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Good Engineering Design – Design Evolution by Languages

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Abstract

This essay for the inaugural issue of *Technology and Language* shows that the mastery of multiple languages is the enabler for good engineering design. Engineers express ideas and for that they need expressive design languages. If a language is a structured system of symbols serving communication, the languages of engineering include German, English, and Russian, mathematical and programming languages, technical drawing and formal modelling, with abstract design elements constituting a further, engineering-specific language. The semantics and thus the basic elements of these languages constitute the design space, whereas the syntax constrains the expressivity of the language and structures the design space.

Keywords: Design; Languages of engineering; Good engineering; Communication

Аннотация

Данное эссе для первого выпуска журнала *“Технологии в инфосфере” (“Technology and Language”)* показывает, что владение множеством языков необходимо для хорошего инженерного проектирования. Инженеры выражают идеи, и для этого им нужны выразительные языки. Если язык представляет собой структурированную систему символов, служащую для коммуникации, то языки инженера включают немецкий, английский и русский языки, математические языки и языки программирования, плюс специфический для инженерной мысли язык, состоящий из технического чертежа, формального моделирования, с абстрактными элементами дизайна. Семантика и, следовательно, основные элементы этих языков составляют пространство дизайна, тогда как синтаксис ограничивает выразительность языка и структурирует пространство дизайна.

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THE ENGINEERING DESIGN PROCESS

The passion of Gaston Lagaffe, the main character of the comic strip drawn by Franquin, is driven by the desire to make his life easier through machines he invents, builds, and operates himself (Bonfillon, 2017, fig. 1). As that, Gaston is a caricature of the intuitive, creative, ingenious engineer. He is curious, open to the design space in front of him. He is courageous and playful like a child – yet not "spoiled" by education: Gaston apparently does not need any language as enabler of good engineering design.

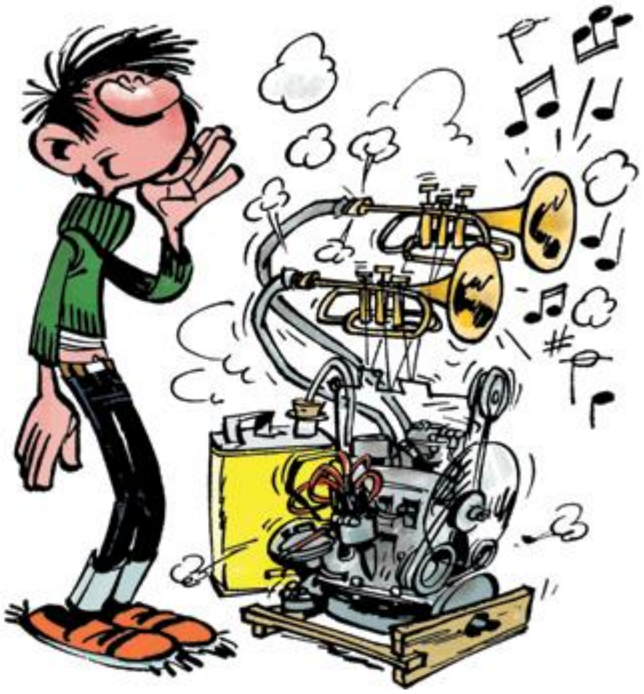

Figure 1. Gaston: le livre des inventions © EDITIONS PRISMA 2017, after Franquin © DUPUIS 2020 www.dupuis.com – All rights reserved

The German word "*Ingenieur*" fits Gaston perfectly. It derives from the Latin word *ingenium*, which means ingenuity. This word stands for the invention process itself. In contrast, the English translation engineer focuses on the result of the innovation process, the engine or more generally the cyber-physical machine.

In fact, the caricature represented in Gaston has its exemplars in today's society. Two examples to illustrate this: The one is the inventive spirit of the ISS astronauts recently praised by the media. They located a leak in the International Space Station by analysing the trajectory of a tea bag. The tea bag and the extrapolation of the trajectory formed the measuring system. Once located, armoured adhesive tape was used to seal the leak. The other example is Artur Fischer who filed his famous dowel invention with the

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German Patent Office in 1958. Up to today Fischer filed more than 1000 patents and created the *fischertechnik* construction sets,

Gaston and his fellow ingenious people teach us that the design process consists of four major steps: (i) the formulation of desired function and quality, (ii) defining the design space, (iii) deriving the composition, and (iv) the evaluation of realised function, quality, and most important acceptance. In the first phase (i) the needs result in the specified function, the expected quality dimensions regarding effort, availability, and acceptability are determined. In the subsequent second phase (ii) the design space is formed out of the available resources, i.e., materials, components, technologies. In the third phase (iii) the overall function is divided into sub-functions forming a function structure. Each sub-function or a group of sub-functions is assigned to one cyber-physical component fulfilling this sub-function. By this assignment process a cyber-physical system is composed. In the fourth and final phase (iv) the system's function, quality and acceptance is verified and validated by means of evaluation metrics and methods.

This final step of verification and validation is where Gaston's inventions go awry in the comic strip, earning him his last name Lagaffe. To master the whole design process and to enable good engineering design, the mastery of languages is essential. To verify this, we have to shed some light on engineering languages first.

TRANSLATING FROM ONE DESIGN LANGUAGE TO ANOTHER

What are the languages an engineer should master to achieve functionality and quality? To answer this question, we start with a statement formulated in the year 1896 by the Chicago architect Louis Sullivan in the English language:

"form […] follows function"

It is a short and elegant design maxim (Sullivan, 1896). But in times of limited resources on the one side and critical environmental impact of technical systems on the other side, there is a demand for economic and ecological quality of systems:

"less but better"

is the quality objective formulated by the influential designer Dieter Rams (1995). This is nothing but Occam's razor, which often is the basis for a perceived beauty of technical systems. In fact, the author is convinced that humans have an intrinsic desire to reduce complexity and achieve beauty. The instruction for good design combines both statements into:

Maximise quality subject to functionality!

This instruction for action is without loss of information translated from the English language to the language of mathematics

$$\max_{x} f(x) \;\; s.t. \;\; g(x) \leq 0.$$

The instruction for action in the background of sustainable systems design is a constraint optimisation problem. Here, $f(x)$ is the multi-criterial quality or objective function, $g(x)$ stands for both functional constraints and constraints given by the techno-economic reality. Hence, good design results from proper selection of the design and operation variants x according to this instruction.

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The third language is a programming language to communicate with a computer capable of solving the constraint optimisation problem. For this a language such as Python (2020) is used to define the objective function and the constraints in a manner a computer can understand:

```
def multi_f(x):
        sum_ = pow((pow(x[0],2) + x[1] - 11),2) + pow((pow(x[1],2) + x[0] - 7),2)
        g[0] = -26.0 + pow((x[0]-5.0), 2) + pow(x[1],2);#constraints.
```

The design space is limited firstly by the techno-economic reality and secondly by the restrictions given by society in form of directives, such as the eco-design directive of the European Union. It may be extended by innovations and new sourcing possibilities. As a result, the design space is given by the available materials, components, and technologies.

SEMIOTIC AND SYNTAX IN ENGINEERING LANGUAGES

In the design process, not the physical items fill the design space but their representation as symbols as sketched in Figure 2 each symbol evokes an intended object, process or model.

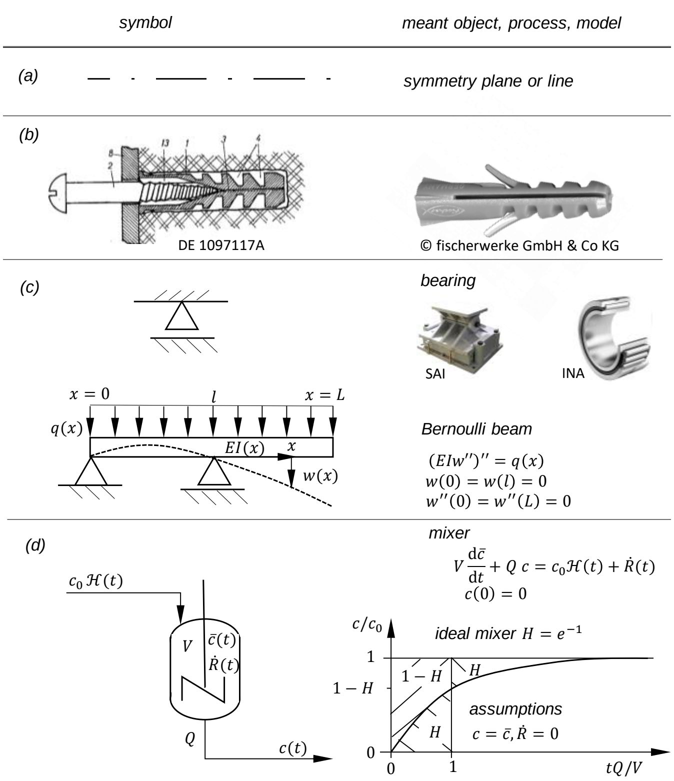

Figure 2. Symbols evoke intended objects, processes or other models such as mathematical physical models; (a) representation of a symmetry line or plane; (b) technical drawing taking from Artur Fischer's dowel patent 1958, (c) symbol of a loose bearing in technical mechanics representing a bridge support or a needle bearing of a rotating shaft; the schematic sketch represents a mathematical boundary value problem for the beam deflection; (d) the symbol for a mixing vessel is standardised by DIN EN ISO 10628. This symbol points to a physical object and/or to an initial value problem for the evolution of the outlet concentration.

The line (a) symbolises a symmetry plane or a symmetry line for an axisymmetric design. The cross section of the dowel (b) symbolises the dowel. The rules in technical drawing are such that the screws are not catted. In fact, Fischer knew this convention typical for a language serving communication. He only missed the symmetry line in his sketch used in his patent.

The technical drawing is an assembly of symbols suggesting the physical dowel and the mounting process. Like symbols in the Chinese written language are often abstracted physical items, the symbol of a bearing is derived from the appearance of a bearing used to support bridges. It indicates such bearings used in civil engineering as well as the bearings used to support a rotating shaft but allowing axial movement as the sketched needle bearing. Engineers are educated to have similar abstract representations of beams, bars, ropes, membranes, plates and so on. Each of these abstract pictures is connected to physical-mathematical models with a convention of idealisation. Thus, the assembled signs in (c) point to the concept of a Bernoulli beam and this concept in turn points to a mathematical model representation in form of a boundary value problem. In process engineering (d) the symbols are standardised in normative texts such as ISO norms. This standardisation of the symbols fosters communication since different engineers do have the same association. Thus the symbol means a mixer. The engineer trained in process engineering further has the model of an ideal mixer in mind. Analog to the Bernoulli beam, the ideal mixer implies some assumptions resulting in knowledge about the residence time distribution.

What was said so far fits to the characteristics of languages. To recapture, a language is a structured system of symbols serving communication. This may be the communication between a person and a second person, furthermore, it may be the communication between a person and a machine, or it may even serve thinking, i.e., self-communication. The syntax gives the way in which symbols are allowed to be structured or represented. The semantic, i.e. the collection of symbols, gives the design space.

ENGINEERS NEED TO EXPRESS THEMSELVES IN DESIGN LANGUAGES

The design process as any intellectual process is strongly influenced as well as supported and indeed limited by the language itself.

"The boundary of my language represents the boundary of my world"

is a well-known statement by the trained engineer and philosopher Ludwig Wittgenstein (1922). This is also true for engineering design. In every language there are different levels of mastering the language. The better a person masters a language using the full set of syntax and semantics, the more expressive the person can be. This is true for all languages an engineer has to speak.

So far the languages for engineering are spoken and written languages such as German or English, the language of mathematics, programming languages and technical drawing. But also abstract design elements such as bearing, beam, mixer are elements of a further engineering language. Those abstract design elements, the components, point to mathematical models or constraints and are understandable for engineers provided he or she masters this language.

The advantage of this abstraction is that the engineer (or the machine) can be focused and can handle complexity.

For good engineering design, the mastery of languages and being able to express oneself in these languages is crucial. Engineering education is all about learning engineering languages. Hence, also Gaston Lagaffe should start studying to express his creativity in a targeted manner to succeed with his inventions.

Peter F. Pelz

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