PROCESS INTEGRATED DESIGN GUIDELINES - SYSTEMATICALLY LINKING MANUFACTURING PROCESSES TO PRODUCT DESIGN

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1. Introduction

In order to develop innovative and successful products, the early phases of the product design process have to be intensified. The consideration of promising manufacturing technologies in product design further adds to the required intensity. As well as ensuring product manufacturability, manufacturing technologies should be applied specifically to initially provide the product function and to improve the product functional context by tapping manufacturing technology potential [Roos et al. 2014], [Gramlich et al. 2015]. Demands for quality and quantity lead to increased complexity, which can only be faced by realising the potential of manufacturing processes. The product designer has to be supported in decision-making, not only by restricting product geometry or material in manufacturing processes but also by specific product solutions for integrating manufacturing characteristics.

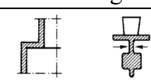
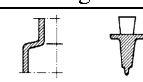
The aim of this paper is to describe a method and format for preparing suitable solutions to realise manufacturing potential in product design. Besides information about product geometry and material, appropriate product solutions always comprise information essential for realising the product function. Above all, solutions, in the context of their realisation by manufacturing processes, have to outline how the characteristics of manufacturing processes could be integrated into the product in its functional context. Special design patterns can be developed and used in a standardised description within process integrated design guidelines (PIDG). A consistent description using product properties is needed not only when acquiring design patterns and process integrated design guidelines but also in a procedure for applying them during product design.

2. Design guidelines - basic format of documentation

The designer has to face various challenges while considering manufacturing characteristics during product design. Usually, the designer's main problem is a lack of experience in the field of manufacturing technologies: The practical knowledge of a manufacturer as well as a deeper understanding of the manufacturing processes are mostly missing [O'Driscoll 2002], [Herrmann et al. 2004]. The success of a product heavily depends on designer experience [Ferrer et al. 2009]. Information not just about product design is required; knowledge that fits manufacturing information to the designer's experience is as well. A further issue is the different languages and objectives of design and manufacturing [Bolte 2000]. The designer has to improve the product function whereas the manufacturer has to ensure its manufacturability, focussing on time, costs and quality (based on [Bolte 2000]). Detailed knowledge about manufacturing processes is mostly outside the expertise of designers [Herrmann et al. 2004]. As part of this challenge, information on manufacturing for designers needs to be gathered. Most

approaches for capturing, organising and representing such knowledge are too short and not applicable. They do not define which information and knowledge is required by the designer [Ferrer et al. 2009]. This leads to the demand for an approach that allows the systematic preparation of relevant knowledge based on coordinated models of manufacturing processes and the product in its functional context. Only by fitting the information within both models, can adequately prepared manufacturing knowledge be provided to the designer. Available manufacturing knowledge is documented in many different sources and formats so many companies develop their own documentation to suit their needs [Ferrer et al. 2009]. Thus, a format has to be chosen that is suitable for illustrating aspects of manufacturing knowledge, i.e. manufacturing process knowledge linked to product function, and is based on established formats whose applicability has already been proven.
There are several established approaches for considering manufacturing characteristics during product design. Summarised as Design for Manufacture (DfM) and Design for Manufacture and Assembly (DfMA), these approaches support the designer with manufacturing process information, with a focus on costs, quality and time-to-market [Bralla 1999], [Pahl et al. 2007], [Ashby 2010], [Boothroyd et al. 2010]. A procedure is described within each of these approaches where design guidelines are essential for making documented knowledge applicable. Table 1 shows an excerpt from existing design guidelines: the first design guideline is universally applicable and not linked to any specific manufacturing technology; the second is specifically for casting processes; and the third refers to the assembly of electronic products.

Table 1. Examples of existing design guidelines

<table>
<tr><th>Source</th><th colspan="3">Design guideline</th></tr>
<tr><td>[Boothroyd et al. 2010]</td><td colspan="3">Try to ensure that the diameters of internal features (rotational components) decrease from the exposed face of the work-piece.</td></tr>
<tr><td rowspan="2">[Pahl et al. 2007]</td><td rowspan="2">Avoid vertical sections (bubbles, blowholes) and reduced cross-sections to the risers.</td><td>Wrong</td><td>Right</td></tr>
<tr><td></td><td></td></tr>
<tr><td>[Bralla 1999]</td><td colspan="3">Minimise the use of sockets. Mechanical connections have diminished reliability compared with soldered connections.</td></tr>
</table>

When analysing existing design guidelines it becomes apparent that their specific purpose, format, structure and scope vary a lot. Besides giving advice, some guidelines support the designer by adding explanatory formulas, graphs, tables and graphical representations of adequate solutions like wrong/right examples [Pahl et al. 2007]. Despite the design guidelines in literature differing in details, some common elements in structure and content can be identified. There is always an instruction that addresses a design element to determine its required properties, for example, diameters. In most cases this is limited to geometry (including structure) and material of the design elements [Tekkaya et al. 2015] (Figure 1). There is a huge number and variety of design guidelines in literature. Most of these guidelines are documented in very different ways, resulting in no consistent and uniform underlying structures for integrating the gathered information. Applying these guidelines proves difficult as there is no consistent procedure for how to apply these guidelines in a design approach. Most manufacturing guidelines cite a corresponding manufacturing technology but do not provide any information about the underlying relevant manufacturing characteristics. Existing guidelines are mostly meant to restrict a product's embodiment design [Gramlich 2013] (Figure 1). They concentrate on restricting the product's geometry and material selection instead of tapping manufacturing potential to improve the product's functional context. A detailed linking of information to the product in its functional context as well as (manufacturing) process information are missing.

3. Process integrated design guidelines

3.1 Extending the process context of design guidelines

As shown above, design guidelines are an established tool for documenting process knowledge that supports the designer, especially in manufacturing and assembly. Manufacturing technologies have a huge impact on product design, resulting in design decisions for different manufacturing technologies. With the help of the cold forming technology linear flow splitting, a flange geometry with a specific material structure can be manufactured. This ultra fine-grained microstructure leads to increased hardness and strength, properties that can be beneficial in the realisation of product functions in various applications [Groche et al. 2012]. Thus, design decisions have to consider these special geometric as well as material properties to synchronise product design and process characteristics. Manufacturing technologies, such as machining, obtain different geometric and material properties with different consequences for realisation of the desired product function.

Design guidelines in their current format have to be adjusted and extended to support design decisions that depend on the manufacturing technology chosen. Manufacturing processes, including assembly processes, have to be clarified and documented in more detail, according to the process parameters that are relevant to the product in its functional context. Also, the process context of the product use processes has to be clearly documented as it concerns the impact of the manufactured products on the planned use processes that accompany the product's purpose. Above all, linking this process knowledge to relevant knowledge about the product in its functional context as well as to appropriate knowledge about use processes is imperative to reveal manufacturing potential. All aspects mentioned for extending design guidelines to represent relevant solutions to better support the product designer lead to these guidelines being realised as process integrated design guidelines (Figure 1, left).

3.2 Design patterns

To enable the development and documentation of process integrated design guidelines, an approach is chosen in which design patterns are used to prepare and represent necessary solutions. In architecture and software engineering, design patterns describe the core of a solution to recurring problems [Alexander et al. 1977], [Gamma et al.1994]. The defined design patterns comprise four main elements [Gamma et al.1994]: Pattern name (useful for identification of the pattern); problem (defines the problem and context for applying the pattern); solution (primarily the elements of the solution and their relationships); and consequences (results, trade-offs). In software engineering, design patterns are mainly used when defining objects and interfaces within software applications. For product designers, design patterns indicate beneficial elements and their relationships to the product in its functional context.

The design pattern appears at different levels of abstraction [Gamma et al. 1994]. Hence, design patterns can be used at different levels of concretisation during product design. This concerns not only product embodiment, but also the product in its functional context. Design patterns can be used in different languages and documentation formats [Gamma et al. 1994], so they provide the basis for process integrated design guidelines in a formalised and documented way to extract and prepare adequate solutions in the context of the design process (Figure 1).

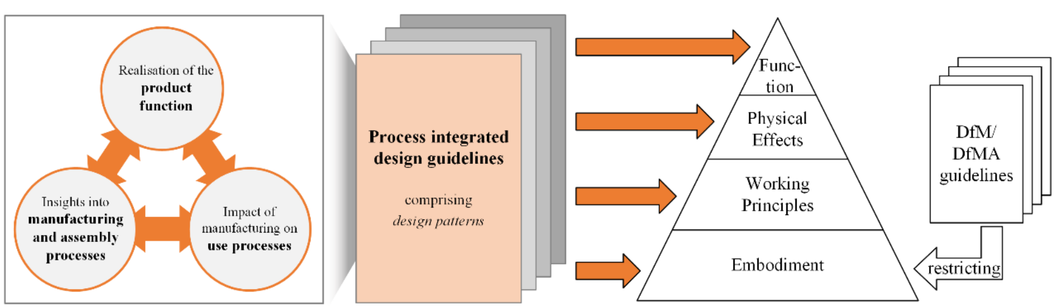


Figure 1. Essential knowledge behind process integrated design guidelines

3.3 Structure and content of process integrated design guidelines

The goal of process integrated design guidelines is supporting the designer during the stepwise concretisation of the product function by providing corresponding solutions based on a manufacturing technology. Thus, existing manufacturing insights have to be systematically documented, so that a designer can understand the corresponding information without depending on additional input from manufacturing experts. Process integrated design guidelines originate from a systematic and combined consideration of manufacturing and functional facets. This consideration leads to products that tap manufacturing technological potential to create highly functional products while employing a cost-efficient manufacturing process. Core elements of process integrated design guidelines are solutions in the form of suitable function carriers for different levels of concretisation, based on the concept of design patterns, and a systematic consideration of manufacturing processes and use processes. Function carriers describe the elements necessary for realising the product function and can be applied at different levels of concretisation. They can be parts and components [Ehrlenspiel and Meerkamm 2013] in embodiment design or a specific set of working elements at the working principle level. Process integrated design guidelines can be utilised at different levels of concretisation, thus providing high transferability of fundamental solutions and ideas. To ensure its applicability, design guidelines always consist of a description of the design guideline's general goal and the designer's ability to pursue this goal. This is reflected in the defined structure and the elements of process integrated design guidelines. Figure 2 shows an excerpt of a catalogue of process integrated design guidelines. In the following paragraphs, the fundamental structure of process integrated design guidelines is illustrated by the guideline that concerns a process integrated mechanical joining of a functional element to realise a positive connection (PIDG 1).

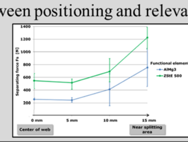
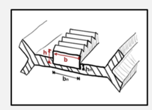
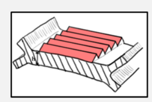
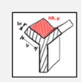
Identifier	Solution	Explanation	Reference
PIDG 1: Mechanical joining of functional elements	Use a **HSC notch** close to the splitting area in a linear flow split web, utilising high residual stresses during the linear flow splitting process, for mechanically joining a **functional element** with corresponding geometry to realise a *positive connection* with high separating forces.	Deformations during linear flow splitting processes can positively fit joined elements in previously inserted notches or holes. Experimental studies show a correlation between positioning and relevant forces: 	 Linear system with rack and pinion drive [Wagner 2015]
PIDG 2: HSC realisation of rack	Use **high speed cut teeth** positioned on the linear flow split web (thickness > 4 mm) with determined teeth geometry for realising **rack teeth** with a geometry fitting to coupled gear teeth.	Integration of teeth in linear flow split webs makes a sheet thickness of at least 4 mm necessary in order to be able to achieve an adequate working depth.	
PIDG 3: Linear Flow Split Flanges as rolling contact area	Use **linear flow split flanges** with UFG microstructure for realising a **rolling contact area** of a *linear guide* with high longevity and surface quality	UFG microstructure with high hardness and low surface roughness	 Integrated linear guide [Karin 2012]
PIDG 4: Targeted deformation under pressure	Use **closed chambers** with sealing and chamber walls with different thickness as **pressure chambers** with one degree of freedom to realise a targeted deformation for a *clamping function*.	Deformation depends on flexibility which correlates with wall thickness	 Linear Guide with integrated positioning function [Lommatzsch 2011]
PIDG 5: Positioning of form elements in the flange area	Use the **flange area** with high notch sensitivity for *adding additional functional elements* to the profile, due to the increased hold capacity of the **form element** in that area	The UFG microstructure is characterised by a lower notch sensitivity, which can be seen by comparing different Woehler curves.	Light crane system [Gramlich 2015]
PIDG 6: Placing welding seams at the end of flanges	Use **welding seams** positioned at the end of the flanges in order to integrate **bifurcations** while minimising effects of welding on material within the UFG microstructure of the *bifurcated profile*.	The hardness of the flanges decreases towards the end of the flanges. Thus the welding operation leads to no significant reduction of the UFG material properties.	Light crane system [Gramlich 2015]
PIDG 7: Using	Use compressed chambers of a welded		

Figure 2. Excerpt from a process integrated design guideline catalogue

The process integrated design guideline is divided into three parts: identifier, solution and explanation, and reference. The unique identifier helps in structuring potential design guideline catalogues and makes access to the documented information easier. It can have a function and application context or just an alphanumerical identifier. An already specified product function is a designer's possible entry point to

the process integrated design guideline. In Figure 2, the identifier of PIDG 1 is "PIDG 1: Mechanical joining of functional elements". By describing the considered function ("mechanical joining") and a specific use case, the context and possible applications of the process integrated design guideline become apparent.
The second part of the process integrated design guideline is its key element: The solution, extended with an explanation of the process integrated design guideline. Figure 3 shows the necessary elements of a process integrated design guideline and how they are connected.

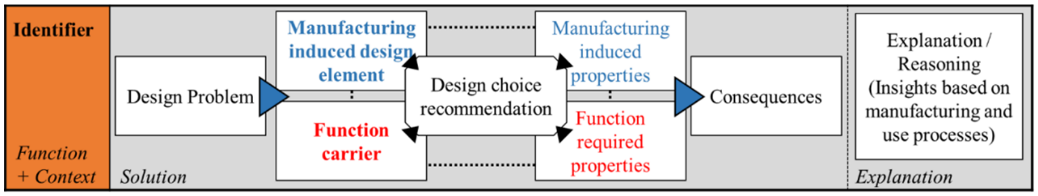


Figure 3. Structure and elements of process integrated design guidelines

The solution consists of a text description comprised of the concrete design choice recommendation for a specific design problem and the consequences of its application. The key to every process integrated design guideline is the design choice recommendation, incorporating a concrete solution to the given design problem. In product design, one of a designer's key challenges is finding and identifying suitable design elements for the realisation of necessary functional elements for the product function. By linking the product function to design elements provided by manufacturing processes, the potential of the specific manufacturing technology for product innovation can be tapped. In the text design guideline, the recurring problem of the underlying design pattern is represented by the desired product function and working principles, effects or embodiments that can be applied to realise this function in the form of a specific function carrier. The core solution is provided by suitable design elements provided by a specific manufacturing process chain and instructions on how to utilise these design elements. Both manufacturing processes and the product function can be described with the help of product properties, thus providing a common "language" to establish a link between these two perspectives [Gramlich 2013]. The design choice recommendation in process integrated design guidelines helps the designer to utilise specific product properties provided by the manufacturing technology to satisfactorily realise the product function.
The starting point for creating process integrated design guidelines is the preliminary determination of a desired product function and application. During product design, different effects, working principles and concrete components can be utilised as function carriers to realise a specific function. Function carriers are characterised by a specific set of functional elements and function-required properties. If set at the working principle level, these functional elements are specific working elements, consisting of working surfaces, working motions, working locations and working geometries [Pahl et al. 2007]. Every single working element can be described by its specific properties that are relevant to the working principle. Systematically gathering possible working principles and comprehensively documenting relevant properties of the working elements enables the realisation of the product function in different manners, resulting in a larger number of feasible solutions in the design process that are documented in process integrated design guidelines.
In Figure 2, the suitable functional element of the solution is marked in bold and red type, with a specific set of functional properties (in this case, geometric properties and separating forces, marked as red) that have to be provided to realise the desired outcome, "positive connection" (printed in italics).
The process integrated design guidelines provide a specific solution to this design problem in the form of manufacturing induced design elements that can be beneficially utilised as a function carrier. Specific manufacturing design elements are provided by and are characteristic of manufacturing technologies and manufacturing process chains [Gramlich 2013]. Flanges with ultra fine-grained microstructure are characteristic manufacturing induced design elements of linear flow splitting. Similarly to the function carrier, the manufacturing induced design elements provided by the manufacturing technology are characterised by a specific set of properties, the manufacturing induced properties. These manufacturing

induced properties are provided and subsequently influenced by specific manufacturing technologies in the manufacturing process chain. They comprise all geometric, material and mechanical properties that are provided by the specific manufacturing technology. By systematically adjusting parameters during the manufacturing processes, relevant manufacturing induced properties can be determined during product design. The manufacturing induced properties become crucial setscrews for product design. They play a key role in process integrated design guidelines. The relevant manufacturing induced properties can be elemental and structural properties. In PIDG 1, they are elemental geometric properties (high residual stresses, marked as blue) and the structural positioning of the manufacturing induced design element (Figure 2).
To thoroughly utilise a manufacturing technology's potential to realise product functions in a cost-efficient manufacturing process, the process integrated design guidelines introduced in this paper are based on the systematic matching of manufacturing induced properties and function-required properties [Gramlich 2013] (Figure 4). By matching the manufacturing induced properties to the specific function-required properties, the link between manufacturing processes and the product function is established. Manufacturing induced design elements that are especially beneficial in realising the product function can then be identified. In PIDG 1, the high speed cut notch (shown as bold and blue) is the manufacturing induced design element provided by the chosen manufacturing technology, which can be utilised to realise the desired outcome.

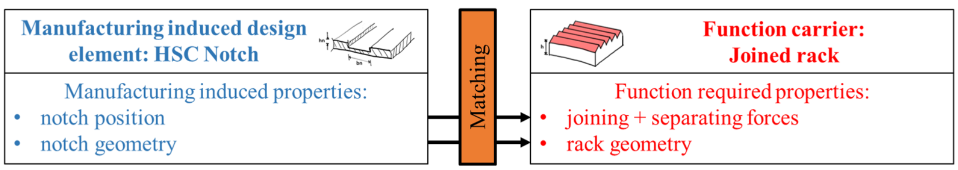


Figure 4. Matching manufacturing induced properties to function-required properties

The design choice recommendation is based on specific insights from experts in manufacturing and assembly processes and the impact of manufacturing on use processes. In a comprehensive explanatory section, these insights are prepared in the form of descriptions and graphs, and help understanding of the given design recommendation and make it easier for the designer to apply the recommendation to their own specific project or adjust the recommendation without needing to consult further experts. In the example in Figure 2, experimental results for the mechanical joining process directly influence the resulting design recommendation: to maximise separating forces of the joint connection, the manufacturing induced notch should be positioned close to the splitting area of the linear flow split web to provide a durable connection [Wagner et al. 2015]. This also enables the designer to make targeted adjustments to the design recommendation when applying it to specific design projects. For recycling purposes, a different notch position might be necessary to create low separating forces that favour later disassembly processes, such as recycling.
The third part of the process integrated design guideline consists of a design reference with further reading sources that also help understanding of the design recommendation as well as references to previous projects where the specific design guideline has been successfully applied. In addition to the PIDG identifier, referencing previous projects makes access to the PIDG easier by providing specific examples of suitable applications. Additionally, a graphical representation of the process integrated design guideline is shown in an abstract form. The graphical representation helps understanding of the design elements and product properties, and can further enhance the applicability of the process integrated design guideline by complementing the text. While providing a visual representation of the design guideline, it should not be dependent on any particular embodiment but should focus on the effect or working principle structure.
Depending on the function carrier's level of concretisation, process integrated design guidelines can be applied at different levels of product concretisation, from function and physical effects to working principles and embodiment (Section 4). While design guideline PIDG 3 in Figure 2 recommends linear flow split flanges as function carriers without describing a specific physical effect, working principle or embodiment to realise the product function, PIDG 4 recommends the use of closed chambers, incorporating a specific physical effect. PIDG 5 addresses the specific positioning of the function carrier

that acts as a working element. In PIDG 6, an already concrete embodiment of welded parts in a bifurcated profile is suggested.

With the help of design guidelines, fundamental results can be reused in subsequent design projects. Not focussing on the design of the whole product but instead addressing specific functional elements makes the essence and underlying insights of the developed design guidelines available to many applications. By implementing the reasoning [Gramlich et al. 2015] behind the specific recommendation given in the text part of the design guideline, the designer can more easily and beneficially apply the process integrated design guideline to a specific problem and application without requiring expertise in manufacturing technologies.

3.4 Process integrated design guidelines in current approaches

The process integrated design guidelines presented in this paper incorporate established concepts of existing DfM and DfMA approaches (Figure 5). The aim of design patterns to provide solutions to recurring problems is reflected in the structure of process integrated design guidelines. Typical design guidelines address specific design elements and give instructions on specific required properties to achieve a satisfactory embodiment design [Bralla 1999], [Boothroyd et al. 2010]. Process integrated design guidelines now explicitly address manufacturing induced design elements and functional elements to utilise the manufacturing technology's potential for product design. The design recommendation also consists of an instruction regarding properties, but is always given in the context of both manufacturing induced properties and functional properties, instead of focussing on technological restrictions. Technological restrictions can also be represented in process integrated design guidelines by restricting the range of possible values for specific manufacturing induced properties (for example, PIDG 2 in Figure 2). The various design guidelines compiled in [Pahl et al. 2007] mainly address how to circumvent manufacturing restrictions in a previously determined manufacturing technology. The design reference used in process integrated design guidelines also helps illustrate the design recommendation but is a more abstract representation than typical wrong/right examples to be independent of specific solutions.

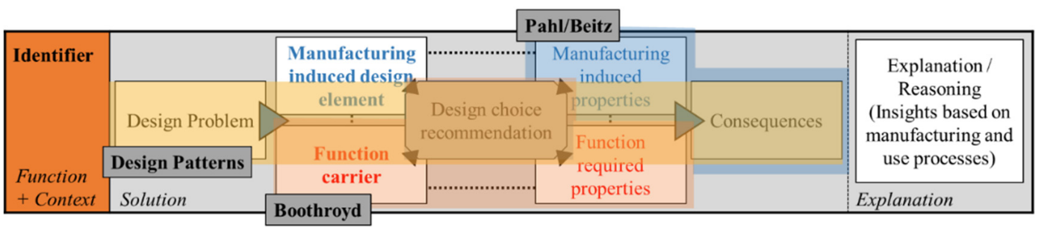


Figure 5. Process integrated design guidelines in existing approaches

4. Integration into product development

According to literature, there is a lack of capability to use manufacturing knowledge even if it is available. The identification and application of relevant information to improve a product are especially important [Bolte 2000]. The variety of data and information on manufacturing technologies is huge but there is little explicitly represented knowledge about how to use these data and information in DfM [Ferrer et al. 2009]. Available knowledge about manufacturing is difficult to apply. Even during the early stages of design, manufacturing implications and upcoming problems are very hard to predict [Herrmann et al. 2004]. Thus, the introduced process integrated design guidelines are assigned in a consistent manner, with the focus on how to integrate relevant information into product design.

The basis of the approach is an integrated view of product design and product life cycle processes, focussing on manufacturing and use. In addition to existing design approaches, like VDI 2221 [1993] or Axiomatic Design [Suh 1998], the product development process is supplemented by further steps to include life cycle knowledge during product development. This contains a systematic analysis of life cycle processes with subsequent preparation and integration of relevant knowledge in the form of process integrated design guidelines into product development (Figure 6).

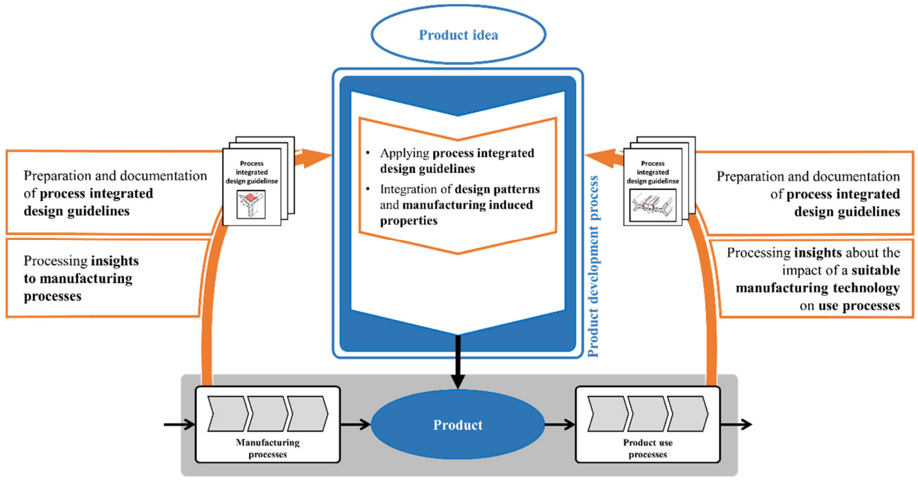


Figure 6. Approach for applying process integrated design guidelines

The approach includes targeted processing of knowledge relevant to life cycle processes for product design purposes. This requires the processing of insights into manufacturing technologies by specialist examinations, simulations and further analyses to identify characteristic information and relations using adequate models. Mostly, this step can only be conducted by an interdisciplinary expert team, which includes the designers, which has to apply the prepared insights. Accordingly, the documentation of this knowledge is indispensable in avoiding expending effort on the same topic in further development projects. In linear flow splitting, the mentioned characteristic information includes manufacturing induced properties, like increased hardness, and their dependence on process parameters. This information has to be systematically linked to information on the product in its functional context to make it applicable to product design. Existing methods like systematic property matching support the specialist during this step [Gramlich 2013], [Gramlich et al. 2015]. Knowledge about the impact of manufactured products within suitable use processes needs to be processed. For the example of linear flow split profiles, especially their application within linear guides and systems seems advantageous, following PIDG 3 in Figure 2. Knowledge about their behaviour in such guides and systems is indispensable in a suitable realisation. Systematic property matching can be used to support this step.

The processed information and relations have to be prepared and documented to apply them during product development. This step follows the above-mentioned layout of process integrated design guidelines to realise this format of documentation. The structure of process integrated design guidelines chosen plays the most important role during this step to fulfil all demands for documenting process information relevant to product design. Above all, process integrated design guidelines are applied to integrate solutions, in the form of design patterns, into product development. The application of relevant process integrated design guidelines is primarily carried out by the designer according to the product's purpose in the context of proposed use. Integration of the design pattern and the function carrier into the product leads to holistic realisation of manufacturing potential.

Early integration of process integrated design guidelines demands prior determination of an appropriate manufacturing technology [Groche et al. 2012], [Gramlich et al. 2015]. Similarly to the property based identification of suitable function carriers (as seen in Figure 4), this step can again be supported by systematic matching of required product properties with manufacturing induced product properties.

Figure 7 shows how PIDGs 1 - 6 are implemented in products and the impact of this integration on product design. This includes the product developed with the function carrier realised by a manufacturing technology, as well as the specific benefit to the product. The examples are chosen for varying levels of product concretisation to illustrate the flexible application of process integrated design guidelines. PIDGs 1 and 2 show two feasible solutions for the same design problem: An integrated rack and pinion drive can be realised with the help of a mechanically joined rack or high speed cut (HSC) teeth. The reasoning and reference parts of the PIDG help the designer to choose the best design for the specific development project: Due to the higher lightweight potential of PIDG 1 in its allowance of a lower wall thickness for the whole profile structure, a mechanically joined rack was realised for the linear system of a multifunctional façade cleaning system [Wagner et al. 2015]. In different projects with different requirements, PIDG 2 might have been the better choice.

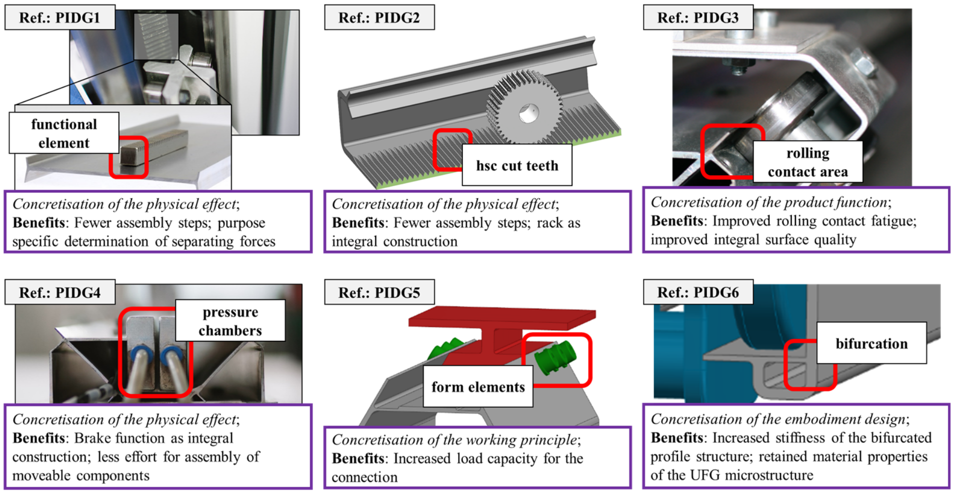


Figure 7. Benefits from integration of process integrated design guidelines

5. Benefits

By applying process integrated design guidelines, manufacturing insights become available for use in later product development projects. The integrated way of documenting product and process information allows for comprehensive consideration of documented knowledge. Geometric and material restrictions of the product are addressed, and manufacturing potentials are revealed. By extending the documentation format with design patterns, additional information can be given that strengthens the basis for decision making with the help of comprehensive explanations.

Process integrated design guidelines provide a standardised format for documenting and preparing appropriate knowledge on manufacturing processes for product design. Existing design guidelines can be extended with process information because of their similarities to process integrated design guidelines. The preparation of new guidelines is easily done and applicable to companies with small or extensive manufacturing. No special software is required for documenting process integrated design guidelines. Common spreadsheet software like Microsoft Excel is suitable for preparing even huge libraries of process integrated design guidelines.

Most importantly, process integrated design guidelines are not limited to embodiment of the product. They can also be used at different levels of concretisation, resulting in a much stronger supported solution finding process.

6. Conclusion and outlook

Starting from established approaches, a standardised documentation that considers manufacturing characteristics during product design is shown in the form of process integrated design guidelines. A structured preparation of appropriate solutions, based on design patterns, helps in the documentation of information relevant to realising function carriers with the help of suitable manufacturing induced design elements. The recommended structure of process integrated design guidelines raises awareness of the importance of systematic consideration and utilisation of the beneficial interaction between manufacturing characteristics and product function. By implementing manufacturing induced properties and function-required properties in the structure of process integrated design guidelines, the designer is forced to think about the link between the two perspectives when processing newly acquired insights and documenting them in the form of new process integrated design guidelines. Based on a property focused approach, process integrated design guidelines can be created for any desired manufacturing technology and product function. Ongoing realisation and documentation of a process integrated design guideline catalogue, comprising many suitable and beneficial solutions for design problems, becomes possible. An additional structure can be added to the catalogue by organising the collected process integrated design guidelines for company specific characteristics that heavily depend on the existing product portfolio and development projects. The process integrated design guidelines then become much more accessible.

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