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MAPPING REQUIREMENTS TO PRODUCT PROPERTIES: THE MAPPING MODEL

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1. Introduction

Customers buy technical products when they perceive needs that might be unsolvable without using appropriate means. However, customers expect that a product will fulfil its planned behaviour due to function fulfilment. An undesirable situation should be transformed into a desirable situation [Andreasen et al. 2015], meaning that the technical product has to fulfil its product function to ensure the intended use processes of the product life cycle. Therefore, designers have to focus on requirements that are related to function-required properties to realise the product function and to achieve technical products with increased value to stakeholders.

Designers have to meet market and stakeholder needs and expectations. Designers have to develop and guarantee the intended use processes by focusing on product behaviour. They, unfortunately, only know the current state and vague statements about the desired state that are to be realised by a change in state. Thus, designers have to develop a means (the technical product with its product properties) for a defined purpose (transformation of the current state into the desired state during use), which leads to concretisation of the product idea. Designers act in a huge and dynamic field - company interests, the user market with its needs and expectations, new arising technologies, forces for innovation, cost reduction pushed by new competitors, and stakeholders who contribute requirements. This leads to continually replaced and systematically extended suggestions for the intended product life cycle (Figure 1). The key question for successful product design has to be focused: Which product properties does a product have to have to fulfil design requirements and to serve the intended purpose?

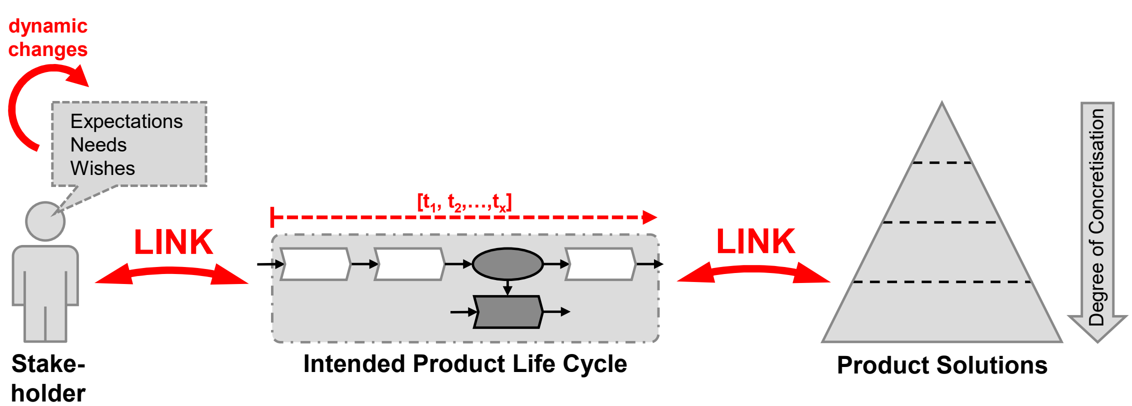


Figure 1. Challenges between domains in engineering design

2. Fundamentals

As recognized in design research, new models that just flood research with more and more unconsolidated models and methods are not needed [Andreasen et al. 2015].This paper focuses on well-known models like [Suh 1998], [Albers et al. 2005], [Weber 2005], [Sauer 2006], [Pahl et al. 2007], [Lindemann 2009], [Ponn and Lindemann 2011] and [Ehrlenspiel and Meerkamm 2013] to close current gaps in the mapping of requirements to product properties, to provide success factors in product design.

2.1 Existing model theories

Existing product design approaches focus only on product function or product properties and consider the influence of manufacturing processes on product design late in development processes. Manufacturing processes are seen as restrictions and are mainly determined late in development processes after the product shape has been concretised. However, these approaches do not answer the key question of how requirements and product properties are interrelated to ensure product design that is focused on function-required product properties that provide product function in envisaged product behaviour during use by tapping the full potential of new manufacturing processes.

The synthesis of new products is mainly initiated by the goal formulation (what should be developed?) envisaged by the designer's ideas for principal solutions [Pahl et al. 2007]. Synthesis goes along with analysis, where behavioural properties of the technical product are predicted by known constructional product properties. The goal formulation has to be considered throughout the entire design process [Pahl et al. 2007]. Key factors for the market success of the technical products developed are mainly around clarification of the design tasks to define essential and constructional product properties that the intended product should have, according to desired properties that may be predefined or required. Designers focus on possible use scenarios, intended product behaviour, product function, appearance, parts and assemblies. The technical product is incrementally designed and is composed of a variety of solutions for specific sub-problems.

Common models, like CPM/PDD [Weber 2005] and Axiomatic Design [Suh 1998], focus on different views to systematically map requirements to product properties. The aim of CPM/PDD is to match product properties to properties demanded by customers. This is done by using analysis and synthesis steps, where characteristics and their values are defined during synthesis to gain the demanded properties. Care has to be taken, since these approaches use different terminology for requirements and product properties, in contrast to the conceptual understanding by Birkhofer and Wäldele [2008] and used in this paper. Axiomatic Design pursues the formalised development of technical systems. Two major questions characterise Suh's Axiomatic Design: "What do we want to achieve?" and "How do we choose to satisfy the need?" to transform customer attributes from the customer domain into functional requirements and constraints within the functional domain [Suh 1998]. These functional requirements have to be realised by design parameters. Process variables characterise appropriate manufacturing processes that physically realise the defined design parameters. Since each domain is mapped to the next one, customer attributes are always considered during the detailed design process. iPeM describes a metamodeling of tripartite systems. Requirements, restrictions, dependencies and relations between requirements are modelled within the target system. Actions within the action system describe all activities that transform the target system into the object system in which the actual developed product is modelled and described [Albers et al. 2005]. iPeM provides purposeful support of the entire development process due to the flexibly arranged activities within the process for problem solving.

However, these models do not focus on envisaged processes that have to be integrally developed with product design to ensure products that best fit their appropriate processes, such as use processes and manufacturing processes. They demand continual and dynamic update of requirements while only a few support documentation of requirements along the entire development process and the resolution of contradictory and conflicting requirements. These models do not consider the detailed relations between requirements and defined product properties of the technical product that emerge continually due to decisions and determination of specific solutions during the entire development process.

2.2 Modelling and describing products and processes by properties

As presented in this paper, technical products are modelled and described by their product properties.

Users usually perceive product quality according to perceived dependent product properties. These product properties cannot be influenced by designers. Only independent product properties [Birkhofer and Wäldele 2008] can be influenced and directly determined by designers [Birkhofer 1980]. Product properties are composed of a characteristic and a value [Lindemann 2009]. Out of necessity, product properties are determined during the entire product development process according to documented requirements [Eder and Hosnedl 2008]. According to the concretisation process, designers have to determine product properties of the technical product in a way that best fits the acquired requirements.

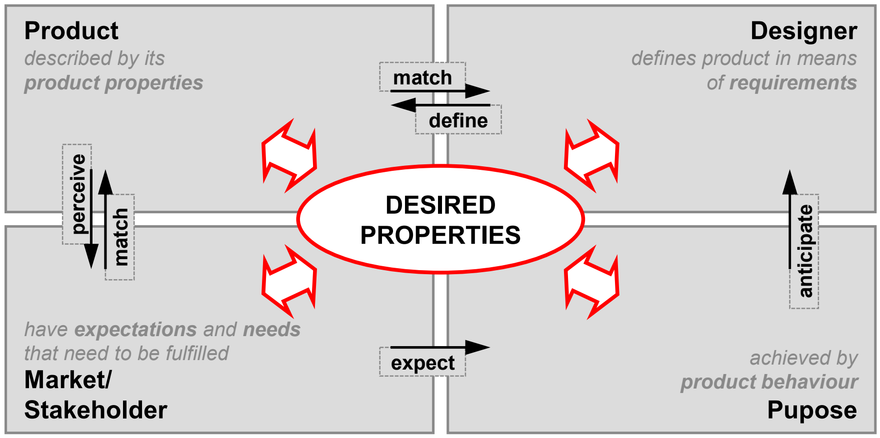


Figure 2. Desired properties as the main link element

The intended purpose of the technical product has to be taken into account as being of of greatest value to stakeholders. Therefore, desired properties are the main link element between the intended technical product, designers, the market stakeholders and purpose (Figure 2). They contain the most essential dependent properties that customers like to have associated with the developed technical product. The value ranges of desired properties may by qualitatively and quantitatively distinctive, whereas values within these value ranges can be discrete. The desired properties and product properties in general are the main aspect in every algorithm-based product design process that ensures a formalised interface that allows the translation of technically formulated requirements (textually represented in requirement lists) into the representation of mathematical optimisation equations with target functions and side conditions. Desired properties are the key to identifying constructional parameters for optimisation, since they contain dependent product properties that can be broken down into independent product properties using the structure of product models. This leads to the composition of property networks to identify the most constructional relevant, independent product properties to best influence desired product properties.
This paper presents the Mapping Model (Figure 3) to transform requirements into product properties. The Mapping Model has been in development since 2013. It aims for orientation and methodological support for designers during product and process development. It is suitable for both technology-pushed and market-pulled development processes. Activities during the ongoing concretisation process of the technical product, and its processes associated with the product life cycle, can be flexibly applied to the transformation of requirements into product properties, concerning relations to product function to create the starting point of an algorithm-based product optimisation process with mathematical optimisation methods. As above, the influence of envisaged product life cycle processes and process chains on the technical product can already be modelled and described by requirements from a solution-neutral perspective of requirements already used for product and process innovation in the early stages of product design.

3. Mapping Model: linking requirements and product properties

The Mapping Model (Figure 3) is based on the established works of [Suh 1998], [Albers et al. 2005], [Weber 2005], [Sauer 2006], [Birkhofer and Wäldele 2008], [Ponn and Lindemann 2011], [Ehrlenspiel and Meerkamm 2013], and [Gramlich 2013], and leads to a consolidated view of incremental property-based product and process design by harmonising requirements and properties.

Most importantly, the technical product and its product function have to be focused during product design to find adequate solutions for each identified function, leading to new and innovative products. The function relates to the intended purpose of the technical product, while designers have to answer the main questions of what function-required product properties the technical product has to have to ensure intended purpose of the technical product during use due to product behaviour. During product design, designers have to consider the technical product as the envisaged means for a defined purpose (product idea) within its envisaged product life cycle processes. This leads to questions, such as how the user will use the product, in which market does it operate and which competing products exist [Andreasen et al. 2015], to gain valuable knowledge about desired properties that the technical product needs to have.

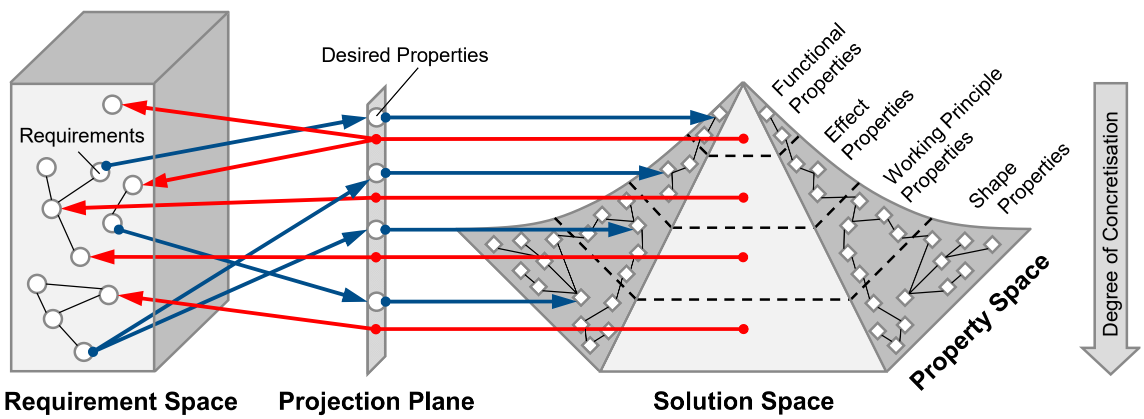


Figure 3. Mapping Model

As highlighted by the Mapping Model, designers differentiate between two views: one for the value-related part of development activities and one for the design-related part of development activities. It is essential to understand the relations between the dependent properties that are responsible for value creation (perceived by the market/stakeholders) and the independent properties that can be directly influenced by designers to achieve the appropriate dependent ones. Both views are united by transformation processes that transform the textual representation of requirements into a highly formalised representation using properties. The Mapping Model focuses on three major spaces: requirement, solution and property spaces. These three spaces are highly interrelated and connected by the projection plane, which captures on the structure of the solution, and property space, which enables the systematic mapping of semantically structured and clustered requirements to the property-based description of product concretisation [Mattmann et al. 2014].

The following case study is used to portray the main elements and views of the Mapping Model to develop a new and innovative linear guide system. It has function-integrated elements manufactured in continual bending processes (Figure 4) to gain integral products with multiple branches [Lommatzsch et al. 2011]. The system should fulfil its purpose by reducing the velocity of a linear guided object to fix the object with high positional accuracy. By using the manufacturing-induced properties of new manufacturing technologies in linear flow splitting and linear flow bending, a new integral manufactured linear guide system [Lommatzsch et al. 2011] is created by using pneumatic pressure to achieve brake force. This can be only achieved by using friction as a physical effect. The function principle of the multifunctional linear guide system shows the main advantage over other concepts: By using the benefits of new manufacturing technologies, as described above, highly integral technical products can be manufactured [Lommatzsch et al. 2011], whereas other solutions may feature design by intuition.

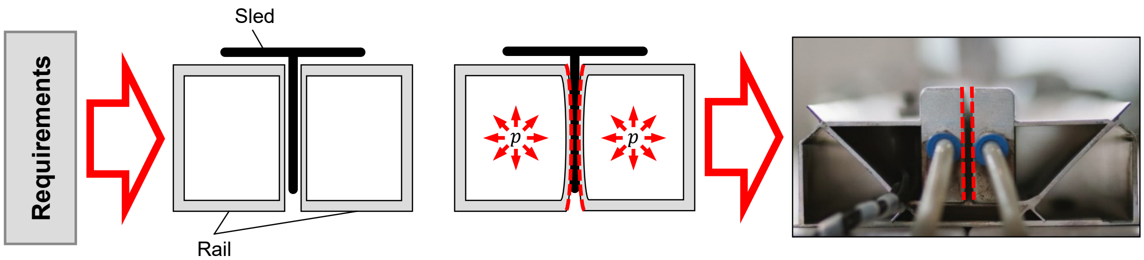


Figure 4. Function principle of linear guide system with integrated pressure chambers

3.1 The requirement space

Requirement acquisition leads to a variety of requirements that are semantically interrelated, partially in conflict or contradictory. The entirety of requirements increases during ongoing product and process development due to property-based determination; changing boundary conditions also contribute new requirements. These dynamically changing requirements have to be considered during every development activity since even one changed requirement can change the entire property network, which describes and models defined design elements during embodiment design of the technical product. Since most important decisions that have consequences are made in the early phases of product and process development, changes in most important functional properties in the late phases of the design process have to be avoided, since these changes would affect cost-intensive changes in design elements and their structural composition.

Requirements are acquired from different sources, such as process analyses of the intended processes in the product life cycle, market and customer expectations, legal regulations, technical standards and corporate restrictions. The requirement space focuses on how stakeholder expectations and needs are represented, including requirements resulting from the envisaged processes of the product life cycle, function-related requirements for provision of product function, and requirements that result from the non-value-adding processes of the product development process [Mattmann et al. 2015]. The requirements space includes the best requirements by considering all processes within the envisaged process chains of the product life cycle. New requirements that result from the ongoing gradual product and process are considered in the requirement space. The requirement space is a dynamically growing space in which new requirements are steadily considered due to ongoing concretisation of the technical product and technical processes.

The requirements within the requirement space are structurally arranged differently since properties and the appropriate property network within the property space. This structural dilemma is solved by transforming requirements into desired properties that capture the property-based structure, thus allowing unambiguous assignment of requirements to desired properties.

Users usually have specific suggestions about product performance and product behaviour during use. Users are not interested in specific product functions. Their perception depends on need satisfaction and value creation when they perceive the product functions during use [Andreasen et al. 2015]. Since stakeholders formulate their specific expectations differently, using contradictory terminology, care has to be taken when translating these expectations into product properties. To simplify varying stakeholder terminology designers formulate requirements that consist of an indicator and a metric. For example, stakeholders want to have a cost-efficient product during manufacturing, resulting in a requirement with an indicator "manufacturing costs" and an appropriate metric, e.g. less than EUR 10,000.

As described previously, requirements are statements about desired properties [Birkhofer 1980] that lead to extraction of specific characteristics and the assignment of appropriate values that match the formulated requirements. To stress the integrated manner of requirements, they may be differentiated using the approach in [Mattmann et al. 2015]. For example, stakeholders may demand reduced noise during use of the multifunctional linear guide system, a specific time for stopping the guided object, position accuracy for the stopped object, and maximum permissible tolerances to assemble the developed multifunctional linear guide system (Figure 5). Most requirements result from the consideration of envisaged use processes by focusing on the technical product's intended purpose. These requirements are achieved during the gradual refinement of the product life cycle processes and process chains using the conditions of a supposed use case (Section 4.3). To identify the importance of requirements in the transformation into product properties, they are prioritised according to demands (necessarily to fulfil) and wishes (optional).

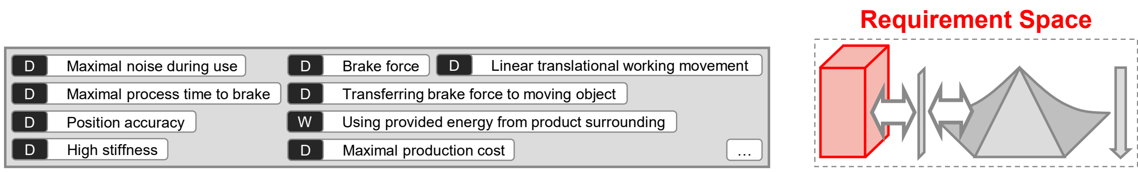


Figure 5. Requirements of the multifunctional linear guide system

3.2 The solution and property space: the well-known in every-day design

Modelling of technical products uses partial product models at each level of product concretisation. The solution space includes all possible solutions that may be suitable for a given sub-problem, which leads to an incrementally generated partial solution space in which the best suitable solution for the fulfilment of requirements is chosen. The product is described from abstract to concrete levels of representation. The technical product developed is described at each level of the product model pyramid by its dependent and independent product properties. Although designers define product properties continually during product design, they think implicitly in models that are directly related to product properties. Product models provide the structure of product properties. It is important to focus on product function and function-required product properties, since the product function contributes to satisfaction with the product's intended purpose. Product performance and product behaviour are mainly determined by product function [Pahl et al. 2007]. Product function models describe products within their functional context providing the main function, further sub-functions, their structural composition and the necessary input and output variables [Pahl et al. 2007]. Therefore, the multifunctional linear guide system can be modelled using its input and output variables, within the functional context in the solution space (Figure 6).

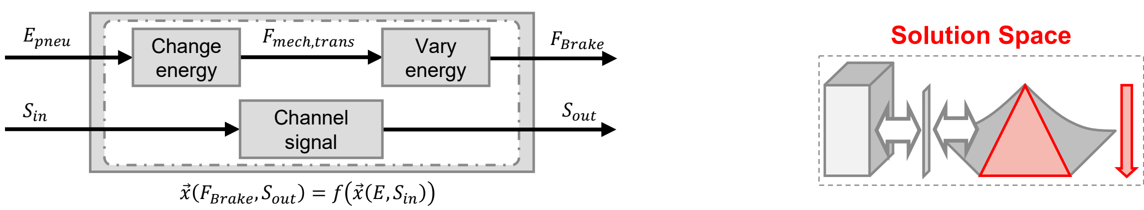
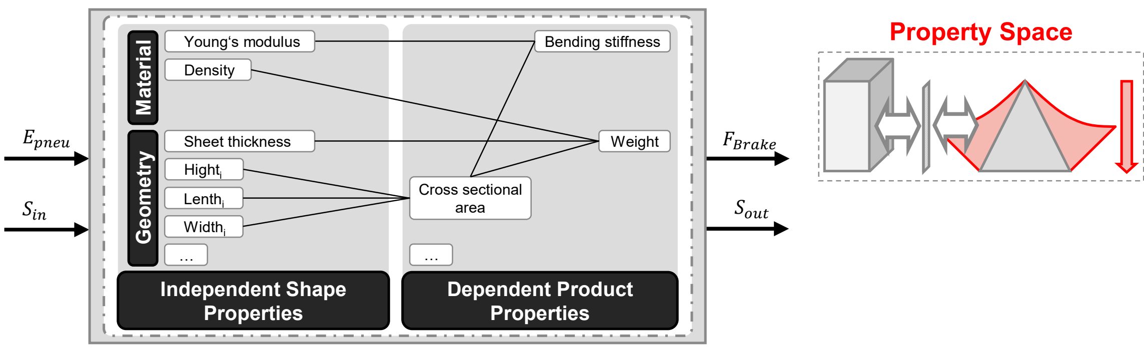


Figure 6. Product function model of the multifunctional linear guide system

Physical effect models include physical effects that unite the working principle, planes, rooms and variables represented in working principle models. Geometrical/material definition of the working principle results in shape models. All solutions that could be used to realise the gradually developed technical product are included in the solution space. Synthesis and analysis lead to the selection of an appropriate solution at each level of the solution space. Technical products are described and modelled by their product properties. Product properties, as modelled in the property space, allow designers to evaluate how good a technical product is compared to other competitive products. Designers face the challenge of determining independent product properties during the development processes that best influence dependent product properties based on stakeholder expectations. Based on various levels of the product model, properties of function, effect, working principle and shape are all differentiated. Structural and element properties are focused at each level [Gramlich 2013].

The property space provides the base for modelling and describing technical products, based on their product properties. Independent and dependent product properties of product elements (and their structural composition within the product structure) [Gramlich 2013] are included at each level of the projected levels of the solution space. The solution space focuses on the solutions developed for each overarching target system, consisting of requirements and desired properties of superior modelling levels. Since product properties are gradually determined during product design in top-down approaches, the total number of determined product properties increases exponentially according to the concretisation degree of the technical product. Technical products are described by a comparatively small number of product properties at the functional concretisation level. However, at higher degrees of concretisation, e.g. during embodiment, the technical product developed is described by a multiplicity of product properties. Whereas the multifunctional linear guide system can be described at a function level by the properties of its input and output variables, as well as their structural dependencies, it is described and modelled at the shape level by an increased number of independent and dependent product properties. There are geometrical properties, such as dimensions of each chamber, sheet thicknesses, etc., and material properties, such as density and Young's modulus (Figure 7). Each illustrated characteristic is associated with a requirement-conform value from the feasible value range of desired properties.



$$\vec{x}(F_{Brake}, S_{out}) = f(\vec{x}(E, S_{in}))$$

Figure 7. Property network in its functional modelling context

3.3 The projection plane: between requirements and product properties

Requirements are related to dependent and independent product properties. Unfortunately, designers do not know which product properties are related to each other, so it remains unclear how to build a suitable property network to meet requirements. This is because requirements within the requirement space and properties within the property space have different structures (semantically structured and clustered vs. relations structured according to their dependencies that can be influenced). These different structures are united and harmonised by desired properties on the projection plane.

Out of necessity, desired properties are semantically equivalent to requirements, since desired property characteristics and values or value ranges are extracted from each requirement or from a combination of requirements by considering their semantic correlations. Requirements describe the intended technical product in the form of statements that should be fulfilled by the manufactured product. They include explicitly and implicitly expressed information about characteristics of desired properties. These characteristics are either explicitly demanded by stakeholders, which implies a high risk of destroying solution neutrality, or are implicitly hidden in the requirement itself. Requirements are never absolutely complete, since they result from consideration of the envisaged product life cycle and many contradictory expectations of stakeholders. They have to be transformed into a representation that allows a complete description of the technical product. Desired properties, however, consist of a characteristic and possible values/value ranges defined by requirements, and fulfil underlying requirements. They mainly represent dependent product properties that are perceived by the market or customer, for which possible qualitative and quantitative values and value range can be defined. These values and value ranges are either continual or discrete sets. They create the potential to optimise the technical product for lightweight design, cost efficiency, topological arrangements and bending/torsion stiffness to achieve the best possible value for specific characteristics, which is also the best possible fulfilment of requirements. This results in a highly formalised representation of desired properties that matches the formalisation scheme of product properties.

Most importantly, desired properties reduce complexity in the highly complex process of transformation of requirements into product properties. Desired properties tap the potential to systematically map manufacturing-induced properties of new manufacturing technologies to function-required product properties. Thus, manufacturing-induced properties can be matched to desired properties in the early phases of product design, which means the production potential of the manufacturing technology selected can be assessed. Desired properties can also be systematically matched to manufacturing-induced properties to identify manufacturing technologies that seem suitable for manufacturing the technical product developed. This match can be achieved at each level of product concretisation during the early stages of development activities.
The projection plane includes the desired properties as a common interface between requirements and product properties (Figure 8). Requirement indicators predetermine the characteristic of each desired product property while requirement metrics specify desired property values and value ranges. For example, when designing technical products in lightweight design, some requirements define “weight” as the indicator and metrics “preferably low”. From this point of view, designers are not able to design the product, since they have just vague ideas of what is meant by “preferably low”. Only transformation leads to determination of the desired product property “weight” and values “less than 1.5 kg”. These desired properties result in a product design that fulfils all requirements.

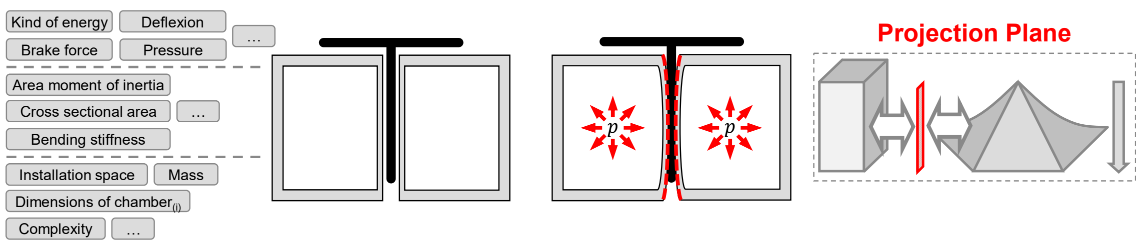


Figure 8. Desired properties of the multifunctional linear guide system

4. Links between the elements of the Mapping Model

A number of links exist between the fundamental spaces of the Mapping Model that join either requirements and desired properties, desired properties and product properties, and product properties to requirements by testing desired properties. The Mapping Model allows the integration of classic, well-known, property-based design knowledge, as used by designers in practice. The following design aspects build the base for design activities to map requirements to product properties.

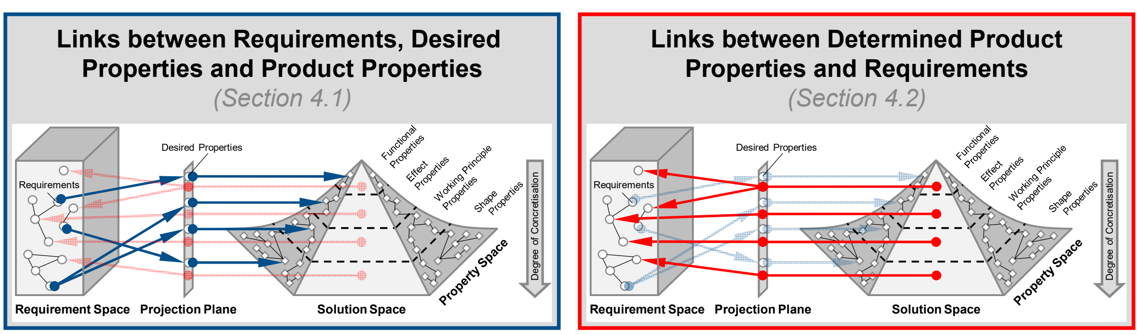


Figure 9. Links between the domains of the Mapping Model

4.1 Between requirements, desired properties and product properties

Satisfying requirements means balancing the possible values of desired properties with available quality profiles of the user [Vajna 2014]. Requirements describe what the product should do [Suh 1998]. They make statements about the desired properties. This enables the extraction of relevant information from requirements and transforms their information into desired properties, or more precisely, into

characteristics that are formulated according to project-specific system of concepts (product and process specific) that are assigned with suitable qualitatively or quantitatively distinct values and value ranges.
Requirements are correlated with ongoing product and process concretisation. Thus, there are complex interrelations between requirements and product properties that are represented in the property space that maps the structure of the solution space. The complex interrelations effect concretisation of the technical product at each level of the solution space, thus building on the following central activities (Figure 9, left-sided):

- Characteristics and feasible values/value ranges of desired properties compatible with their underlying requirement(s) are extracted from requirements according to the project-specific system of concepts. The focus is on process-relevant and functional-relevant desired properties that essentially correlate with behavioural properties of the technical product in its functional and process context.
- Characteristics of desired properties are assigned to the property space in which one value is chosen out of the value range of desired properties.
- The property space is continually refined by assigning the structure of the solution space and defining independent product properties to best influence dependent product properties. This results in the systematic structure of property networks that grow along with the degree of product and process concretisation.
- Due to the determination of product properties in the property space and the selection of solutions at each level of the product model pyramid, further requirements result, which are then included in the requirement space. These new requirements have to be considered during the ongoing product and process concretisation.
- The determination of product properties is continually matched to desired properties to guarantee the systematic and purposefully oriented development of the technical product according to requirements.

The solution space captures the property space that maps the structure of the solution space. Desired properties within the projection plane have to be extracted from requirements to systematically transform requirements into product properties. One or more requirements are the base for each desired property. However, there may be more than one requirement mapped to more than one desired property, resulting in highly complex interrelations between requirements and desired properties. The values and value ranges of the desired properties are determined by the corresponding requirement.
The projection plane and its desired properties are highly relevant. It unites different model-based views, represented by the requirement space and the property space. The more the technical product is concretised the more characteristics with desired properties and suitable values are determined. Desired properties and product properties comply with the structure of the property space according to functional properties, effect properties, working principle properties and shape properties. They can be directly mapped to the property space during product synthesis by gradually defining property networks. This leads to the continual definition of product elements and their structural composition, which is steadily matched with desired properties and extracted from the continually growing number of requirements within the requirement space.

4.2 Between determined product properties and requirements

The determination of product properties results in new requirements that have to be included in the requirement space (Figure 9, right-sided). They have to be considered during ongoing concretisation of the technical product. Determination of one product property may result in one or more requirements. Determination of product properties means the attribution of one suitable desired property value to one characteristic, thus building up product properties and their property networks that conform to requirements.
Requirements and newly desired properties can only be derived from determined product properties if designers use appropriate models in which the product properties' structure is captured. Key to success is anticipation of new information from analysis of product models used in the solution space or superior models, such as process models that are used to model envisaged processes of the product life cycle.

4.3 Consideration of envisaged life cycle processes

The product life cycle describes the processes that a product runs through during its life cycle. The key goal must be to create the best match between the technical product, described by its product properties and the envisaged life cycle processes to fulfil the product's intended purpose by transforming the actual state into the desired state. Conflicting stakeholder expectations have to be considered throughout the entire product life cycle to design a good technical product. A key aspect of the Mapping Model is the systematic anticipation of envisaged use processes and product behaviour during use.

However, realising the intended purpose by an appropriate mean is one of the most important drivers during product design, since the user uses the developed and actively operating technical product. The technical product becomes the operator during use. Here, the technical product as the envisaged means of a defined purpose has to fulfil the envisaged use processes by providing appropriate working variables as the output of its product function, thus fulfilling the intended purpose. This leads to the key question: Which function-required product properties does the technical product have to have to fulfil its intended purpose by realising envisaged use processes and intended product behaviour during use?

- First, use cases have to be determined, enabling the prediction of processes that may occur during use of the technical product, as the envisaged means of a defined purpose. Designers predict the intended use of technical products to answer the question of which use processes transform the current state into the desired state.
- Product functions enable envisaged use processes by providing working variables. The determination of suitable working variables leads to the starting point for focusing on product function and function-required product properties. Desired properties are matched to function-required product properties to determine appropriate function properties.
- Function-required product properties lead to the determination of desired properties, combined with other desired properties that result from the consideration of other processes in the product life cycle, such as assembly processes.

Consideration of the envisaged product life cycle processes allows designers to create technical products with appropriate product properties that match the envisaged life cycles processes. The Mapping Model balances the intended use processes and the desired properties to determine function-required product properties that deliver the necessary working variables to fulfil the envisaged use processes. Thus, the product life cycle and use processes within the use phase in particular are actively developed and integrated.

Requirements have to be fulfilled by the technical product developed to provide its required product function and thus satisfy its intended purpose, envisaged processes, and process chains of the product life cycle. The envisaged processes of the product life cycle demand specific product properties, resulting in new requirements that have to be transformed into desired properties.

5. Benefits and value of the Mapping Model

The Mapping Model ensures the representation of relationships between requirements and product properties within an integrated view of product synthesis. Existing approaches deal unsatisfactorily with complex relational dependencies between requirements and product properties. They also do not consider the exact relations between requirements and product properties for systematic design of the best technical product for an intended purpose, thus ensuring an increased value for stakeholders. This gap is closed by the Mapping Model due to systematic consideration of requirements that are mapped to product properties by transformation into desired properties, as well as the global mapping of anticipated processes in the envisaged product life cycle. Incremental design is promoted, with new and valuable property-based product and process design activities to break down complex systems into manageable system elements and their structural composition, which are directly addressed by requirements that are systematically transformed into desired properties of the correlating sector of the system.

Design science focuses on a gradual search for solutions and synthesis of design in accordance with acquired requirements [Chakrabarti 2002]. Product properties are determined as long as characteristics of identified desired properties, based on underlying requirements, are assigned to appropriate values.

Product properties at superior levels in the property space of the Mapping Model combined with desired properties build the target system for the determination of further product properties in sub-levels of the Mapping Model. Therefore, solution neutrality, as demanded by Pahl et al. [2007], exists only at the same level as concretisation, not the level reached during concretisation processes.

Trade-off situations become apparent when two or more requirements refer to the same desired product property and assign that desired product property contradictory values or value ranges. Thus, trade-offs can be solved before the actual design synthesis starts. However, there can be trade-off situations that become apparent only when determinations are made in the property space that impact more than one level. This presents another challenge.

The Mapping Model allows the consideration of selection and evaluation processes during design synthesis. Determined product properties are constantly matched to desired properties, which guarantees the clear selection of possible variants at each level of product concretisation. The solution's appropriateness is evaluated by mapping product properties to desired properties (targeted product description vs. as-is product description). Current approaches that claim to determine the best product properties focus on numerous iterations. Independent product properties that best influence dependent product properties are mainly defined by designer experience. The Mapping Model allows the systematic transformation of requirements into independent product properties, supported by essential product and process design activities. Thus, the technical product is gradually concretised from function-required product properties at each sub-level of product concretisation, in which finally the independent shape properties can be directly determined by the designer. This approach, as shown in the Mapping Model, leads to new and innovative products despite high system complexity with high product and process maturity in the early stages of product and process design. New manufacturing technologies and their potential are tapped in the early phases of product design. Their manufacturing-induced properties can be directly integrated into the defined property networks to achieve best possible values of product properties that best fulfil market and customer expectations.

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