

Steps Toward the Methodological Principles of 3D CAD Modelling

The book I wanted to write would take a different approach than the CAD textbooks I had read up to that point. But it wasn't at all clear to me that, in terms of content, I would end up focusing on the methodological fundamentals of 3D CAD modelling. That's the story I want to tell.

Frequent decision-making is a defining feature of the design process. For any design problem, there are generally many possible approaches to ensuring the required functionality¹. To narrow down the optimal approach, it is helpful to use design methods: These help clarify the problem statement, narrow the range of possible solutions, make decisions transparent, and document them. Examples of design methods include functional structure, morphological box, and utility analysis².

When creating a 3D CAD model, the question arises as to which methods should be used. Many users notice that 3D CAD models exhibit a certain behaviour: When changes are made, the model reacts unexpectedly, often with an undesirable result. To correct the error, the model must be repaired. In practice, I observe that many users make only limited efforts to systematically understand the causes of these problems and to design their models in such a way that such effects can be avoided or better controlled. Apparently, routines learned early on remain unchanged, and the primary goal is the consistent display of the design on the screen. It is surprising that there is little acceptance of rules and methods in 3D CAD applications. Models could meet the following requirements: stability in the face of changes, consistent model orientation and positioning in space, user-friendly handling, the reuse of existing information, and much more. These are objective characteristics of model quality and application efficiency.

The belief that methods simplify the modelling process motivated me to identify, develop, and document rules and methods for efficient modelling. The thesis is that their application is a sign of high-quality models.

¹ The reasons for the variation in concepts, design, and component sizing relate to the designer's training, experience, and creativity, as well as their spatial awareness and persistence in optimizing the design.

² See also: Konstruktionslehre, Methoden und Anwendungen; Pahl, Beitz; Springer-Verlag Berlin

The course focused on the importance of the coordinate system, derivations, the reuse of parameters, the definition of motion positions, and the top-down approach. The focus was not on how individual INVENTOR commands work (i.e., the “how”), but rather on their advantages and disadvantages, possibilities, and limitations. To explore these aspects, CAD experiments were conducted using the respective INVENTOR features. This is the concept behind my first book, **Characteristics of Efficient Modelling**³. A total of 54 rules for improving model quality and modelling efficiency are presented here.

However, upon reflecting on this book, the following points have come to my attention:

1. A collection of rules and characteristics does not constitute a method.
2. And this means that the question of what exactly is meant by a “structured approach” remains unanswered (this is a common call found in traditional training literature).

Thus, a methodological approach for reliably ensuring reproducibly high model quality is not yet apparent. The idea is that a methodological approach should be able to be presented as a sequence of logical steps. The VDI guideline 2221⁴ describes a product development model that can be used as a template here. The steps involved are clarifying the task, determining the functional structure, identifying solution principles, evaluating solution concepts, etc. This framework is generally applicable, meaning it is industry-independent (Note: My texts do not refer to a specific version of INVENTOR).

(Note: A VDI guideline has been published for 3D product modelling⁵: While there are useful practical recommendations here, a methodological approach is not apparent.)

The key consideration in formulating a methodological approach was the premise that the quality of a 3D CAD model is determined during the early modelling phase. Fundamental decisions made at this stage influence the entire subsequent modelling process. Taking this line of thought one step further leads to the realization: Yes, there is a moment common to **all** 3D CAD models—namely, the early modelling phase. This is the prerequisite for developing a method. It is obvious that this phase can be structured using universally applicable logical steps. The early modelling phase is less a matter of software operation and more a process

³ The book has been out of stock since September 2026.

⁴ VDI 2221, Entwicklung technischer Produkte und Systeme

⁵ VDI 2209, 3-D-Produktmodellierung – Technische und organisatorische Voraussetzungen – Verfahren, Werkzeug und Anwendungen – Wirtschaftlicher Einsatz in der Praxis.

of structured and logical thinking. The early modelling phase can be structured using universally applicable logical steps because this is where the model structure is created, and the underlying structuring principles are the same for all 3D CAD models. I refer to the organization of these logical steps in the early modelling phase as a top-down design strategy.:

- *“Design (Draft)”*: Refers to the early modelling phase.
- *“Top-down”*: Focus on the reuse of information.
- *“Strategy”*: Standardized best practice.

The description of the top-down design strategy is the focus of my second book, **3D-CAD Design with Autodesk Inventor** ⁶.

I then turned my attention to issues in CAD didactics. This field examines, for example, how students can learn a structured approach to modelling. The most important thing I learned in this process is the difference between declarative and procedural knowledge⁷, two concepts from cognitive psychology. **Declarative** knowledge is fact-based knowledge that can be expressed in language and is therefore communicable. **Procedural** knowledge is experience-based knowledge and cannot be easily shared. The significance of this distinction becomes clear when considering the individual phases of the 3D-CAD learning curve. This illustrates (symbolically and qualitatively) the increase in application expertise as a function of the time spent using the software. The early learning phase is characterized by rapid progress. The learning content consists of declarative knowledge and can therefore be clearly conveyed (the content of the INVENTOR Online Help, training manuals, and seminars consists almost exclusively of declarative knowledge). As the fundamentals are reinforced, routines are practiced, which flattens the learning curve. Subsequently, a new component of knowledge gains importance: procedural knowledge. The growth in experiential knowledge depends on the user's motivation; the learning curve for this component will be significantly flatter. Assistance in the form of clear instructions—such as best-practice recommendations—is

⁶ Herstellung und Verlag: BoD – Books on Demand, Norderstedt, 2024, ISBN: 9783758320453

⁷ Rynne, Anthony; Gaughran, William. 2007. Cognitive modelling strategies for optimum design intent parametric modelling (PM). Computers in Education Journal 18(3). S.58

helpful during this phase⁸. I have been largely interested in procedural knowledge, something I wasn't aware of for a long time. Procedural knowledge determines the quality of a 3D CAD model. If it is insufficient, models can be unstable. CAD systems themselves do not have a button for the optimal procedure. Nevertheless, there is a point that enables a methodical approach to a structured workflow. With this foundation, the top-down design strategy can be further developed while simultaneously creating a methodological foundation for 3D CAD modelling.

The struggle to find the right language took up a large portion of the time spent working on the text. A consistent definition and a clear, unambiguous understanding of certain terms are important to me. This was not a linear, steady process, but rather many small steps taken over a long period of time. The key procedural skill is organizing the drafting phase according to the following organizational principles:

- *Design View*
- *Design Intent*⁹
- *Top-down Approach*

Other important terms include:

- *Spatial-visual imagination*
- *CAD-Automation*

Understanding the relationships between these concepts is now the most important component of the **top-down design strategy**. The starting point for the design is a **spatial, visual conception** of the solution concept. This condition applies independent of the design method—that is, regardless of whether the design is created on a drawing board or using 2D- or 3D-CAD systems. Spatial visualization can be achieved in a variety of ways. It is based on

⁸ See also: Paul Munford & Luke Mihelic; *Reliable Modelling Techniques for Complex Part Design in Inventor*; Autodesk Class Handout MFG226705

⁹ Martin II, David. *Design Intent in Creo Parametric* (Creo Power Users Book 7), (S.3-4), 2020, Kindle-Version.
(Anmerkung: Obwohl sich das Buch an Nutzer des 3D-CAD-Programms Creo richtet, bietet es allen Nutzern eines 3D-CAD-Systems einen umfassenden Überblick zum Thema.)

the consideration of available information in line with the top-down approach, which considers knowledge of orientation and position in three-dimensional space, as well as the requirements of processes, interfaces, or installation space constraints. Sketches, templates, and similar tools support this process. The ability to visualize in three dimensions is essential here, since the development of a solution does not begin with a blank sheet of paper. Spatial visualization is based on the premises that the orientation and position of a 3D component in three-dimensional space are known and that there is a viewing direction that contains the most information regarding shape and dimensions. Thus, the **design view** can be derived as a conclusion from these premises. In 2D, this is the drawing area where the design begins; in 3D CAD, it is the content of the first sketch. The design view is a projection. The concept of orthogonal projection is the foundation of every technical drawing¹⁰. Another conclusion concerns the origin plane for the first sketch: It is perpendicular to the projection direction of the design view—that is, the view containing the most information. The steps leading to the first sketch and the representation of the design view are unambiguous, communicable, and thus constitute descriptive knowledge. The design view breaks down the procedural knowledge for this phase into a spatial, visual conception of the task. Once the design view has been sketched, its geometric features—including dimensions, shape, form, orientation, and position—must be defined. The goal is to ensure that the sketch behaves in a predictable and consistent manner when changes are made later. This captures the **design intent**. Examples of this include defining parallelism between surfaces, accounting for symmetries, and establishing relationships between dimensions. Determining the design intent is based on procedural knowledge and can be achieved using numerous techniques and methods, such as constraints, parameters, construction lines, or blocks. The concept of dimensioning and parameterization is of particular importance for ensuring and preserving the design intent after changes. If a defined condition is addressed during a subsequent model change and is not interpreted as expected, the sketch's specifications can be adjusted at any time. The design view is an intermediate step and ultimately transforms into the design intent. Although defining the design intent is of great importance for model stability, it is difficult to formulate guidelines for establishing the design intent, as it involves a significant procedural component.

¹⁰ 2011. Tabellenbuch Metall. Verlag Europa Lehrmittel. S. 65

The top-down approach¹¹ represents the third principle of a structured methodology. Numerous sources are available to help understand this approach. Here, I propose a two-part definition. The fundamental focus of the top-down approach is the organization of the information structure of the 3D-CAD model. The term itself provides a clue to the methodology: it describes the starting point (*top*) and the direction (*down*). I identify the following areas of application:

1. The reference to information available as a starting point for the design—that is, the information status prior to the start of modelling. Here, we focus on the core of the design task. The result is the design view. The information status consists of parameters or geometric features that describe both the design task and the concept. Without these elements, no design is possible. Referencing the information status ensures that, during the early design phase, secondary design considerations do not take center stage. To understand and contextualize the significance of the initial sketch for the top-down approach, it is also worth looking at the recent history of engineering design. Within 30 years, design practice evolved from working at the drafting table, through designing with 2D-CAD systems, to 3D-modelling. The top-down approach also applies to the question of what initiates the development of the design view. In 2D, this question did not arise; the top-down approach was the only option. Designing at the drafting table was pure top-down!
2. The second area of application for the top-down approach is the reuse, inheritance, or linking of information in the modelling process. In a 2D assembly drawing, a line often represents the boundary between two neighbouring components. In a 3D CAD model, the neighbouring surfaces of 3D-CAD components initially have no relationship to one another. The information regarding dimensions, shape, orientation, and position is redundant. After the first component is modified, the second must be adjusted accordingly. However, Inventor offers numerous and flexible options for setting up such a relationship. Geometric features can be derived—that is, inherited by other parts—and parameters can also be derived or selectively linked. This allows for the rapid

¹¹ Martin II, David. Top down with Creo Parametric (Creo Power Users Book 7), 2017, Kindle-Version (see also footnote 8)

implementation of optimization loops and scaling, which fundamentally reduces the risk of errors. Reduced redundancy also means lower model complexity.

The question arises as to whether—and to what extent—the effort involved in linking parameters is justified. Transferring global features—such as primary dimensions—from a master model to multiple components is both practical and efficient. Inheriting the parametric properties of design details, however, offers only limited benefits. In contrast, the evaluation of the reuse of geometric features is clearly positive. This can be justified by the fact that the geometric details of neighbouring components must be recorded in sketches anyway. This raises the question of why the creation of sketches for several neighbouring components should not take place within a common context. This approach corresponds to the procedure used in two-dimensional drafting, such as on a drawing board. Although this increases the scope of the sketch, the practical limit—that is, the complexity—is determined by the interpretability of the profiles. The approach for this concept involves working with blocks; that is, sketch blocks capture the design view of several neighbouring components. The ability to represent a design view—for example, in an integrated 2D layout—is key to the efficiency and quality of a 3D-CAD model. This method offers remarkable advantages in the early modelling phase: it enables the rapid creation of meaningful concepts.

The discussion so far makes it clear that the top-down approach covers much more than just skeleton modelling. AUTODESK INVENTOR offers numerous options for reusing information. In particular, the high degree of flexibility when working with blocks opens a wide range of approaches that can be summarized under the term “CAD automation.”¹²

¹² It is worth noting here that the ability to structure geometry using the Block function was already available in the very first versions of AUTODESK AUTOCAD (1980s)!

It should also be noted that AUTODESK INVENTOR provides a powerful top-down modelling environment with its CREATE COMPONENT feature. Based on a master file, numerous steps involved in creating an assembly are automated.

This raises the question of why Autodesk does not more clearly highlight and further develop the potential of the top-down approach (there are limitations, for example, in managing inheritance: the parameters of block sketches are no longer displayed after the block is defined. My current workaround is to take a screenshot.)

Once the organizational principles have been clarified, defining motion positions is the final step in the top-down design strategy. This requires consistency in the origins. The `GROUND AND ROOT` command enables the automatic placement of components. This allows motion positions to be defined as early as the initial design phase, for example, to clearly present process flows and motion concepts. Defining motion positions is thus part of the design intent.

This text summarizes a proposal for a structured approach to 3D-CAD modelling. It outlines the logic behind the early design phase and the resulting work steps. To this end, key terms are defined and their interrelationships are illustrated. The focus is on model behaviour and model quality, the early design phase as the common starting point for all 3D CAD models, descriptive and procedural knowledge, spatial visualization, and an understanding of a component's orientation and position. Furthermore, the course covers the consistency of component origins, the design view, the design intent, the information status, the top-down approach, CAD automation, motion positions, and, finally, the TOP-DOWN DESIGN STRATEGY. Finally, the following diagram illustrates the relationships between the organizational principles of the design phase as the most important components of the top-down design strategy.

