within the Preferendus. The idea behind this solver is to let the Preferendus generate alternatives that give the stakeholder insight in what or where they have to be willing to move in order to come to a feasible solution. The Preferendus makes the most effective and efficient proposal for this, as a true next generation stalemate solver to 'confronting the conflict'. The Preferendus might even be able to support Hamelink's invitation to disarming conversations in urban spaces, as one of the approaches to preventing mass media aggression, see Hamelink (2015).

Some concluding remarks. In the Odesys's examples weights were used to express the importance of criteria but also of stakeholders. When using weights to express the importance of stakeholders we introduce the power game. Who is to decide what weight/power each stakeholder gets? In a sociocratic setting all individual inputs will be taken into account and by using the consent principle any principled and reasoned objection against the distribution of weights will be removed. However, the rationale for choosing the weights for expressing a stakeholder's power in a typical design problem remains a matter for a genuine social debate.

Before we concluded completely with the open-ending, we also want to put down an outreach to ODL. After some 10 years of experience with this new education concept, we are convinced that it is mature enough to cross over to other domains. Besides being embedded in the engineering and management domain, ODL is also suitable for all other empirical studies. The condition is that the study is not only focused on the accumulation of existing (research-)knowledge only, but is open to innovation through integrative design in a real-world context. Thus, we are convinced that with ODL, even, for example, the subject of literary history can be studied by associating it with a "design task" in the actual social context as an experiential learning vehicle. It should be noted here that ODL is absolutely not a ready-made method, but a learning concept in itself. ODL is not instruction, but a concept with constructivist design learning principles that you have to experience yourself and further tailor and develop specifically for your educational context.

We started this book in the Preface with some questions, the first of which read as "Why, so often, do we build what no one wants?" and later, "Why, so often, do conflicts stem from failed attempts to constructively design?" If stakeholders dare to openly confront with the conflicts, then pure best-fit for common purpose design solutions will become possible.

We finish this book with a final question: "Why, so often, do decisions lead to normative absolutions?" In other words, it is not uncommon that design processes lead to predetermined solutions that represent what politicians or policy makers consider to be the group optimum. The design process is in that case not open ended or unbiased, but predetermined and normative. The methodology we present takes human interests as starting points and are considered to reflect each stakeholder's preferences. The output of applying this socially responsible design methodology is initially unknown but, from a logical point of view, because only mathematical operations are applied to the input, non-biased and free of any manipulation. That is Odesys' real potential of designing "getting into yes" dis-solutions in many kinds of multi-stakeholder conflict or interest situations, where so far only subjective and political judgments and preconceptions have mattered.

Figure: 'A bridge for anywhere', bridging the socio-technical gap.

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Connect

If you have any questions or comments, or if you see any omissions in the book and/or our Github site, we kindly ask you to share them with us via the websites below.

Odesys connectors

We would be delighted if you would like to embrace Odesys and start working with it yourself. For more inspiration, see all our creative commons and the Preferendus at the Odesys Github:

`github.com/TUDelft-Odesys/`

If you have interesting and novel design applications (academic and/or industrial context, preferably also outside the civil engineering domain) for example for a next edition of the book, we would be grateful if you would connect with us. Should you want support in implementing Odesys within an industrial environment, we are more than happy to facilitate that. Please feel free to contact us via:

`odesys.nl`

ODL connectors

To further grow and branch out the Open Design Learning concept into the education world, we are cooperating with our connectors who practice and tweak the ODL concept to their specific local learning needs. We are convinced of ODL's potential even beyond civil engineering and management education. Together with you we would like to form an open source community of enthusiastic ODL education professionals, an open design school. Should you have any questions regarding the local implementation of ODL in your education, please feel free to contact us via:

`open-design.school`

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Appendices

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Appendix A

Research & Development Methods

	Modeling and simulation (silico)[0]		
	Type	Orientation	Method/technique
Mngt. & Phys.	Mathematical	Development validation	• (Non)-linear programming[1] • Dynamic programming • Preference Function Mod.
		Research evaluation - Development validation	• Stat. meth.[2]/data mining • Neural networks • Prob. Methods[3]/ forecasting
		Research evaluation - Development validation	• Analytical (PDE continuous) • Numerical (finite elements) • Discrete events • System dynamics • Agent based • Adaptive pathways
	Logical	Research evaluation - Development Validation	• Diagramming[4] • Functional/OCD design • Scenario validation
	Digital	Research evaluation	• Diagramming[4] • Software utilization[5]
		Development validation	• Software developing[5]

Figure A.1: Research and development methods overview.

[0] Research modeling has generally a descriptive/confirmative orientation to understand questions/hypotheses for the body of knowledge. Development has generally a ameliorative/constructive orientation to enable problems/prototypes for the body of products.

	Experimenting and observation (vitro/vivo)		
	Type	Orientation	Method/technique
Mngt. - vitro	True experimental	Research evaluation - Development Validation	• Statistical methods[2] • Serious gaming / observ. methods (human process)
Mngt. - vivo	Quasi[6]-true experimental	Research evaluation - Development Validation	• Statistical methods[2] • Observational methods[8]
	Pre experimental[5]	Research evaluation	• Statistical methods[2] • Observational methods[8]
Phys. - vitro	True experimental	Research evaluation - Development Validation	• Statistical methods[2] • Lab or mock-up / observational methods[8] (physical object)
Phys. - vivo	Quasi[6]-true experimental	Research evaluation - Development Validation	• Statistical methods[2] • Observational methods[8]
	Pre experimental[5]	Research evaluation	• Statistical methods[2] • Observational methods[8]

Figure A.2: Research and development methods overview.

[1] Using different algorithms such as genetic algorithms, simplex algorithm, negotiable constraints, etc.

[2] Regression analysis, q-method, structured expert judgement, Multi Criteria Decision Analysis (MCDA) (eg. Preference Function Modeling (PFM), Analytical Hierarchy Process (AHP)), random forests, data and image processing, etc.

[3] Such as Bayesian networks, Markov chains, stochastic processes, etc.

[4] Frameworks, process flow charts, organization models, breakdown structures, swimming lanes, relation diagrams, etc.

[5] Object models (e.g. UML), entity relationship models or XML schemas or other computer programming languages techniques (Python, semantic web design, JSON, etc.)

[6] Could also be performed as a pre-modeling context analysis

[7] Quasi is like a true experiment, a quasi-experimental design aims to establish a cause-and-effect relationship between an independent and dependent variable. However, unlike a true experiment, a quasi-experiment does not rely on random assignment. Instead, subjects are assigned to groups based on non-random criteria.

[8] Active and structured data and information acquisition from a primary source (objects/human) that also involves observing behavior in the environment in which it typically occurs (structured, controlled, naturalistic, participative): e.g. sensors, inter-views, audits etc. It also contains a specific research method to observe the impact of human actions named action research: i.e., action research is a philosophy and methodology of research generally applied in the social sciences.

It seeks transformative change through the simultaneous process of taking action in vivo and doing research, which are linked together by critical reflection.

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Appendix B

Linear versus non-linear optimisation

When it comes to optimisation problems with multiple objectives, three different approaches can be taken:

- A-priori – preferences of stakeholders are defined before the beginning of the optimisation process.
- A-posteriori – preferences are defined after the optimisation process is complete and a set of possible solutions is found.
- Interactive – a combination of the abovementioned methods where preferences are provided during the optimisation run.

Within this course, you will only be working with a-priori methods. As mentioned, within those methods preferences of stakeholders are being collected and introduced into optimisation before running it. When preferences – expressed as weights and preference functions – are collected, we can transform our multi-objective optimisation problem into a single objective one. This, in turn, enables us to use single-objective optimisation algorithms that are less complex and faster (optimisations with multiple objectives are essentially running multiple single-objective optimisations within a single run).

There are multiple optimisation algorithms available for solving single-objective optimisation problems and it is very important to understand what kind of problem you are dealing with. The following characteristics of the problem should be considered:

- What objective function you are dealing with - linear/non-linear, continuous/intermittent, differentiable/black-box? If the objective function is non-linear, is it convex or non-convex?
- What kind of variables do you have - real, integer, Boolean? Do they have bounds?
- Do you have constraints?
- If you have constraints, what kind of constraint function you are dealing with? (The characterization is the same as for the objective function)

The very first thing to think of is if your problem is linear or not. Linear problems are those problems where both, objective and constraints, are linear. If either the objective function or one of the constraints is non-linear, your problem is non-linear. Linear problems are simple to solve and you will always get a definitive solution to your optimisation problem. However, when it comes to non-linear optimisations, things become more complicated.

Within non-linear optimisation, non-linear functions are generally divided into two subcategories: convex and non-convex. Take a look at Figure B.1 depicting two functions – one convex and one non-convex. By definition, a function is convex if when you draw a straight line between any two points of this function, the resulting line will lie above every single function point within this interval. Or, in other words, the resulting straight line will not intersect with the function graph (see the red dotted line in the figure).

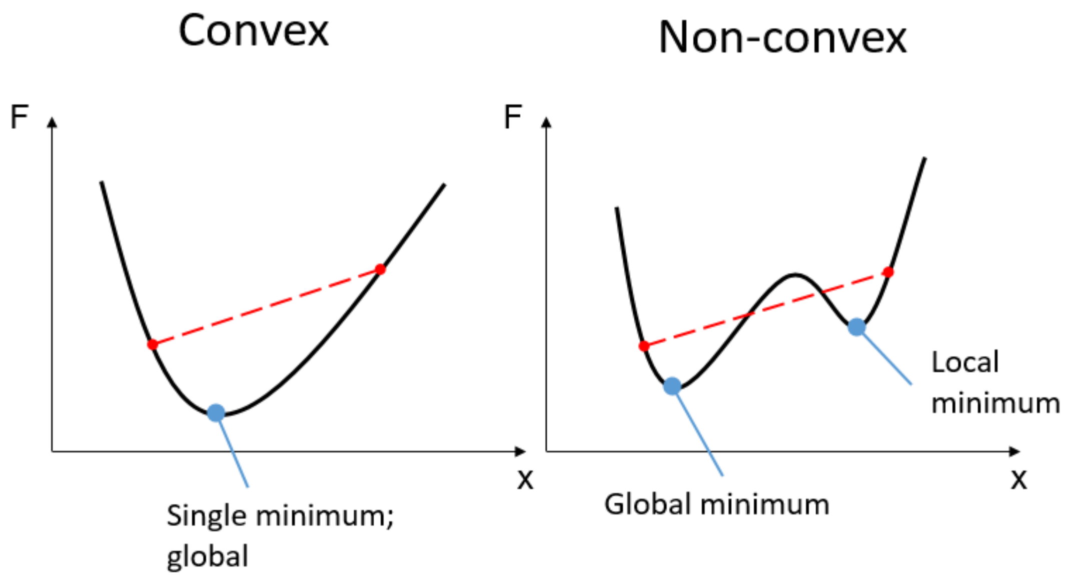


Figure B.1: Convex and non-convex functions.

non-convex functions introduce another complication to optimisations –multiple optima. Look at the figure above, at the non-convex function. Let's say we want to minimize it. It has two minima – one local and one global. Looking at the figure, you can clearly say which point is lower (and, thus, better) because you can see both of them. However, when running optimisations, we don't see the whole picture and basically are trying to find the best option while being blindfolded. We can first find the local optima and stop there thinking it is the best because we don't know that another one exists and is better. When it comes to convex problems, they always have only one optimum and this optimum is global.

Following this logic, non-linear optimisation algorithms can be divided into local (suitable for convex problems, looking for a local optimum) and global (suitable for non-convex problems, looking for a global optimum).

As it was mentioned, the number of existing optimisation algorithms is very large. Similar can be said about the ways of classifying those. Figure B.2 provides a simplified classification of optimisation algorithms and further in the text you can find a short description of each category. Be aware that this is not a definitive guide to optimisation algorithms and that the landscape is much more broad and complex. However, a deep dive into optimisation concepts and mathematics is beyond the scope of this book.

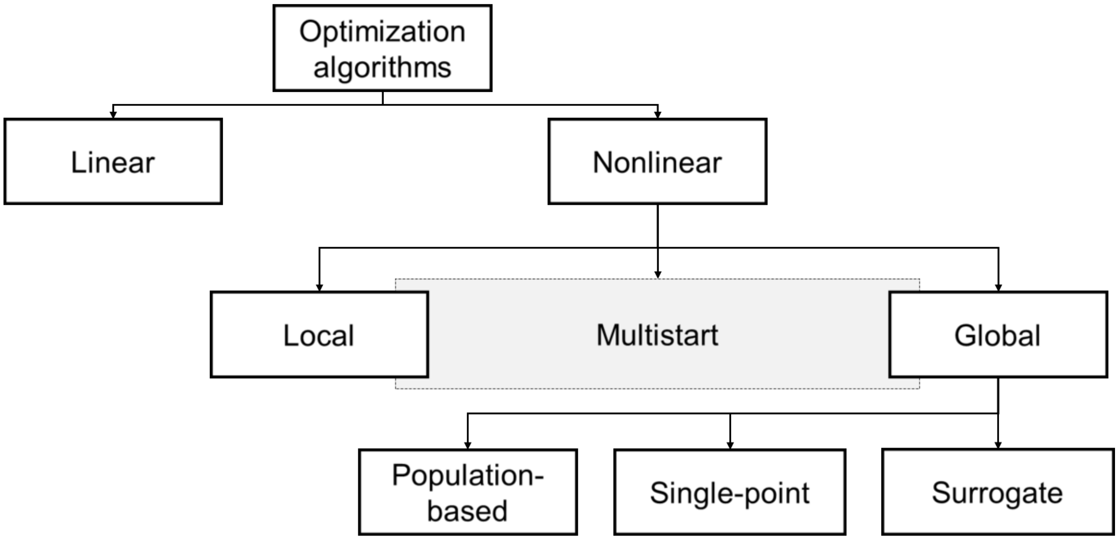


Figure B.2: Classification of optimisation algorithms.

B.1. Linear optimisation algorithms

Linear optimisation algorithms are dealing with problems where both, objective and constraints, are linear.

Those algorithms are very fast. Different variations are available and can handle mixed-integer problems (problems where some of the variables are integer and some are real-valued) as well as equality and inequality constraints. However, the applicability of those algorithms is limited since not many real-world optimisation problems are strictly linear. For the linear Examples in this book we used the following linear solver: docs.scipy.org/doc/scipy/reference/generated/scipy.optimize.minimize.html.

B.2. Non-linear optimisation algorithms

When the objective or one of the constraints in an optimisation problem is non-linear, it is necessary to use non-linear solving algorithms. These can be roughly classified into local, multistart and global.

Local optimisation algorithms

As follows from their name, this category of algorithms is looking for a local optimum. Or to be more exact, they look for any optimum that they can find and stop as soon as they have found an optimum. It can happen that they will find a global optimum this way but it is impossible to know and depends on the optimisation parameters. A typical example of this group of algorithms are gradient-based algorithms.

Figure B.3 shows the same non-convex function we used before. Let's say we want to minimize it. The algorithm is initiated by the user providing a feasible starting point that lies within the solution space. Let's say it is point A in the figure. Then, the algorithm calculates the gradient in that point – a derivative of the objective function. We know that in the point where the function reaches its minimum, the first derivative is equal to zero and the second derivative is positive. In point A our gradient is negative so the algorithm will start searching for minimum by moving in the direction of the increasing gradient (following the arrow in the figure). It will continue until it finds the point where the gradient becomes equal to zero – point A'. Since the second derivative in point A' is positive, this is our optimum and the algorithm stops the search.

However, if we will start from point B, the algorithm will end up in point B' which is a local minimum and will not find the global optimum. This illustrates the key limitation of local optimisation algorithms – the optimisation result is highly dependent on the starting point. Those algorithms can be safely applied to convex problems but are not suitable for non-convex ones.

Depending on the complexity of the problem, it might be complicated to find a suitable local solver. For example, while many of them accept continuous variables, much fewer work with mixed-integer problems. Not all of the algorithms allow constraints or only allow inequality constraints. In many cases, they require functions to be differentiable and are not working with black-box functions.

Multi-start optimisation algorithms

The idea behind multi-start algorithms is to use a local solver but instead of starting from a single initial point, start from multiple. Then when each instance has found a solution, those are compared between each other and the best one is selected. This way, it is possible to explore a larger area of the solution space and find a better solution compared to a regular local optimisation while using

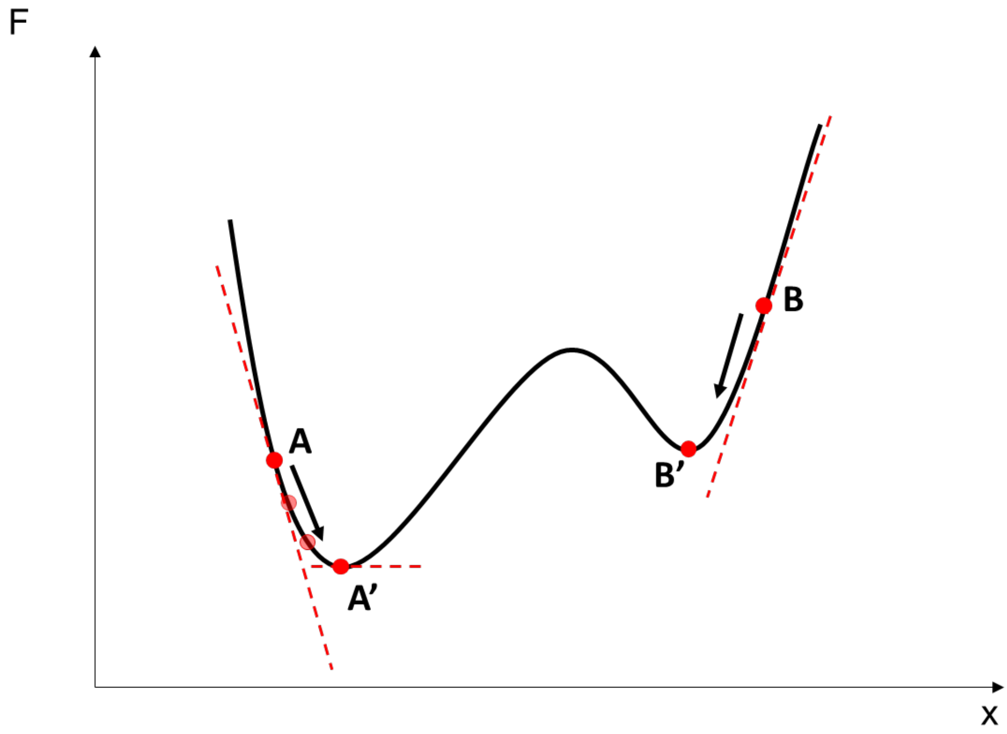


Figure B.3: Gradient-based optimisation.

the same algorithm. Those methods are, thus, taking an intermediate position between local and global algorithms.

Global optimisation algorithms

Global optimisation algorithms have tools that allow them to search for the global optimum in optimisation non-convex optimisation problems, to more efficiently explore the solution space and to avoid getting stuck in a local optimum. However, outside of some special cases, even global optimisation algorithms cannot guarantee to find the global optimum for non-convex problems.

Population-based algorithms The idea behind population-based algorithms is instead of working with a single point, they work with populations of solutions. A population is a set of feasible solutions. It is initiated somewhat randomly in the beginning of the optimisation (it is more complex than that but this is beyond our scope) and then evolves as time goes by. A single step is called a generation. Population-based algorithms are developed in a way that each new generation is better than the previous one and, thus, is closer to the optimum. Figure B.4 illustrates an example of population-based optimisation progress. We start from an initial population consisting of 10 members scattered around the solution space. At the intermediate population, you can see it is migrating towards two minima that this function has. In the final population, most of the members ended up in the global optimum and some beyond it. The best member of this population is then selected as the optimum solution (in this case, it will be one of those 6 members that ended up close to the global optimum). The ways populations evolve depend on the algorithm and we will not go into detail on describing it here.

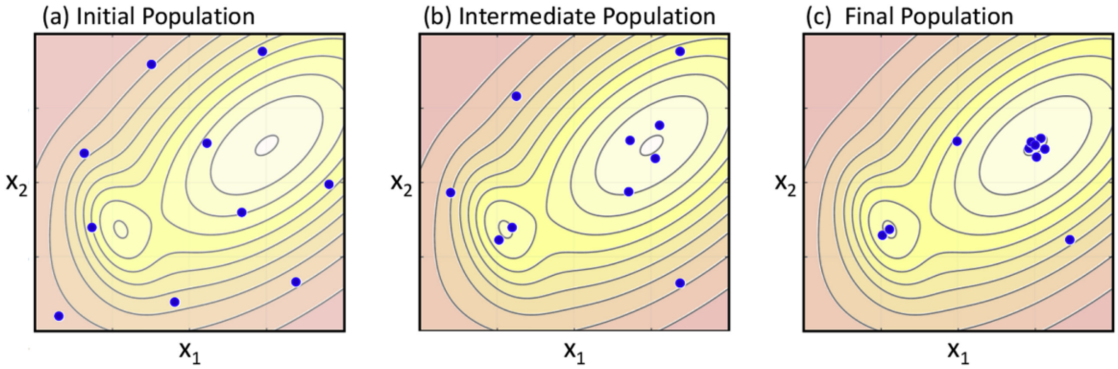


Figure B.4: Population-based algorithm progress (taken from Maier, Holger R., et al. "Introductory overview: optimisation using evolutionary algorithms and other metaheuristics." Environmental modeling & software 114 (2019): 195-213.).

The number of different population-based algorithms is immense but the most commonly used are gGenetic Algorithm (GA), differential evolution algorithm, particle swarm algorithm, ant colony algorithm and artificial bee algorithm.

There are differences when it comes to what kind of problems each of those algorithms support and there are also multiple modifications and additions to each of the algorithms. However, it is safe to say that population-based algorithms are much more universal than local ones. For example, some genetic algorithms can be used for solving black-box problems as well as mixed-integer problems with linear and non-linear equality and inequality constraints.

Note that a GA is inherently stochastic in nature. The (semi-)randomness of the initial (start) population makes it necessary to validate the optimisation result(s) by running it multiple times with different start populations. This is to check if there are no convergence issues that prevent the GA from resulting in an ambivalent optimisation outcome. Moreover, within the Odesys methodology that has to result in a best-fitting design, it is even more important to do this generic validation step to check if we truly arrive at a single design point.

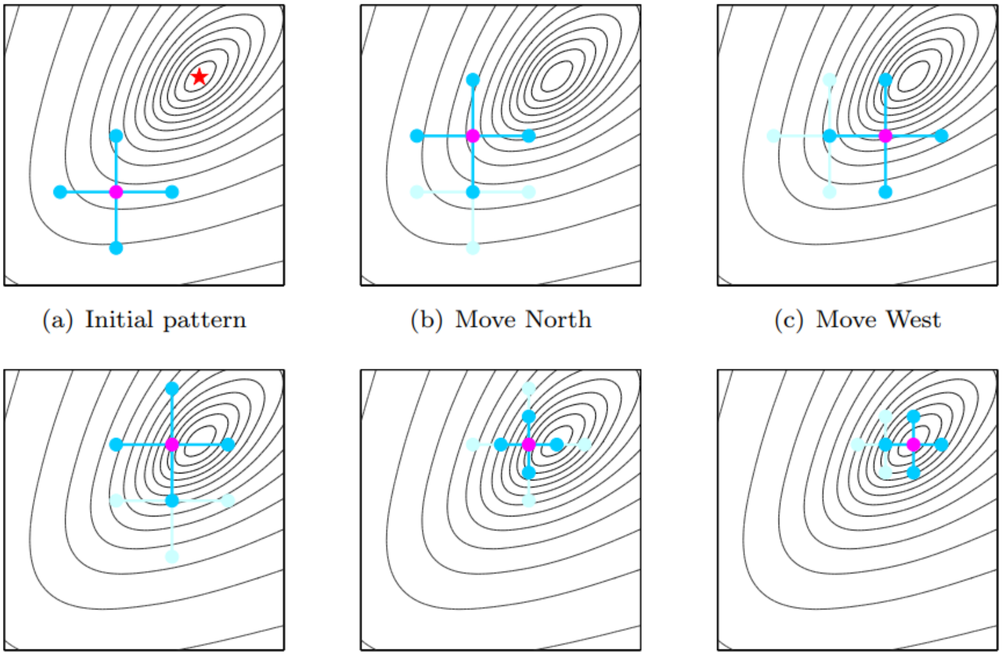
In the Examples of this book where we use the Preferendus methodology (link between the optimisation algorithm and the Tetra) a proprietary algorithm was developed based on the fundamentals of different standard GA solvers[1]. This Preferendus algorithm can be found on `github.com/tudelft-odesys/preferendus_core_scripts`.

Single-point algorithms As it follows from the name, this category of algorithms is not operating with populations but instead with a single point. In this regard, they are similar to local algorithms. However, in contrast to local ones, single-point global search algorithms have features allowing them to escape local optimums and search a larger area of the solution space. However, the result to a high degree depends on the parameters selected. Two typical examples of this type of algorithms are pattern search and simulated annealing.

Let's take a quick look at how the pattern search algorithm works. The idea behind it is very simple. Figure B.5 illustrates the search process using the pattern algorithm. We have a starting point around which we build a pattern. An example of a commonly used pattern is a so-called compass or cross where we have four pattern points located right, left, above and below the central point (see panel (a) in Figure B.5). The algorithm evaluates the function value in the central point and all pattern points and finds the best of those (in case we want to minimize a function, the lowest value). Then it moves the central point to the one that had the best function value. In our example provided in Figure B.5, it is moved North/up. Then the process is repeated. Sometimes it can happen that the central point will have the best value compared to the pattern points. In this case, the pattern is contracted (shrunk) and the values are evaluated again (panel (e) in Figure B.5). The process continues until we reach termination criterion which is normally related to the size of the pattern – when it becomes very small, there is no feasible upgrade in results anymore since the central point almost doesn't move. There are versions of single-point algorithms that allow constraints and can work with mixed-integer problems. However, they are generally not as thorough as population-based algorithms and are better used for smaller problems. When the search space is large, population-based algorithms perform better.

Surrogate optimisation If the objective function is computationally expensive and takes a long time to evaluate or when it is a black-box function, surrogate optimisation can be utilized. The idea behind surrogate optimisation is to build a "surrogate" – a function that approximates another function that is normally too computationally expensive. The whole surrogate optimisation process can be divided into three stages:

[1]GA sources (as also can be found on Github): Brownlee, J. (2021, March 3). Simple genetic algorithm from scratch in Python. Machine Learning Mastery. Retrieved November 25, 2021, from https://machinelearningmastery.com/simple-genetic-algorithm-from-scratch-in-python/. Kramer, O. (2008). Self-adaptive heuristics for evolutionary computation. Springer. Solgi, R. M. (2020). geneticalgorithm: Genetic algorithm package for Python. GitHub. Retrieved April 20, 2022, from https://github.com/rmsolgi/geneticalgorithm



(a) Initial pattern (b) Move North (c) Move West

(d) Move North (e) Contract (f) Move West

Figure B.5: Population-based algorithm progress (taken from esa.github.io/pagmo2/docs/cpp/algorithms/compass_search.html).

- Sampling
- Surrogate function fitting
- optimisation of the surrogate

Surrogate optimisation is often used in cases where your objective function is calculated within some dedicated software package but it is not known how exactly it is calculated or it is known but the process is slow. For example, the energy consumption of a building is a very important parameter and is a commonly used objective in building design optimisation. However, it is normally being calculated using energy simulation software such as EnergyPlus where each simulation takes several minutes. The whole optimisation process includes many iterations and can take days in this case. However, it is possible to build a surrogate model that would approximate the outputs of energy simulation software and use it in optimisation. That would greatly speed up the optimisation process.

Appendix C

Preferendus Genetic Algorithm

To find the design configuration which reflects the integrative maximum preference aggregation (Preferendus/IMAP), it is necessary to use an optimisation algorithm. Moreover, this IMAP algorithm will also need to be able to inter-operate with Tetra, which is the Preference Function Modeling (PFM)-based Multi Criteria Decision Analysis (MCDA) software tool. The algorithm of the non-linear Tetra solver is based on minimizing the least-squares difference between the overall preference score and each of the individual scores (on all decision criteria) by computing its closest counterpart (for more information on the Tetra software, see scientificmetrics.com).

For this purpose, a Genetic Algorithm (GA) has been developed that is specifically tailored to inter-operate with Tetra and its specific features of normalized scores and relative ranking. We will first describe these.

C.1. Normalized scores

Preference scores are expressed as number on a defined scale, here ranging from 0 to 100, where 0 reflects the 'worst' scoring design configuration/alternative and 100 the 'best'. This means that when aggregated preference scores are normalized, the best alternative will always get a score of 100 and the worst alternative will always have a score of 0. As a GA will typically check whether the best score of the current generation (G_n) outperforms the previous one (G_{n-1}), normalized scores will lead to problems in convergence because the GA can not determine whether improvement is occurring since the best alternative always scores 100.

Also in the case of constrained problems, where the alternative with a score of 100 might be unfeasible and should be taken out of consideration, problems with convergence persist. As a result, it might be possible that the best feasible design alternative will have a lower preference score in generation G_n compared to generation G_{n-1}. This is because due to normalization, the score of one alternative always depends on the performance of all other alternatives. This needs to be accounted for within the GA solver.

C.2. Rank reversal

Rank reversal, the notion that ranks might change when an alternative is added or removed, is commonly encountered in different MCDA models, and is also present in Tetra Wang and Luo 2009; Aires and Ferreira 2018. This phenomenon is commonly observed when a non-competitive (i.e., irrelevant) alternative is added or removes from the population Aires and Ferreira 2018. In short, especially when extreme or 'irrelevant' (i.e., no real-life meaning) alternatives are added/removed, rank reversal can occur, potentially leading to convergence problems in finding the best solution by evaluating whether generation (G_n) outperforms the previous one ($G_(n-1)$). Moreover, as an initial population is generated (quasi) randomly, it is not unlikely that extreme or irrelevant alternatives will be part of the first generation evaluated by the GA. These alternatives would never be considered in reality, creating a discrepancy between the GA solver and real-life design alternatives that should be mitigated to achieve convergence.

C.3. Modifications to the GA

To solve the aforementioned issues resulting from normalization and/or rank reversal, the following modifications were applied resulting in a so-called intergenerational GA solver:

(1) an additional step must be added in the evaluation of a generation. After determining the aggregated preference scores for the complete population, the member with the highest rank is added to a list. This list contains the best members of all generations ($G_n, G_{n-1}, ..., G_0$) and is evaluated separately to acquire an aggregated preference score for all members of this list. In case the aggregated preference score of generation G_n yields a lower score than G_{n-1}, no improvements are made. However, if the score of generation G_n equals 100, the GA has either improved or, if the score of generation G_{n-1} also equals 100, a temporary optimum has been found.

(2) the initial population can be built from user defined initialized solutions. These solutions can be arbitrarily chosen or guided by the single objective and/or min-max design optimisation outcomes. Thereby, the initial population is not (quasi) random anymore because it reflects true potential design points, reducing the probability of non-convergence from the start. After this first starting evaluation, mutation will start diversifying the population, making it again possible to reach another optimal solution even though the initial population is directionally determined.

Note that this implementation of 'arbitrary' initialized solutions is also of great benefit for the validation of the final results. Running the same problem with different starting points can confirm that the result is indeed optimal.

(3) at the re-evaluation of the function U (see Equation 6.1), always an additional specific re-evaluation is introduced by feeding the GA as much as possible with potential real life design points. Here, a re-evaluation of the population is implemented as follows, so that the very worst alternatives are left out, which reflect irrelevant non-competitive alternatives. This means that after this population is evaluated, only alternatives with an aggregated preference score higher than a specific lower limit P^* (which can be set by the designer, here fixed at 40) will be re-evaluated a second time, improving GA convergence.

The three aforementioned modifications have been added to a fit for purpose inter-generational solver GA, where key elements from standard available GA Python packages have been integrated enabling comparing the aggregated results of one generation with another. See the data availability statement for the code of this solver.

Note that the aforementioned modifications are the result of pragmatic engineering judgment using the principle of reflection, and after validation of a multitude of example problems. As a possible specific step for further research, it may be of interest (partly in the perspective of improved solving speeds) to investigate whether other optimisation algorithms than a GA might be more suitable for this specific purpose.

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Appendix D

A-priori versus a-posteriori methods

Multi-objective optimisation applies to decisions that need to be taken in the presence of trade-offs between several objectives (of different stakeholders) that are in conflict. Objectives relate to design/decision variables that stakeholders are interested in. In terms of decision making these are the decision criteria. Several methods have been devised to solve multi-objective optimisation problems. A limited but most commonly used set is described below and the pros and cons of each is summarized in a table. We distinguish between two main approaches: 1) a-posteriori methods and 2) a-priori methods. For background information the reader is referred to classical literature on engineering design optimisation (e.g. Martins and Ning (2021)).

D.1. A-posteriori methods

A-posteriori methods: we determine (all the) potential solutions and make a decision afterwards.

Weighted objective function

We use the 'weighted objective function' method, and give different values to weights to cover all the possible combinations. We use an optimisation algorithm to find optimal solutions. We plot the solutions we arrived at: the Pareto front. We select a solution within the Pareto front.

Pareto optimal solution: none of the objective functions can be improved in value without degrading another objective function values. All Pareto optimal solutions are considered equally good. Stakeholders still need to negotiate on selecting the design point on the Pareto front. The Pareto front is used in the a-posteriori decision-making process.

Preference Function Modeling

We determine the preference ratings of solutions we obtained by optimizing on single objectives i.e. relevant criteria. We assign weights to the criteria. We use the Preference Function Modeling (PFM) algorithm to determine the overall preference ratings of solutions to determine which solution has the highest overall preference rating. Preference ratings for decision variable values (criteria) are determined using linear or nonlinear interpolation (curve fitting).

D.2. A-priori methods

A-priori methods: we translate the multi-objective problem into a single objective optimisation problem.

Weighted objective function

Assign weights to criteria which define the relevance/importance of the criteria. Use the weighted sum method to aggregate scores of candidate solutions to and use an optimisation algorithm to find the local/global optimum solution. We use an optimisation algorithm to find optimal solutions. We plot the solutions we arrived at: the Pareto front. We select a solution within the Pareto front.

Pareto optimal solution: none of the objective functions can be improved in value without degrading another objective function values. All Pareto optimal solutions are considered equally good. Stakeholders still need to negotiate on selecting the design point on the Pareto front. The Pareto front is used in the a-posteriori decision-making process.

Goal attainment

Each criterion has an associated target value. We use an optimisation algorithm to find the optimal solution by minimizing the largest difference between target values for criteria and the values of a candidate solution. Also called the min-max method.

Preference Function modeling

For each criterion preference function curves are defined and weights attached. The PFM algorithm is used to aggregate scores and weights into overall preference ratings. An optimisation algorithm is used to find the local/global optimum solution.

Figure D.1 summarizes the pros and cons of each approach.

A posteriori methods

	Pros	Cons
Weighted objective function (as used within Pareto front)	• Relatively easy to apply.	• Mathematical operations are applied in mathematical spaces where they are not defined. • Problems with representation when preference or utilization are ignored, since then only weights are evaluated. • Negotiation or a method like PFM is still needed to select the best fit for purpose solution from a Pareto Front. • Conveying / representing outcomes is problematic when more than 3 objectives are considered. • Ignores the social aspect of decision-making, which is unnatural.
Preference Function Modeling	• Based on a sound mathematical foundation. • Stakeholder preference is the basis of optimization. • Considers the social aspect of decision-making problems (socio-technical optimization)	• Aggregated alternative scores are relative and dependent on the set of alternatives under consideration. • Aggregation algorithm unknown.

A priori methods

	Pros	Cons
Weighted objective function	• Searches for a global/local optimum that decision makers can accept/reject. • Easy to apply. • No major problems with convergence.	• Mathematical operations are applied in mathematical spaces where they are not defined. • Problems with representation when preference or utilization is ignored, since then only weights are evaluated.
Goal attainment	• Searches for a global/local optimum that decision makers can accept/reject. • Relatively easy to apply. • Does not violate PFM theory.	• Stakeholder preference is translated in deviation from target value in relative terms – linear proxy of preference. • Limited representation of a decision problem because individual satisfaction is considered more important than group satisfaction.
Preference Function Modeling	• Based on a sound mathematical foundation. • Allows stakeholder to express non-linear preference functions. • Stakeholder preference is the basis of optimization. • Considers the social aspect (preference) of decision-making problems (socio-technical optimization) • Relative ranking of alternatives is representative for real-life DM	• Aggregated alternative scores are relative and dependent on the set of alternatives under consideration; requires modification of optimization algorithm. • Search algorithm convergence is problematic. • Aggregation algorithm unknown. • Can be slow for large complex objective functions (e.g., railway dynamics)

Figure D.1: Overview of optimisation approaches.

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Appendix E

Choice matrix algorithms

This book uses a variety of optimization algorithms. However, not all of them are applicable to every design/decision problem. To give a quick overview of the different algorithms and their applicability, Table E.1 is made, which can be found on the next page.

The listed examples can be found on GitHub: `github.com/TUDelft-Odesys/Preferendus_core_scripts`.

Table E.1: Overview of the different optimization algorithms used in this book and their applicability.

Decision variables	Functions (P or O or F)	SODO	MODO/IMAP (Preferendus)	MODO/Min-max
$x_n =$ **continuous** $x_m =$ **integer**	**Linear**	**MILP** *Examples:* • *Computer production*	**GA** (option 'aggregation' = 'tetra')	**GA** (option 'aggregation' = 'minmax')
$x_n =$ **continuous** $x_m =$ **integer**	**Non-linear**	**GA** (option 'aggregation' = None) *Examples:* • *Dutch rail level crossing* • *South Korean floating wind farm*	**GA** (option 'aggregation' = 'tetra') *Examples:* • *Dutch rail level crossing* • *German power transmission line* • *Norwegian light rail* • *South Korean floating wind farm*	**GA** (option 'aggregation' = 'minmax') *Examples:* • *Dutch rail level crossing* • *German power transmission line* • *South Korean floating wind farm*
$x_n = x_m =$ **continuous**	**Linear**	**Minimize** *Examples:* • *Bridge design* • *Railroad maintenance plan* • *Shopping mall*	**GA** (option 'aggregation' = 'tetra') *Examples:* • *Shopping mall* • *Bridge design*	**GA** (option 'aggregation' = 'min-max') *Examples:* • *Shopping mall*
$x_n = x_m =$ **continuous**	**Non-linear**	**Minimize** *Examples:* • *Building design*	**GA** (option 'aggregation' = 'tetra') *Examples:* • *Shopping mall* • *Supermarket*	**GA** (option 'aggregation' = 'min-max') *Examples:* • *Supermarket*

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About the author

Prof.dr.ir. A.R.M. (Rogier) Wolfert has been appointed professor of engineering asset management in the faculty of Civil Engineering and Geosciences at Delft University of Technology since 2013. Here he has lectured within several MSc curricula and was an advisor of several PhD and MSc students. He has worked with R&D groups at various universities and research institutes for the past 30 years, both nationally and internationally. He gained R&D experience both at the level of fundamental engineering design and at the level of applied engineering asset management. He is the author of several papers published in scientific journals and/or presented at international conferences. He has acquired both governmental funds (EU and Dutch NWO/TTW) and industrial research funds, and managed the associated projects. Rogier has built a proven track-record for operating various industrial management roles both within infrastructure service provider and engineering projects & services contractors. Over the past 20 years, he has been involved in the design, construction, financing, maintenance, and operation of various types of inland and offshore infrastructures. He has contributed to the planning, development, and management of leading projects and services contracts, all of which have had a significant impact on Dutch society. He has extensive experience in managing multidisciplinary and international teams with professionals from different cultural backgrounds. He is used to working at different levels within the organization. He has authored several industrial reports.

As a person, Rogier is focused, goal-oriented, fast in grasping the big picture, and able to quickly put his finger on the key problems. As a problem solver, he is effective in implementing solutions to get results. As a systems integration thinker, he is very much able to connect different domains and parties while retaining their strong individual values. As an open design systems engineer, he is able to find the golden mean and is prepared to follow creative, non-conformist, and/or non-conventional paths for seemingly insoluble problems. He is in his element in dynamic and complex systems environments where new solutions must be found. He is convinced that everyone has a designer inside themselves, and his purpose is to foster Odesys & ODL to awaken them. Last but not least, Rogier considers both the outer mechanistic-matter observation and the inner spiritual-mind experience as companions on his journey into the emerging future.

Rogier holds both doctor (Dr.) and master (Ir.) degrees from Delft University of Technology. He is 53 years old, married, and has four children.