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Preface

This book is for the reader who wants to acquire new engineering skills related to concrete, complex solutions through the modeling of objects in 3D space. Anyone who has ever dealt with modeling, or just simple drawing, soon finds out that the straightforward examples from exercises are easily repeatable. However, there are few such examples in real-life. Therefore, we have decided to offer a better and more detailed presentation of the complex shapes and problems associated with the modeling of real objects. Based on our years of experience with a large number of people through graduate and master's study programs we have decided to opt for the gradual acquisition of knowledge, which leaves it well grounded in the student.

The extent of the material exceeds that required for regular study. However, there are a couple of universities that deal in detail with such basic knowledge, the basic language of engineers, i.e., the ability to present new products and ideas. Our cooperation with industry, various institutes, and our long experience in designing products with various complexities have resulted in a wide range of examples compared to regular monographs. We leave the readers to form their own opinions about the large number of presented examples.

We should point out that the transferring of dimensions and details to technical documentation represents the pinnacle of modeling. Of course, anybody dealing with the quality and perfection of products is aware of this. Should the readers find that the presented knowledge about detailed modeling and the special forms of technical language are both new and interesting, and that they are able to generalize and use it confidently, we will derive great satisfaction.

During the Bologna reforms, our colleagues suggested that in the first semester students should acquire new knowledge about descriptive geometry and technical drawing. In the second semester, this knowledge is upgraded with skills related to space modeling. At the end of the semester, the students are made familiar with transferring a shape to the high-quality representation of a product by means of technical documentation. Our 8 years of experience has shown that in later stages—in machine elements, energy systems, and manufacturing engineering courses—students can easily present their ideas using complex models. This was a proof of our intention to also include knowledge about the high-quality presentation of ideas in the 3D environment in a new profile of engineering competences.

Developing methods and the complexity of models for industrial design, for example, requires familiarity with free-form surfaces, which will be the next logical step after the content of this book. We believe that the presented systematics will allow both students and their teachers to easily recognize the upgrade to their existing knowledge. This belief was also confirmed by our staff engineers, who were willing to attend special courses to upgrade these skills, mainly in 2D space.

The hand-sketching chapter was taken from the book “Engineering Graphics,” where a co-author is Prof. Milan Kljajin from Strossmayer University (Osijek, Croatia). He confirmed that we were able to use this content. We would like to express many thanks to him for this permission. Our book would be incomplete without this chapter.

A book of this size cannot be written by a single author. A substantial contribution to its final form came from a team of Ph.D. students, Damijan Zorko and Pavel Tomšč. Mateja Maffi, Simon Demšar, and Paul McGuiness took care of the translation and proofreading, and the technical editing was carried out by Janez Krek. They all deserve sincere gratitude for their tolerance and patience.

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Contents

Chapter 1
Introduction

Abstract Various layouts are presented for the working places in a classroom that allow communications between the tutor and the students. This is followed by a presentation of the different forms of engineering graphics that are subject to changes in the Research and Development (R&D) process. This R&D process includes three loops in the research and strategic parts, and a golden loop in the development phase. The developments of the graphic expression from the sketch to the working documentation are specified, and directly connected with the phases of the R&D process.

A knowledge and understanding of space and its dimensions are important for both engineers and designers. Some people are born with a talent to understand space, objects and their distribution, while others can learn it. However, such a talent must be developed, which makes learning about and understanding the concept of space vital, even for the most talented of individuals. Learning provides a solid basis for a detailed study of space, particularly the systematic organization of space. Excellence in terms of knowledge is acquired through constant training and the resulting improvement. Should engineers or designers not learn about the fundamental forms of expression, such as a sketch on a piece of paper and/or a digitised model on a screen, they will gradually lose the ability to present their ideas with clarity.

Without training, they forget that it would be better to replace their gesticulating and gobbledygook with a pencil and paper in their hands. Of course, instead of a pencil, it is often enough to take a piece of clay brick, and some concrete or a rock for the writing surface. With a sketch it only takes a few lines to present our thoughts clearly. At first sight, this method of presentation might seem too rough to create new ideas; however, it is a fact that an initial idea is often presented with very rough concepts. An idea that originates in the abstract, conceptual world of an engineer represents creativity that is later reflected in the real-world environment. This is the virtue of having an engineering understanding of the world, as each line, each thought, expressed by a sketch, provides the reliability of connections. Together with numerical proofs it provides the possibility for modern man to be able to live in

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tall buildings and to travel by aeroplanes, trains and ships. It is difficult to imagine a person using a flat in a skyscraper or flying in aeroplanes with a feeling that the skyscraper might fall apart or the aeroplane might not take off because, in such a technical system, an object would not have been specified in all the required details.

The objective of a space-modelling course is to acquire the practical engineering and designer skills to express 3D shapes and the necessary variations by assorted means of expression. The exercises during this course provide training that will reinforce an individual's knowledge. The course is suitable for the first year, second semester of a university study programme, in order to provide a student of technology or design with the fundamental knowledge of expressing and specifying a shape in space, similar to the need for a solid basis in mathematics, physics, materials science.

It is possible to gain an understanding of space modelling immediately after gaining the basics of descriptive geometry and technical documentation. The lectures and exercises take place weekly. They are structured in such a way that the students upgrade their knowledge from simple objects to complex models. The whole course of exercises includes three interactive knowledge assessments. Such a course of exercises requires quality software and computer equipment. Special attention has been paid to this area as it is not possible to acquire high-quality knowledge without high-quality hardware and software. Good computing equipment provides a good response during the use of individual routines, while high-quality software provides reliability for the performance of the modelling.

Particular knowledge is presented through examples of characteristic shapes and features. Each characteristic shape is presented with a short introduction, followed by presenting the use of the feature in the manufacturing process. General description is presented, which is useful for all modelling software. In the next two sub-chapters we describe modelling with SolidWorks software, which is more user-friendly for beginners. This is followed by NX, which belongs to the area of advanced modelling software. Our objective is not to teach the routines for a particular software package, i.e., SolidWorks or NX in our case, but to teach the modelling philosophy with the use of features from different shapes that are more or less the same for all modelling software. The differences between the different modelling-software packages lie mainly in the user interfaces.

In preparing the work programme for basic modelling we have included all the necessary skills, knowledge and findings that complement the need for acquiring a comprehensive knowledge of solid-body modelling. Table 1.1 shows the topics that a student at a good university will cover (2 h per week) and the knowledge that he or she can acquire with additional study and training at home after 30 h of exercises.

From the presented programme it is clear that there is a special emphasis on the individuality of the exercises. This means that it is not appropriate for two students to do the exercises behind a single screen or on one computer. It goes without saying that the structure of the classroom and the software for systematic exercises require a special approach, i.e., a special architecture for the room. High-quality software, integrated into a unit, is also vital.

Table 1.1 The topics and the order of tutorials for space modelling

Excercise no.	Topic covered during exercises	Note
1.	Role and meaning of modelling for engineering	Introductory tutorial, Boolean algebra, sketching
2.	Making a sketch and extrude	
3.	Making a sketch and revolve	
4.	Auxiliary shapes of modelling	Fillet, chamfer
5.	Assessment—combined models	
6.	Complex shapes—sweep, loft	Sweep, loft
7.	Welded structures	
8.	Sheet-metal products	
9.	Measuring a physical model, digitising, parameterisation	
10.	Assessment—physical models	
11.	Assemblies of structures with models—bottom-up technique	
12.	Assemblies of structures with models—top-down technique	
13.	Documentation—assembly drawing	
14.	Documentation—working drawing	
15.	Assessment—examples as finished units	Seminar work

1.1 Arranging Rooms for the Study of Modelling

Organizing a suitable room for a small group is an important task. Exercises can only be performed well if at least one assistant (a leader and an assistant, who could be a student from a higher grade) is available for every 6–8 students. A suitable group has between 12 and 16 students. With two experts in the room for an accelerated interaction with the students, the access to the students should be fast. This is achieved by providing at least 60–70 cm of space behind the seats for the expert to gain access to each student.

Larger classrooms with up to 30 places are possible; however, the work then slows down significantly, despite having up to twice as many experts. In this case there are four experts in each classroom (and three in special cases). The classroom plan for 16 places is shown in Fig. 1.1. A classroom with 32 places is shown in Fig. 1.2. In the case that the classroom is narrower and longer, the plan can be designed in accordance with the template in Fig. 1.3.

Because a programme-integrated environment is vital for a quick response and good communications with the students, it is shown on its own in Fig. 1.4. The concept involves a joint server with 16 working places and the main specifications of the hardware that were available on the market between 2010 and 2014.

Fig. 1.1 Classroom plan for 16 working places and connections

1.2 Development and Design Process and Engineering Graphics

Engineering uses different demonstration techniques: writing (describing), mathematical formulae (equations) and drawing (sketching, modelling). Writing is a matter of general human education, whereas mathematical formulae are a way to use equations in order to describe natural phenomena. Engineering drawing is used to show nature in space. Artistic drawing, on the other hand, serves a different purpose. The latter describes things as realistically and as clearly as possible, whereas engineering drawing in its final form yields a plan. This plan should be as clear to as many users of different cultures and skills as possible, and was the basis for the introduction of the standards for engineering expression, i.e., technical drawing. Such engineering expression through drawing is generally referred to as engineering graphics.

The more sophisticated is a product, the more detailed is the knowledge of engineering graphics that needs to be applied. While thinking, in the abstract world, when a rough, immaterialized idea is emerging, we should begin with a freehand sketch. Freehand sketching uses specific techniques and requires a certain level of knowledge. The techniques of freehand drawing are based on manual dexterity, and on refined motoric functions of the hands and fingers. For this reason it is vital to learn

Fig. 1.2 Classroom plan for 32 working places and connections

freehand-drawing techniques so that our records will be clear and unambiguous, in a similar way to clear writing.

Unskilled engineers, not using a sophisticated freehand-drawing technique, will express themselves with a lower quality. It is difficult for them to articulate an idea; it is difficult to place it in space. With freehand-drawing techniques it is vital to take account of the abilities in proportional ratios, in both details and dimensions.

As engineers, we develop and study how to make people's lives in their surroundings easier in practical terms. And so, developing the world, we think how to work smoothly in a process that allows us to materialize an idea with a product in the form of an object. In this view we have developed different approaches and procedures, one of them being the R&D process. In this process, individual phases are specified. They are then processed consecutively, depending on the expected results of the task during each phase. As a rule, they are not limited in terms of detailed analyses and researches in a particular phase, nor by going back to the previous phase for further information. The R&D process is known as iterative, supplementing and generally based on the decisions of the team or its decision makers. What to expect as a result in each phase is specified in descriptive, analytical-mathematical, and graphic forms. Generally, there are several forms of R&D processes as well as different methods

Fig. 1.3 Classroom plan for 32 working places and connections (an extended classroom with a screen of the same size)

of processing. In this book we will elaborate on one that was developed in both theory and during work on projects. The model is not limited to a traditional industrial product. It is generalized and includes all the necessary synergy of knowledge. The R&D procedure was first published by Duhovnik [7] as the Golden Loop in the Design & Development process in 2003 at TU Delft and University of Wroclaw. It was then supplemented with early-phase research on the technology of processes [12] that a product should provide (Fig. 1.5).

At this point the focus will be on the main parts of the R&D process. More information and a more detailed explanation are available in the literature.

The innovative loop is of key importance for recognizing a problem and placing it in space. In the innovation loop we specify the task, the requirements and the wishes that play a part in defining a problem or a technological process (e.g., cutting

Fig. 1.4 Network lecture room with hardware capabilities

bread, lifting a liquid and taking it into the mouth—a spoon is intended for the same process in both Chinese and European cuisines). All rough starting points are generally supported by rough sketches, rough models (Plasticine, real models made out of wood or virtual—digitised). Together with specifying the shape of an expected object, its function—described by parameters—should also be defined. However, not all parameters are of the same importance. The important parameters are identified by means of various methods. They are called the winning parameters. The winning parameter of each function is the one that significantly affects the fulfilment of a particular function, so it is called the winning parameter of the main function (it can be physical, chemical, biological, etc.).

The system-engineering loop places an expected result (innovation, a high-quality product)—vital for the materialization of a product—logically into space and time. An innovation that is not system-defined in the engineering, general, social environments, generally receives no response from the market or users, which keeps such an invention at the level of a hobby.

The application research loop is important in order to define the parameters that provide an optimum choice of function in the material, the conceptual and the user's

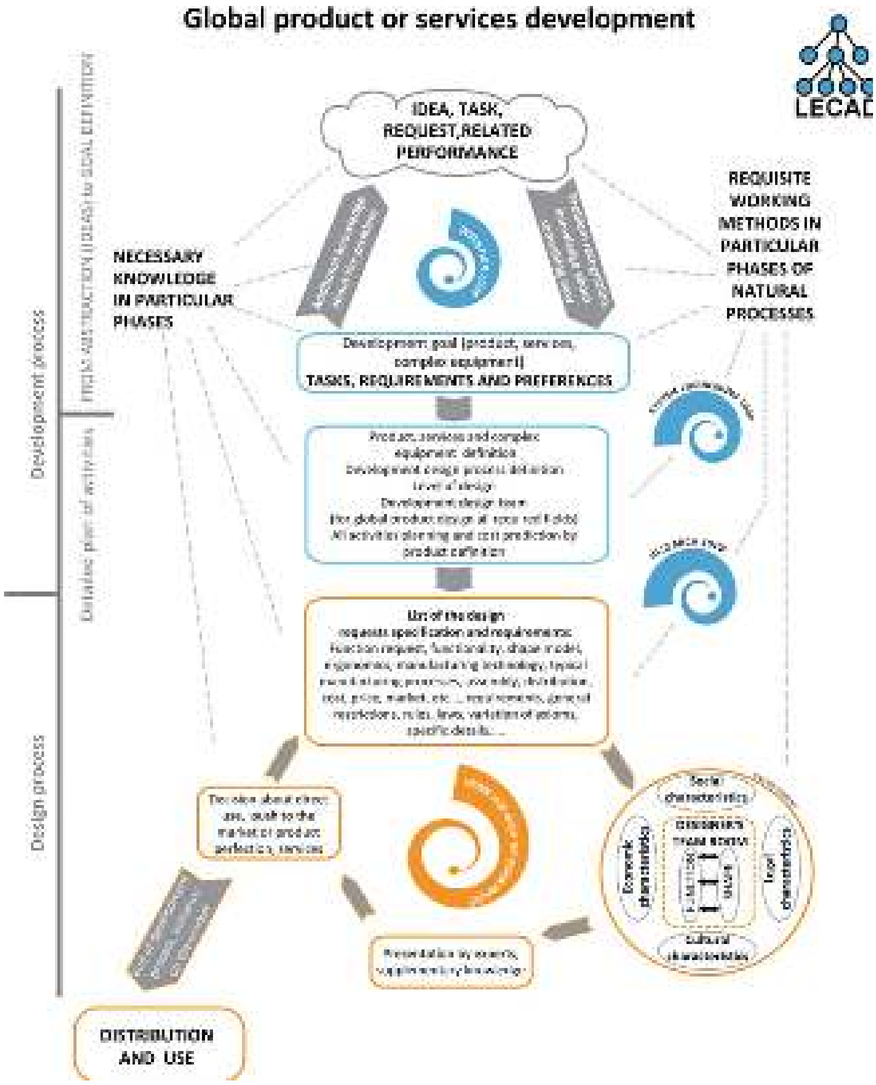

Fig. 1.5 The R&D process includes four loops [12]

environment. Fundamental and application researches are in tune with and of vital importance for the development of mankind. Supported by engineering solutions, they are the key to the reliable, high-quality and long-term development of mankind. Any deviation from the integrity and the connection between fundamental and application researches is a clear sign of the level of the development of a particular environment.

The golden loop in the development process defines a product in all its details, supplements fundamental researches for all key parameters that define the details and quality materialization of a product. These are referred to as application researches, and they are vital for defining the perfection of a product. Without detailed application researches—dealing with the interaction between the basic process and the material environment—a product cannot be sustainably and well placed in space and time. It was for this reason that it was termed the "golden loop".

With such a recognized R&D process it makes sense to determine the role of engineering graphics. It is up to the engineer to chose the forms of engineering graphics to be used during the individual phases of the R&D process.

At the beginning of development, man expressed quantity in the form of analogue notes and tried to reproduce them. However, there has always been a desire to digitise analogue records. Therefore, besides text digitising (in the form of ASCII code) at an accelerating rate due to its simplicity, there were increasing attempts to digitise the notes. At first, dot recognition was used; however, high-quality records take up a lot of memory. Together with dot recording, there were also attempts to describe sketches with vectors. Vector graphics found their way into engineering sketching, and recording specific shapes, including free, random areas, takes up significantly less memory.

Vector expressions are presented in various books and form the basis for the development of mathematical relations in all modelling software, including SolidWorks and NX. For reasons of simplicity and accessibility for a larger number of users, this book expresses engineering shapes using commands that will become standard in the communications between man (the user) and computer. The mathematical basics will be briefly presented in the third chapter. In engineering graphics it is our objective to quickly acquire a digitised record of a developing product, which is then translated into other types of analyses and simulations. So, we will skip transferring shapes from one software package to another, e.g., from modelling software into FEMs (finite-element methods), CFD (computational fluid dynamics) or Moldflow (Simulation Moldflow software provides simulation tools for injection-mould design, plastic-part design, and the injection-moulding design process).

A sketch should be digitised as soon as possible and presented in 2D or 3D space. When we have rough, less-accurate data in the sketch, the product model (Fig. 1.6) is rough, too.

We can then proceed to a rough product model, or a wooden model, clay, hard polystyrene or Plasticine. In this case, 2D or 3D scanners are used to capture their dimensions, which are then transferred into modelling software in a digital form (Fig. 1.7).

Prior to the system engineering loop we need and expect to develop significant engineering details with rough calculations of the loads and deformations. Text and mathematical equations are generally used to describe the functions for such analyses. For shapes, it is a freehand sketch or sketching in a digital model. With modelling software, there are different approaches to sketching detailed shapes, which are then logically introduced into the basic digitised model. A shape, presented with a model, forms the basis to establish a link between the function and the shape in the research

Fig. 1.6 Engineering graphics in the R&D process for the four characteristic loops

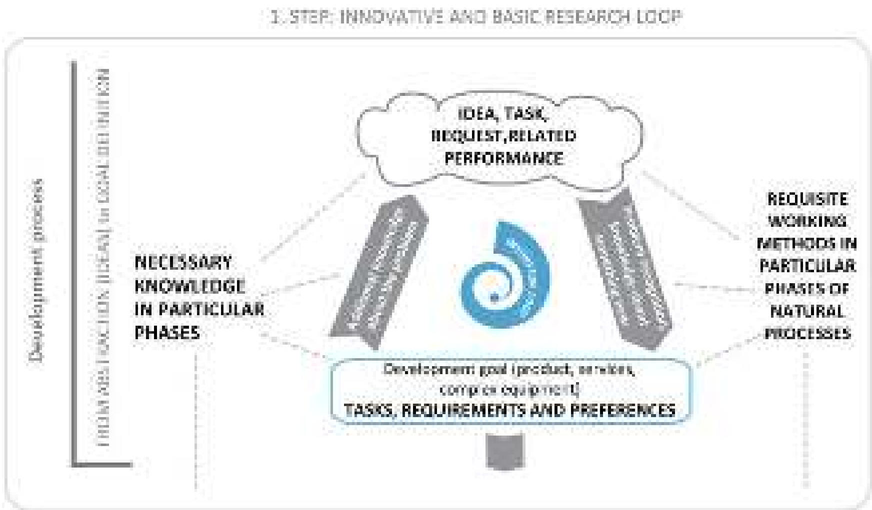

Fig. 1.7 Research and innovative loop and its detailed activities