# Chapter 8
# Major Technology 2: Computer-Aided Industrial Design—CAID


**Executive Summary**

This chapter deals with the following topics:

- Basics and advanced techniques of Computer Aided Industrial Design (CAID)
- Providing insight into how engineers benefit from using CAID technologies
- Describing functioning, benefits, and limitations of CAID technologies in practice.


**Quick Reader Orientation and Motivation**

The intention of this chapter is:

- to give an overview of CAID technology in Virtual Product Creation as driver and enablers for Digital Transformation in engineering
- to present CAID technology as part of Virtual Product Creation from a practitioner's point of view to analyze the need and usefulness for day-to-day industrial work practice
- to give instructions on how to use CAID technology
- to explain models, frameworks, and mathematical representations that help to grasp the internal working modes of CAID technology.

Designers in the automotive industry—in the sense of designing the shape/style—most intensively use Computer-Aided Industrial Design (CAID), which is also known as Computer-Aided Styling (CAS). It supports the design/styling process much better than CAD systems because it is more intuitive to work with and allows inaccuracies in sketching as well as in modeling. Techniques, which belong to CAID, are e.g. creating high quality freeform surfaces, 3D sketching, virtual clay modeling and high-end rendering. In the automotive industry, CAID is used intensively for car body and interior design. In general, however, it finds its use in every industrial design sector from consumer goods, via design shapes of other transport systems such as trains and planes up to machine box design.



R. Stark, *Virtual Product Creation in Industry*,
https://doi.org/10.1007/978-3-662-64301-3_8

## 8.1 Engineering Understanding of CAID

This section explains why and in which phases designers (styling experts, shape modelers) use CAID instead of CAD. Furthermore, it will be shown how CAID works in reference to the context of digital and physical product development as part of the overall product creation process.

### *8.1.1 Why Does an Engineer Use CAID Instead of CAD?*

As shown in Fig. 8.1a CAID allows a much higher level of detail in sketches than CAD and by doing so it even allows for time savings in digital modeling. CAID finds its use primarily in the design sector because there it is important to create different eligible solutions in a short time and thereby support the creative process. If CAD was used for this phase significant more time would be needed: the reason is that CAD systems offer less stringent surface modeling capabilities compared to CAID capabilities. Amongst several modeling laminations, CAD does not allow easily for any modeling inaccuracies and it is deemed to be difficult to work intuitively with it within the highly creative phase of modeling. Another advantage of CAID consists of the possibility of making quick alterations in a sketch by simply deleting curves without causing inadvertent effects as it would happen in a CAD system. At the same time, it is even not necessary to change an entire sketch.

In conclusion, CAID enables considerable time savings and it reduces the efforts during modifications, which comes into interplay a lot during a design & development process.

### *8.1.2 Where is CAID Being Used?*

CAID is mainly used in the first stages of product development. As shown in Fig. 8.1b these stages are the concept, design and verification phase. Within this context, designers use CAID partly in the concept and in the verification process (during the rework of the shape after design modifications). Its main usage, however, is part of the design phase. CAID therefore builds an intersection between different product development stages and between engineers and designers. The two main fields of application for CAID consist of the design study as a starting point for the technical development and of the design process of creative and aesthetic product modules. The design phase includes different engineering tasks beginning with the search for solution principles followed by the separation into feasible solutions or modules, the design of the chosen module itself and finally the integration of the module design into the overall design.

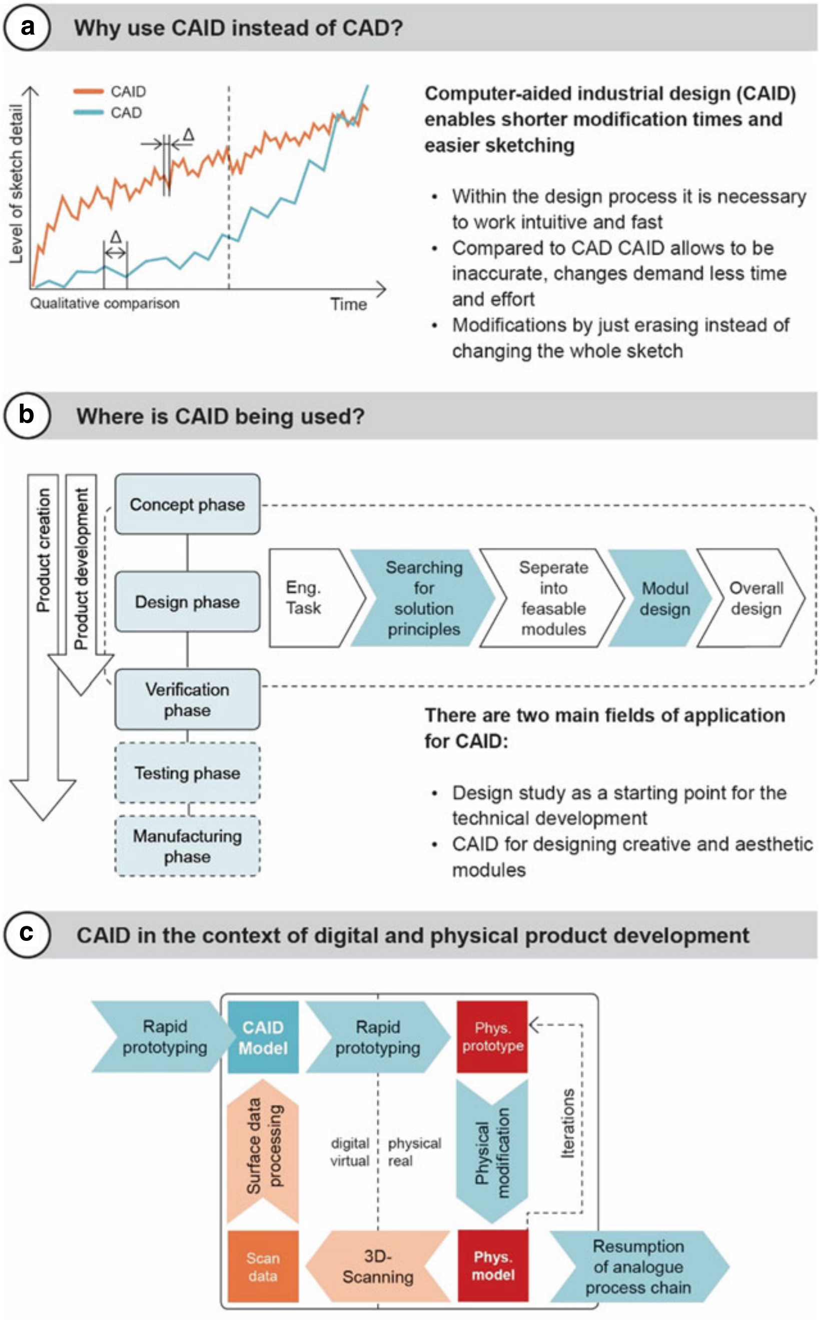


**Fig. 8.1** Engineering application of CAID

#### 8.1.2.1 CAID in the Context of Digital and Physical Product Development

The modeling process of CAID consists of two areas, the digital or virtual environment and the physical or real environment. As shown in Fig. 8.1c, the modeling process usually starts with the creation of a virtual model with the help of CAID software. As part of rapid prototyping, the digital model becomes a physical model. Rapid Prototyping is also known as “3D Printing” or more accurately stated as *Additive Manufacturing* and it uses techniques such as *Stereolithography* (STL), *Selective Laser Sintering (SLS), Selective Laser Melting (SLM)* or *Fused Deposition Modeling (FDM)* (see more details in [1]). Afterwards the manufactured prototype might get modified until the desired shape is achieved. There is no limit to the number of alterations during the physical modification and it is also possible to resume this analogue modification process chain after having passed through the following “digital” steps. Those “digital” steps comprise a 3D Scan that converts the physical into a virtual model again and generates scan data within the scanning process. The gained data can be imported into CAID software and there the surface data gets processed until the desired shape is reached—or this process chain can be continued until this aim is finally achieved.

## 8.2 How Does CAID Work?

This section defines the basic IT technology of CAID and explains how a classical design process works with CAID. Furthermore, it will clarify two input devices of CAID as well as the technique of three-dimensional immersive modeling.

### *8.2.1 How Does a Classical Design Process Use CAID?*

As shown in Fig. 8.2a, there are three stages of the engineering process which comprise the concept, design and detail modeling phase. Within this context, the detail modeling phase is to be understood as a sublevel of the design phase.

CAID is used in all of these phases but in the detail modeling phase, it is used only in a specific way. First, designers (styling experts, shape modelers) need to work out a first concept based on the given appearance assignment and the principal idea of style. After this initial design phase in most of the cases, still a physical mock-up gets build up by means of rapid prototyping. The shape data of the physical part can be added to CAD via the technology process called *reverse engineering*. Through the fact that CAID and CAD can be both managed in product data management systems (PDM) it is possible to work in both areas and exchange data from one to the other software. As shown in Fig. 8.2, CAID gives information of shaped surfaces to the CAD system and CAD transfers information in the form of engineering constraints

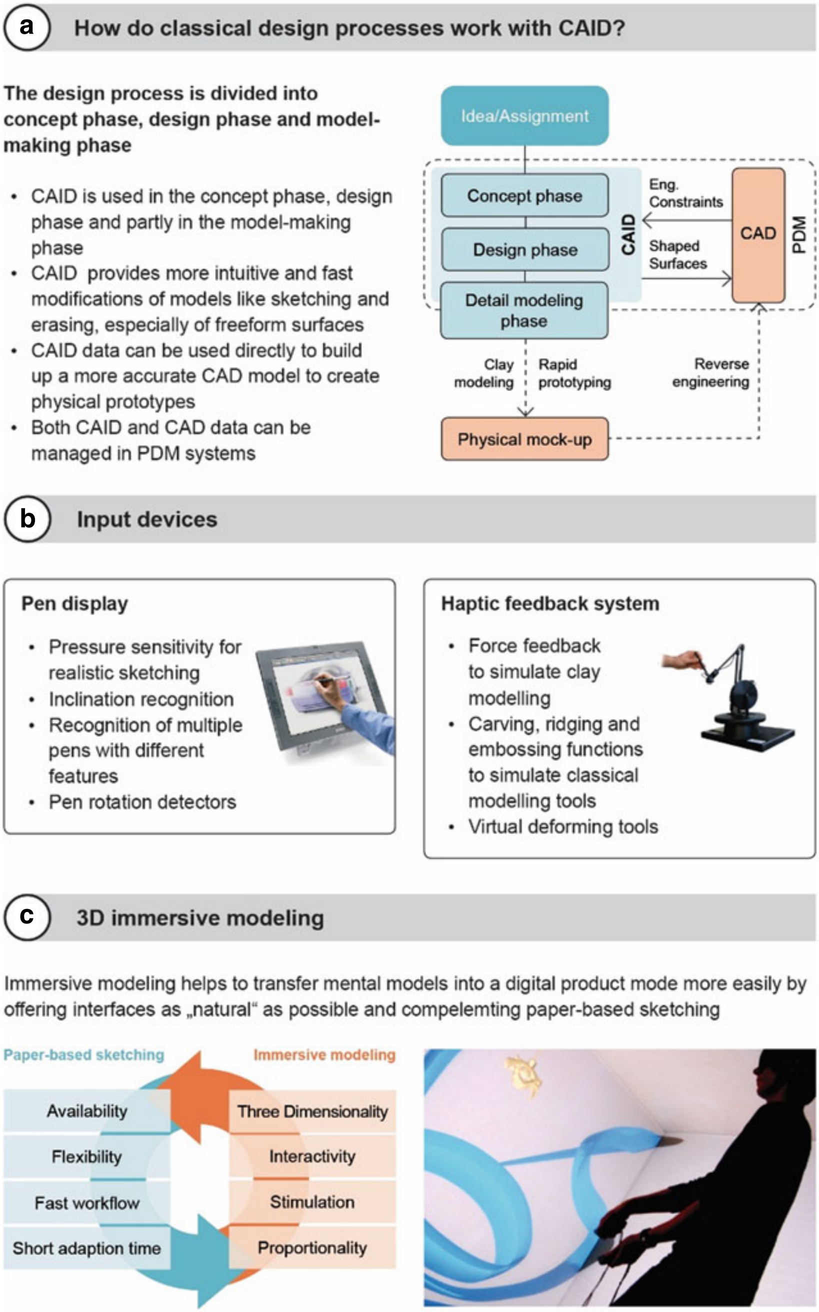


**Fig. 8.2** Basic IT technology of CAID

to the CAID system. The reason for extending work outside CAD is the specific set of extra surface related modeling capabilities of CAID to better support the styling design process of product shapes. The main advantage of CAID is that it provides more intuitive and faster modifications of models than CAD, especially in the field of freeform surfaces. Specialized CAID modeling capabilities are also key during the final class. A (visible styling surface of the outer shapes of products) high precision generation.

### *8.2.2 Input Devices*

Figure 8.2b shows two typical input devices of CAID, a pen display and a haptic feedback system. The pen display on the left side in Fig. 8.2b provides 3D sketching. Principally 3D sketching works like 2D sketching but the designer needs to employ the method of sketch rotation in order to work in different views to create the three-dimensional shape. To support the function of virtual rotation the pen comes with a rotation detector. Furthermore, the pen has a pressure sensitivity and an inclination recognition for realistic sketching and it can recognize multiple pens with different features. The display itself can be connected to a computer like any other device (e.g. keyboard or mouse).

The second technology shown in Fig. 8.2b on the right side is the haptic feedback system, which helps to imitate the classical process of clay modeling in a virtual environment. This technology is mainly used in design studios in the automotive industry so far. With the help of such a device, the designer receives a volume dependent force feedback during the modeling operation. Through its various functions in the virtual environment, it is possible to simulate classical modeling tools like carving, ridging, embossing or other deforming tools.

### *8.2.3 Three-Dimensional Immersive Modeling*

During the last 10 years, intensive research has been conducted in order to achieve the next level of 3D immersive design (see [2], 3). As shown in Fig. 8.2c three-dimensional immersive modeling is part of a Virtual Reality environment. With the help of different input devices, the designer is enabled to create virtual shapes by moving the device in 3D space—all active movements are recorded and mathematically translated into digital line, surface or even volume data. Those interfaces support the efficiency and naturalness of the design process through their intuitive handling and interaction. Moreover, three-dimensional immersive modeling can be understood as a complementation of the traditional two-dimensional paper-based sketching. As the schema in Fig. 8.2c shows, it increases quality characteristics of 2D manual sketching and it offers additional properties of 3D modeling. Consequently, 3D immersive modeling supports traditional paper-based sketching qualities like availability, flexibility, faster workflows and shorter adaption times. In addition, it enables new elements such as three-dimensionality, interactivity, stimulation and proportionality.

The user in Fig. 8.2c works with special input devices like brushes which can be provided in different sizes with various functionalities and grippers. In general, there are four types of input devices: discrete, continuous and hybrid devices as well as miscellaneous input like speech. The operator in the figure uses continuous input devices.

Artists, designers and animators mainly use the technology but the application also starts to be popular for engineers. By offering new ways of modeling, immersive technologies help to merge the traditional disciplines of art, design and engineering to a new comprehensive skill set. This circumstance paves the way for distinctly easy communication between designers and engineers in the product development process. Within this context, it provides 3D sketching, 3D modeling as well as it helps to present and to alter virtual models in a spatial environment.

## 8.3 Advanced Technology of CAID

In order to provide intuitive human interfaces for CAID Designer, it is necessary to implement refined mathematical algorithms, which enable traditional sketching and drawing techniques of the analog designer work practice into digital CAID environments.

Figure 8.3a explains the principle of virtual tape drawing, one specific way of realizing a successful analog/physical way of using tapes to express feature lines of outer shape design into the digital/mathematical interaction world of CAID. This interaction method provides the notion of a fixed and loose tape that can be activated and fixed to each other by using two mouse buttons. Usually, there exists a degree of freedom for the CAID designer in terms of which configured input device should be used: besides the traditional mouse device (and its different buttons) other 3D interaction devices might be used.

Figure 8.3b presents another rather intuitive CAID functionality: the spline curve creation (a free from 3D line in space or on the surface) based on multi-stroke sketching with a time-dependent drying ink metaphor. The interaction cycle allows using the successful interaction technique “multi-stroke” of a traditional painter and sketcher from the analog world to describe lines of proportions. This rather innovative digital technique enables the use of an intelligent “latency mechanism metaphor” of drying ink to give the opportunity to modify and change the line sketch before making a final commitment to it in the digital CAID modelling environment.

Figure 8.3c describes the principle of how simplified light models are used to create highlight lines (left-hand side, independent from point-of-view) and reflection lines (right-hand side, dependent on point-of-view). Since CAID tools are used to create aesthetic free form surfaces it is necessary to provide special tools to CAID designers. One key function of such toolset enables the control of the quality of the

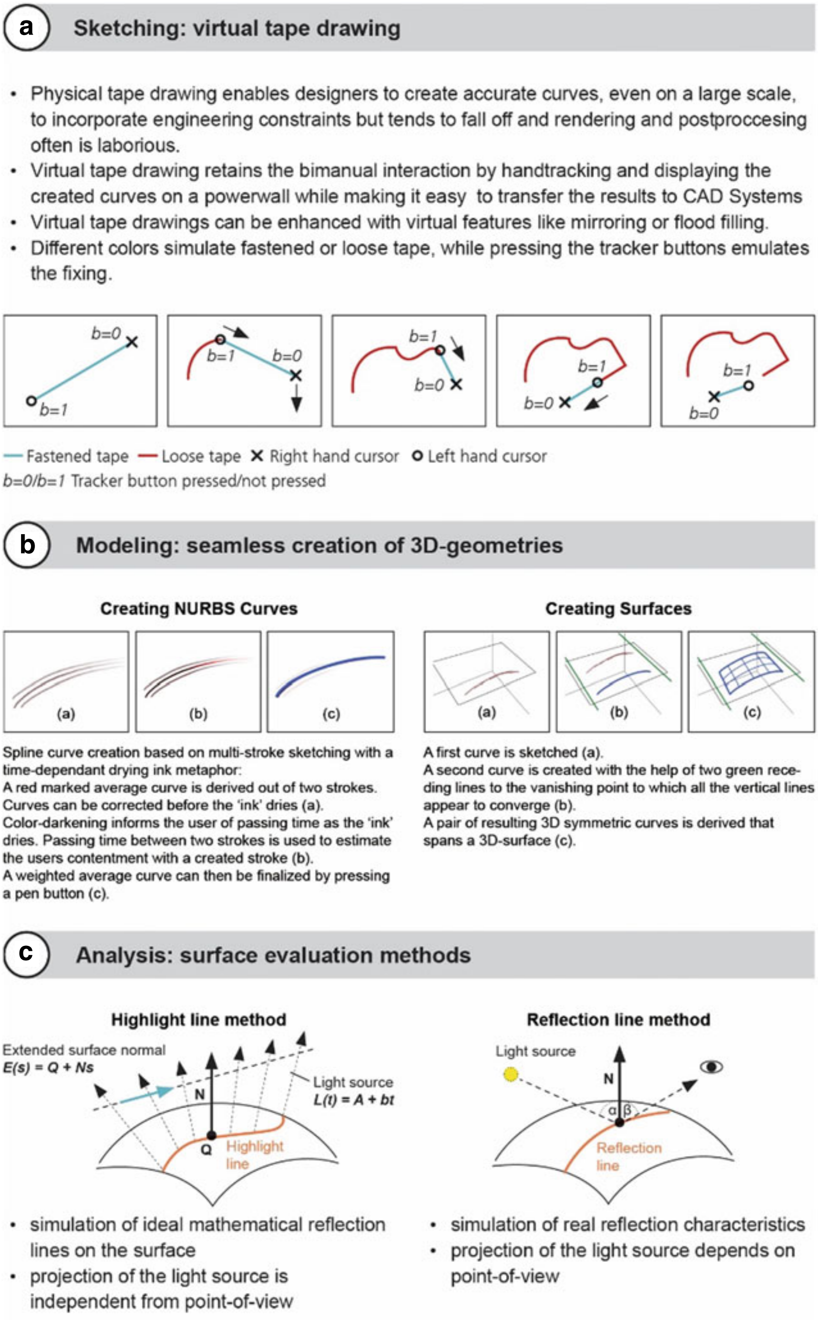


**Fig. 8.3** Advanced technology of CAID

surface flow: in order to avoid unwanted light reflections at those aesthetic surfaces the continuity of the surface curvature control (2nd derivative of the mathematical notation of the free form surface) needs to be ensured. CAID designers use such "highlight and reflection analyzing" tools in order to test and modify the original free form surface definition, i.e. the NURBS (Nun Uniform Rational B-Splines) polygon itself and other NURBS geometrical parameter settings.

**Highlight Lines**

The highlight line is one of the surface evaluation methods. It is a simplified form of the reflection line by eliminating the point-of-view factor for the assessment. Independency from the point-of-view allows the surface to be rotated for further inspection, without changing the properties of the highlight line.

A highlight line is created by positioning a light source over the assessed surface in consideration of the highlight line's position/location and its orientation. The projected light source on the surface is a set of points, whose extended surface normal intersects with the light source. The equations for both, the light source and the extended surface normal, are as follows (compare [4]):

$$L(t) = A + Bt \tag{8.1}$$

*L(t)* the idealized linear light source, which is placed over the assessed surface (see Fig. 8.4).
*A* a point, which is located in the idealized linear light source/the point of origin of the light source.
*B* describes the direction vector of the linear light source *L(t)*.
*t* a parameter, which determines/"limits" the range of the light source.

$$E(s) = Q + Ns \tag{8.2}$$

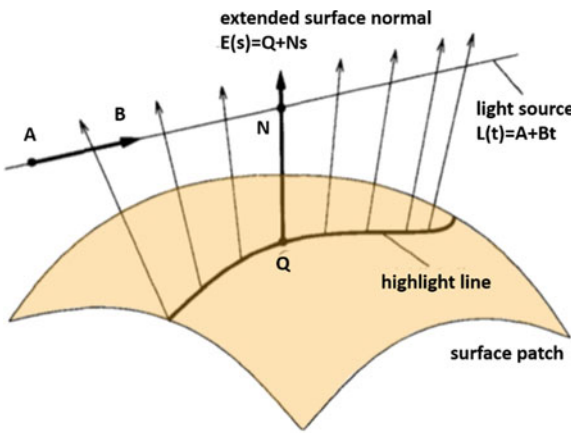


**Fig. 8.4** Surface evaluation method: highlight line. Original source [4]

*E* describes the extended surface-normal of the observed point *Q*.
*Q* the observed point on the assessed surface.
*N* the normal of the observed point *Q*.
*s* the parameter which dictates the extension of the normal of the observed point *Q*.

If point *Q* belongs to the highlight line, the extended surface normal *E(s)* would then intersect with the light source *L(t)*, or in other words, the signed distance between the extended surface normal and the light source would be zero. As the name suggests, the light source is in the form of a line or does not possess any radius. The equation for the signed distance between extended surface-normal and the light source and the conditions that are to be met for the highlight line are explained in Eqs. 8.3 and 8.4 and in Fig. 8.5 (compare [4]).

$$d = \frac{(B \times N) \cdot (A - Q)}{\|(B \times N)\|} \tag{8.3}$$

A light source with a radius r = 0 results in a highlight line with

$$d = 0 \tag{8.4}$$

A light source with a radius r > 0 results in a highlight band with

$$d \leq r \tag{8.5}$$

As shown in Fig. 8.5, d$(u, v) \neq 0$ since point S$(u, v)$ does not belong to the highlight line.

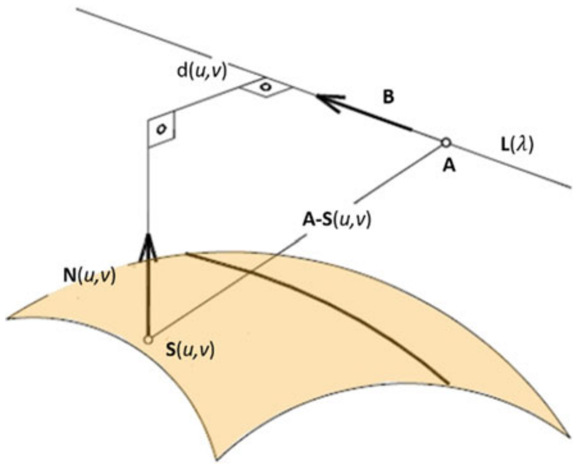


**Fig. 8.5** Illustration of the perpendicular distance of the observed point and the light source. *Note* notations are different from the equation written above. *Source* [5]

Even though the highlight line method is independent from the observer's point of view, the placement/location of the light source, the orientation and the shape of the surface influence the resulting highlight line.

Placing a highlight line over a planar face would result in a single and uninterrupted projected curve on the face. However, placing/ using highlight lines on a non-planar face may produce various results. Placing a highlight line over a convex side of a non-planar surface still produces a single and uninterrupted curve on the face. This is shown in Fig. 8.6.

Placing a highlight line over a concave side of a non-planar surface would however result in a loop, interrupted or intersecting projection on the face. These occurrences are shown in Fig. 8.7.

This happens because the surface-normal directions on the planar and convex face are scattered out. The surface normal directions on the concave surface, however, are

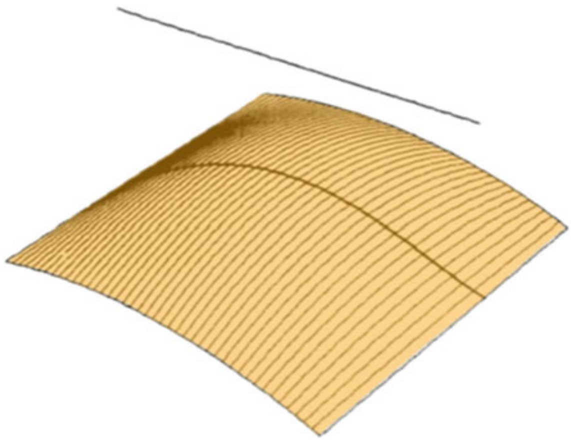

**Fig. 8.6** Application of a highlight line placed over the convex side of a surface (single uninterrupted curve). Original source [4]

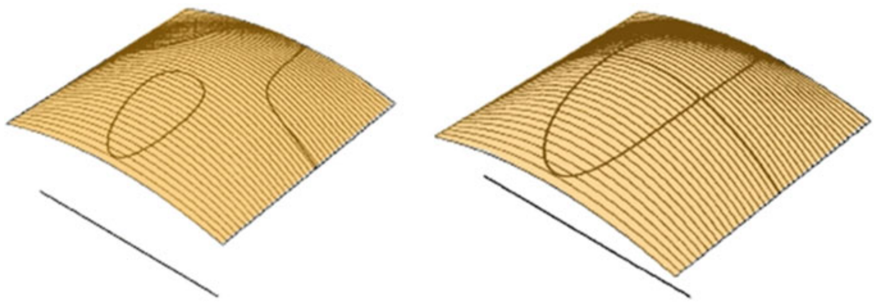

**Fig. 8.7** Application of highlight line place over the concave side of a surface. Loops, discontinuity and intersections occur. Original source [4]

more "focused" in a certain direction and intersecting with each other, thus creating the projected light would result in a loop, intersections and/or interrupted curve.

Figure 8.8 shows two examples for interactive surface analysis functions provided by the CAID module of the CAD system CATIA from Dassault Systèmes for Designers.

Figure 8.9 shows the direction of the normal vector of a concave surface. Multiple parallel highlight lines placed over a surface can also be used for a more thorough and complete assessment of the surface quality.

The light source is generally described with a single line from a given point A with the direction B. However, this light source model can be expanded into a boundary

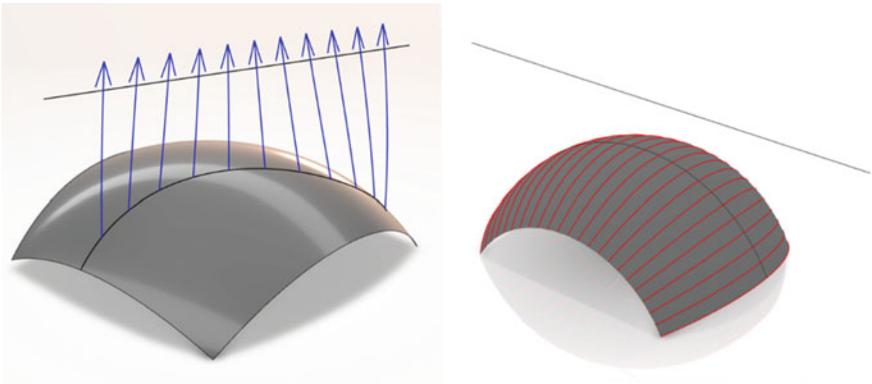

**Fig. 8.8** Implemented highlight analysis functions in the CAID module of the CAD system CATIA; left side: vectors to highlight curvature change, right side: highlight line created point projection onto the surface to establish redlined curves through individual cutting planes. *Source* Dassault Systèmes

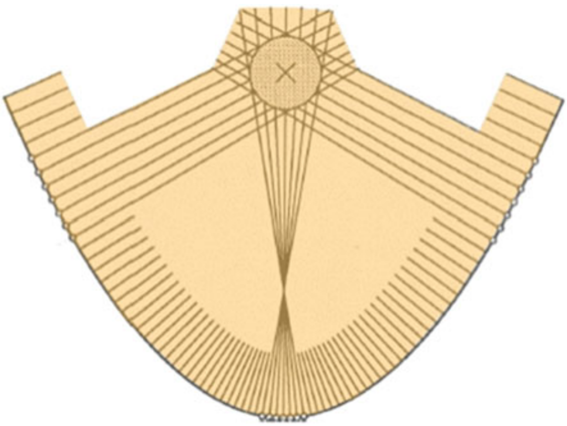

**Fig. 8.9** Surface-normal vectors of the concave surface. Original source [6]

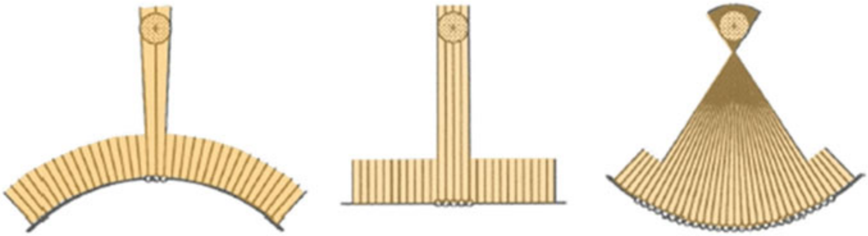

**Fig. 8.10** Application of highlight band on planar and non-planar surfaces and illustration of normals on different surfaces. *Source* [6]

band model, when an idealized light source is given a certain radius. This model would better simulate a real light source (compare cases in Fig. 8.10).

The light source model can be expanded by giving the light source a certain radius $r$. The condition, which has to be met for a point on a surface to belong in the highlight band, also changes. With the former light source model (highlight line) the distance between the extended surface-normal and the light source has to be zero, in order for the surface point to be included in the highlight line.

For the highlight band, the distance between the extended surface-normal of a point on the surface Q and the centre axis of the light source has to be smaller than the radius of the light source. The equation and condition which are needed to be met for the highlight band are shown in Eqs. 8.3 and 8.5. A highlight band provides additional information to the surface quality assessment aside from the detection of irregularities. As seen in Fig. 8.10, light source with the same radius projects highlight bands with different widths on different types of surfaces. Therefore, the observation of changes in the width of the highlight band enables the detection of changes in contours.

In practical CAID modeling work it is important to be competent in specific CAID system functionalities to ensure proper surface generation and testing. Based on the principals explained earlier in this sub-chapter the following figures show various applications of surface quality analysis functionalities.

Figure 8.11 shows two methods based on the *angle pitch value* in the CAID module of the CAD System CATIA of Dassault Systèmes.

Working mode of the *normal to the surface approach* (left side of Fig. 8.11): the system draws a series of curves on the surface. At all points along a given curve, the angle between the *local normal to the surface* and the coordinate axis Z is constant. The spacing between each curve represents a change in the angle of the local normal given by the *angle pitch value*. The origins of the curves are the points on the surface at which the coordinate axis Z is normal.

Working mode of the *tangent to the surface approach* (right side of Fig. 8.11): the system draws a series of curves on the surface. At all points along a given curve, the angle between the *local principal tangent to the surface* and the coordinate axis Z is constant. The angular spacing between each curve is given by the *angle pitch*

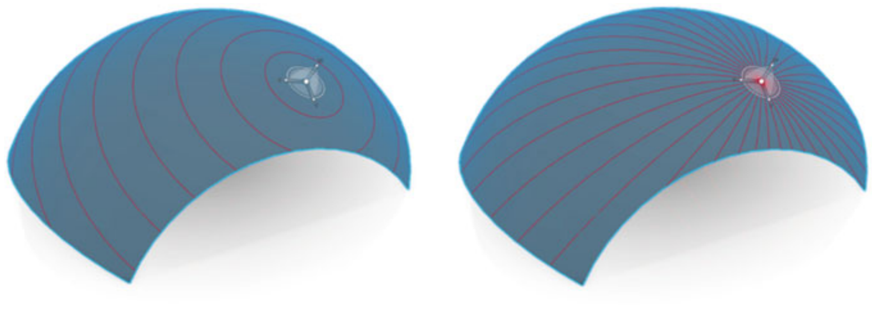

**Fig. 8.11** *Angle pitch value* between the local normal to the surface (left side) and the local principal tangent to the surface with respect to the determined (in this case outgoing) axis of the coordinate system at the top. *Source* Dassault Systèmes

*value*. The origins of the curves are the points on the surface at which the coordinate axis Z is normal.

Figure 8.12 shows the *explicitely controllable intersection method*. Within such *surface quality analysis method* intersections (red lines) are ceated onto the target surface, always referred to defined cutting planes. The cutting planes can be explicitely controlled in the following ways:

1. Parallel based on the orientation of the black plane as shown in Fig. 8.12
2. Normal in relation to any curve
3. Based on an already existing plane in the CAID model.

The amount and the stepwidth of the cutting planes can be flexibely controlled and determined, as well as the start and end points (boundaries) relative to the reference plane.

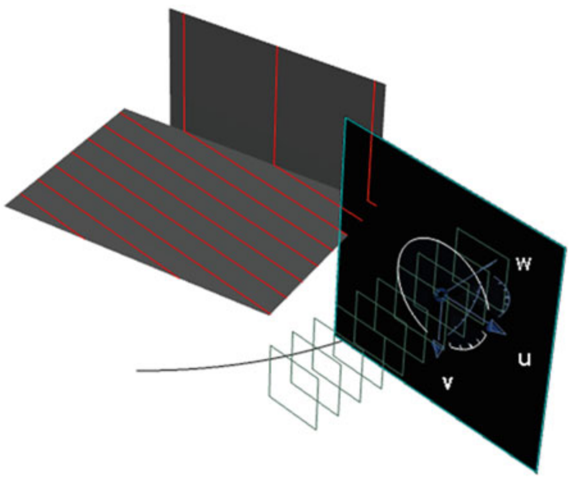


**Fig. 8.12** Intersection method. *Source* Dassault Systèmes

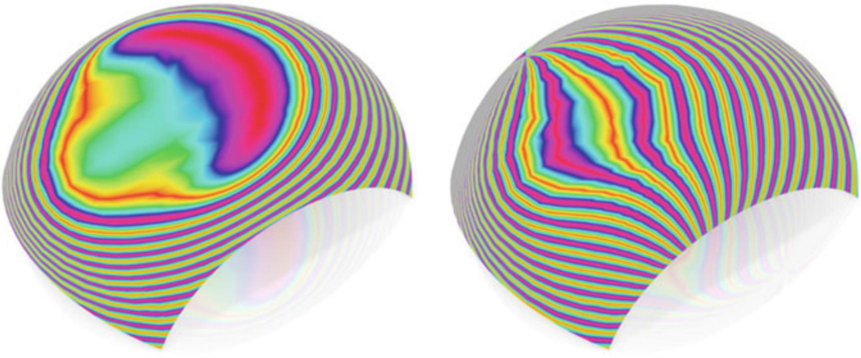

**Fig. 8.13** Color coded high light lines; left side: lines directly from the light beam of the parallel light source, right side: by reflection of stripes on the interior side of an imaginary cylinder around the geometry. *Source* Dassault Systèmes

Finally, Fig. 8.13 illustrates the method application of highlight lines based on the principle of *color coded "zebra" line projections* onto the target surface.

Overall, there exist a wide range of additional CAID surface modeling functionalities with integrated testing procedures, both similar across different CAID/CAD systems but also with specific custom oriented features and unique solution implementations in different CAID/CAD systems.

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