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# Reference System Element Identification Atlas – methods and tools to identify references system elements in product engineering

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ABSTRACT

Companies target innovations, successful new products. One major challenge is to increase efficiency and decrease the risk of developing new successful products. We want to reach these goals by improving the reusability of already existing knowledge elements extracted from e.g., already existing (sub-)systems or their documentation. These elements are called reference system elements and are meant to be the starting point for product development projects. Based on a systematic literature review complemented by an expert workshop and analysis of established methods and tools in product engineering, we developed the Reference System Elements Identification Atlas to support the identification of suiting reference system elements. Within the Reference System Elements Identification Atlas, we collected 30 methods and tools to identify reference system elements and allocated them to the various knowledge spaces they search. All 30 methods and tools were grouped in five clusters – creativity methods, data analysis methods, market/competition analysis methods, similarity methods, and trend analysis methods. We observed that methods and tools are hardly related to the identification of reference system elements in literature explicitly. We believe the Reference System Elements Identification Atlas provides valuable support to collect valuable reference system elements as the starting point in product engineering.

## 1. Introduction

This paper is based on the presentation *Methods and Tools to Identify References in Product Engineering*, at ISPIM Connects Valencia – Reconnect, Rediscover, Reimagine, on 30 November to 2 December 2021 [1].

Just recently, Tesla took the $1trillion threshold in its market capitalization – more than three times the market value of Toyota, the second most valuable car manufacturer [2]. Looking back on the beginning of this success story, it all began with the development of the tesla roadster. Being new in the market, Tesla did not have any experience in building cars, themselves. Thus, they used existing subsystems from other companies to join them within their roadster. For example, they took the chassis of the Lotus Elise to start with and battery packs commonly used in laptops [3,4].

But not only newcomers have to refer to existing knowledge and designs. Generally speaking, products are based on so-called references, e.g. already existing (technical) solutions, their documentation, or the experience of experts [5]. For example, new generations of combustion engines are developed based on their predecessor, and recent cars use the communication technology of mobile devices. Even using creativity methods to come up with *new* solutions is based on existing principles or solutions and the association of the participants.

A former survey discovered that engineers spend ~60% of their time looking for the right information [6]. Thus, it becomes evident, that having suitable references or the knowledge about the suitable references at hand, easily, is a competitive advantage in product engineering. To support the identification of these suitable references, the main target of this contribution is to provide an overview of existing methods and tools to search for references. Thereby, we want to support product engineers in the development of successful new products by increasing efficiency and decreasing the risk of product engineering.

### 1.1. *References in product engineering*

Product engineers develop new products based on existing solutions as a mix of successful old designs and newly designed shares [7,8]. Iyer

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et al. [6] conclude, that only 20% of subsystems initially planned to be designed newly required new designs; 80% can either be modified or taken over based on existing designs. Thus, more than 75% of engineering activities involve the reuse of engineering knowledge to meet new design tasks [6]. The main goal of Design Reuse is to reduce development time and costs as well as to increase flexibility [7,9]. While the relations of new designs to references are generally acknowledged in literature and executed in practice, a formalized way to describe these relations is hardly possible.

#### 1.1.1. Describing product engineering based on references – the model of PGE – Product Generation Engineering

Albers, Bursac, and Wintergerst [5] addressed this issue by presenting the Model of PGE – Product Generation Engineering to describe the basic principles of new product development and thus enable research and development of supportive methods for product engineering. The Model of PGE – Product Generation Engineering describes the development of a new product as the development of a new product generation $G_n$ based on a product-specific reference system $R_n$ that summarizes e.g., existing (sub-)systems, concepts, or architectures as reference system elements (compare Fig. 1). These elements can originate from previous product generations, competing products, products from other sectors, or university research. In addition to existing systems on the market, prototypical product solutions or university research elements can also be used as reference system elements during development [10].

From the perspective of a product engineering project, there are several areas of knowledge, reference system elements can originate from (see Fig. 2). Only a subpart of the overall existing knowledge is accessible for a product engineering project. This accessible knowledge can be split into knowledge within and outside the company. A subpart of corporate knowledge is the project-specific reference system containing the knowledge already gathered for the engineering project [11].

Hajialibeigia [12] divides possible sources into four groups and gives examples of sources:

- “vertical class: suppliers, private clients, public clients
- horizontal class: competitors
- societal class: consultants, government, private research institutes, professional associations
- specialized class: universities, conferences, scientific journals”

Generally speaking, reference system elements “originate from already existing or already planned socio-technical systems and the associated documentation”. This reference system is “the basis and starting point for the development of the new product generation” [10].

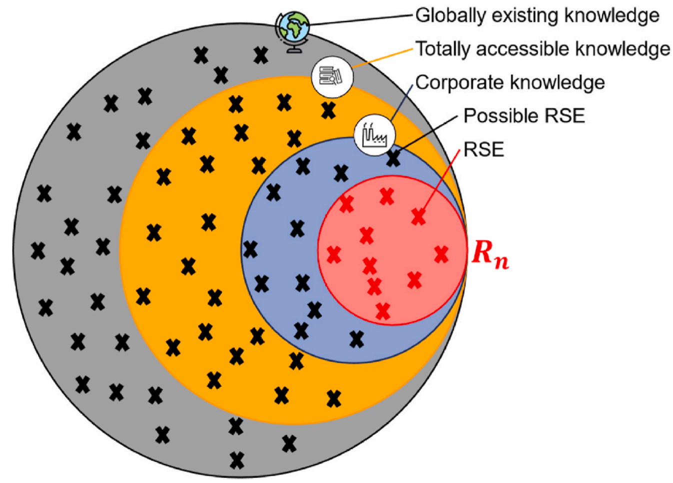


**Fig. 2.** Possible reference system elements can originate from different knowledge shells. The accessibility of these reference system elements depends on the shell of origin (based on [11]).

Through three principal operators (types of variation) they can be used to describe the relation of *new* subsystems to their reference system elements. These operators are carryover variation (CV), embodiment variation (EV), and principle variation (PV) [5].

By the carryover variation (CV), the design changes are minimal since the solution principle and embodiment/attribute is taken from a reference system element. Adaptations are only implemented at the interfaces of the subsystem for system integration. During embodiment variation (EV), the solution principle of the reference system element is maintained, only the embodiment is changed. A principle variation (PV) is on hand if the solution principle of the reference system element is changed [5].

#### 1.1.2. Different engineering activities require different reference system elements – product engineering processes

As already stated, references are the starting point of product engineering activities. Wouters and Kressens-van Drongelen [13] already observed reuse on different levels such as solution, design, or physical level. It becomes obvious, that ideation requires a different type and level of detail of references as the modeling of an embodiment for example.

Numerous models exist in the literature to describe the processes of product engineering. Gericke and Blessing [14] compare and discuss 124 such models. They conclude that engineering processes are interdisciplinary processes interacting with other business processes within a

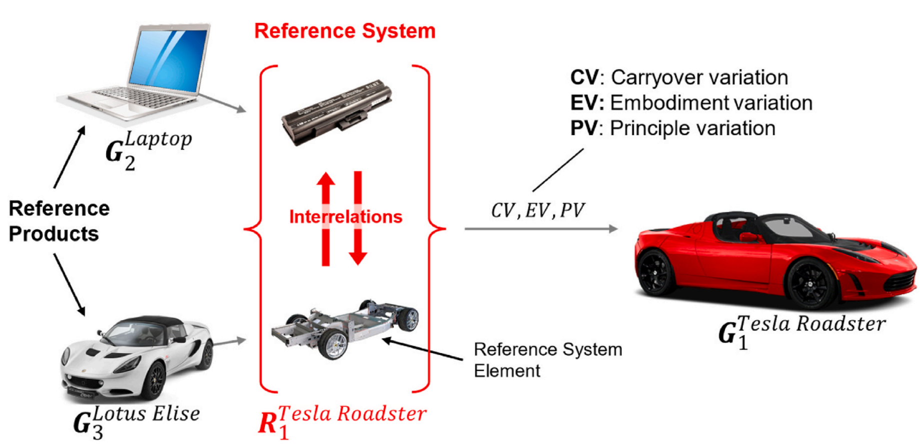


**Fig. 1.** The reference system within the Model of PGE – Product Generation Engineering. The reference system contains all elements used as references within the product engineering project as well as their interrelations (based on [10]).

company. Thus, a suitable process model should reflect these characteristics as well as foster knowledge transfer between the participating people and cover the life-cycle of the products [14].

The iPeM – integrated product engineering model as illustrated in Fig. 3 offers a meta-model to describe engineering processes and activities for the development of new products. The activities conducted during product engineering can be sorted into the activities *detect profiles*, *detect ideas*, *model principle and embodiment*, *built up prototype*, *produce*, *analyze and design market launch*, *analyze and design utilization*, and *analyze and design decommission*. These activities are tackled as engineering problems based on references. [15].

Furthermore, the iPeM – integrated Product engineering Model can be used to model the development of several product generations, the validation system, production system, and strategy in an integrated way [15].

## 2. Research profile

### 2.1. Aim of research

The main goal of this contribution is to provide an overview of methods and tools described in the literature to identify reference system elements. Through this overview and description of methods and tools to identify reference system elements, we want to support engineers in the selection of a method or tool to identify suiting reference system elements according to the engineering activity at hand. Therefore, the first research question aims at collecting suitable methods and tools.

Research question 1: What methods and tools exist to search for and identify reference system elements?

In the second step, we developed a model to organize the identified methods and tools to illustrate the areas of applicability. This is addressed in research question 2.

Research question 2: How can methods and tools to identify reference system elements be classified according to the knowledge areas they search?

### 2.2. Research methodology

To answer the first research question, we conducted three studies - first, a systematic literature review, second, a workshop with experts from product engineering research of engineering methods and third, the analysis of a database of methods commonly used in product engineering (see Fig. 4).

To get an overview of methods and tools to identify reference system elements described in the literature, we conducted a systematic literature review. The search engines and databases we chose, were Scopus and Web of Science. These were chosen because of their high coverage of published scientific papers and because of the similar search options in Scopus and Web of Science. For the selection of relevant publications, the following criteria were used as inclusion criteria:

- Language: English (/German)
- Publication within 2010 and 2021 to ensure actuality/search was conducted in September 2021 and updated in June 2022 to include new publications and to update the search string based on the learnings from the expert workshop
- Open access journals and conference proceedings
- Subject area: engineering, computer science, and business management accounting
- Presents a description of a method or tool that supports the identification of reference system elements

And exclusion criteria:

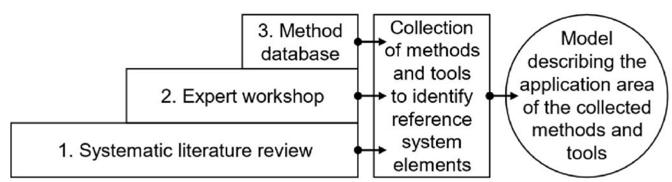


**Fig. 4.** Approach of three studies to collect methods and tools to identify reference system elements.

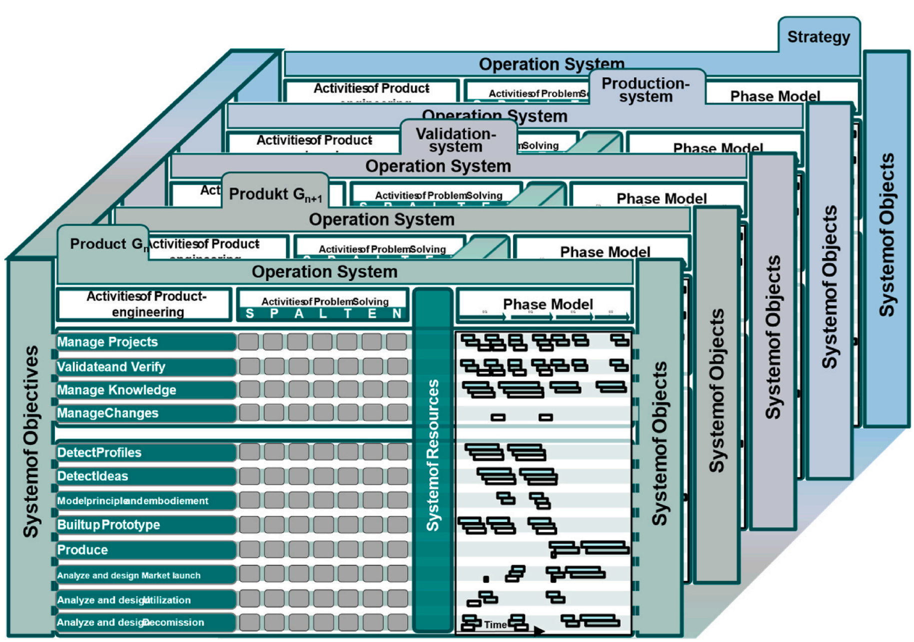


**Fig. 3.** The iPeM – integrated Product engineering Model is a meta-model enabling the integrated modeling of the development of new product generations, validation system, production system, and strategy. Activities of product engineering are tackled as engineering problems based on references ([15]).

- Methods or tools for structuring gathered information (e.g., describing how to design a database)

With the following search string we searched the titles, abstracts, and keywords:

> (method OR instrument OR procedure OR tool OR model OR approach) AND (pattern OR reference OR reuse OR sample OR "existing product" OR "existing system") AND (“product design" OR "product development" OR "product engineering") AND (identif* OR analysis* OR bench* OR scout*)

We conducted the filtering and selection process in consecutive steps as illustrated in Fig. 5. Within the forward and backward search, we looked for referenced publications of relevance.

In the second step, we complemented the results of the systematic literature review by conducting a short virtual workshop with six researchers on product engineering methods. In the workshop we asked for further methods or tools to identify reference system elements. The experts in this workshop are represented by product development researchers from the Karlsruhe Institute of Technology (KIT) of the IPEK – Institute of Product Engineering. In research, they deal with methodical support of product engineering and engineering processes in regards to e.g., the collaboration of distributed teams, creativity, agility in product engineering, or standardization and engineering kit. As experts in product engineering based on a reference system with different thematic foci, this group represents a well-suited panel. In the workshop, we first presented the methods and tools we already identified in the systematic literature review to the participants. Based on this input, we asked the experts to add further methods and tools known to them to the list by writing sticky notes on a virtual white board. After the workshop, we analyzed the results by researching the named methods and tools. In an iterative approach, we used the learnings of the expert workshop to update the search string of the systematic literature review.

Lastly, we analyzed a method database containing generally acknowledged and established methods to support various engineering activities within product engineering. This database was developed in a former research project under the participation of IPEK – Institute of Product Engineering at Karlsruhe Institute of Technology [16,17].

## 3. Results

### 3.1. Methods and tools to identify RSEs described in literature – systematic literature review

As illustrated in Fig. 6, a total of 908 papers were identified with the above search string and the criteria described above. Of these papers, 609 hits are from Scopus and 299 are from Web of Science. Duplicates

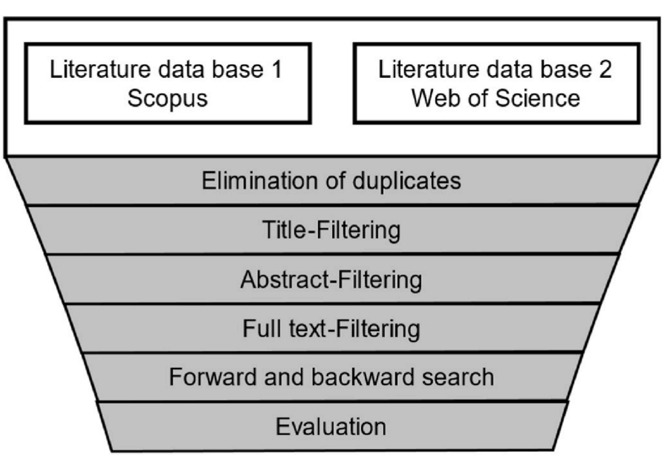


**Fig. 5.** Systematic literature review – filtering and selection process.

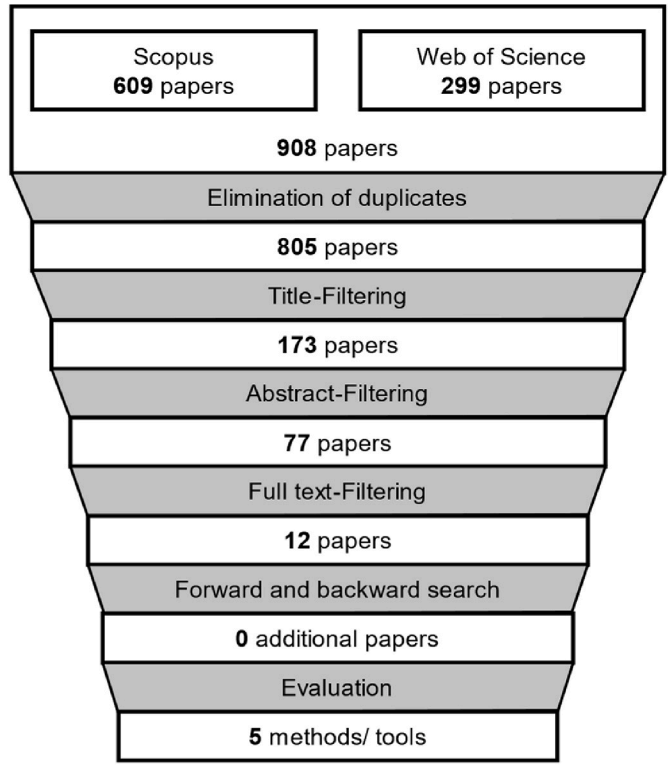


**Fig. 6.** Resulting papers according to the consecutive steps of the systematic literature review.

were identified in the first filtering step and then eliminated. A total of 103 duplicates were removed from the literature list. Accordingly, the number of papers was reduced to 805. In the next phase, a further 632 papers were excluded after reading the title resulting in 173 remaining papers. Subsequently, the number was reduced to 77 papers after reading the abstract. The final filtering step was filtering after the full text. 65 papers were sorted out and 12 papers remained. In the next step, we conducted a forward and backward search, but no further references describing methods and tools could be identified.

After the evaluation, five methods and tools were found that allow the identification of reference system elements.

All identified methods and tools are described in brief within Table 1 including the reference sources that are searched by the methods or tools as well as exemplarily types of reference system elements as the output of the method or tool.

### 3.2. Methods and tools to identify RSEs added by expert knowledge - expert workshop

A total of 12 methods and tools were mentioned by the experts. After filtering the results, eight methods and tools were adopted, which are explained in more detail in Table 2.

### 3.3. Methods and tools to identify RSEs added by established methods for product engineering - analysis of a method database

In the last step of identifying methods and tools that assist in the search for reference system elements, we analyzed a method database of established methods in the product engineering process collected by the IPEK - Institute of Product Engineering at Karlsruhe Institute of Technology. 20 methods and tools were identified in the collection of methods. The following Table 3 lists and describes these methods and tools.

**Table 1**
Methods and tools identified by the systematic literature review.

| Method/tool | Paper | Short description | RSE source | RSE type |
|---|---|---|---|---|
| Similarity analysis – Case based reasoning (CBR) | [18–22] | Identify useful information by searching for similar data. Support with CBR, by using similarity measures project data is found. | Internal/ accessible database | e.g., product data, process data |
| Patent analysis | [23–25] | Analysis of patent databases for useful patents. Various approaches are available to support the analysis, e. g. an automated classification procedure. | Patent databases | Patent |
| TRIZ - method | [26,27] | “Theory of Inventive Problem Solving”, in which a problem is analyzed and then abstracted into a standard problem. A standard solution is derived with the help of various tools, such as ARIS. This is concretized into a special solution. | Standard solution principles | e.g., standard solutions and problems |
| Process mining | [28] | Extract data on development processes from past product development projects. Identified patterns of knowledge can be used to uncover good practices and lessons learned. | Internal/ accessible database | Processes |
| Data mining/Knowledge discovery in databases (KDD) | [29] | Data is analyzed, patterns in data are identified and connected knowledge can be gained. | Internal/ accessible database | e. g. product data, process data |

## 4. Methods and tools to identify reference system elements from various fields of knowledge – a descriptive model

As presented in the previous section, we identified 30 distinct methods and tools in total conducting a systematic literature review, expert workshop, and analysis of the method database. These 30 methods and tools can be used to search for reference system elements in various sources as described in Tables 1–3.

In the following step, we clustered the 30 identified methods and tools according to their characteristics into five clusters. These five clusters are creativity methods, data analysis methods, market/competition analysis methods, similarity methods, and trend analysis methods. Table 4 shows the allocated methods and tools of each cluster. Hereby, it is important to state that the methods are not completely disjunct. Thus, e.g., methods or tools of the cluster data analysis methods can be used or are implemented within methods or tools of the market/competition analysis methods (e.g., data mining within benchmarking).

Using the categorizations from literature we distinguish 12 knowledge spaces. All of these contain elements that are possible reference system elements. First, there are the three fields of knowledge *corporate knowledge*, *totally accessible knowledge which is not corporate,* and *globally existing knowledge which is not accessible regularly*. All three fields of knowledge can be classified into four subspaces. These are *same branch*, *other branch*, *research,* and *society/nature*. In Fig. 7, we show the knowledge spaces that can be searched by each of the 30 methods and tools.

Taking off on Hirschter [11] we developed the Reference System Element Identification Atlas (RSE Identification Atlas) by translating Fig. 7 into a graphical representation as shown in Fig. 8.

The RSE identification atlas matches the identified 30 methods and tools to identify reference system elements to the already described 12 knowledge spaces to search in. In the RSE Identification Atlas, the 12 knowledge spaces to search in are given by the three circles representing *corporate knowledge* (blue), being a sub-space of the *totally accessible knowledge* (orange) being a sub-space of the *globally existing knowledge* (grey). We used the brightness of color within the circles to indicate *same branch*, *other branch*, *research,* and *society/nature* as classification of the knowledge elements. Finally, we added the reference system $R_n$ (red) of a specific development project to the atlas. The reference system can contain elements from the four sub-spaces same branch, other branch, research, and society/nature, too.

## 5. Conclusion and Outlook

We identified a total of 30 methods and tools for the identification of reference system elements. Using these methods, reference system

**Table 2**
Methods and tools identified by the expert workshop.

| Method/tool | Short description | RSE source | RSE type |
|---|---|---|---|
| A2MAC1 | Platform reengineering vehicles of all brands (reverse engineering) and offering scans and data of the subsystems and parts [30]. | A2MAC1 database | Data on competing products e. g. scans or images |
| Benchmarking | Systematic comparison of own products or processes with other companies. Thus, best practices are identified. These can be used to improve products and processes [31]. | Competitors/ market | e. g. product data, process data |
| Competitor analysis | Comparison of the capabilities of direct, potential, and indirect competitors. Mainly on an economic and portfolio level. The goal is to identify the strengths, weaknesses, and strategic development of the companies. One aspect is the fulfillment of customer needs [32]. | Competitors | Competitive products and processes |
| Cross industry innovation | Based on analogical thinking, cross-industry innovation makes use of successful solutions from other industries (outside-in) [33]. | Competitors/ market | e. g. technologies, patents, business models, and processes |
| Head hunting/direct search/ executive search | Targeted recruitment of experts from competitors' employees or other market participants, for example, with the help of a head hunter [31]. | Competitors/ market/research | Expert/Expert knowledge from previous projects |
| Joint-venture cooperation (other forms of co-operation) | Two or more companies join to form a common legal organization. This allows companies to access and use certain parts of the cooperating company, such as products and processes, as a reference. [34]<br>Other forms of cooperation can range from “occasional information” to “fusion” of companies. This enables the usage of knowledge elements of the cooperating companies to various extents [31]. | Competitors/ market | e. g. product and process data of the competitor/market participant |
| Random picture technique | In a limited time, abstract ideas are collected through the creativity of participants. Creativity is encouraged by randomly selected images not related to the topic [35]. | Creativity/ experience | e. g. product data, process data |
| Technology scouting | Early identification of developments in science and technology relying on formal and informal sources. “[Characteristics of a scout] include being a lateral thinker, knowledgeable in science and technology, respected inside the company, cross-disciplinary orientated, and imaginative” [36]. | Competitors/ market/research | New technologies |

**Table 3**
Methods and tools identified by the analysis of a method database of established methods in product engineering.

| Method/tool | Short description | RSE source | RSE type |
|---|---|---|---|
| Analogies | Identifying possible analogies to solve problems based on already existing technical or non-technical systems [37]. | Internal/accessible database/ creativity/experience | e.g., physical effects, structural data, process data |
| Benchmarking | see expert workshop | Competitors/market | e. g. product data, process data |
| Bionic (analysis of natural systems) | Solutions and principles of biology are investigated. Identified solutions and principles are the basis for the synthesis of technical solutions. (Just one aspect of the field of bionic) [37] | Nature | e.g., physical effects, structural data, process data |
| Brainstorming | Ideas from a group of participants on a particular topic are collected uncommented and unstructured. Stimulating memory and associating ideas in the current context is the basis of brainstorming [37]. | Creativity/experience | e. g. product data, process data |
| Cluster analysis | Homogeneous groups (clusters) are formed based on similarities. The aim is to create groups in which the objects within the group are as similar as possible and the different groups are as dissimilar as possible. The process of cluster analysis is divided into six steps: Select cluster variables, determine similarities, select fusion algorithm, determine cluster number, and interpret cluster solution [38]. | Internal/accessible database | e. g. product data, process data |
| Competitive intelligence | Identification of competitive knowledge. In the first step, information needs are identified with the help of corporate intelligence audits. Subsequently, the raw data is collected, evaluated, and analyzed. In the final step, the results are processed, presented, and used [39]. | Competitors | e. g. Competitor products |
| Delphi Method | In this method, experts are selected and then interviewed in written form. In the first round, they are asked for starting points for solving a problem. Based on the combined list of starting points, they are asked to make further suggestions in round two. Lastly, they are asked to identify the most valuable suggestions from rounds one and two [37]. | Creativity/experience | e. g. product data, process data |
| Design catalogs | This is a tool that offers a summary of existing and proven solutions for special construction tasks. These catalogs show objects as a line sketch, equation or drawing, or illustration and additionally their respective properties [37]. | Design catalogs | Construction data |
| InnoBandit | Megatrend, microtrend, and reference products are offered to foster creative impulses in problem-solving during product engineering [35]. | Creativity/experience | e. g. product data, process data |
| Lateral Thinking | This method is about restructuring and provoking new patterns. Based on "outside, unplanned stimuli to provide events that do not follow the natural sequence of development of an idea" new solutions are created [40]. | Creativity/experience | e. g. product data, process data |
| Literature search | Used to find important information about the current state of research and state of art. The method provides an important overview of existing solutions [37]. | e. g. libraries, patent offices, standardization organizations | e. g. literature from research, product data, guidelines, processes, patents, standards |
| Market analysis/ environmental analysis | The market is considered. The different characteristics of the business environment are evaluated, and conclusions are drawn. The market analysis can be divided into a situation analysis and a market observation [41]. | Market | e. g. technological trends, market products |
| Method 635 | Based on Brainstorming. In this method, six participants write down three ideas. The ideas are then passed on five times and supplemented [37]. | Creativity/experience | e. g. product data, process data |
| Product Reverse Engineering | A method for acquiring knowledge from products and machines of competitors. Competition products are tested, broken down into their sub-systems and components, and then analyzed. Subsequently, knowledge about materials, manufacturing processes, etc. Can be gained [31]. | Competitors | Competitor products |
| Synectic | After an introduction to a problem, familiar assumptions are rejected. References are drawn from other spheres to start analogies [37]. | Creativity/experience | e. g. product data, process data |
| Technology Portfolio | Assessment of technological potential. The evaluation is based on a comparison of technology attractiveness to the resource strength of a company. Technology attractiveness and resource strength are plotted on a two-dimensional matrix. This can then be used to recommend different technologies for pre-prioritization [37]. | Competitors/market/research | New technologies |
| Technology Scouting | See expert workshop | Competitors/market/research | New technologies |
| TILMAG | The ideal properties of a system are formulated. These properties are abstracted and transferred to another field. In the other field, elements are identified that fulfill these properties. These elements are the basis to solve the original task [42]. | Creativity/experience | e. g. product data, process data |
| Trend analysis | First, an identification of the current developments takes place and then a forecast of the future development is made. Trend analysis can be supported with various methods, such as trend scanning and monitoring [43]. | Competitors/market/research/ society | potential future trends |
| TRIZ - Method | See systematic literature review | Standard solution principles | e.g., standard solutions and problems |

elements for all aspects of product engineering – such as the derivation of requirements and objectives, process definition and resource allocation, and design of the new product – can be identified. Developing the RSE Identification Atlas, we matched these methods and tools with knowledge spaces that can be searched for reference system elements by the methods and tools from the perspective of the development team.

Providing a good overview of the width and applicability of the various identified methods and tools, we created the RSE Identification Atlas as an open model. Thereby, further methods and tools to search for reference system elements or search areas can be added later on. Surely, the current state of the RSE Identification Atlas is not a complete model of all existing methods and tools. Thus, the methods and tools included in the five clusters are only exemplary representatives of the clusters.

Creativity methods, the first cluster of methods and tools, is the most controversial, too. The main goal of these methods is the stimulation of ideas. Therefore, reference system elements are often input into these methods. RSEs mostly serve as starting points for engineers to sparkle creativity or association for coming up with new solutions for their design problems. On the other hand, these methods (such as brainstorming and related methods) can be used to search the "brain" of

**Table 4**
Five clusters of methods and tools to search for reference system elements.

| Creativity methods | Data analysis methods | Market/competition analysis methods | Similarity methods | Trend analysis methods |
|---|---|---|---|---|
| Brainstorming | Data mining/KDD | A2MAC1 | Analogies | Trend analysis |
| Delphi method | Design catalogs | Benchmarking | Bionic (analysis of natural systems) | |
| InnoBandit | Literature search | Competitive intelligence | Cluster analysis | |
| Lateral thinking | Patent analysis | Competitor analysis | Similarity analysis (CBR) | |
| Method 635 | Process mining | Cross industry innovation | | |
| Random picture technique | | Head hunting | | |
| Synectic | | Joint-venture (co-operation) | | |
| TILMAG | | Market analysis/environment analysis | | |
| TRIZ - method | | Product reverse engineering | | |
| | | Technology portfolio | | |
| | | Technology scouting | | |

engineers for references. Making use of the experience and creativity as well as associative capabilities of the engineers, they can identify reference system elements that serve as the starting point for following engineering activities and/or integration into the system to be developed. Even if these reference system elements are directly used for the derivation of new solutions within the creative process, they still serve as reference system elements. Other creativity methods such as TRITZ directly offer reference system elements by providing elements of basic solutions and principles. We think, this twofold relation of creativity methods and reference system elements is of high importance and not sufficiently considered in literature yet. Besides TRITZ (where offering reference system elements is a core component), we could not identify any creativity method with our systematic literature review. Since this procedure did not specifically search for creativity methods and these are rarely related to references in literature, we assume that a search more focused on these methods would offer an extended selection.

The second cluster of methods and tools is the data analysis methods. Existing and accessible databases are searched for interesting patterns or solutions as starting point for engineering activities. Compared to the cluster of creativity methods, these methods and tools follow structured approaches to identify possible reference system elements. Process mining is a method of special interest within this cluster. While all other methods and tools of all clusters have a focus on technical (sub-)systems or components, process mining targets reference system elements for the development or improvement of processes, specifically. Nevertheless, the other methods and tools (competitive intelligence or joint-venture, etc. In particular) can be used to identify reference system elements for the design of processes, too.

Third, we summed up methods and tools in the cluster of market/competition analysis methods. The focus of these methods and tools is the analysis of socio-technical (sub-)systems, elements, or technologies in the market or of competitive actors in the market. Even though the main focus of these methods and tools is the identification of reference system elements explicitly, we could not find any of these eleven methods and tools in our systematic literature review. Possible explanations are first, that the goal of identifying reference system elements is not stated within the literature describing market/competition analysis methods. But that is rather unlikely in terms of methods such as benchmarking or technology scouting since the identification of reference system elements is their major goal. A second explanation is the non-sufficiency of our search string. But, since *bench** and *scout** are part of the string, explicitly, we believe the time scope is the most reasonable explanation. Since the methods and tools in this cluster are all well established in product engineering most literature regarding them probably was published before 2010 already.

Fourth, we collected methods and tools concerning similarities. One of the methods we allocated in this cluster is bionic. Nature as a source of reference system elements was of great importance for product engineering since always. However, bionic – as well as technology scouting of the previous cluster – is rather a field than one specific method or tool. Several methods and tools can be used within this field. Still, we identified these as methods in our studies mentioned by experts or as part of the database of methods. Therefore, we included these as methods in the RSE Identification Atlas, too, knowing they can be representing a collection of methods and tools.

Last, methods and tools looking into the future and deriving reference system elements from trends are gathered in the cluster of trend analysis methods.

Relating the low amount of five methods and tools we identified through the systematic literature review compared to the total number of 30 methods and tools, we concluded methods and tools to search for existing knowledge are of no focus of current research. Another possible explanation could be the non-sufficient design of our search string. But the fact, that references describing the other 25 methods and tools are from before 2010, leads to the conclusion, that methods and tools which can be used to identify reference system elements are already state of the art and well established and thus, were not identified because of the limitation of years of publications. This assumption is also supported by the description of many of the methods and tools in standard references (e.g. Refs. [31,37]). To partly overcome this shortcoming, we conducted the expert workshop as well as the analysis of the database of established engineering methods.

A second conclusion we draw from our findings is, that many methods and tools established in engineering practice are used to look for reference system elements implicitly. For example, the goal of creativity methods is not primary to collect reference system elements. Bringing up reference system elements implicitly to their mind, engineers directly use the reference system elements to create new solutions. Similarly, e.g., company co-operations such as joint-ventures do not explicitly target the identification of reference system elements. Nevertheless, co-operations offer the possibility to use already existing socio-technical systems, expertise, etc. of the second co-operating company as reference system elements, too. Thus, we could not catch these methods and tools with our systematic literature review as the relation to reference system elements is not part of the method/tool description.

One limitation besides the restricted years of publication of our search string is the second section of the string:

> pattern OR reference OR reuse OR sample OR "existing product" OR "existing system"

Thereby, the description of the results of the methods or tools is already limited, also regarding the wording. This could be the reason that we could not identify any method or tool of the cluster market/competition analysis methods.

One way to expand the collection of methods and tools is to adapt the systematic literature search. For example, the search string can be refined and extended. In addition, the search criteria can be softened. Furthermore, fields of methods and tools such as bionic or technology scouting can be analyzed specifically.

We compensated this shortcoming of our systematic literature review with the analysis of established methods and tools in product

| | Knowledge fields / Methods/ tools | Corporate knowledge | | | | Totally accessible knowledge - not corporate | | | | Globally existing knowledge - not accessible | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Same branch | Other branch | Research | Society/ nature | Same branch | Other branch | Research | Society/ nature | Same branch | Other branch | Research | Society/ nature |
| Creativity methods | Brainstorming | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Delphi method | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | InnoBandit | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Lateral thinking | ○ | ● | ● | ● | ○ | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Method 635 | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Random picture technique | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Synectic | ○ | ● | ● | ● | ○ | ● | ● | ● | ○ | ○ | ○ | ○ |
| | TILMAG | ○ | ● | ● | ● | ○ | ● | ● | ● | ○ | ○ | ○ | ○ |
| | TRIZ - method | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| Data analysis methods | Data mining/ KDD | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Design catalogs | ● | ● | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ |
| | Literature search | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Patent analysis | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Process mining | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| Market/ competition analysis methods | A2MAC1 | ● | ● | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ |
| | Benchmarking | ● | ● | ● | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ |
| | Competitive intelligence | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ |
| | Competitor analysis | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ |
| | Cross industry innovation | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ● | ● | ○ | ○ |
| | Head hunting | ○ | ○ | ○ | ○ | ● | ● | ● | ● | ● | ● | ● | ● |
| | Joint-venture (co-operation) | ○ | ○ | ○ | ○ | ● | ● | ● | ○ | ● | ● | ● | ○ |
| | Market analysis/ environment analysis | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ |
| | Product reverse engineering | ○ | ○ | ○ | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ |
| | Technology portfolio | ○ | ○ | ○ | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ |
| | Technology scouting | ○ | ○ | ○ | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ○ |
| Similarity methods | Analogies | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Bionic (analysis of natural systems) | ○ | ○ | ● | ● | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ |
| | Cluster analysis | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| | Similarity analysis (CBR) | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |
| Trend analysis methods | Trend analysis | ● | ● | ● | ● | ● | ● | ● | ● | ○ | ○ | ○ | ○ |

**Fig. 7.** Knowledge spaces that can be searched by each of the 30 identified methods and tools to identify reference system elements.

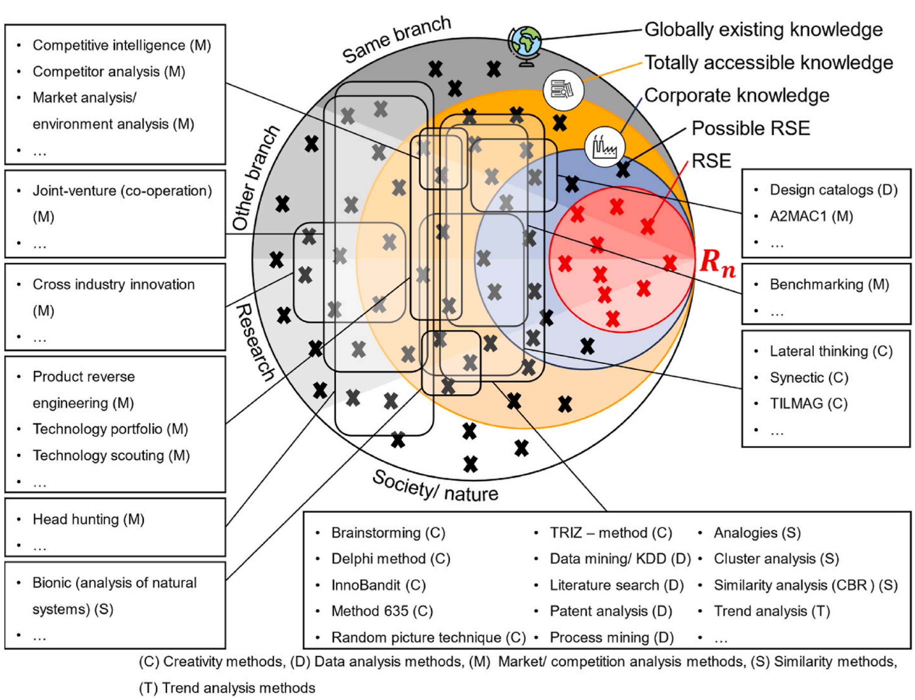


**Fig. 8.** Reference System Element Identification Atlas – different methods and tools support the identification of reference system elements (RSE) from various knowledge sources. From the perspective of a product development team and their reference system R (red circle), RSEs can be searched in the own company (blue circle), generally in accessible sources other than the own company (orange circle) and in all existing knowledge usually not accessible (grey circle). All knowledge spaces can contain elements of the same branch, other branches, research, and society/nature (brightness within the circles). The RSE Identification Atlas matches a total of 30 methods and tools to 12 knowledge spaces to search in, explicitly. The search spaces are indicated in the figure and linked to the methods and tools, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

engineering. Nevertheless, as stated before, we do not claim completeness for the RSE Identification Atlas. To further extend the completeness of the RSE Identification Atlas, further research is needed for all knowledge spaces of the atlas. The main goal of our research, as given in research question two, was to provide a general overview and classification of methods and tools to search for reference system elements in various search fields. Based on our three-step research approach, this goal is achieved by the RSE Identification Atlas.

In the next step, we plan to conduct an interview study with corporate product engineers to complement the scientific point of view with a practical assessment. Thereby, we intend to gather information on the actual usage of the identified methods and tools as well as barriers and problems in their application.

Setting up on the results of the presented research, we aim on developing systematic support for engineers in corporate environments. With this support, we want to assist engineers to fill their specific reference system according to the engineering activities at hand. Therefore, we already conducted initial research to understand the implications of different influencing factors such as the product engineering activities, sector, or experience of engineers on the reference system or its elements (compare [44]). Matching these findings with the findings in the given publication, we intend to suggest methods or tools to identify reference system elements according to the specific engineering situation described by the actual status of the influencing factors.

## CRediT author statement

**Christoph Kempf**: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Visualization, Supervision, Project administration **Simon Rapp**: Conceptualization, Writing - Review & Editing, Supervision **Kamran Behdinan**: Writing - Review & Editing, Supervision **Albert Albers**: Writing - Review & Editing, Resources, Supervision, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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