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A morphological analysis tool for complex future-oriented scenario researches

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MORPHOLOGICAL ANALYSIS AND FUTURE-ORIENTED INNOVATION MANAGEMENT:
LESSONS FROM FORESIGHT RESEARCH

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ABSTRACT

Projecting a concept derived from an analytical level is a complicated but established process in innovation management. However, conventional design processes will face methodological obstacles, when a future system with rapid changing key factors is addressed, since: (1) the time-scale, in which the problem space is introduced, addresses users that are non-existent yet; and (2) continuing changes in key factors and their interactions make the process incapable of conceiving the relationships and delivering synthesizable data. In this case, the rational core, upon which the projection is established, suffers itself from the lack of substantiation. Morphological Analysis and Delphi technique are stablished tools, each having known advantages and disadvantages in the foresight research. We suggest that a morphology-based Delphi technique can support the process of projecting the future in innovation-demanded large problem complexes. In addition, these two tools can mutually cover each other's theoretical and functional deficits by illustrating transparent value-based arguments in a modifiable iterative manner.

KEYWORDS

Innovation Management, Morphological Analysis, Systemic Design, Future Oriented UX-Design, Delphi Technique, Scenario Development, CAD, Product Development, Foresight Research

1. Introduction

The practice of systemic design has in any case a procedural overlap with foresight research, as it principally aims at a wished state in the future (Fig. 1). This overlap grows specially when systemic design as a user-centric approach, is incapable of researching the user, i.e. the subjected system addresses users of a mid or long-term future (e.g. 10 years from now)

A further problem in future-oriented designs are the ever-changing values of the key-factors. Under this dynamic, the rational core, upon which the projection is being established, will need itself a constant validation (Ritchey, 2011).

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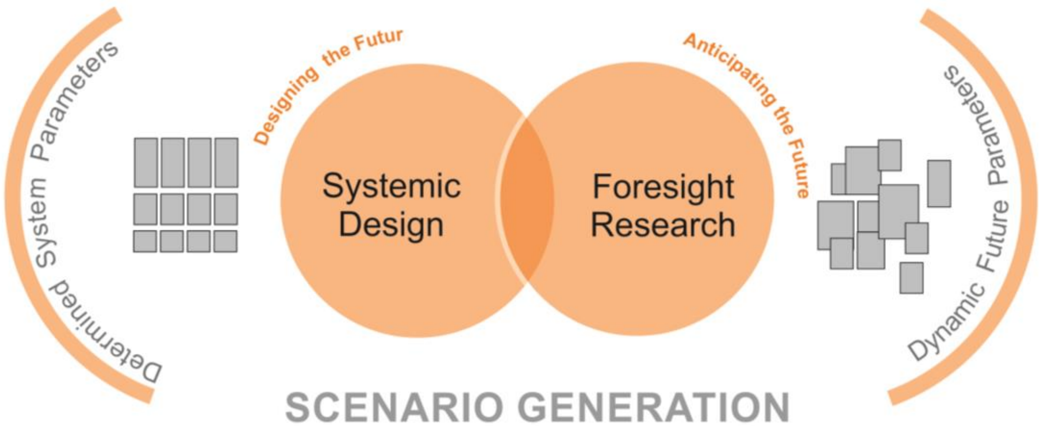

Fig. 1 overlap of systemic design and foresight research in practicing scenario generation

For coping with this problem, designing future systems will have to draw methodological fundaments (theory and practice) from the domain of foresight research (Godet, M., Chapuy, P., & Menant 1991).
One of these fields is the adaptation of scenario techniques into future-oriented systemic design. However, these techniques seem not to be satisfying enough, as creative design demands extra skills than predicting the future.
The benefits of matrix-based approaches in modelling highly complex problem-spaces have been discussed by various researchers (see for example Mocko et al., 2007; Steward, 1981). These approaches are mostly known in design and engineering as "Generative Design", and in foresight research under the term "Morphological Analysis". The clustering possibility that matrix-based approaches provide, is a comprehensive scheme for modelling dynamic key-factors, simulating their interactions and displaying all (mathematically) possible solutions. Many of these techniques are implemented in CAD[3] algorithms. Yet, some researchers refer to the lack of nobility and/or the deficit of these algorithms in stimulating the creativity of a design team (see for example Krish, 2011; Singh & Gu, 2012).
Delphi technique is considered in foresight research as a reliable alternative to user research. The technique is recognized for delivering highly innovative scenarios (due to its rich mental asset) yet weak in a systematic exploration of entire solution-space. We suggest that a matrix-based cumulative expert survey (a hybrid algorithm of Delphi technique and morphological analysis) can support the process of innovation-management in very complex future-oriented environments. In addition, these two tools can mutually cover each other's theoretical and functional deficits by illustrating transparent value-based arguments in a modifiable iterative manner.
In the following (1) we discuss the theoretical framework of matrix-based system thinking, where foresight research meets "research through design"(Jonas, 2007), (2) review the advantages and disadvantages of both Delphi technique and Morphological Analysis in generating scenarios in design and foresight research and (3) propose a generic approach, in which Delphi technique receives a systemic framework from morphological analysis.

[3] Computer Aided Design applications such as *CATIA* and *SolidWorks* in Design and *Carma* and *ScenLab* in foresight research

2. Epistemological and methodological background

In foresight research, matrix-based approaches are known under the term *Morphological Analysis(MA)* or *General Morphological Analysis*. Morphological analysis is the act of splitting and clustering objects, phenomena and concepts to such detail that our mental world image could conceive and visualize the interrelations among them (Zwicky, 1967).

A methodological equivalent of Morphological Analysis in the design practice, is *Generative Design (GD)*. GD aims at computerizing the classic intuition-based process of generating concepts. GD algorithms follow the principle of designing a scheme for creating ideas by an autonomous machine, instead of designing the product directly (McCormack, et al., 2004).

Generative design itself draws heavily its theoretical framework on parametric algorithms.[4]

Parametric modelling is the idea of using key factors to describe a model.

Many CAD software (e.g. SolidWorks) utilize already since 3 decades geometric and numeric key factors but also constraints to determine a shape. Constraints are descriptive key factor values that define what the model could not be, so that finally only one shape remains that suits the attributes defined.

Both morphological algorithms and generative systems are strongly associated with the application of computing software in overtaking the tremendous calculating of key factors and their relationships. Their differences are mostly in the manifestation of APS[5] steps in a classic research-through-design demonstration: while in GD the matrix is built to find maximum design solutions and ranking best ones (A⇨S⇨P), in morphological analysis the aim is to find the most likely futures and “discuss” them (A⇨P⇨S). (Fig. 2)

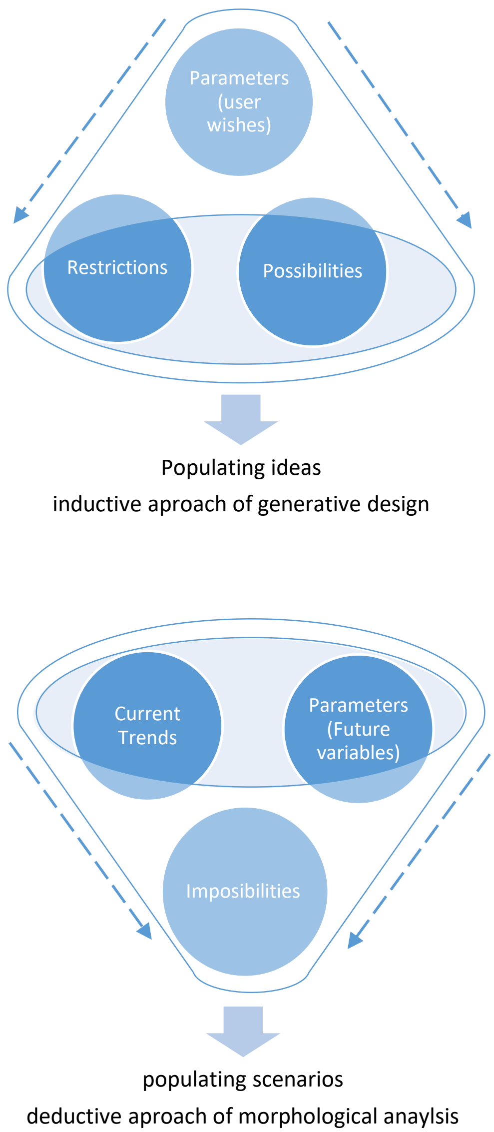

Fig. 2 Morphological Analysis vs Generative Design , Matrix-based approaches in design and foresight research

[4] Although discussing parametric modelling in detail would take us away from the main route of the research, we however find interesting cognitive and epistemological linkage between the MA approach and relatively older and more established approaches of parametric modelling such as Parametric Design procedures (Hernandez, 2006) and Parametric Design Thinking (Oxman, 1997; Oxman & Gu, 2015).

[5] Analysis, Projection, Synthesis (see Chow & Jonas, 2009)

2.1. Morphological Analysis in Innovation Management

Although MA has been invented rather for developing scenarios in foresight research, there are still a notable number of studies applying the tool in supporting the creativity in a design practice. An pioneering attempt is performed by Zwicky (1967) using MA for designing jet engines. He argued that a requirement for designing novel concepts is having a bird's-eye view over the entire solution space.
Nonetheless, a larger solution space doesn't necessarily lead to optimized designs and can even cause extra confusion and inefficiency. Questions on how to identify promising combinations from a MA matrix is for example reflected in Card et al. (1991). They discuss different filtering algorithms and propose that splitting the solution space to regions of interests and investigating regionally could reduce the time needed for judging all solutions.

Alike other CAD instruments, MA tools are considered as auxiliary means and merely serve the generation of raw possibilities and not a projection of novel designs or revolutionary ideas. They won't generate any creativity value on themselves. Still they enable the designer to systematize the ideation process and optimize the results by delivering quantitatively as many solutions as possible. Some researchers however advocate the idea that MA is more than a mere "morphological box" and can actively contribute to a creative process (e.g. Dartnall & Johnston 2004 & 2005, Seidenstricker et al. 2014).

2.2. Computation of MA

Methods suggesting the usage of computation for supporting human's creative repertoire in tackling wicked problems have been suggested in many innovation-demanded disciplines (see for example Nordin et al., 2011; Strobbe et al., 2011). Computation can drastically increase the quantity of mathematically possible configurations (concepts, scenarios, solutions etc.).

Nonetheless, the huge quantity of generated solutions will still need to be evaluated and compared for the final decision. This can "*place a significant cognitive burden on the designer*" and is considered by a series of researchers as a combined advantage and issue (Krish, 2011; von Buelow, 2002).

Another crucial aspect of conventional creative design that CAD researchers struggle to simulate is the reflection of the designer to already existing designs: How can a CAD algorithm distinguish novel ideas from a bunch of old ones? This intuitive cognitive structure is the essence of classic innovation management that evolves the designer's inputs into further inspirations.

Dartnall and Johnston for example applied a MA approach in a creative process of designing water pumps and realized that many settings, generated by the visualizing of the configuration, are already existing products or registered patents that for any reason have never become a finished product(J. Dartnall & Johnston, 2004). They received this as a positive indicator showing morphological matrix is properly arranged and is capable of generating concepts (since patents are well elaborated novel designs). Besides, enough non-patented concepts will still remain for further reflections. On this ground, we can argue that a MA matrix can contribute actively in a design process via:

1. **Preventing the process of being a haphazard practice:** unlike a designer who may conclude with a few concepts based on his talents and biases, MA indeed illustrates all possible designs including those already available, and in this way, MA illuminates design gaps that had never been detected yet and worth to assess.

2. **Enabling decision-makers to decide between evolutionary or revolutionary ideas:** Within a MA matrix, combinations of those middle-range variables most likely will deliver conservatively only new configurations (or evolutions) of already existing designs, whilst marginal variables in the list and those extreme indicators will lead to revolutionary and totally novel ideas. This will enable operators to actively rethink their decisions during the iterations.

2.3. Delphi Inquiry

Delphi is an established method in the foresight research with known advantages and disadvantages (see for example Goodman, 1987; Hasson, Keeney, & McKenna, 2000; Malhotra et al., 2014). The technique utilizes expert opinion to support decision making mostly on future-related questions. It employs consensus knowledge for providing sufficient awareness of an interdisciplinary case or when other data collection methods are not available. (For instance, field research can deliver a synthesizable data about the demands of the youths of today, but will be incapable of researching those youths who will exist 20 years from now.)

An incorporation of Delphi method in design-related scenario inquiries for increasing the creativity value was first suggested by Nowack (2011). His view rest on Kahn's (1962) emphasis on the importance of forecasters' creativity and genius in "thinking the unthinkable" for achieving meaningful scenarios. Nowack raises the question what if the forecaster doesn't possess Kahn's mentioned genius. He then examines and concludes that consensus knowledge can improve the quality of outputs in terms of generating creative but at the same time credible and objective scenarios.

Depending on the typology and the purposes of the scenario research, the intervention point and intensity of the expert knowledge should be adjusted when planning the research scheme. Most researchers differentiate scenario approaches in three categories: *predictive, explorative* and *normative*, referring to the expert's attitude towards the expected scenarios. "What will happen? What can happen? And how can a specific target be reached?" (Dreborg 2004; see also Börjeson et al. 2006; De Smedt et al. 2013).

In future-oriented systemic design, the objective is rather approximating to definition of explorative future studies. Considering this assumption, a Delphi technique can contribute to the morphological research in coping with following sub processes:

1- Determining the design factors
2- Determining External influence factors and trends
3- Judging cross-factors interactions
4- Converting configurations to scenarios or to designs

2.4. Designing the Future on the Basis of Mega-trends

Mega-trends are long-term all-encompassing transformation processes. In foresight research, trends are factual maps indicating an evolutionary transformation of things and thus the most reliable and probable state of future. In this context, mega-trends differ from other trends in two aspects: first, they cover a time-horizon of at least 15 years, some of which existent in the present with perceptible demonstrable indicators. Second, they act universal, transmitting interconnected social, cultural, political and economic transformations over the world, causing sustainable (mostly irreversible) global changes (Von Groddeck &

Schwarz, 2013; Z_punkt, 2014). Because of their reliability and long-lasting effect, mega-trends are understood in foresight research as a reliable source of innovation and strategic planning.

However, there are two points that distinguish a designerly approach towards mega-trends from a strategic planning approach:

- Design practitioners are better skilled in synthesizing and converting multi-dimensional transformation implications in (for co-researchers) conceivable visual information.
- The creativity reservoir inherent in design methods often enables the practitioners not to follow mega-trends to predict the future but to process mega-trends to design the future and generate new values.

The later one is a notable advantage, since similar solution-oriented approaches from other disciplines such as backcasting are criticized for being heavily dependent on different assumptions and therefore delivering impractical results, when the future event upon which the solution is delivered, does not occur as predicted. The designer in return avoids often predicting the future and envisions instead analogue worlds in which, a wished service or product possibility could exist either within a linier or nonlinear development of future trends. Thus, his solutions won't become falsified by either projection of the future.

However, the process of evaluating mega-trends and generating scenarios in design research is normative and strongly biased to researcher's (designer's) viewpoints (Fehr & Jonas, 2013). The role and impact of researcher has been the subject of controversy and discussion. While human's creativity and interpretation-skills are essential to an innovative scenario process, the biasing impact and also his limitation in understanding the complexity in the interaction between mega-trends will cause the results to be disputable in terms of reliability (see Schoemaker 1993; Busenitz & Barney 1997; Nowack et al. 2011).

In respond to this insufficiency, some researchers have suggested a hybrid usage of CAD algorithms and human innovation to be the optimal solution. Struggles for an entire substitution of researchers (designer's) role with computer intelligence has failed in the past few decades (see2.2; see KAN & Gero 2008; Salim & Burry 2010).

2.5. Scenarios as the Conveyer of Innovation

Scenario-generation seems to be a practice, standing at the fuzzy border between creative design and foresight research. In foresight research there is not one future but multiple probable futures, hence developing scenarios is a widespread tool in this area of science. A good scenario can capture pathways and sources of changes from a complex phenomenon and provides new material to think (Schoemaker, 1993). In most future research cases, the process of generating scenarios demands a certain level of human innovation as the input data postulated for building a vision for tomorrow are fuzzy, uncertain and hardly processable via scientific methods.

Perhaps estimating the future has proven to be less useful in strategic forecasting, than opening up the discourse for an innovative exploration of perspectives and possibilities in the context of utopian still reachable concepts. Huss (1988) sees developing scenarios more important than the act of foresighting itself. Especially in the context of corporate planning, scenarios will "assist management not only in reacting to future conditions, but more importantly in developing strategies which can proactively change these conditions." Evans (2004) argues that future scenarios often convey "stories" rather than facts. The further the perspective we are looking at, the less defined our factual information, the fuzzier our insight will become. Here visual information remains an essential communication medium and this is where designer's strengths often lie.

The notion of *design* has been widely used in the foresight research community to imply this innovation part of conjecturing foreseeable and unforeseeable future. For example Aaltonen (2010) compares multiple foresight techniques and differentiates between "*design"* and "*emergence"* within the landscape of innovation-centred foresight techniques. "Design" encompasses all known engineering and systemic (system thinking) approaches. Design is also person-oriented and the quality of their outputs depends therefore on the designers' skills "to stand outside the system and design the system as a whole".
Emergence in contrast "emerges" via a collective collaboration of actors (experts/stakeholders) with local knowledge. The outputs are not designed but are the result of interactions.

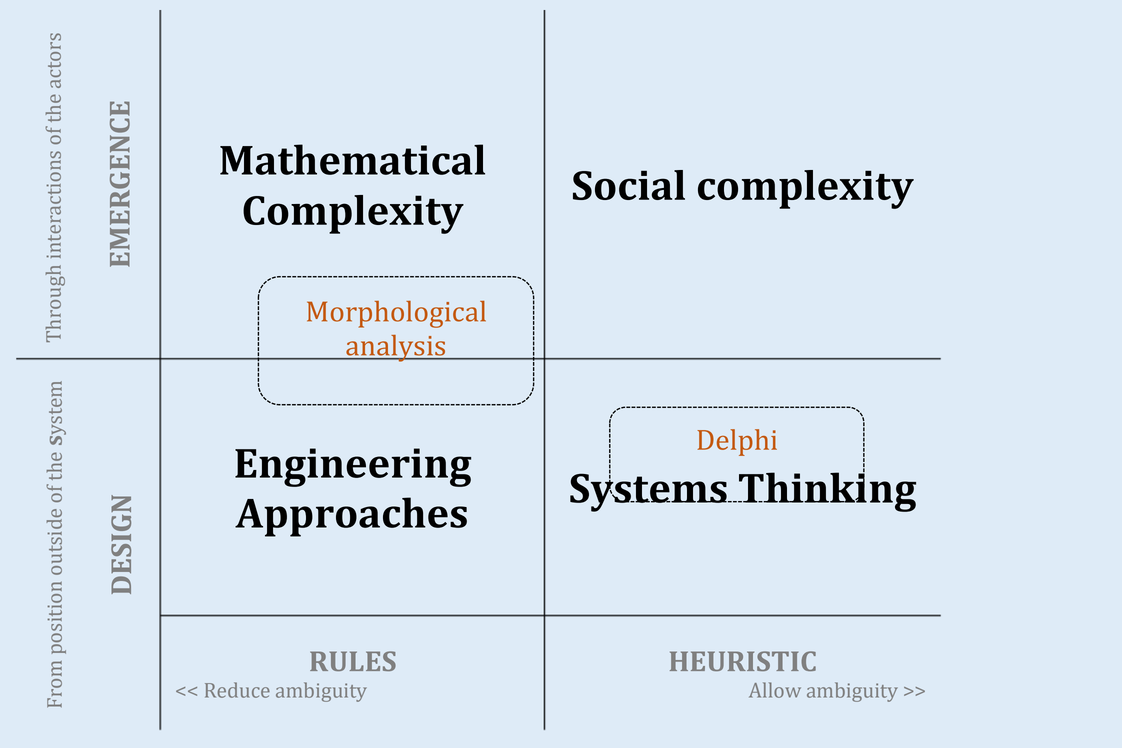

Table 1 Aaltonen's categorizing of foresight technics

Based on this definition, the Delphi technique enriches the "design" quality of morphological analysis. Morphological analysis in return increases the possibility of the Delphi panellists to capture new insights extra to their collective knowledge.

3. Matrix-based Delphi, a Generic Solution

As discussed in the previous section, future-oriented systemic design is a research area with multiple theoretical and procedural obstacles. We also discussed that a Morphological Analysis, a Delphi survey and a design expertise can each partially cover some of these problems. Multiple issues such as lack of comprehensiveness, operators biasing or lack of sufficient knowledge were referred to.

Table **2** shows a list of issues that a combination of Delphi and MA can address.

ISSUE	TOOL
Non-existent user (User research infeasibility)	Delphi
Solution space comprehensiveness (covering maximum possible concepts)	Morphological Analysis, Computation
Designers biasing (human factors e.g. background, talent or personal preferences)	Delphi
Designer's insufficient domain knowledge (multidisciplinary domains)	Consensus knowledge
Dynamic key factors (changes in technological and social key factors during the development of time)	Computation, APS iteration

Table 2 Issues existing in future-oriented design , addressed by a Morphological Delphi

An illustration of a possible contribution of Delphi and Morphological analysis in a *"Matrix-Based Delphi" (MBD) tool* is proposed in ***Error! Reference source not found.***. Perhaps the tool can not only be applied in future-oriented design, presumably can be used also as a generic algorithm in the wider domain of team-work innovation management.

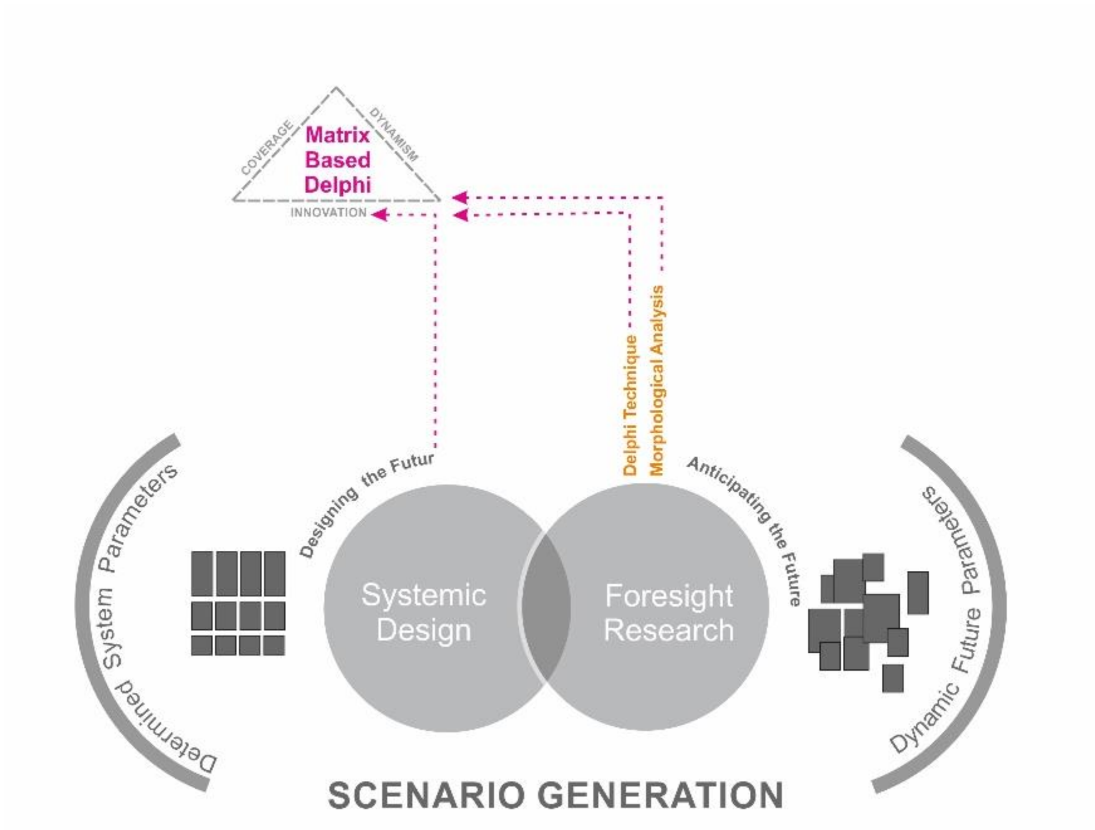

Fig. 3 Matrix-based Delphi, integrating foresight research tools in future-oriented systemic design

3.1. Example

To outline the proposed procedure of a Matrix-based Delphi, we carry out an example in the maritime industry:

"*Feasibility inquiry on offering a zeppelin-flight experience on a cruise ship launching at 2025*"

The procedure will be as follows:

1. A moderator (with design expertise) launches a Delphi round (collecting panellists according to expertise requirements).
2. Panellists discuss and select most important key factors and assign each key factor an index (multiplier) indicating the importance or priority of the key factor.

3. Each key factor receives a set of values[6]. The values also receive one or multiple indexes (multipliers) reflecting feasibility, likelihood, novelty or any criteria concerning the objective of the research (Fig. 4).

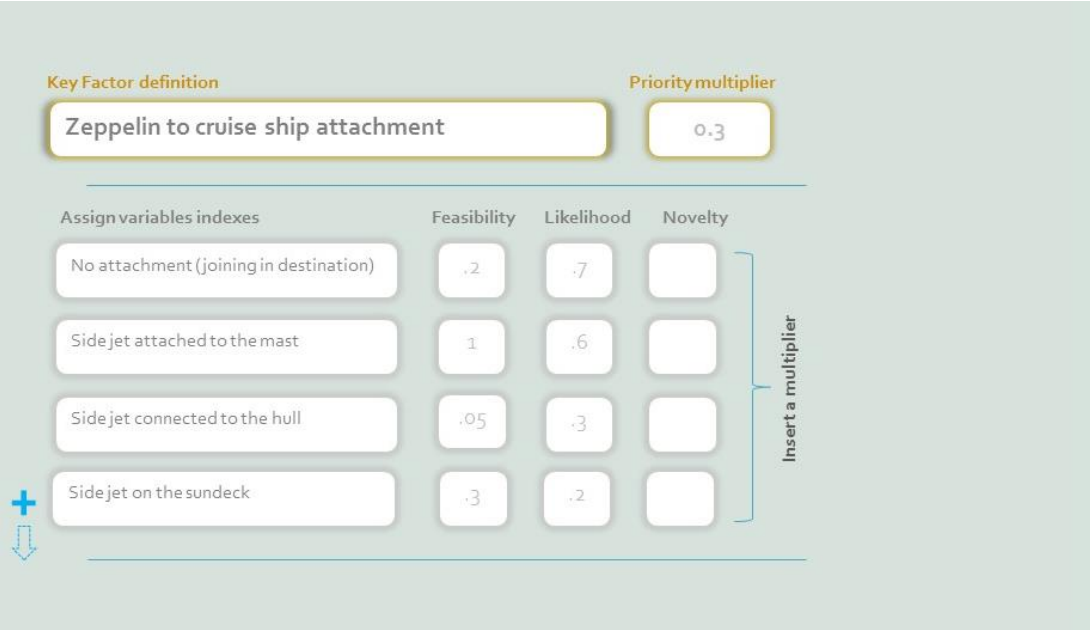

Fig. 4 A single "Key factor" and its 4 assigned values. Both Key factors and values are associated with one or more multipliers (decided by respective experts)

4. Once all key factors, values and their respective multipliers are determined, the moderator can build the morphological matrix. (Fig. 5)

A hypothetical solution (scenario) will be a combination of multiple key-factors, each represented by a value. The multipliers that experts have assigned to each key-factor and respectively each value, will help the system to calculate and rank most feasible, likely or novel configurations. These criteria are decided in advance, according to the typology of the inquiry (design optimisation, strategic decision, product development etc.)

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[6] Values are different states of a single key factor, e.g. different wishes, technological possibilities, event likelihoods etc.

- However, in the real world key-factors don't act independent of each other. The existence and chronological development of many values is strongly associated to the presence of some values from other factors. This dynamic (see Table 2) is principally an important driver for the development of innovations and revolutionary designs. In the Zeppelin example, the value "20 Persons or more" from the key-factor "Capacity" can only exist when the value "30m^3 and higher" in the key-factor "dimension" occurs. Thus, in order to integrate this dynamic in the system in the fifth step:

5. Experts responsible for each key-factor are asked to review other experts' key-factors and if found one of own values related to an external value, link them together.

   This linkage structure will be particularly useful, when during the development of concepts, decision-makers decide to grant a value for fixed, all related values will get a higher ranking in the index.

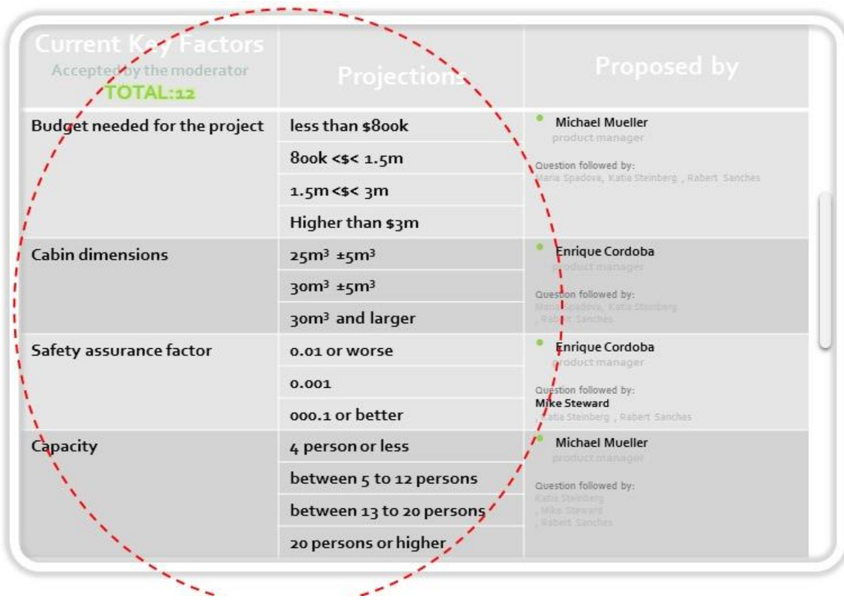

Fig. 5 Experts detect and elaborate themselves relevant Key Factors gradually via exchanging ideas. The results are then reflected to the moderator

6. After the system generated possible scenarios and ranked them according to the entered criteria (by experts), now the design team can easily convert output to visual information and design outputs.

7. If the results are not satisfying, an iteration with minor adjustments in the "pre-permutation" inputs will let the system recalculate the possibilities and generate real-time results.

The final model of the matrix-based Delphi is illustrated in fig. 6.

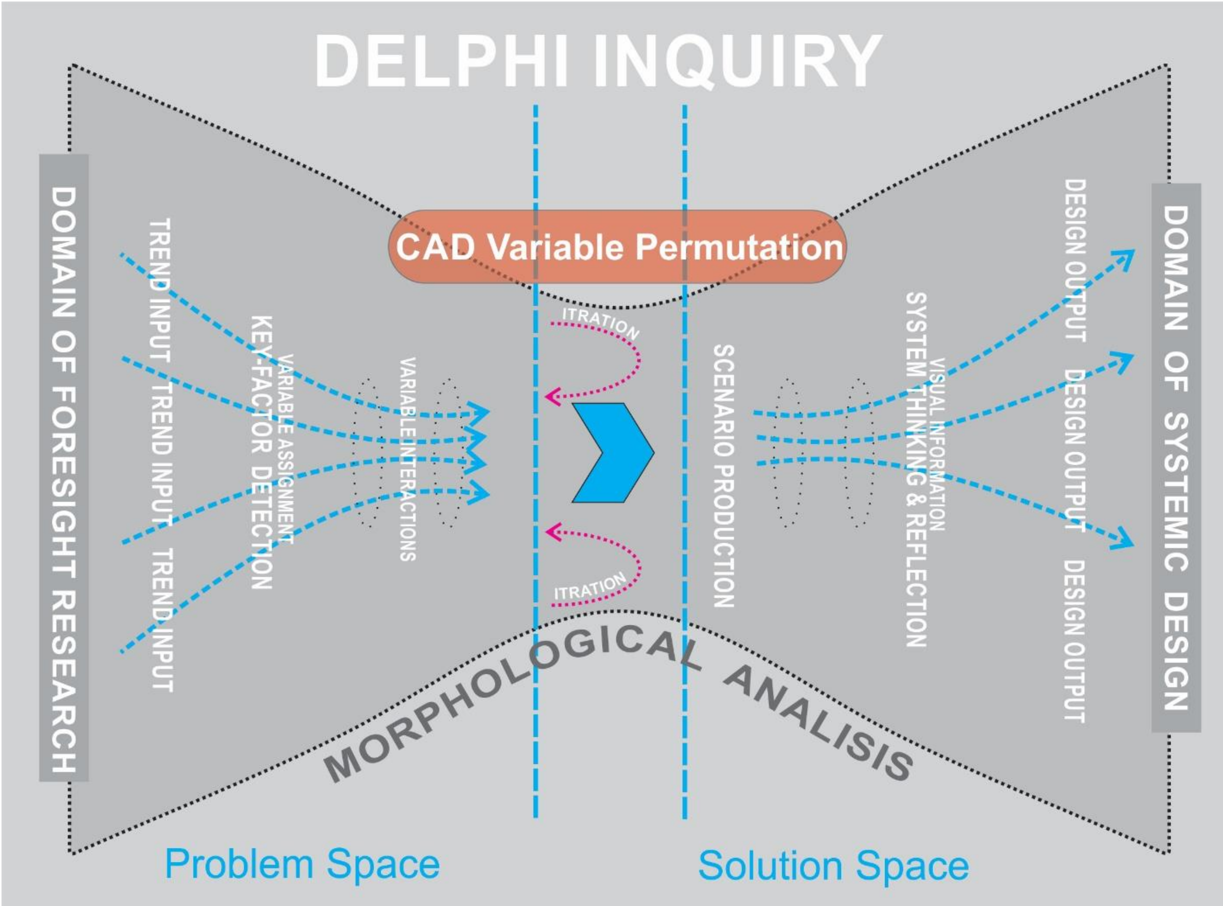

Fig. 6 The final model of a Matrix-based Delphi procedure

4. Conclusion

Future-oriented systemic design is based on not following the trends to predict the future but to follow the trends to design the future. Defined in general terms, matrix-based research is about algorithms enriched by heuristics. In the conventional design practice, a concept is the designer's heuristic conclusion of his cognitive perception of the problem space. Morphological analysis goes through a systematic clustering of key-factors involved in a system and applies algorithms to populate different key-factors arrangements and generate concepts.

The proposed Matrix-based Delphi tries to integrate both heuristic and algorithms in systemic design and utilize the advantages of both approaches. Human's Heuristic (Delphi) is effective, highly innovative but not comprehensive, algorithms are the opposite (MA), covering the whole solution space but time-consuming in delivering clear design outputs. The matrix-based Delphi can be implemented in a CAD application and support the process of idea generation (and idea management) in future-oriented systemic design inquiries, where a user research is not possible and mega-trends and expert knowledge act as the analytical base. The suggested algorithm enables the decision-makers to only focus on the assessment of highly ranked scenarios and not the entire solution space.

In innovative design there are recorded documents attesting that MA can accelerate the visualization time of concepts: a single setting (made of one scenario per key factor) in a morphological array is not different than a narrative sketch of a conceptual design. The feature is especially useful when large numbers of solutions need to be graphically compared and discussed (e.g. aesthetical settings). The later feature is in fact the essence of many documented attempts of instructing computers to design concepts based on parametric algorithms.

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