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THE DILEMMA OF MORPHOLOGICAL ANALYSIS IN PRODUCT CONCEPT SYNTHESIS – NEW APPROACHES FOR INDUSTRY AND ACADEMIA

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1. Introduction

Today, enterprises see themselves confronted with challenging market conditions resulting from globalisation. Customers' requests for individualised products are reflected in meanwhile established trends like mass customisation [Pine 1993]. If engineering departments want to remain competitive in this contested environment, they have to adjust their engineering processes to be both faster and more cost efficient. Systematic innovation, already applied during the early stages of product development, is a key factor to achieve this. Hence, it is vital for entrepreneurial success. [Wheelwright and Clark 1992], [Pahl et al. 2007].
Several methods exist to support these innovation processes in a methodical way on the engineering side. One approach is to analyse the main function according to the purpose of the product and to further structure that into sub functions subsequently [VDI 2221]. This is conducted in order to make the initial problem manageable. Picking up from there, numerous possible solutions are elaborated for each sub function with the aim to cover a complete solution field. However, as with all approaches that split up larger and initially unsolvable problems into smaller ones that are manageable, at some point, the granularly developed solutions have to be integrated to form one complete solution that fulfils the previously defined purpose. Thus, a synthesis step is needed. In many cases, a morphological box is used to assemble product concepts by combining the individual solutions [Koller 1998], [Pahl et al. 2007]. One concept has to be chosen for further realisation. Typically, this is done through evaluation based decisions. The procedure for this general approach to get from a product idea described by its purpose to a product concept is illustrated in Figure 1.

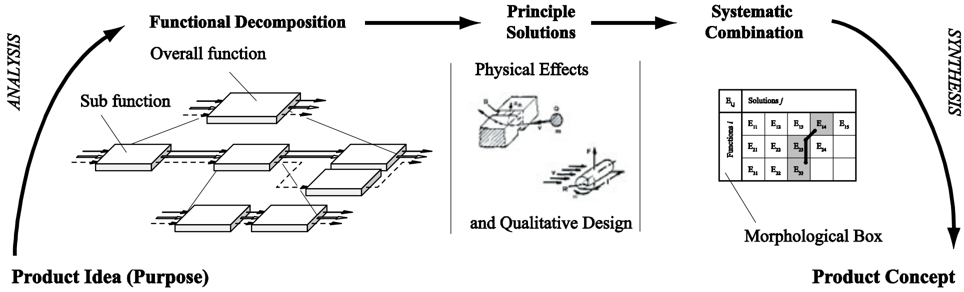

Figure 1. General procedure for systematic product conception based on function structures

Although this method is extensively published, it is not well-established in industrial use and often improperly applied in educational environments. It does not secure to avoid wrong decisions. In addition to that, approaches relying on combinations of single elements axiomatically suffer from

combinatorial explosion. This expression is referring to the vast number of overall solutions that can be created by systematic combinations of the single elements. Until now, several approaches are published that are addressing this downside. Nevertheless, none of them is capable of resolving the core problem: the effort that makes it unfeasible for industrial application while covering a complete solution field. Since a systematic examination of the solution field is still promising, particularly when exploring innovative principle solutions, new approaches have to be researched.
After this short introduction, the state of the art concerning morphological analyses forms the topic of this paper’s second section. The third and main section investigates existing mathematical approaches trying to make combinatorial explosion manageable for the application in product development processes. A new method overcoming the researched challenges is presented, that is simultaneously assistive and iterative. A prototypical software solution implementing the method is discussed before the paper concludes with an outlook.

2. About morphological analyses

The roots of the morphological analyses are not to be found in the discipline of design methodology or conventional engineering design processes. Moreover, its application is not limited to this area. Instead, it is utilised in many sectors. The basic thoughts that led to the term *morphological analysis* have already been documented in the forties of last century by Fritz Zwicky [1947], a Swiss physicist and astronomer.

2.1 The morphological approach according to Zwicky

Fritz Zwicky can be considered as the initiator of morphological research. According to him, it deals with both analysis and synthesis of a total and comprehensive solution space for a specific problem formulation [Zwicky 1949]. This procedure involves the open-minded investigation of all possible solutions. It has to be emphasised that Zwicky suggests the establishment of a separate scientific discipline for morphological research, opposed to only discussing morphological aspects in specialised domains like biology, anatomy or geology [Zwicky 1966]. Moreover, he introduces several morphological methods. The most important three methods are (1) the systematic field coverage, (2) the morphological box and (3) the method of negation and construction [Zwicky 1966].

Systematic field coverage
Zwicky introduces the so called systematic field coverage as a methodical infiltration of new areas of knowledge and the intrusion in yet undiscovered scientific domains as the central mind set of morphological analysis. To achieve the mentioned mind set, he argues that he constantly begins his examination at what he calls pegs of secured knowledge. From there, he starts to investigate several other domains in all possible directions [Zwicky 1966]. According to Zwicky, this approach enables experts and amateurs alike to create a comprehensive overview of the problem with no trouble, provided, an adequate number of so called pegs are available [Zwicky 1966]. The method of systematic field coverage has to be interpreted in a way more drifting towards a view or mind set of how to generally approach problem solving rather than a robust and directly applicable tool. Domains of design methodology, engineering design or product concept synthesis in particular are not addressed directly by Zwicky. However, they are also not excluded explicitly.

Morphological box
The main instrument of the morphological analysis is the morphological box. It can be interpreted as a visual depiction of the morphological field. Thus, it directly assists the method of the systematic field coverage introduced in the previous section. Honouring its initiator, the morphological box often is mentioned as the Zwicky Box [Ritchey 1998] in English language dominated domains.
A morphological box with three dimensions under examination is displayed in Figure 2a). The style applied in the image uses the so called drawer metaphor which Zwicky originally applied. The morphological field is represented by a block made of drawers, where each box of every drawer represents one overall solution comprised of the combination of one element from every dimension. In the example, a grey colour is used for the solution that consists of the individual elements E_{14}, E_{23} and E_{33}.

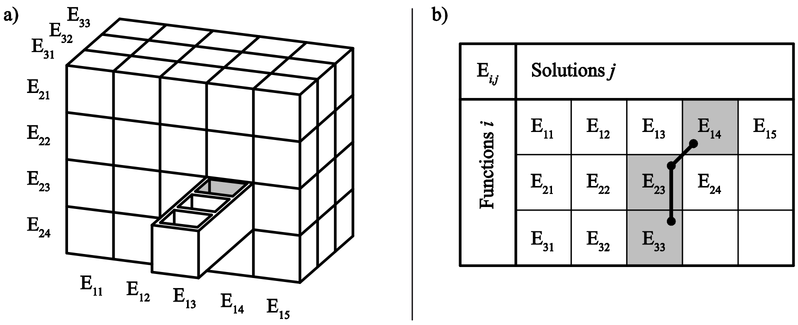

Figure 2. Morphological boxes according to Zwicky [1966] adapted for engineering design

While this style of visualisation supports an easy understanding of the morphological box, it cannot be used to display more than three dimensions. However, the drawer visualisation can be used to directly provide an impression of the amount of possible overall solutions. The matrix visualisation is able to show an infinite number of dimensions. It is exemplarily displayed in Figure 2b). Rows are representing sub functions of the problem. They are indicated by the index i. The corresponding individual solutions are stacked in the columns and accordingly indexed with j. The same overall solution as for the drawer visualisation is drawn in grey colour (E_{14}, E_{23}, and E_{33}).

Negation and construction

The third morphological procedure proposed by Zwicky is the method of negation and construction. Similar to the method of the systematic field coverage and thus opposed to the method of the morphological box, it cannot be interpreted as a tool which can be applied to a problem directly. Rather, it has to be regarded as a further style of thinking aiming at covering the complete extents of a problem. According to Zwicky, technological progress is often constrained by false or misinterpreted dogmas or axioms [Zwicky 1966]. Zwicky makes the case that the purposeful denial of those constraints and the constructive exploitation of the apparent insights resulting from them might lead to new explorations and inventions. Likewise, this approach is not explicitly addressing the solution of technical problems in the engineering domain. However, amongst other purposes, Zwicky suggests to apply this method to shed some light on some mental relations [Zwicky 1966].

2.2 Applications in design methodology

The morphological box can be applied in many cases within the engineering domain of design methodology. Often, the expression is used synonymously for the systematic retrieval and variation of the solution field. The box in particular is used for the graphical, tabular representation of the single elements which comprise the potential overall solutions [Pahl et al. 2007]. Referred to as an ordering scheme it is characteristically applied for combining principle solutions. Individual sub functions of the product are put in the first column of the box for this purpose. The corresponding rows are used to agglomerate the various underlying working principles [Pahl et al. 2007] or respectively the function carriers [Bernhardt 1981]. A synthesis step is then conducted in order to create product concepts by choosing one element from each row. In case tasks instead of functions are collected in the first column and the matching solutions that are either already known or taken out of catalogues are collected in the cells, the approach presented by Roth is achieved [2000]. Many design methodology related research undertakings focus on the provision of design and solution catalogues for a selection of different tasks [Roth 2000], [Koller and Kastrup 1998], [VDI 2727]. For example, Birkhofer investigates both analysis and synthesis of technical products in his thesis, particularly using the morphological box [Birkhofer 1980]. Besides its purpose as a means for the mentioned systematic combination, the morphological box offers the possibility of documenting the various concepts in a clear and simple way. This is achieved by its tabular structure, where e.g. rough sketches of the single solutions can be inserted. Tomiyama et al. review different methods of several authors and compile a comparison of these approaches. In particular, they make the case that the approach of Pahl et al. – being mainly influenced by the guideline VDI 2221 and vice versa – might be the most taught method.

In spite of that, they argue that this method could easily be misused by engineering design students as well as professionals. They base this fact on their analysis stating that operators could use the box as an argumentation for their personally and in most cases intuitively found solutions as opposed to the intended procedure for the morphological analysis, i.e. the investigation of the total solution field [Tomiyama et al. 2009].

3. The dilemma of morphological analyses

Franke introduces the so called axiom of systematic engineering design. He postulates the exigency to always research all possible solutions for the complete covering of the solution space. This is done in order to obtain the best solution thinkable [Franke 1999]. Apparently, this approach coincides with those of Zwicky [1949]. The complete investigation is probably not feasible for enterprises which naturally underlie economic constraints. Furthermore, it is not only not required but in some cases it might be unhelpful to research all solutions. Seen from a commercial point of view, it is satisfactory to find one working solution that fits manufacturing, distribution and further constraints of the company. It is however, important to immediately elaborate this solution at the first try. This results in a contradiction with the application of morphological analyses.

In the past, several approaches have been published intending to overcome this dilemma. Roughly, they can be sorted in two categories. First, those, that use morphological analyses as a creativity technique. They are aiming at finding new solutions or at expanding the investigation into areas that previously were not lying within the focus. Second, those that utilise the morphological box for the synthesis of new product concepts taking into account already existing or new sub solutions. Not the expansion of the solution field is pursued but the systematic combination of all existing components aiming at the identification of a viable solution. Those two categories spanned by the two axes of a coordinate system are shown in Figure 3.

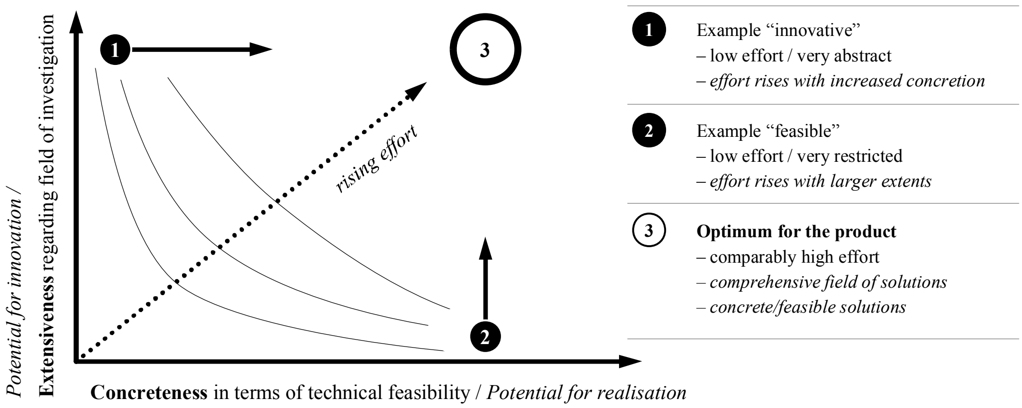

Figure 3. Dilemma of the morphological approach

Exemplarily, two investigations using morphological analyses are pictured. Both investigations are visualised using a black circle. With increasing distance from the origin on the vertical axes the respective analysis covers a more extensive space from which the various solutions are taken (1). Thus, both knowledge used and effort required are increased by each single solution that is additionally integrated into the investigation. Correspondingly, the farer to the right an investigation is charted along the horizontal axis the more concrete the solutions are regarding their technical feasibility (2). Similarly, the effort rises with increasing distance from the origin. Concluding, ideal for new product development is to increase the totality of the solution field covered by the research as well as to choose individual solutions as concrete as possible (3) to conform with the axiom of Franke.

3.1 Requirements for optimisations

Each of the approaches, which are focusing on the efficient management of the morphological box, requires two theoretical constructs that are needed in addition to the box itself. They can be identified as a priority evaluation for the individual solutions that results in a rank for each solution and as a compatibility matrix that evaluates the viability for combining two or more individual solutions. Birkhofer suggests so called sub complexes N_n. The priority evaluation is referred to as complex N_1 and the compatibility evaluation accordingly as sub complex N_2 [Birkhofer 1980].

First complex: ranking

The total number of individual solutions that make up the overall solution space is addressed with the first sub complex. It is similar to the number of entries in the morphological box. In general, N_1 represents the absolute grading of all individual solutions and thus can be interpreted as a ranking. Let x represent the number of rows of the morphological box and $k_i = j$ the number of elements within the i-th row. The values $r_{i,j}$ then represent the respective ranks of the individual solutions which can be combined as vector R. The number of the entries of the vector is directly representing sub complex N_1.

Second complex: compatibility

Synthesising the individual solutions into an overall solution requires more than only obtaining knowledge about the respective ranking. The compatibility of all sub solutions has to be evaluated as well. Birkhofer presents five possibilities of how to set up compatibility matrices [Birkhofer 1980]. Depending on how the morphological box is applied, the effort for the evaluation of the compatibility can be significantly diverse. An interpretation of the efforts and its influences on the development process is given in detail by the authors in [Heller 2013]. In general, it is sufficient to only assess combinations of exactly two different individual solutions. Regarding this optimised evaluation, the effort is less than half compared with the initial effort for the complete evaluation. Birkhofer refers to these assessments as the sub complex N_2. Concluding, the selection of one possible solution out of the vast amount of theoretically possible solutions requires exactly the number of evaluations represented by the scalar values of the two sub complexes N_1 and N_2. Apparently, as the structure of the equations given for N_1 and N_2 shows, big problems exhibit not manageable effort and complexity. While N_1 is only rising in a linear way with each additionally investigated sub solution, N_2 is growing in a factorial way. This behaviour is referred to as the so called combinatorial explosion.

3.2 Mathematical optimisations

In case the morphological box is used for generating or synthesising overall product concepts consisting of the individual solutions for each sub function opposed to the use as a creativity tool, it has to be taken into account that a holistic and comprehensive research will be almost impossible if the problem exceeds a certain size. Nevertheless, mathematical approaches exist which are aiming at making the application of the morphological box practicable. In many cases, the morphological analysis is applied in the form of a morphological box. It is mostly used in a conventional, paper based way. An exemplary box formed by seven sub functions and seven solutions for each sub function, already generates 823,543 overall solutions. However, N_1 is only comprised of the 49 entries of the box. Hence, a complete investigation will require a manual assessment of these 49 elements regarding their general suitability. In addition to that, a compatibility evaluation of as much as 1.029 comparisons of two element combinations is needed (N_2). A finalising evaluation of all 823,543 solutions will be impossible to handle economically.

Optimising for efficient application

Therefore, Birkhofer suggests theoretical considerations for the efficient application of the morphological box that were later also adopted by Roth [Birkhofer 1980], [Roth 2000]. He researched the best size and shape of the morphological box optimised in regard of the specific evaluation effort. A math-based optimisation for a minimum effort concerning the evaluation obviously leads to a box with only one row and one column if no other constraints are applied. This trivially results in a box that only consists of one entry. Both ranking and compatibility evaluation are not required in that case. However, the intended module would consist of only one function realised by one part. Although the effort seems to be reduced, it is in fact shifted to higher levels on which the modules are integrated.

That is why Birkhofer assumes that there is a given, constant number of overall solutions, resulting in a constant number of entries in the morphological box. In accordance with the previously presented sub complexes, he refers to this number as the sub complex N_x. Taking this into account as the constraint for mathematical optimisations, the optimal numbers of rows and columns can be derived.
If the morphological box is completely filled with solutions, resulting in the number of elements in each row being equal ($k_i = k = const.$), the optimal number of rows (x) can be determined as $x_{opt,N1} = \ln(N_x)$. Similarly, the optimal number of columns (k) can be established for a minimised evaluation effort regarding the ranking of the individual solutions (minimised N_1) as $k_{opt,N1} = e$ [Birkhofer 1980].
Likewise, equations for the ideal dimensions of the morphological box can be determined in case of an optimised evaluation effort regarding the investigations of compatibility (minimised N_2, constrained again with a constant N_x). (ref. [Birkhofer 1980], Eqn. 1, 2):

$$x_{\mathrm{opt,N_2}} = \frac{2 \cdot \ln(N_x)}{\left(\ln(N_x) + \frac{1}{2}\right) - \sqrt{\left(\ln(N_x) + \frac{1}{2}\right)^2 - 4 \cdot \ln(N_x)}} \quad (1)$$

$$k_{\mathrm{opt,N_2}} = e^{\frac{1}{2}\left(\ln(N_x) + \frac{1}{2}\right) - \sqrt{\left(\ln(N_x) + \frac{1}{2}\right)^2 - 4 \cdot \ln(N_x)}} \quad (2)$$

One conclusion that can be directly determined from the formulas, is that the ideal number of individual solutions for each sub function is approximately three (precisely: Euler's number e, but the number of entries in the box can only be an integer). The condition, under which the equations are valid, is a constant number of overall solutions. If the number of individual solutions is altered and the number of overall solutions has to stay constant, inevitably, the number of sub functions has to be changed. Thus, it is doubtable if this is rational or even possible for real product development. However, it becomes obvious that a minimum number will lead to an ideal effort for the evaluation of solutions according to the mathematical equations. Concluding, it is arguable, if the morphological analysis that was originally intended by Zwicky (see section 2) and that is characterised by the potential research of the complete solution field can still be met by only investigating just three sub solutions for each sub function.

Hierarchical Multicriteria Morphological Analysis

Although the determination of theoretically valid overall solutions can be achieved with the previously presented method, the actual effort is not reduced. Birkhofer confirmed that the size of the morphological box is the only relevant parameter. Decomposing the solution field in a hierarchical way can be a possible answer to the problem of combinatorial explosion, as investigations show [Weber and Condoor 1998]. A different approach is the Hierarchical Multicriteria Morphological Analysis (HMMA) of Levin [1996]. Both the vector R consisting of the individual ranks (see section 3.1) and the compatibility matrix of the evaluated two-element comparisons are used by him as well. For the determination of the overall excellence of every possible solution, Levin presents the vector N as $N(S) = (w(S); n(S))$. It results from a mathematical inspection of the two sub complexes N_1 and N_2 [Levin 2012]. Therein, the term $w(S)$ represents the minimum of the value for the compatibility of the regarded sub solutions. A value of zero is assigned for incompatibility and a positive number is assigned for weighted compatibility. In contrast to that, the term $n(S)$ brings in the number of those individual solutions that have been evaluated with a rank of m. For an evaluation of one overall solution the vector $n(S)$ consists of three elements that represent the number of individual solutions with the respective rank if the rank itself is measured with values from 1 to 3. The formal structure can be determined as $n(S) = (n_1, \ldots, n_m, \ldots, n_n)$. Thus, a vector $N(S)$ can be identified for every solution from N_x, which enables the determination of the most promising overall solutions. Additionally, Levin proposes to divide the main problem in a number of sub problems to avoid the large amount of required evaluations. A separate morphological analysis can be conducted for the sub problems with decreased effort. The results of these investigations of the sub systems can be included in an additional, synthesising morphological analysis in order to obtain the overall solution [Levin 1996]. Summarising, the HMMA approach of Levin is simple to apply and bases on a mathematical model. Yet, it seems to be an appropriate tool to handle combinatorial explosion. However, like the conventional approach or Birkhofer's optimisations, the evaluations for the ranking vector as well as for the compatibility matrix are still needed.

Pareto optimum

In addition, Levin suggests the evaluation of the solution field with Pareto efficiency algorithms [Levin 2012]. This implies that the solution field is evaluated searching for those combinations consisting of the best individual solutions that are the most balanced overall solutions at the same time. For this approach, only the results of the ranking evaluation are required [Levin 1996]. The filtering process does not require the compatibility matrix. Therefore, the effort for performing the actual evaluation is reduced significantly. Nevertheless, some of the overall solutions that remain in the Pareto optimum might not be compatible as this investigation was skipped. Those solutions can be excluded from the result and the algorithm for Pareto efficiency can be conducted a second time. As a fact, the Pareto algorithm aims at finding the most balanced solutions. That is why its operator has to be aware that solutions which might be excellent in their technical realisation in some parts but might only be average or even below average in other parts will not be included in the Pareto optimum.

Further approaches

Levin discusses other approaches in addition to HMMA and Pareto efficiency. However, they do not reduce the amount of required evaluation effort. One example is HMMA with uncertainty. An overview of different approaches and their applications is given in [Levin 2006]. A further approach presented by Tiwari applies genetic algorithms to extract optimum solutions from the morphological box [Tiwari et al. 2009]. Although the approach looks promising in terms of the actual algorithm, an excellence measure is still needed similar to Levin's proposals. Tiwari et al. refer to it as the 'cumulative performance' of a solution. Opposed to that, Schneider suggests evaluating only a small number of so called representative solutions [Schneider 2001]. This procedure seems to be appropriate to reduce the evaluation effort. However, the chance to find new and innovative product concepts is reduced likewise. In addition to that, the suggestion to only research a small part of the complete solution field stands in contrast to the originally proposed method of Zwicky.
Concluding, the presented mathematical approaches are not capable of solving the main dilemma of the morphological analysis. One possible solution is keeping the number of functions and solutions small. However, this contradicts with the initial intention of Zwicky to cover a total solution field.

4. New method for product concept synthesis

In order to support design engineers during the conceptual phase of product development projects in an efficient way, a new method is set up. A software prototype accompanies its implementation. Figure 4 presents the six steps of the method.

4.1 Steps of the method

The first step is similar to the conventional procedure and comprises the search for both sub functions and individual solutions for them. The ranking has to be conducted in the second step. It incorporates all sub functions individually, therefore no compatibility is evaluated. It is executed to determine the first sub complex (N_1). With the determined rank values, a preliminary optimisation can be executed with the help of an algorithm that only relies on this data in step 3. One suitable algorithm is Pareto efficiency as described in section 3.2, although others, like genetic algorithms are feasible as well. The output is all possible solutions that adhere to the optimisation scheme. However, these solutions have not been evaluated yet regarding their technical compatibility. This limitation is set aside by the fourth step. The compatibility evaluation, which is now reduced in its complexity, has to be filled with values estimating the possible contradictions and benefits of every combination of two-element comparisons. The result is the second sub complex (N_2). In case none of the solutions are compatible, the reduction step can be conducted again after the removal of those individual solutions that are found incompatible. The next step serves to secure the broadness of the solution field by determining the quality indicator (see section 4.2). In the last step one or more overall solutions are selected for further realisation. Suitable algorithms for the selection process based on the two sub complexes can be conventional benefit analyses or more particularised approaches like HMMA (see section 3.2). In case no appropriate solutions are found, a repetition of the process with changed constraints is required.

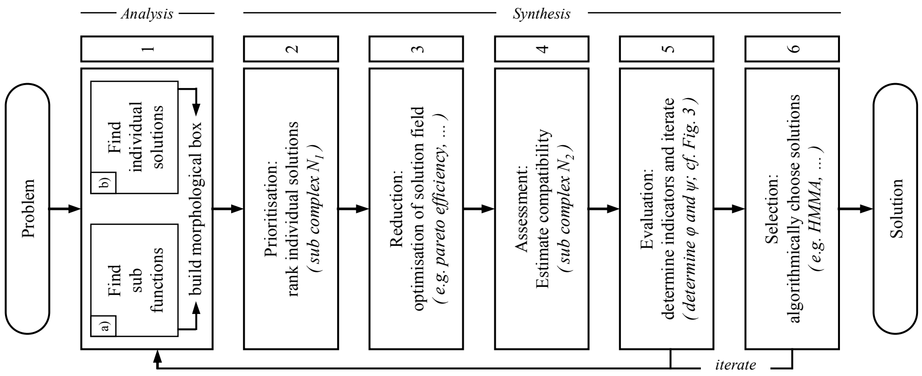

Figure 4. Proposed method for efficient and holistic morphological analyses

4.2 Establishment of quality indicators

This iterative approach is able to reduce the evaluation effort significantly. However, a fundamental problem of the efficient application of morphological methods is still not solved: the risk of not researching the complete solution space and thus rendering its application useless. To overcome this challenge, the fifth step has been integrated in the method. It offers an evaluation of the solution field regarding possible innovation as well as technical feasibility. Conforming to the illustration in Figure 3, this step aims at moving the overall quality indicator Q towards the upper right corner. For both directions indicator values are introduced as φ and ψ. These values are determined by the operator on a scale from 1 to 4. Therefore, they only represent a subjective sight. However, they support the characterisation of the solution field regarding covered extensiveness and immediate technical feasibility. For a high-quality solution field covering both innovative and very concrete solutions the two indicators have to adopt their maximum values. As discussed in section 3, an analysis where both indicators feature the highest value possible at the same time will most likely require an evaluation effort that is not practicable for enterprise applications. Superior to this, several small morphological analyses must be executed sequentially. To eliminate the risk of both omitting large parts of the solution field and only researching already known solutions, a quality indicator Q is used. It is derived by extracting the root of the product of the two indicator values. φ_i measures the operator-estimated possible innovation within the i-th iteration of the morphological analysis and ψ_i the technical feasibility correspondingly. Q is determined after each morphological analysis and carried over to the next iteration. Again, the indicator values φ_{i+1} and ψ_{i+1} are estimated. The maximum of the i-th and i+1-th iteration is taken into account for the estimation of Q_{i+1}. The Q value has to be maximised in the course of the single analyses, accordingly.

4.3 Evaluation and prototypical software implementation

Figure 5 shows the general structure of the prototypical implementation as well as a screenshot of the demonstrator. The software is conceptualised in a modular way. Individual applications have been implemented to map function structures or to establish the solution field using the morphological box. Moreover, modules for analysis with the methods mentioned in section 3 have been implemented. One module assists the operator in his decisions for the confinement of combinatorial variety and proper covering of the solution field. The modules currently are realised as Microsoft Excel Worksheets that are integrated through Visual Basic Macros. Optimisation algorithms are implemented as macros as well. The software demonstrator implements the approach presented in section 4.1. Besides being able to conceive the solution field by featuring modules for sub functions and corresponding solutions, the morphological box can be generated using the matrix visualisation. Additionally, algorithms to determine the sub complexes N_1, N_2 and the number of overall solutions N_x have been implemented.

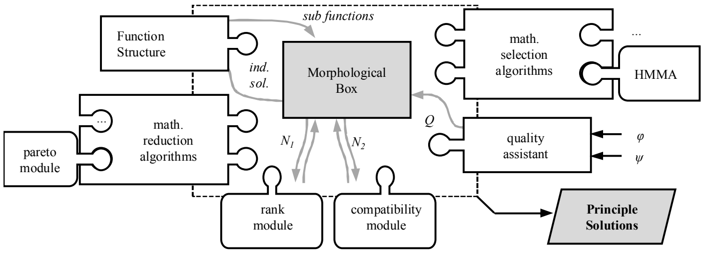

Figure 5. left: module-based structure of the prototype / right: software demonstrator

As a further novelty, the implementation does not require the box to be fully occupied (i.e. the number of elements in each row can differ). Algorithms to perform investigations regarding Pareto efficiency as well as to determine Levin's vectors *N(S)* have been modelled and integrated. A quality assistant module has been implemented in addition to that, which supports the operator regarding the extensiveness of the solution field coverage by requesting the two indicators φ and ψ to estimate the quality measure. Concept generation for multi-technology machine tools (MTPs) has been addressed with the iterative and assisted morphological approach. The effectiveness of the method has been evaluated for concept synthesis within early phases of the product development process. An example demonstrates the effectiveness: three sub functions are researched with three individual solutions each.

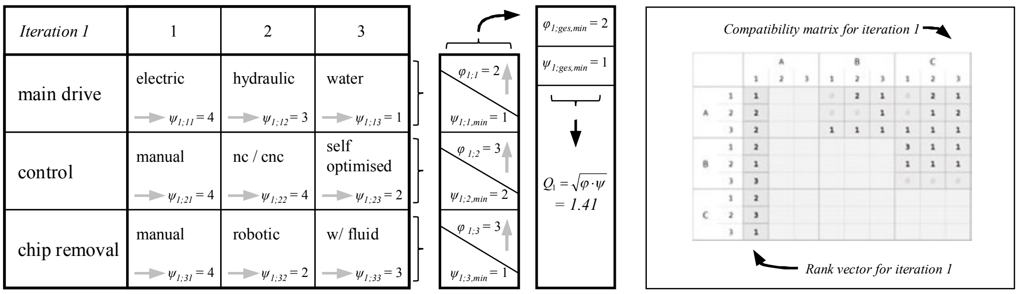

Figure 6. Exemplary morphological box with quality indicators

Thus, with the systematic combination of those 9 elements (N_1) as many as 27 unalike overall solutions (N_x) can be conceived. The evaluation effort can be estimated to as well 27 investigations of combinations of two-element comparisons (N_2). Figure 6 displays the first iteration of the morphological box. Under these circumstances, the possible overall innovation indicator φ_1 was assessed with a value of 2 because the solution field is comprised with rather conservative entries. The overall feasibility indicator ψ_1 instead was estimated with a value of 1 as both entries that already have been realised in products (ψ = 4) and entries that are more futuristic (ψ =1) are present. The overall quality *Q* thus results in 1.41 which implies further iterations are needed. The solution space successfully was limited to only one possible overall solution (< 4 %) with the help of the Pareto algorithm and the use of the rank vector.

5. Conclusion and outlook

The discussion of the presented approaches consistently demonstrates that the application of morphological analyses as introduced by Zwicky for synthesis of product concepts intending a complete solution field implies an unmanageable effort for evaluation. Math-based optimisation approaches do not change this observation prominently. Thus, industrial use of the method is challenging. A method consisting of an assisted approach to iteratively cover parts of the complete solution field was introduced to improve the situation. A supporting software demonstrator using optimisation algorithms and a quality measure has been introduced. The evaluation of the method in a case study for MTP conceptualisation has been outlined. This research is subject to current investigations at RWTH Aachen University. The next steps will be to evaluate the effectiveness of the presented method in more industrial projects and educational applications. Moreover, the automatic and more importantly objective determination of the two indicators required for the quality assessment measure using context information for the entries will be thoroughly investigated.

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