USE OF DESIGN METHODOLOGY TO ACCELERATE THE DEVELOPMENT AND MARKET INTRODUCTION OF NEW LIGHTWEIGHT STEEL PROFILES

Nehuis, Frank; Ziebart, Jan Robert; Stechert, Carsten; Vietor, Thomas

ABSTRACT

In the transportation sector –as in most other branches– demanded time-to-market becomes shorter whereas at the same time demanded diversity becomes wider and lightweight requirements become tougher. For this reason the project "Development of a highly integrated modular profile family for the automotive and transportation sector from high and ultrahigh-strength steels with stress-matched sheet thickness gradients" (HIPAT) was established. The project aims to accelerate the development and market introduction of new lightweight rolled steel profiles. As means to achieve this aim a special design catalogue with HIPAT components, design tools and design rules pertaining to lightweight constructions and the integration of functions was developed and combined to create a continuous design methodology. This design methodology is distinguished mainly by its applicability in early design phases.

Keywords: design methodology, lightweight design, stress-matched sheets, design catalogue, design rules, integration of functions

1 INTRODUCTION

Many trailers and trucks are made up out of steel beams. Traditional beams with constant cross section over its length are often in parts overdimensioned. This leads to overweight trailer trucks that are expensive in investment and lifecycle costs. Task-specific roll forming in combination with multiphase steel is able to create lightweight beams that already provide integrated functions. One approach in fundamental research deals with the development of a new technology to split steel sheet and bend it to multi-chamber profiles [1]. Even though these beams are lightweight, topology and cross-section are nearly constant over length. The here shown approach aims to create beams with cross-sections specially adapted to the certain load at that length parameter.

However, the design process requires deep knowledge of the complex manufacturing constraints. Therefore, the project HIPAT aims to develop a suitable process for the roll forming of task-specific rolled multiphase steel profiles. Here the adopted approach is based on the known economic production of rolled profiles in conjunction with the tailor rolled blank technology. Using modern design methods, the new manufacturing process will provide opportunities to exploit the potential of the new profiles, leading to quicker development of new roll profiles and accelerated market introduction. The development process of HIPAT profiles is shown in Figure 1.

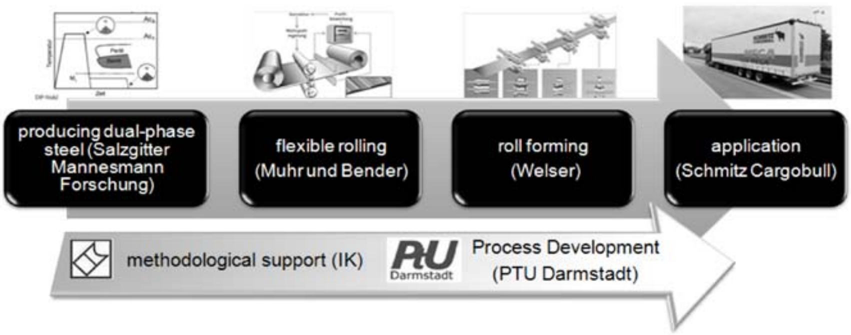


Figure 1. Schematic representation of the HIPAT process chain

For the new process, Salzgitter Mannesmann Forschung GmbH developed a robust dual-phase steel alloy, which properties fit to the flexible sheet metal rolling process of Muhr und Bender KG. During

this process the thickness of the steel strip is changed in the longitudinal direction. Sheet thickness is controlled with a roll gap as a function of the coil feed. After cold rolling the heat treatment to adjust the dual-phase microstructure within the alloy takes place. Here the challenge is to adjust the homogeneous structure within the steel band, independent from the different thicknesses.
The challenge of Welser Profile Deutschland GmbH is to use existing industrial facilities to manufacture a roll profile out of the specified material and thus to create the cross section of the profile. Besides the basic feasibility of the manufacturing process, the Institute for Production Engineering and Forming Machines also investigated the further development of the process chain in terms of production on an industrial scale. In addition, the Institute developed a process that uses an adjustable rolling tool to improve the profiles tolerances.
The possibilities of the new profiles were verified by Schmitz Cargobull by means of a demonstration in a truck trailer [2].
To achieve the project objectives, not only the material and the forming processes were optimized, but also a customized design methodology was developed by the Institute for Engineering Design. The restrictions that resulted from production were collected systematically along the process and were deposited in a structure in the form of rules. In addition, functionally structured design catalogues of economically producible profile geometries were built. In combination with the appropriate rules for the integration of functions, with the catalogues the designer should be led to components that take advantage of material properties. In this way the rules and the catalogues help to design innovative and weight-reduced profiles [3].

2 STATE OF RESEARCH

2.1 Design Process

As a result of increasing complexities in the development of technical products a VDI working group with the participation of leading design scientists and senior engineers from industry developed the draft directive for the methodical development of technical products. Meanwhile, the 1993 as VDI 2221published directive is a widely accepted approach for developing technical systems and products. The approach can be used in mechanical engineering, precision engineering, as well as in software development or planning of process plants [4]. In Figure 2, the proposed process model is shown.

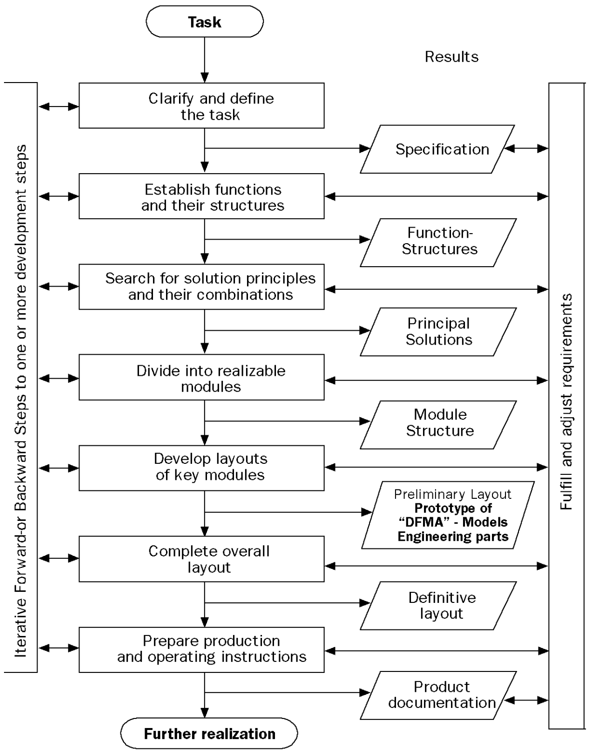


Figure 2. Process model VDI 2221 for the Systematic approach to the development and design of technical systems and products [4]

The model involves seven steps, starting with the task and proceeding to the necessary documents, which must be developed for the realization of a product. In every work section, testing, evaluation and selection operations are provided. If necessary, iterations will be done. At the start of the design process only limited information is available. Therefore the ability to work iteratively is important to improve the essential work results. This possibility is suggested by the lateral connection of all the steps.
Through the use of tailored methodological tools in the early stages of the development process, however, solutions can be developed faster and more selectively [5].

2.2 Design Catalogues

The knowledge of individual development engineers on, for example, physical effects or possible manufacturing processes for components contribute significantly to the successful completion of a construction task. However, designers have often only limited and, to some extent, highly-specialized knowledge. To complete a design task, therefore, additional knowledge must be acquired. The acquisition is often very difficult and time consuming. As a means to improve the subsequent results of the design process using the knowledge and experience of individual persons, it is appropriate to collect information and known (partial-) solutions and provide this targeted information [6].
Design catalogues –some kind of simple-to-use knowledge management system– are intended to provide knowledge to the designer by providing solutions for recurring sub-tasks and by encouraging the further search of possible solutions. Nowadays, the originally paper-based design catalogues [7] are replaced by flexible catalogues that allow user specific access from all over the world, e.g. [8]. To facilitate the use, design catalogues have a uniform structure. They consist of a classification part, a main part and an access part and possibly additional notes [9]. The schematic structure is shown in Figure 3.

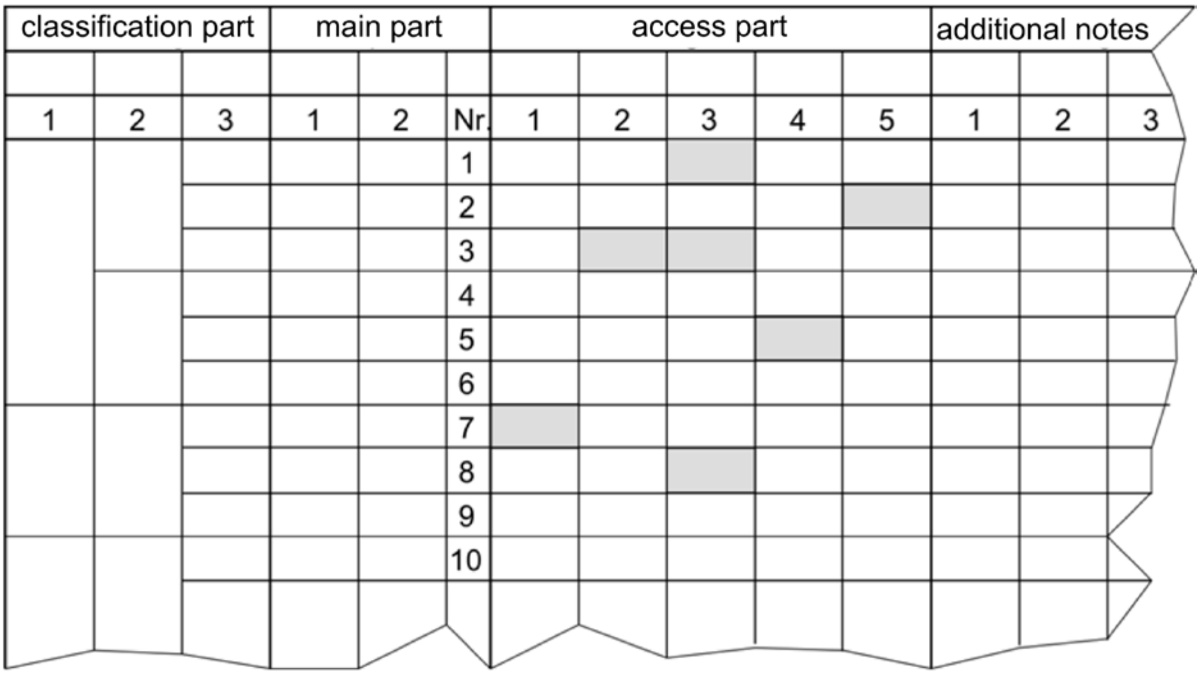


Figure 3. Schematic structure of a design catalogue divided into the four parts classification part, main part, access part and additional notes

The classification part of the design catalogue guarantees the systematic arrangement of the contents and the shell of the catalogue. This part shall be done before the other parts of the catalogue are worked out. The classification part also provides a framework for theoretically possible, but currently not yet known solutions (the so-called "white fields" in the main part that can serve as starting points for finding new solutions). The classification part comprises only the classification attributes. These classification attributes are preferably quantifiable or logical/structural attributes that divide the solutions of the main part into content that is clear, nearly complete and consistent.

The main part is the part of a design catalogue that contains the contents of the catalogue. The contents can be objects, solutions or operations. These are displayed as clearly as possible in the form of words, phrases, symbols, formulas, sketches, drawings, etc.
In the access part, the assignment of the access attributes will be organized according to the catalogue solutions. This part is adaptable to the needs of different users and can be extended. The listed access attributes in addition to the classification attributes help the designer to find a targeted solution in the catalogue [6].

2.3 Calculation Tools

A fundamental challenge in the determination of product characteristics is to achieve a good balance between accuracy and effort required of the analysis. The overall objective is the early identification of major characteristics with sufficient accuracy and low cost. However, this objective is in opposition to the following facts:

- The accuracy of the analysis largely depends on the available information. The time invested in the development process during which an analysis is carried out, has thus a substantial effect on the accuracy. Only with the progress of product development it is possible to take on certainty and the extent of the statements continuously. For example, a FEM analysis can provide results with high accuracy, but requires detailed information on the geometry. In contrast for design calculations first rough dimensions are sufficient, but the accuracy of the results and the certainty of the results are low.
- The effort that is caused by the change of insufficient product characteristics rises with increasing size of the specified properties. If failures are detected late in the product development process, their disposal results in considerable costs and time (see Figure 4).

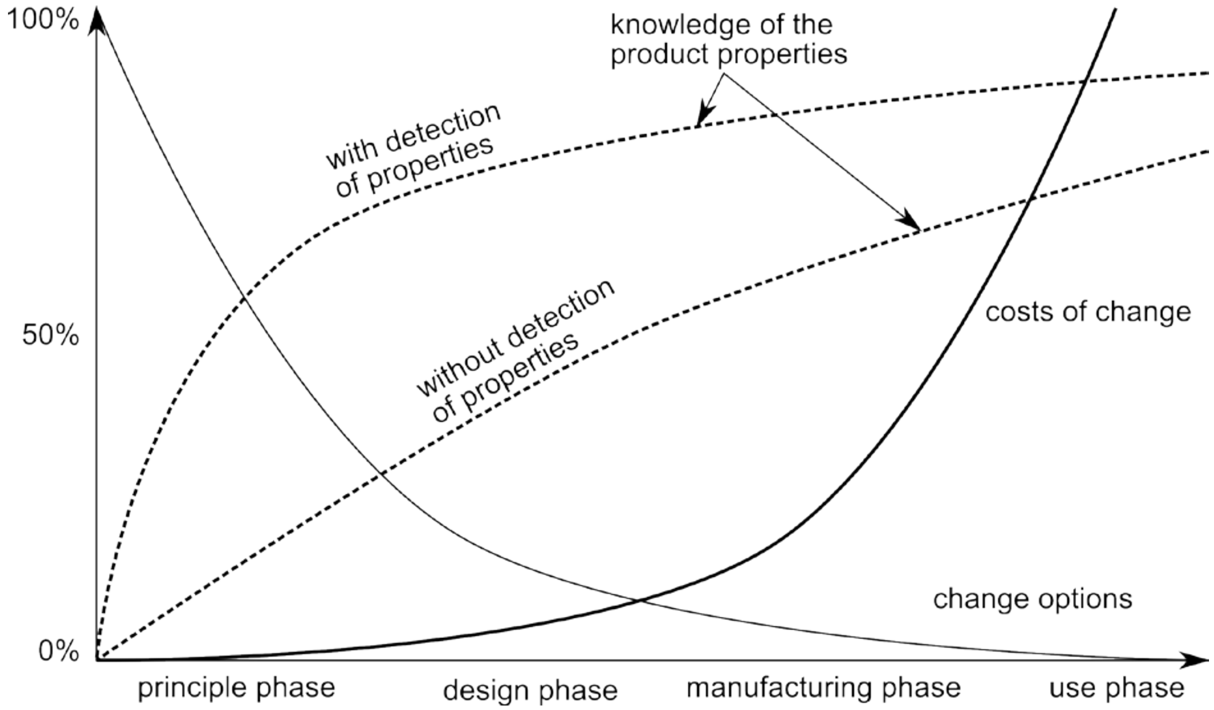


Figure 4. Schematic representation of the knowledge about the product characteristics with and without property detection during the product development process and highlight the options for change and the resulting change in cost [according to 10]

Only through early identification of product characteristics, it is possible to ensure the characteristics which are defined in the beginning. Using suitable analysis methods, the designer has to identify the product properties early and has to review and possibly adjust the product. To select an analytical method, the intended purpose is important. Depending on the current phase of the development process, for example, the basic behavior of a solution (concept phase) or the comparison of alternative solutions (design phase) is of interest. Furthermore, the trend to use calculation and simulation methods in product development continues unabated. This is caused by increased time pressure, with less and less time available for building prototypes and testing. In addition, prototypes are often very

expensive. As quality of virtual prototypes increased much during the last years, simulation can save time and money. Calculation and simulation methods allow to identify essential properties and thereby to reduce iterations in the early stages of the development process. This can reduce the costs for required changes and improve the product properties.
The application of calculation and simulation methods is based on mathematical and virtual models. Depending on the model type complex calculation methods and for example appropriate computer-based tools are necessary. Based on their use, calculation tools and simulation methods can roughly be divided into three classes:

- A methods are suitable for dimensioning parts in the early stages of the development process. The use of these methods is associated with low cost. However, A methods lead only to uncertain statements. To use A methods basic knowledge about the conditions of application is required. Relatively simple tools such as a calculator or computer algebra systems (CAS) support the application.
- B methods include, for example, linear finite element simulations or machine elements calculation software and are associated with a medium level of time invested and usually require a training period before using the application. These methods can be used by designers and lead to statements of average quality.
- For the use of C methods, extensive knowledge is required. They are executed with the support of specialists. With C methods it is possible to achieve statements of high quality, but on the other hand they are very time-consuming. Examples of this class of methods are non-linear finite element simulations (FEM) and Computational Fluid Dynamics (CFD) simulations.

The use of a calculation tool depends on the phases of the development process. At the beginning of the development process, just little information is available. To get statements for the product in this phase it is advisable to use tailored A methods. In the course of the development process more and more information can be determined. Then B and C methods are used, that provide more detailed and more reliable results.

3. DEVELOPMENT OF A CONTINUOUS DESIGN METHODOLOGY

As a part of the project, individual tools were developed. These tools will assist the designer in determining the basic shape of a HIPAT-component. To demonstrate the systematic application of the tools, a continuous methodology based on VDI221 (cp. 2.1) was developed [4]. This development methodology is shown schematically in Figure 5.

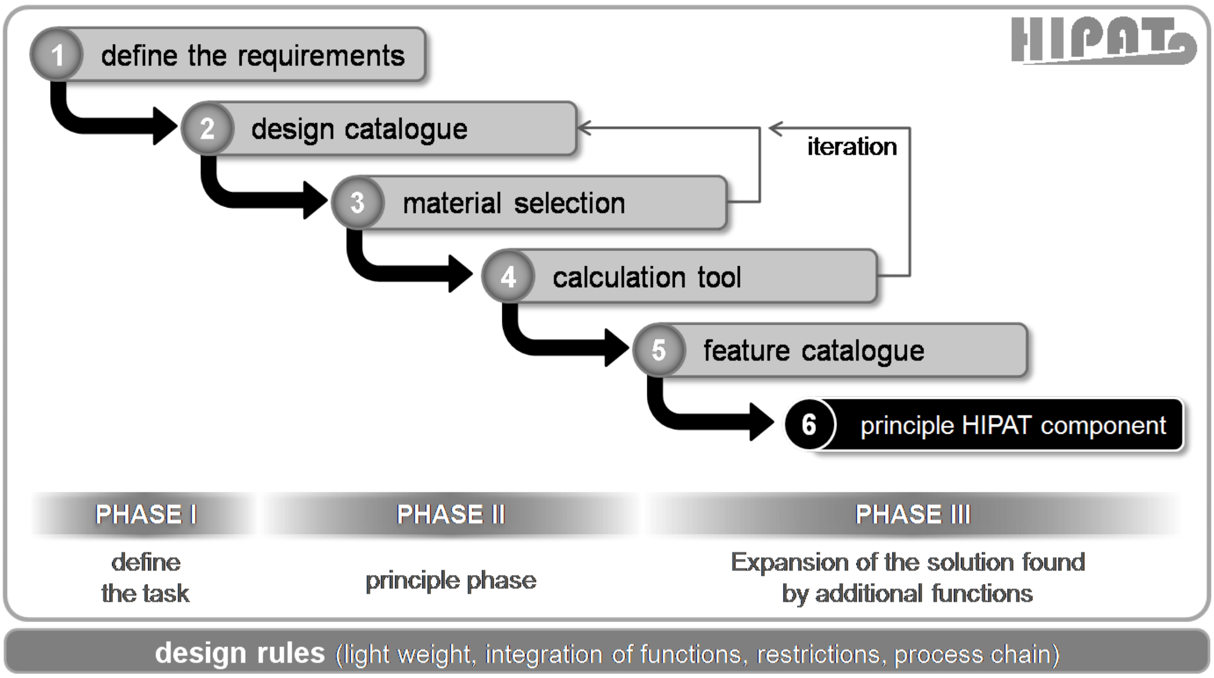


Figure 5. Schematic representation of the construction methodology for determining the basic shape of a HIPAT-component

The methodological Design process begins with clarification of the task. This phase aims to define the requirements for the developed product and to gather them in the list of requirements. In this context the designer has to consider about the conditions and restrictions, which must be clarified from the component environment [11][12].
In the next step of the design process, a design catalogue was developed. This catalogue includes basic HIPAT profiles and considers the identified constraints and restrictions. Through the systematic comparison of the basic profiles, the fundamental appropriate profile geometry for the design task can be selected. This selection will be explained in section 3.1.
Before the selected HIPAT basic profile can be refined in the calculation tool, the material must be selected. The material data is required to calculate, for example, the mass of the profile and the profile deformation. In the project, the material is already set so its selection is no longer a step. If the results of the selected profile in the calculation tool don't satisfy the requirements, the designer must jump back into the design catalogue and choose a different basic HIPAT profile.
As soon as the in the calculation tool observed profile fulfils with the requirements, in the next step further functions can be integrated into the HIPAT profile. To this end, an additional catalogue includes features, which can be integrated into the profile.
Through this specific design process shown above, the designer quickly gained a customized solution for a principle HIPAT component.
In addition to the applicable tools the design rules provide an additional source of information. The design rules are applicable during the entire design methodology. They point to additional potential to design lightweight products and to integrate functions. Furthermore they provide a simple way to bring the boundary conditions of the process chain into mind.

3.1 The design catalogue

The special process chain enables potential for lightweight and the integration of functions. For the utilization of the process chain, the designer has to provide specific knowledge about the possibilities, but also the limitations in the design.
Therefore users from the transportation industry were asked to systematically identify meaningful component functions. These functions are allocated to normalized standard profiles, the so-called "basic HIPAT profiles". The basic HIPAT profiles were collected systematically in a solution catalogue. This solution catalogue makes it easy to find suitable HIPAT-profiles quickly for each task. The catalogue also represents the functional capabilities for each profile, so it is a collection of ideas for the integration of functions. For the selected profile, the possible currently unused "free functions" are shown and checked for usability in a design context. "Free functions" are features that can be used in the component without additional design cost. An example of a "free function" is the use of a body part as a linear guide. In Figure 6a detail of the design catalogue is shown:

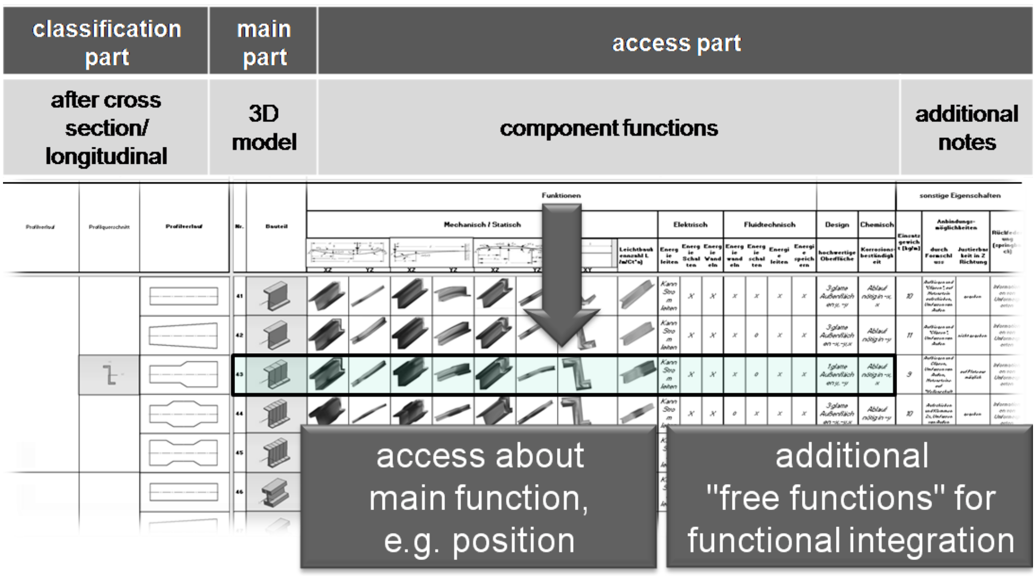


Figure 6. Detail of the design catalogue with standardized components, the so-called "basic HIPAT profiles"

During the project, an interactive design catalogue with additional features was developed. In the interactive design catalogue, hyperlinks on the basic HIPAT profiles can be selected. If the designer opens the hyperlink on a profile, the production drawing of the component opens. In the drawings there are shown the precise geometry and all important dimensions of the basic HIPAT profile [3].
The simulation images of the individual load cases can also be selected in the interactive design catalogue. This will open a 3D-pdf, which allows the viewer to consider the load case from different perspectives in color code and exaggerated deformations. Both applications are shown in Figure 7:

Figure 7. Example of a selected HIPAT profile or a load path in the interactive design catalogue and opening the production drawing of the component with the precise geometry or the 3D-pdf of the component

3.2 The calculation tool

The calculation tool helps the designer to refine the sheet thickness of the profile, starting with the HIPAT basic profile selected from the design catalogue. Therefore the calculation tool narrows the gap between the pre-selected basic HIPAT profile and the design in principle. In a user-friendly interface, as shown in the figure below on the left side, the designer first fixes the known constants. These include the entry dimensions of the basic HIPAT profile and the material constants, which are in this special case determined by the high-strength dual-phase steel.
In a subsequent step, the cross-section of the profile, as determined in the design catalogue, is selected and any missing dimensions are added. In the design catalogue the basic sheet metal thickness curve of a profile can be chosen for example by the load case that is to be applied. This curve proposed in the catalogue will be detailed then in the calculation tool. For this step, the bearings and the forces are entered in the calculation tool. It can accept any number of individual forces and bearings in the calculation tool, as long as it is a statically determinate system. Results are then displayed in a new window. The input and the output interfaces of the calculation tool are shown in Figure 8. There a basic HIPAT profile is put on two bearings on either side and four forces exert between them. This arrangement is for example typical for a roof rack:

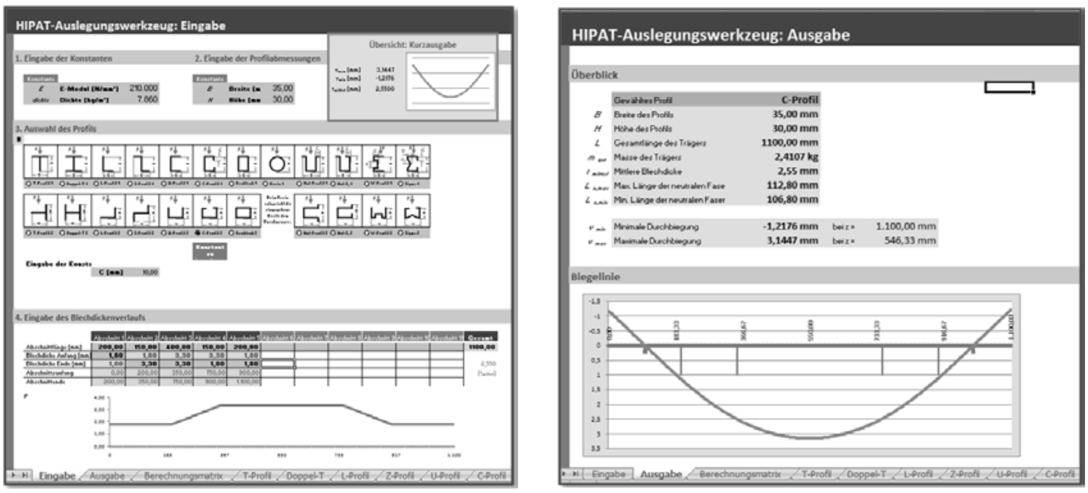


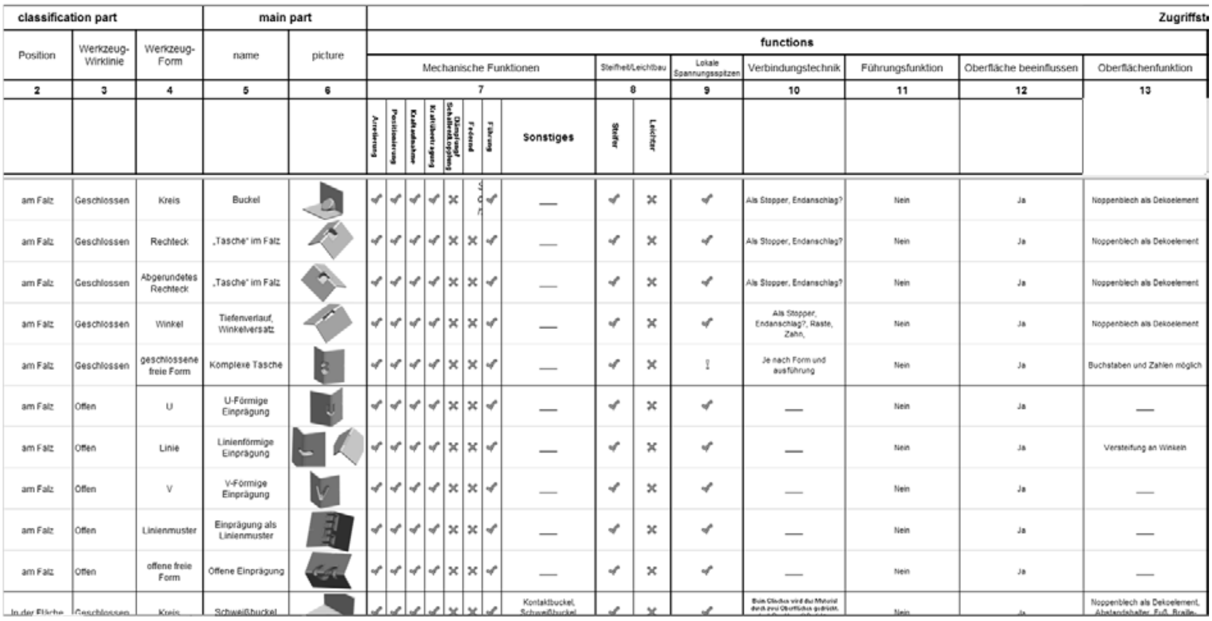
Figure 8. Input and output views of the user interface of the calculation tool, which helps the designer to refine the sheet thickness of the basic HIPAT profile

In the illustration, the bending line of the calculated HIPAT profile is visible. In addition, the maximum and minimal bending of the profile are calculated. These can be compared with the requirements of the component. If the requirements are not met, the sheet thickness profile has to be optimized, for example, to achieve less bending. As early as in the initial stages of the design process, the designer can draw first conclusions on the total weight and the average thickness of a HIPAT profile by using the described calculation tool. Thus, conclusions can be made on the potential weight of the HIPAT profile, especially in comparison with conventional profiles.

3.3 The feature catalogue

In addition to the design catalogue, which lists the HIPAT basic forms systematically, a feature catalogue was developed. The purpose of this catalogue is to integrate more functions by including additional profile features into the component.

The classification part generates a solution space of possible features that can be provided in principle on a HIPAT component. In the main part of the catalogue, the methodical developed features were designated and provided with sample images. The access part of the feature catalogue lists the possible functions, which can be integrated into the profile as well as additional information, for example, the manufacturing process of the feature. A part of the feature catalogue is shown in Figure 9:



classification part			main part		Zugriffsteil														
					functions														
Position	Werkzeug-Wirklinie	Werkzeug-Form	name	picture	Mechanische Funktionen								Steifheit/Leichtbau		Lokale Spannungsspitzen	Verbindungstechnik	Führungsfunktion	Oberfläche beeinflussen	Oberflächenfunktion
2	3	4	5	6	7								8		9	10	11	12	13
					Arretierung	Positionierung	Kraftaufnahme	Kraftübertragung	Dämpfung/Schallentkopplung	Federnd	Führung	Sonstiges	Steifer	Leichter					
am Falz	Geschlossen	Kreis	Buckel		✓	✓	✓	✓	✗	[illegible]	✓	—	✓	✗	✓	Als Stopper, Endanschlag?	Nein	Ja	Noppenblech als Dekoelement
am Falz	Geschlossen	Rechteck	„Tasche" im Falz		✓	✓	✓	✓	✗	✗	✓	—	✓	✗	✓	Als Stopper, Endanschlag?	Nein	Ja	Noppenblech als Dekoelement
am Falz	Geschlossen	Abgerundetes Rechteck	„Tasche" im Falz		✓	✓	✓	✓	✗	✗	✓	—	✓	✗	✓	Als Stopper, Endanschlag?	Nein	Ja	Noppenblech als Dekoelement
am Falz	Geschlossen	Winkel	Tiefenverlauf, Winkelversatz		✓	✓	✓	✓	✗	✗	✓	—	✓	✗	✓	Als Stopper, Endanschlag?, Raste, Zahn,	Nein	Ja	Noppenblech als Dekoelement
am Falz	Geschlossen	geschlossene freie Form	Komplexe Tasche		✓	✓	✓	✓	✗	✗	✓	—	✓	✗	!	Je nach Form und ausführung	Nein	Ja	Buchstaben und Zahlen möglich
am Falz	Offen	U	U-Förmige Einprägung		✓	✓	✓	✓	✗	✗	✓	—	✓	✗	✓	—	Nein	Ja	—
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am Falz	Offen	offene freie Form	Offene Einprägung		✓	✓	✓	✓	✗	✗	✓	—	✓	✗	✓	—	Nein	Ja	—
In der Fläche	Geschlossen	Kreis	Schweißbuckel		✓	✓	✓	✓	✗	✗	✓	Kontaktbuckel, Schweißbuckel	✓	✗	✓	[illegible]	Nein	Ja	Noppenblech als Dekoelement, Abstandshalter, Fuß, Braille-

Figure 9. Detail of the feature catalogue with additional profile features, which can be integrated into the HIPAT profiles

3.4 The design rules

Providing the knowledge about the boundary conditions of the process chain for the designer in terms of work practice, design rules were developed for the roll forming process, the flexible forming process and the use of high strength dual phase steels. Each design rule is formulated with a clear statement, for example "Take supporting effect by curvature", and added to a corresponding image as well as references. All rules are available in digital form and are structured by subject matter.

The rules here are specifically tailored to the problems encountered in engineering practice of the project partners. The meticulous, simply formulated instructions allow quick access to the knowledge.

A detail of the design rules is shown in Figure 10.

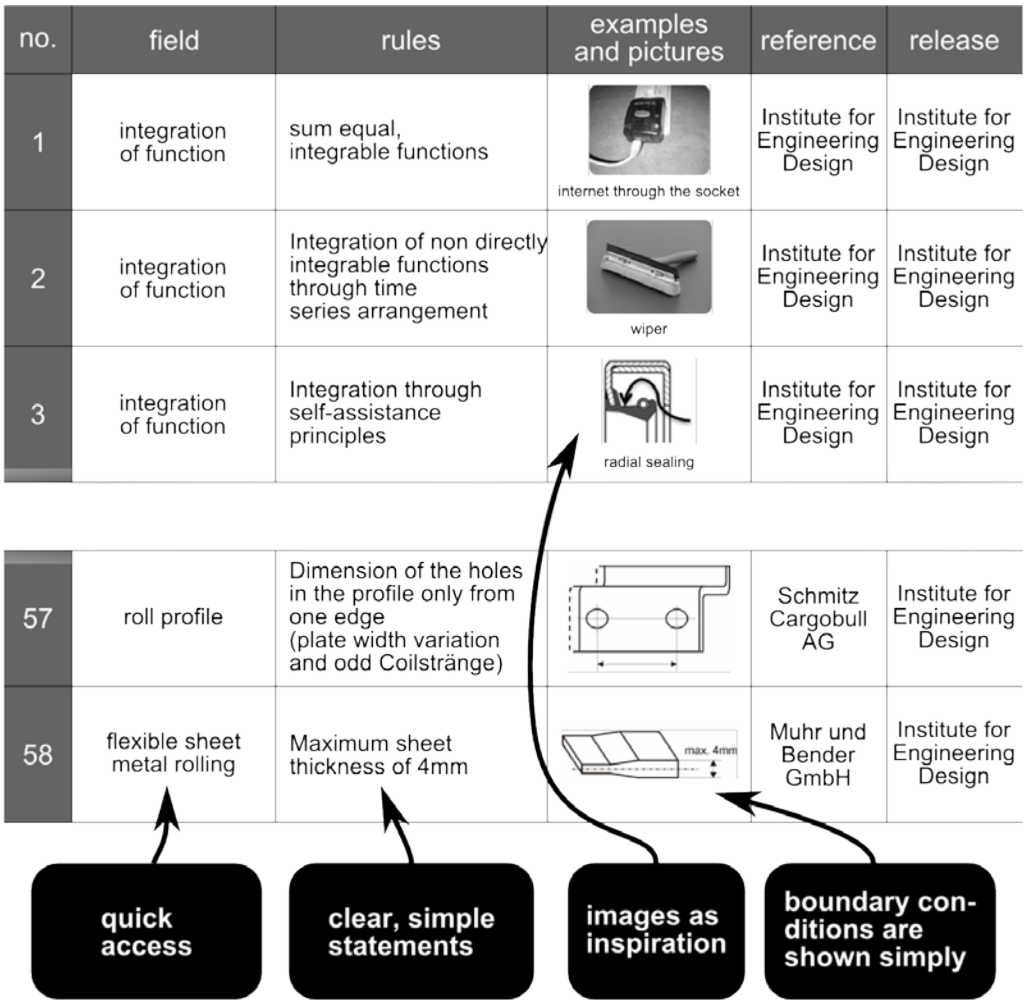

Figure 10. Detail of the structured design rules with a clear statement, the corresponding image and the references

The images of the design rules also allow inexperienced designers to understand complex situations quickly [13][14]. This helps to avoid unnecessary iterations reducing development costs and time.

The representations of the design rules on the subject of the integration of functions will be centered on proving the designer's with inspiration for light and innovative designs. The rules on lightweight and the integration of functions were adapted to early stages of the design process, when there is still little knowledge on the part design. Therefore, general statements were made, which support, for example, the selection of an optimal solution principle [15].

Here, the presented approach differs significantly from other lightweight construction approaches, those which often focus on optimizing already predefined geometries with respect to their dimensions [16]. Lightweight potentials that result from different solution principles get lost in such an optimization. The here presented approach helps finding the best solution principle first. Optimization can come later.

4. CONCLUSION

Due to short development times for technical products, it is difficult for designers to consider new process chains. Usually the time to obtain the information for a new process chain in short term is missing. For this reason a continuous design methodology, which is distinguished mainly by its applicability in early design phases, was developed for the HIPAT process chain. With the design methodology it is possible for a designer to grasp the possibilities of the new process chain quickly**.** In addition, by considering the topics lightweight construction and the integration of functions, the potential of the HIPAT process chain is shown. Through the methodology the development and market introduction of new lightweight rolled steel profiles can be accelerated.

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