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Title

Brainstorming to harness the spontaneity of problems as opportunities: EIDeM

Keywords

brainstorming, problem solving, idea generation, divergent thinking, design conflicts

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Statements and declarations

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Abstract

Brainstorming methods are examples of popular tools for divergent thinking used to generate new ideas for solving problems and seeding design projects. The objective is to maximize the number and diversity of ideas while critical analysis is postponed for convergent phases. However, without appropriate mechanisms for navigating the infinite parameter space of designs, the divergent leaps can become piloted by irrelevant factors failing the objective. A new entropy-inspired design method (EIDeM) for divergent thinking is proposed that replaces the instinctual avoidance of problems with more organized and probabilistically favorable problem-positive exploration. In nature, a macrostate manifested by a large number of microstates can spontaneously overwhelm a smaller macrostate, making the presence of the latter rare or practically nonexistent. Similarly, the enormous number of characteristics manifesting problems can be forbidding for a problem-negative thinker. However, the abundant problematic factors can be considered as spontaneous natural phenomenon governed by the laws of probability, enabling extensive guides for searching new manifestations for the complementary functions of interest with improved performances. The conflicts can also be used as isolated targets for conscious efforts to detach from cognitive limiting fixations. The EIDeM integrates well with conventional design methods, and seems to be especially suitable for relaxing compulsory functions that have turned into bottlenecks slowing down or totally halting the overall development. The versatile use of the EIDeM is demonstrated using two artificial design scenarios, and real-life applications are also reported. Wider reproduction of the EIDeM's potential could enhance the pace of the forward-going humankind.

1 Introduction

Generally accepted good design practices include controlled alternation between divergent and convergent thinking phases (Van Boeijen et al. 2020). Methods for divergent thinking can be used to generate new ideas to solve problems or seed design projects, ideally free from the designer's conceptual or knowledge-based fixations explained by unconscious adherence or conscious blocking (Youmans and Arciszewski 2014). Good examples of general-purpose methods for divergent thinking are popular brainstorming techniques (Osborn 1953; Whiting 1958). SCAMPER, which is an acronym of words *Substitute*, *Combine*, *Adapt*, *Modify*, *Put to another use*, *Eliminate*, and *Reverse,* provides reminders about various ways the subject of ideation should be considered to gain new aspects on the problem (Eberele 1996). A similar list is provided by the WWWWWH, an acronym of words *Who*, *What*, *Where*, *When*, *Why*, and *How* (Sloan 2010). Morphological chart helps to divide designs into smaller function-based portions around which a great number of characteristics and their combinations can be ideated (Zwicky 1967). To solve certain types of design problems, TRIZ matrix uses conflicting factors as coordinates to locate potential approaches (Altshuller 1999). Among other features, a more general-purpose derivation of TRIZ called ASIT reduces these approaches to a fewer and more abstract forms (Horowitz 1999 and 2023). Using these methods, designers can take cognitive steps away from the current design focuses and gain new insights beyond the apparent limits of the non-provoked thinking. Convergent thinking is then needed for analytically excluding non-feasible or sub-optimal ideas from the further scrutiny. Convergent thinking can be assisted with methods such as Pugh matrix (Pugh 1981), PMI (De Bono 1986), and COCD box (Byttebier et al. 2007).

An intuitive approach to engage with problems, which must be managed to make viable designs or which the designs try to solve, is the exclusion of the problematic factors. This is reasonable to some extent, especially during the convergent phases of designing (Van Boeijen et al. 2020), because the problematic factors as such are nuisance. However, the instinctual avoidance of problems could unnecessarily limit the divergent exploration. Viable and optimal designs could become rejected due to misjudged problematic factors, or the designs are not discovered at all without looking at right places with appropriate mindset. It is easy to see why the problematic parameter space of designs is so vast and unavoidable in probabilistic sense, even if a single parameter is considered. As an example, the number of different shaft lengths for an axe is infinite, while only a small range is convenient considering the human anatomy, are cost efficient to manufacture, and so on. And the relative size and complexity of the problematic space increases, exponentially, as more parameters are incorporated in the designs, even if the parameters have definite ranges (figure 1). Luckily, some design methods do encourage to consider also the problems as potential sources of opportunities, with more or less organized manner. Reverse brainstorming helps to establish new aspects on designs by listing ways how to make them worse (Whiting 1958). More specific approach titled ”Convert Harm into Benefit” in TRIZ matrix proposes to utilize problematic factors to obtain a positive effect, remove them by combining together, or increase their intensity to a degree until they stop being problematic (Altshuller 1999). Synectics, which is a somewhat laborious method, utilizes invented analogies to represent the problem in different imaginary contexts for provoking new and non-intuitive solutions (Gordon 1961; Van Boeijen et al. 2020). Sharing similar motivations, the PMI (De Bono 1986) and COCD box (Byttebier et al. 2007) were developed to limit unjustified rejection of novel ideas during convergent phases. Pugh matrix (Pugh 1981) can be used to better understand designs that satisfy certain requirements inadequately in relative sense, and possibly remedy them by borrowing characteristics from the other compared designs.

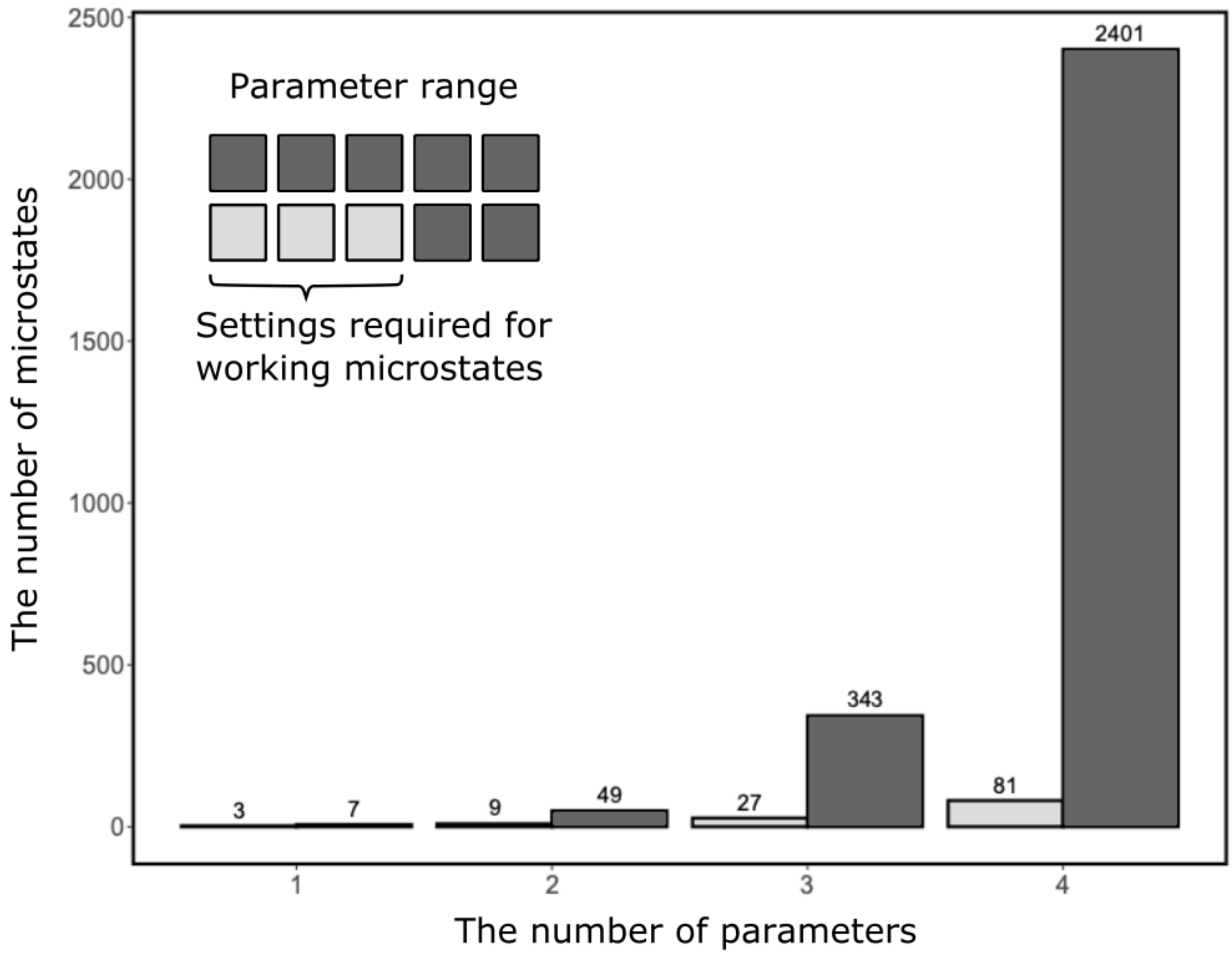

Figure 1. An example of the exponential escape of the number of assumed-faulty microstates (darker right-hand bars) in comparison to the working microstates (lighter left-hand bars) in limited imaginary designs. The numbers of microstates are calculated using the formula S^P; where S is the number of parameter settings required to manifest a particular microstate (working or faulty), and P is the number of parameters per design. In this example, one of the three specific settings per parameter are required to have a working microstate, and seven settings lead to assumed-faulty microstates. Word "assumed" is used to provoke seeing the abundant problematic microstates as potential missed opportunities. False-working microstates also exist and are ideally recognized using convergent thinking.

Whether the problem-positive expansion of ideation is utilized or not, divergent thinking is prone to become piloted by fixations limiting the ideation (Youmans and Arciszewski 2014). For example, the conventional brainstorming, during which participants become exposed to ideas of others, can suffer from collaborative fixation leading to reduction of explored domains and ideas conformed to each other (Kohn and Smith 2011). Even prior visual fixations on earlier designs has been found to associate with the success of the idea generation in alternative-uses test (Kwon et al. 2020). Combining the effects of the irrelevant secondary factors with the problem-negative mindset can severely limit the search space of ideation. Thus, it would be beneficial to improve the efficiency of the divergent leaps by having a problem-positive divergent-thinking method utilizing relevant references for navigation in the vast parameter space of designs (figure 1). The references should also work as extensive targets towards which conscious efforts can be taken for detaching from the cognitive fixations, obtained before or during the divergent thinking (Youmans and Arciszewski 2014; Kohn and Smith 2011; Kwon et al. 2020). The method should also be straightforward to utilize to avoid excessive consumption of attention and increased bar of adoption. On the other hand, as the idea resources of the designers will become exhausted at some point, an open framework should be provided for employing other methods of divergent thinking to push the ideation even further when necessary.

A new entropy-inspired design method (EIDeM, figure 2) is proposed for general-purpose problem-positive divergent thinking and managing the above-mentioned problems. The EIDeM was developed to solve design conflicts between functions of interest and the complementary problematic factors (figure 2A). Instead of avoidance, the problems are considered as spontaneously emerging natural phenomena governed by the laws of probability (figure 1), from which the frequency can be extracted and combined with the desired technical effect. The EIDeM utilizes the conflicts as references around which broad exploration of ideas for improving the performance of the function of interest can be executed within the relevant parts of the infinite parameter space. Regular conscious efforts for breaking away from cognitive fixations (figure 2B) are also part of the EIDeM. Once the idea resources seem to become depleted, other design methods can be used within the EIDeM framework to provoke even more ideas. In this paper, the EIDeM is demonstrated in single-person use with two artificial design scenarios. Diverse starting materials are covered ranging from concrete technical implementations to digital software, structured by function-level (Zwicky 1967) and requirement-level (Pugh 1981) frameworks, respectively. How the various thinking processes became realized were recorded in detail (supplementary notes) to help the readers to understand the basis of the results and conclusion. Real-life applications are also reported, including a case where the EIDeM promptly exposed a viable design, which was also immediately embodied, under moderate mental pressure to solve and unexpected problem in difficult conditions. Motivated by the intriguing and repetitive positive usage experiences of the EIDeM, an attempt was also taken to more formally define the underlying hypothetical mechanism the EIDeM utilizes for the divergent navigation.

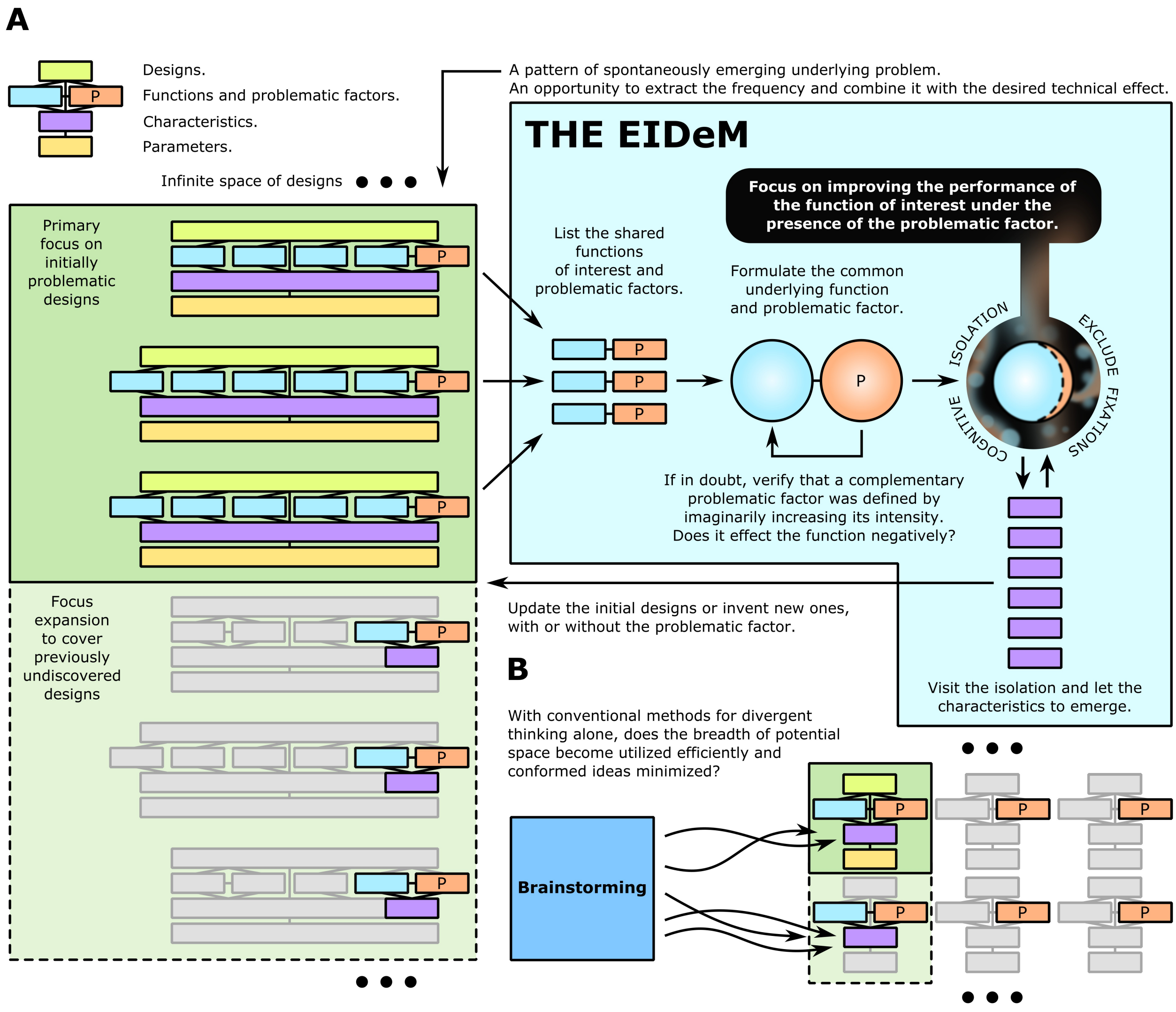

Figure 2. Overview of the new brainstorming method named EIDeM for general-purpose problem-positive divergent thinking. Terminological hierarchy used and illustration of an example design scenario on which the EIDeM is applied (**A**). The primary design focus comprises three design candidates sharing the same underlying function of interest and conflicting problematic factor. After the EIDeM, new characteristics for manifesting the function with improved performance has been found for all the primary design candidates, and three previously unrecognized yet potential design candidates were discovered. Possible fundamentally faulty or sub-optimal designs are rejected during the following convergent-thinking phases. Illustration how less structured methods for divergent thinking, such as conventional brainstorming, relate to the hypothetical patterns of opportunities (**B**).

2 Materials and methods

2.1 EIDeM protocol

2.1.1 Preparatory work for EIDeM sessions

How the EIDeM is executed step by step is illustrated in figure 2A. The first task of preparation is to list the function of interest and the conflicting problematic factor, possibly shared by multiple conceptual designs, physical prototypes, or products. The occurrences of these elements can be observed using design frameworks such as morphological charts (Zwicky 1967), Pugh matrices (Pugh 1981), or unstructured experience can be the source. Without function-level framework additional function analyses might be required (Van Boeijen et al. 2020). Seeing the repetitions alone can induce significant new insights, and make the formulation of the underlying forms easier. Starting from a single occurrence is possible, but observing the repetitions provides better evidence for the existence of bigger structures of opportunities in the parameter space (see chapters 4.1 and 4.4).

Formulated using the listed occurrences, the underlying function of interest and problematic factor should represent the purest possible essence of the elements, with as little as possible features which could limit the explored parameter space (figure 2A). For example, if the design is a quadcopter manifesting a function of “agile movement”, weight could be the primary recognized problematic factor. To formulate the underlying elements, it is assumed that limiting the focus on any specific geometry, material, density, or other characteristics is not beneficial considering the scope of ideation. Considering the example problematic factor, even being subject to the gravitational fields in this case can be too specific. The overall resistance against any forces could be optimal, which would now include also the inertia and air resistance making a better match with the function. However, the formulation of the underlying elements should not override the case- specific relevancy, a balance the designer needs to consider. For example, although not recommended, must-have characteristics could be included in the final definitions of the elements, if the cost of limited search space is accepted. Finally, if necessary, the appropriate complementarity can be validated by imaginarily increasing the intensity of the problematic factor and verifying that it will interfere or possibly fully disable the function of interest (similar analysis to the “qualitative change” in ASIT method, Horowitz 1999 and 2023).

2.1.2 Idea generation using EIDeM

After doing the preparatory work, the conflict between the underlying function of interest and problematic factor is considered in cognitive isolation from the primary designs and any other concepts (figure 2A). Similar to conventional brainstorming, the aim is to invent as many ideas as possible while delaying analytical assessment and criticism (Osborn 1953; Van Boeijen et al. 2020). However, in the EIDeM the problematic factor is tolerated, and if the mind tends to exclude the problem, it is consciously pulled back into the focus. The primary approach is not to remove or avoid the problem in the intuitive sense, although all emerging ideas are allowed. The main principle is to enhance the performance of the function of interest under the presence of the problematic factor. This is possible by assuming that modifying the characteristics manifesting a problematic factor or attenuated function of interest to a certain extend does not erase them, such as by screwing a bolt in a design. This way, the scope of the plastic problematic factor can be followed to expose a diversity of new characteristics manifesting the elements.

Practicing the described mindset while focusing on the reference conflict, the designer lets the ideas to emerge and records them promptly by writing or drawing. And when the flow of ideas ceases, the designer returns back to the cognitive isolation, trying to break away from the recently generated ideas and other concepts on mind to avoid limiting fixations (Youmans and Arciszewski 2014). After this alternation does not produce more ideas, other design methods can be applied on the isolated conflict, such as SCAMPER (Eberele 1996), TRIZ matrix (Altshuller 1999), or ASIT (Horowitz 1999 and 2023). Another more indirect approach, similar to reverse brainstorming (Whiting 1958), is to first ideate new characteristics to manifest the underlying problematic factor, then use them as the base for inventing manifestations for the complementary function of interest. After the overall exploration has produced a satisfying number of ideas, appropriate design methods for convergent thinking can be used to limit the coming design focus on viable and optimal designs.

2.2 Priming artificial design scenarios

The use of the EIDeM was demonstrated using two artificial design scenarios: function-level and requirement-level scenarios. Both of the scenarios represent impact-fixed manifestation-open design problems (Van Boeijen et al. 2020). The prime for the function-level scenario was a morphological chart (Zwicky 1967) representing sets of candidate characteristics trying to manifest general functions of designs solving the same main problem (the primary function-level focus). The prime for the requirement-level scenario was a Pugh matrix (Pugh 1981) representing a set of candidate designs trying to satisfy general requirements of designs solving another main problem (the primary requirement-level focus). In the requirement-level scenario, an interactive Pugh matrix coded by the author was used. It allows the input of the designs (columns) and requirements (rows) in text format, selection of the datum and Equal-Better-Worse ratings with chromatic enhancements (removed from the article for printing in black and white), and automatic summation of different types of ratings per designs.

Everyday contexts were searched for priming the design scenarios to make the thinking process easier to interpreter by a variety of readers with different backgrounds. It was expected that when the morphological chart and Pugh matrix were populated, the functions of interests and the complementary problematic factors will emerge, which can then be extracted and the EIDeM started. To populate the morphological chart and Pugh matrix during the priming, imagination and general internet resources readily available were used without doing extensive patent-literature search or similar demanding work.

2.3 Idea counting and performance meters

After priming the design scenarios, the EIDeM was applied on the found problems as described above and in figure 2A while internet for searching ideas was disallowed. The aim was to generate as many ideas as possible for solving the conflicts between the chosen functions of interest and the complementary problematic factors. If more than one conflict was recognized within a design scenario, only one was chosen as conscious target for the EIDeM ideation. The results were quantized using the absolute number of new and distinct characteristics needed to solve the conflict, i.e. the EIDeM-generated ideas. Before counting, it was verified that same characteristics were not present in the primary design focuses. Possible combinations or duplications of the characteristics were also not counted as new and distinct. The ratios of the EIDeM-generated ideas per the initial number of the occurrences of the problematic factors were also calculated. Thus, ratios > 1 indicate the arithmetic flooding of the EIDeM-generated ideas over the primary design focuses. The absolute and relative numbers were obtained for the following categories: the EIDeM-generated ideas dealing with the primary target conflict or other ideas, and ideas generated without or with using other design methods within the EIDeM framework. Thus, the total number of the obtained performance meters was 2 x 2 x 2 = 8 per design scenario.

2.4 Schedule for design scenarios

To mimic the requirements of modern work environments, relatively short scheduled time periods were allowed for the design scenarios. Furthermore, as the mind can subconsciously process information and ideas maturate progressively, time for the problem familiarization was limited forcing the idea generation to be more definite and easier to record. However, moderate time for idle thinking was allowed outside the more active thinking sessions, including ad-hoc breaks and one night's sleep per design scenario, as breaks are natural and important elements for creative cognitive work.

Following the above principles, a target schedule was set for the design scenarios. For each design scenario, approximately 5 and 8 hours were allowed for priming the design scenarios and active utilization of the EIDeM, respectively. The total allowed time for the EIDeM per design scenario was 24 hours covering two partial days including also the idle phases. Possible ideas generated after the schedule were excluded from the results.

2.5 Recording of thinking process

How the primings of the design scenarios and the idea generations using the EIDeM and other design methods became realized was recorded as a timeline diary (supplementary notes). The recorded times correspond to the approximate moments when the different phases described in the notes started. The EIDeM-generated ideas were shortly described in writing so that the readers can judge whether to agree with the calculated performance meters. The notes were corrected and supplemented afterwards if necessary for the sake of clarity and readability, without changing the fundamental subject matter. The transitions from the priming phases to the use of the EIDeM was expressively declared to make distinction of the EIDeM-generated ideas from the prior ones. All relevant observations were recorded as appropriate.

3 Results

3.1 Function-level scenario

The priming of the artificial function-level design scenario led to consider a main problem of having cold or uncooked foods when a consumer is hungry or soon hungry (supplementary notes). In the desired situation the consumer would have the foods warm and cooked ready for consumption. A design needed to close the gap between these two states was considered and function analysis was conducted (Van Boeijen et al. 2020). The obtained general-level functions were used to prepare a hand-drawn morphological chart (Zwicky 1967, figure 3) which was populated with function-specific characteristics obtained using unstructured and WWWWWH-assisted divergent thinking (Sloan 2010; Van Boeijen et al. 2020) with internet browsing (supplementary notes). The chart included rows for functions (6) and columns for characteristics (42). This primary design focus itself included a variety of divergent ideas, such as heating foods using mechanical friction. A combination of characteristics representing a microwave oven was selected as the best intuitive design to solve the problem, which was later judged to be suboptimal for cooking foods. The selection was possibly the result of a cognitive fixation caused by the recent use of a microwave oven during the experiment (supplementary notes).

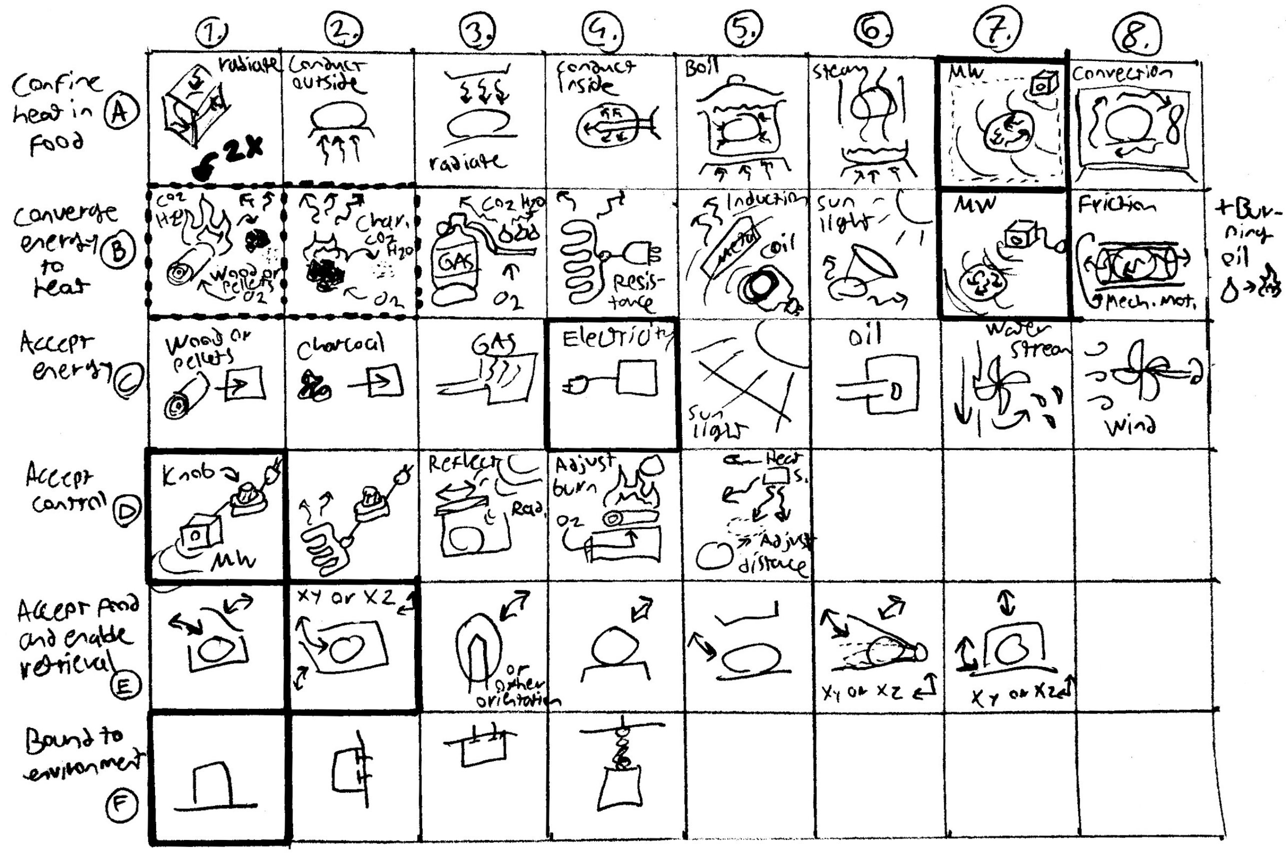

Figure 3. The prime for the function-level design scenario. A hand-drawn morphological chart representing different functions (6) and characteristics (42) for manifesting designs

capable of warming and cooking foods. The cells enhanced with thick solid lines represent the intuitively chosen best combination of six characteristics (basically a microwave oven) to manifest the functions of a design needed to solve the main problem. The cells enhanced with thick dashed lines represent the three occurrences of the problematic factor of interest (“slow-igniting fuels”) selected for further ideation with the EIDeM. The B1 cell actually contains two characteristics: wood and wood-based pellets (noted by the “2X”).

The “converge energy to heat” became selected as the function of interest for the further ideation with the EIDeM. The recognition of the repeating problematic factor of “slow-igniting fuels”, reproduced three time in the corresponding function row (B in figure 3), resulted in the reformation of the function to “converge energy to heat quickly”. The cognitive steps occurred very quickly leading to the first stream of spontaneous ideas, which were later completed further after breaks and using the SCAMPER (Eberele 1996; Van Boeijen et al. 2020) within the EIDeM framework (supplementary notes). The total number of the EIDeM-generated ideas was 26, which was 8.7 times larger than the number of the occurrences of the problematic factor in the primary function-level focus (figure 4). The more indirect approach to ideate the manifestations for the problematic factors first, a similar approach to the reverse brainstorming (Whiting 1958), was not tested.

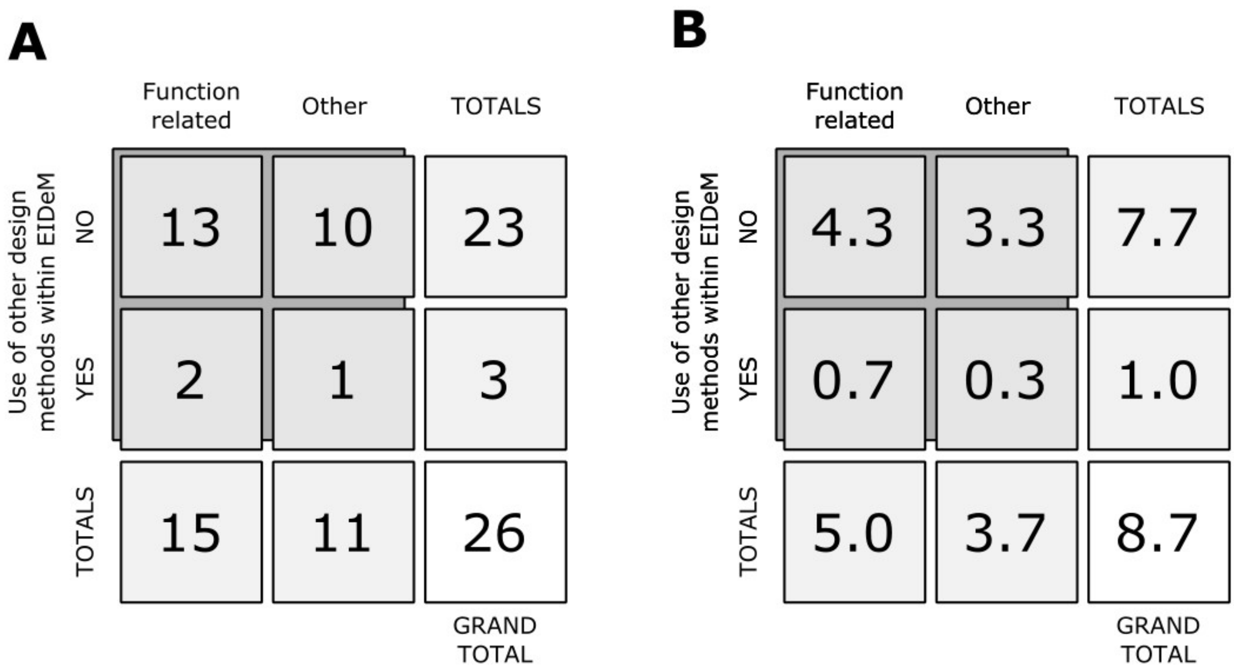

Figure 4. The performance meters of the EIDeM during the function-level scenario in which the reformulated function of interest was “converge energy to heat quickly”. The absolute numbers of the EIDeM-generated ideas is shown in A. The numbers of the EIDeM-generated ideas in relation to the occurrences of the problematic factor of interest (“slow-igniting fuels”, three occurrences) is shown in B. Three idea generations were assisted using the SCAMPER (Eberele 1996; Van Boeijen et al. 2020) within the EIDeM framework (supplementary notes).

3.2 Requirement-level scenario

To demonstrate the versatility of the EIDeM, the previous context of kitchen and concrete technical implementations was changed to office while focusing mainly on digital software (supplementary notes). The priming of this artificial requirement-level design scenario lead to consider a project-management-related main problem of consumed attention and time for secondary matters while trying to achieve a primary goal. In the desired situation there would be no distractions while conducting daily operative project management. For this task, a variety of virtual designs was acquired using WWWWWH-assisted (Sloan 2010; Van Boeijen et al. 2020) internet browsing. A personal, mainly manual tactic was included as a familiar project-management method suitable for primary datum for the requirement comparisons. After the search, a diverse cross section of characteristic and requirements of the software products for the primary design focus was obtained: the Pugh matrix included rows for requirements (11) and columns for designs (5, figure 5). Two Pugh-matrix analysis rounds were conducted to validate the self agreement, after which the secondary datum (a memory-assistant tool Heyday) hold its position as the best overall design (supplementary notes).

A

	Personal tactic	Heyday	Elicit	ClickUp	Google Assistant
Overall automatization	Equal	Better	Better	Equal	Better
Reliability (or at least the sense of control)	Equal	Equal	Equal	Equal	Worse
Capability to bring directly usable relevant information	Equal	Better	Better	Worse	Better
Help to build upon previous information or made tasks	Equal	Better	Equal	Equal	Equal
Help to framework a project	Equal	Equal	Equal	Better	Worse
Suitability for a variety of goals	Equal	Equal	Worse	Equal	Equal
Context, app, and platform applicability (e.g. all internet vs research literature, whole screen assistant or within app/software)	Equal	Equal	Worse	Equal	Equal
Visual tidiness (anti-clutter	Equal	Better	Better	Equal	Equal
Logical tidiness (easy to comprehend, or at least does not bother)	Equal	Better	Better	Equal	Equal
Focus on the current relevant things (no project-management escalation)	Equal	Better	Better	Equal	Equal
Gentle learning curve	Equal	Worse	Worse	Worse	Equal
	Equals: 11 Better: 0 Worse: 0	Equals: 4 Better: 6 Worse: 1	Equals: 3 Better: 5 Worse: 3	Equals: 8 Better: 1 Worse: 2	Equals: 7 Better: 2 Worse: 2

B

	Personal tactic	Heyday	Elicit	ClickUp	Google Assistant
Overall automatization	Worse	Equal	Worse	Worse	Worse
Reliability (or at least the sense of control)	Better	Equal	Better	Better	Better
Capability to bring directly usable relevant information	Equal	Equal	Worse	Worse	Better
Help to build upon previous information or made tasks	Better	Equal	Worse	Equal	Equal
Help to framework a project	Better	Equal	Equal	Better	Worse
Suitability for a variety of goals	Equal	Equal	Worse	Equal	Equal
Context, app, and platform applicability (e.g. all internet vs research literature, whole screen assistant or within app/software)	Better	Equal	Worse	Equal	Equal
Visual tidiness (anti-clutter	Worse	Equal	Better	Worse	Better
Logical tidiness (easy to comprehend, or at least does not bother)	Worse	Equal	Equal	Worse	Equal
Focus on the current relevant things (no project-management escalation)	Worse	Equal	Worse	Worse	Worse
Gentle learning curve	Better	Equal	Equal	Worse	Better
	Equals: 2 Better: 5 Worse: 4	Equals: 11 Better: 0 Worse: 0	Equals: 3 Better: 2 Worse: 6	Equals: 3 Better: 2 Worse: 6	Equals: 4 Better: 4 Worse: 3

Figure 5. The prime for the requirement-level design scenario. An interactive Pugh matrix (Pugh 1981) coded by the author, representing five different project-management-supporting designs and personal tactic. These were compared qualitatively using the Equal-Better-Worse ratings considering the satisfaction of the eleven requirements. As a familiar datum (enhanced with solid continuous line) for the first Pugh-matrix comparison, the mainly manual personal project-management tactic of the author was used (**A**). The best-performing design in the first round, a commercial software named Heyday was chosen as the datum for the second round of comparison (**B**). The cells enhanced with thick dashed lines represent the five occurrences of the problematic factor of interest ("consumed attention for search") selected for further ideation with the EIDeM.

In the second round of the Pugh-matrix analysis, a repeating pattern of "Worse" cells in the "Focus on the current relevant things (no project-management escalation)" requirement was observed (figure 5). This problematic area was chosen for the further scrutiny. It was concluded that the requirement-level assessment alone did not lead to further cognitive progress with the EIDeM, why an additional and intentional function-level analysis was conducted (Van Boeijen et al. 2020). For the requirement, a function of "get information relevant for the currently focused matter" was formulated, which was in conflict with the problematic factor of "consumed attention for search". After these underlying forms were defined and focused in cognitive isolation, the first stream of spontaneous ideas started to emerge, which was completed further after breaks and using the TRIZ matrix (Altshuller 1999) within the EIDeM framework (supplementary notes). The total number of the EIDeM-generated ideas was 12, which was 2.4 times larger than the number of the occurrences of the problematic factor in the primary requirement-level focus (figure 6). The more indirect approach to ideate the manifestations for the problematic factors first, a similar approach to the reverse brainstorming (Whiting 1958), was not tested.

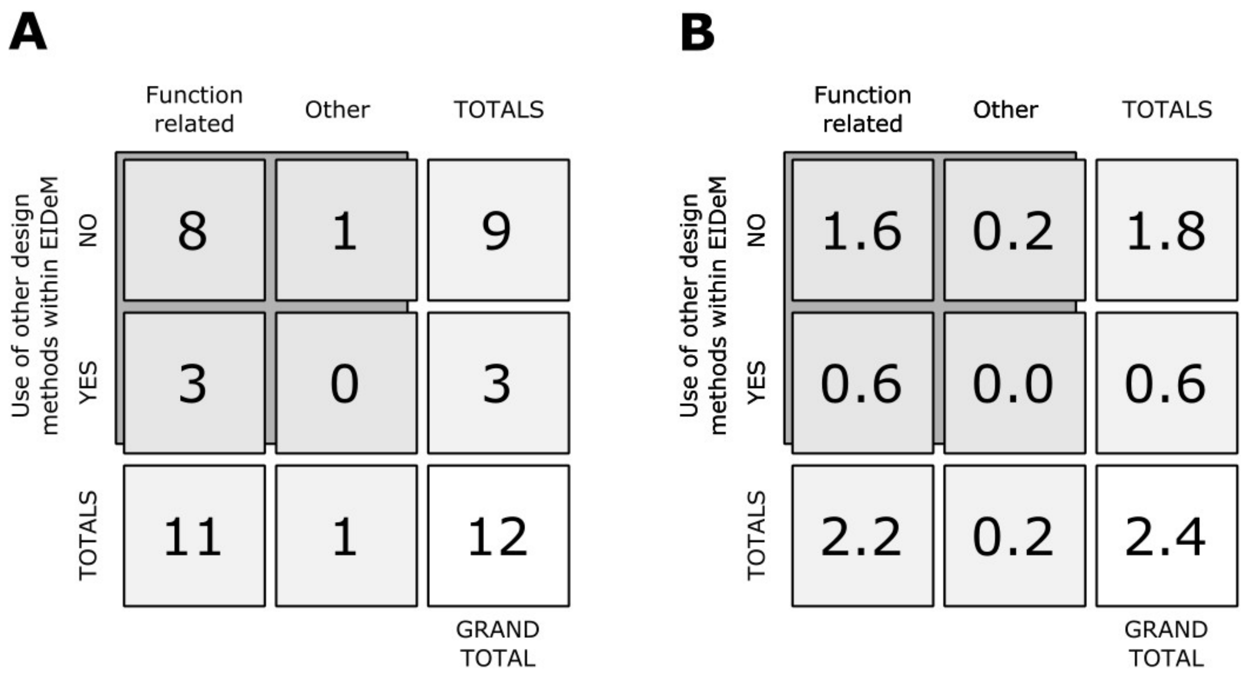

Figure 6. The performance meters of the EIDeM during the requirement-level scenario in which the function of interest was “get information relevant for the currently focused matter”. The absolute numbers of the EIDeM-generated ideas is shown in **A**. The numbers of the EIDeM-generated ideas in relation to the occurrences of the problematic factor of interest (“consumed attention for search”, five occurrences) is shown in **B**. Three idea generations were assisted using the TRIZ matrix (Altshuller 1999) within the EIDeM framework (supplementary notes).

4 Discussion

4.1 Inspiration behind EIDeM

The development of the EIDeM was inspired by the elemental yet capable natural mechanisms running on probabilistic phenomena. Instead of avoidance or exclusion, the EIDeM concerns the observed problematic factors as spontaneous glints from bigger structures of opportunities hidden in the infinite parameter space of designs. Instead of absurd noise, the structures represent meaningful qualities on which the characteristics of the functions of interest can be assembled upon with varying performances (figure 2A). The structures situate in the legal parameter space of designs, in which different bodies of matter cannot overlap in 3D space, like charges do not attract each other, and so on, otherwise the problematic factors would not be able to emerge in the physical reality. While focusing on the underlying design conflict of interest, the prior understanding about the elemental reality and other domains of knowledge can help designers to extensively explore these structures to find new ways to manifest the functions of interest with improved performances. Simultaneously, conscious efforts can be taken to exclude limiting fixations (Youmans and Arciszewski 2014) by focusing on the essence of the design conflict in cognitive isolation.

The EIDeM utilizes the problem-positive kernel of thoughts around which the new complementary characteristics of the function of interest can be build upon. Inspirationally, this can be considered to resemble how disorder can actually create order in nature. One such example is when non-polar molecules become spontaneously sorted from water by the laws of entropy, as the number of microstates manifesting the fixed ice cages required for the solvation are severely overrun by the microstates representing the free water molecules (Frank and Evans 1945; Silverstein 1998). Similarly, problematic factors can emerge spontaneously, without conscious decisions or acts to realize them, when design choices are made and concepts embodied, due to the unavoidable number of microstates the problematic macrostates cover. Even the functions we consider flawless could actually coexist with attenuated complementary problematic factors, possibly with multiple ones. The designers might be unaware of these, because the recognition and description of the more virtual problematic factors would be impractical and pointless with the already satisfactorily working functions. And similar to how the molecules can become spontaneously ordered into higher-order structures such as cell membranes, the dispersed problematic factors, and thus also their complementary functions, could coexist as whole viable designs in the legal parameter space. However, unlike the life, which survival relies on the dynamic continuum of appropriate states, the options of designs is similar to a library designers can explore when needed.

These inspirations lay down the tentative mechanisms for the divergent navigation that can be used to avoid the shortcomings in the conventional divergent-thinking methods (figure 2B).

4.2 EIDeM demonstration

The artificial design scenarios used to demonstrate the EIDeM were primed using the morphological chart (Zwicky 1967, figure 3) and Pugh matrix (Pugh 1981, figure 5) as function-level and requirement-level frameworks, respectively. The performance meters showed how a single person using the EIDeM was able to generate many new and distinct characteristic needed to solve the conflicts between the function of interest and complementary problematic factors by improving the function performance (figures 4 and 6, respectively). This was possible within the relatively short periods of time (per design scenario 2 x 4 = 8 hours of more active thinking and 24 hours with idle thinking in total) allowed to augment the already diverse range of designs and characteristics (figures 3, 5, and supplementary notes). In the relative arithmetic sense, the number of the EIDeM-generated ideas also flooded over the initial occurrences of the problematic factors exposing new designs approaches outside the primary focuses (figures 3, 4, 5, and 6). Thus, it seems that the EIDeM-generated ideas could be used as new characteristics for the designs that were already present in the primary frameworks, such as speeding up the ignition using electrical means in the masonry ovens (figure 3, supplementary notes, a more usual approach). In addition, the characteristics can be used to constitute designs outside the primary design focuses, such as making ovens utilizing mechanical means to speed up and adjust the combustion (supplementary notes, a more surprising new opportunity).

Once the functions of interest and the complementary problematic factors were extracted and their underlying forms assessed (figure 2A) the first spontaneous ideas emerged (supplementary notes). The process felt especially sudden and intense during the function-level scenario. In the scenario, observing the repetition of the problematic factor lead to reformulation of the function of interest to better match with the scarcity of the characteristics utilizing ecological wood-based energy sources. After the initial idea resources started to feel depleted, breaks and other methods for divergent thinking used within the EIDeM framework helped to produce even more ideas in both scenarios (figure 4, 6, and supplementary notes). It is believed that even further number of ideas could have been generated if more time would have been allowed. However, the second days during the design scenarios were always more difficult, why the SCAMPER (Eberele 1996; Van Boeijen et al. 2020) and TRIZ matrix (Altshuller 1999) were used to aid the tired mind during the function-level and requirement-level design scenarios, respectively.

During the function-level scenario, concrete designs relating to warming and cooking foods were dealt with, as well as digital project-management tools in the requirement-level scenario (supplementary notes). Thus, it was demonstrated how diverse range of problems and starting materials the EIDeM can be applied on, ranging from technical implementations to virtual software. The frameworks used to organize the design scenarios enabled structured means for manifesting and recognizing the repetitions of the problematic factors; evidence about the bigger structures of opportunities hidden in the infinitely large parameter space (chapters 4.1; 4.4; and figure 2A). Other design frameworks could also be used for priming the EIDeM, such as COCD box (Byttebier et al. 2007). For example, a cluster of designs being innovative yet difficult to implement could lead to the recognition of a shared function of interest and the complementary problematic factor. However, design frameworks not inherently assessing the functions of the designs likely require the execution of a separate function analysis (Van Boeijen et al. 2020), as was the case in the requirement-level scenario (the Pugh matrix did not lead to spontaneous recognition and formulation of the function of interest, supplementary notes).

In addition to the primary function of interest in the function-level scenario, the EIDeM also helped to find a significant number of new characteristics for manifesting the “accept control” function (figure 4 and supplementary notes). The function, which was not selected as the conscious objective for the divergent thinking, also became a target for intensive ideation resulting in 9 control-related and 7 mixed ideas (supplementary notes). Part of the explanation could be that controlling the heating is so important element in the usual concepts of preparing food that this background knowledge was difficult to diverge off from when the conflict of interest was approached in the cognitive isolation (figure 2A). On the other hand, all the more active EIDeM sessions during the function-level scenario not guided by the SCAMPER (Eberele 1996; Van Boeijen et al. 2020) started with series of ideas relating to the primary function of interest followed by the other or mixed ideas (supplementary notes). This could indicate that after the maximal cognitive isolation was reached, the more involuntarily generated ideas for the control were build upon the obtained seed of thoughts around the primary conflict. Whatever the explanation is, this phenomenon could be considered positive if other relevant yet incomplete areas of the designs also become spontaneously supplemented. Possible similar major leakage to serve other than the main requirement of interest in the requirement-level design scenario was not examined in detail: only one idea categorized as “other” was found (figure 6 and supplementary notes). Although in the final Pugh matrix, the repetition of “Worse” cells was also observed in the “overall automatization” (Figure 5) which can be considered as overlapping and co-ideated requirement with the primary one. Thus, in some design scenarios, the EIDeM seems to be able to steer the cognitive resources also on the other incomplete areas of the design focuses, where additional unoccupied opportunities might be available.

4.3 Motivation and real-life applications

The motivation for developing the EIDeM arouse when conventional methods for divergent thinking seemed to provoke too few, confined, and even irrelevant ideas for a design project. After developing the method, the EIDeM was used to relax (i.e. many new ways for manifestation were found) an essential function that became problematic in multiple physical prototypes and conceptual designs during product development. After the distinct reproduction of the problem was recognized, the problematic factor and the function of interest were isolated in their common underlying forms. The conflict of interest in cognitive isolation was considered by the author without using other design methods, and within 24 hours a spontaneous stream of ideas covering a variety of new characteristics manifesting the function of interest emerged, suitable for the current designs at hand and applicable beyond the primary design focus. Experiencing the phenomenon was surprising, as the multiplication of ideas and "flooding over" the primary design focus was well in line with the initial vision why the EIDeM was developed.

After getting used to the EIDeM mindset and memorizing the principal steps, the author has used the EIDeM also more promptly to ideate solutions for everyday problems. In all cases, after considering the underlying functions of interest and problematic factors in cognitive isolation, in time scales of tens of minutes, the emergence of diverse yet relevant ideas was repeatedly experienced. In one particular case the EIDeM performed surprisingly well despite the presence of moderate mental pressure and hurry caused by an unexpectedly occurred practical problem. The author was even able to implement a viable embodiment from one of the EIDeM-generated ideas, which is still in use at the time of writing this article (figure 7). The scenario related to slightly leaking door gaskets of a chicken coop causing minor frost that sometimes jammed the door (appropriate internal temperatures in the coop were always sustained suitable for Finnish landrace chickens). The primary gaskets used were a few millimeter thick EPDM-rubber strips which did not appropriately adapt and seal the door structures made by the author, as the wooden construction materials deformed due to mechanical stresses and also possibly due to varying ambient air moisture. The strips were changed to more thick and elastic gaskets owning D profiles. This caused an unexpected other problem of noticeable force resisting closing the door, making it very hard to use the sliding-bolt latch improvised earlier. A third problem was also noticed: how to adjust the closing mechanism in the future once the structures of the door deform again and the new gaskets lose some of their elasticity.

Figure 7. The new closing mechanism which was promptly invented using the EIDeM. The embodiment was done immediately, as the door became unexpectedly difficult to close after the earlier gaskets were replaced to thicker ones in a freezing and dark evening. The threaded rod, which is greased to avoid jamming, works as a rotation axis for the handle, and is also used to adjust how far the door is pushed during the sealing

During the occurrence of the unexpected problem and poorly performing function of "seal the door", the author stood outside in dark evening and sub-zero-celsius temperature in mental hurry while keeping the door of the chicken coop closed by temporal means. Following the steps of the EIDeM protocol (figure 2), in mind the author listed the reproduction of the forces the different types of gaskets exerted against the closing door, and formulated a common problematic factor of "forces resisting the door". Then the author imagined the door levitating in an empty space, the sensation of, and different characteristics for pushing the door against soft elastic forces that sometimes turned into harder and springier. After visiting the cognitive isolation a couple of times, the author had multiple different characteristics in mind for bringing the door to its sealed state in practice. As an example, one approach utilized rails in the corners of the door for pushing the gaskets more evenly against the contact surfaces on the frames. Another option was to divide the door frame into spring-loaded sub-elements that will adapt with the gaskets circulating the back face of the door. The eventually implemented idea utilized a threaded rod on the outside face of the door, around which a relatively long handle can rotate enabling a force-increasing lever, flip latch, and depth adjustment by screwing the handle into different positions along the threaded rod (figure 7). Once the initial mental image about the potential solution was obtained and improved to its final state, the author embodied the idea from metal and installed it at the same evening when the unexpected problem occurred.

After a few days of testing, it was observed that the new closing mechanism (figure 7) fixed both the initial and unexpected problems, the jamming door due to the minor frost (with the aid of the new gaskets) and the difficulty to seal the door due to the thicker gaskets, respectively. In the chosen solution, the problematic factor of forces resisting the door is still clearly present and it is tolerated, while the performance of the function of interest was improved by finding new characteristics to manifest it. Simultaneously, the EIDeM exposed viable characteristics to manifest also the adjustment function of the closing mechanism. This was not the primary target of ideation, but was still essential for finding the proper depth of closing required to seal the door in the first place. It was also notable how the EIDeM-generated ideas were limited to include the door as the must-have characteristic, as the door was kept part of the pseudo-underlying function of interest and conflicting problematic factor. This was a practical approach considering the urgent need to utilize the available resources as quickly as possible. However, more essential formulations, such as an underlying function of "isolate space", could have enabled more divergent solutions to emerge.

4.4 Hypothetical mechanism for divergent navigation

Motivated by the repetitive positive experiences, it is attempted to better understand the underlying hypothetical mechanism utilized by the EIDeM for the divergent navigation, to complete the tentative inspirational picture (chapter 4.1). The more formal description is build upon premises for which simple clarifying examples are given. Other and more non-obvious cases on which the described logic can be applied are not excluded.

The first premise is that the problematic factors can be considered as gradient continuums or varying patterns in the parameter space (figure 2A). For example, if the manifestation of a problematic factor comprises a nut, screwing the nut (chancing a parameter or more) does not necessarily erase the problematic factor which is plastic, and the same applies also on the functions. The second premise is that the problematic factors occupy significant portions of the parameter space, emerging spontaneously (chapter 4.1) like natural phenomenon governed by the laws of probability (figure 1). The problematic space is so vast, possibly infinite, that it is very unlikely that designers can ever become aware of all the possible options, especially without proper means for the divergent navigation. The third premise is that if there is a problematic factor, then there can be characteristics manifesting complementary functions (figure 2A). For example, a supportive elongated metal object in a design could be a physical obstacle for a moving element manifesting a cutting function. Or the object could conduct damaging mechanical vibration or high voltages to a delicate circuit manifesting digital functions. In the plurality of these complementary functions, one of them could be the function of interest also owning many characteristics for manifestation and varying performances along the extensive problematic factor. One of these characteristics is likely dealt with when the problem was observed in the first place.

From the above premises the following is reasoned. The manifestations and performances of the functions of interest can vary along the extensive problematic factors (the bigger structures of opportunities, chapter 4.1), and it is possible that all the potential options from the infinitely large parameter space have not been exposed. Designers can also make false judgments about the true nature of the problematic factors why their mere presence is not a justified reason to abandon designs. Focusing on the underlying essence of the conflict enables unveiling new facets of the plastic problematic factors to which new complementary characteristics of the functions of interest can be assembled upon, utilizing spontaneous ideas based on the prior understanding about the elemental reality and other domains of knowledge. The performances of the functions can vary from practically inactive ones to the ways making the functions immune against the presence of the complementary problematic factors. Improving the function performance requires that the manifestation of the problematic factors, functions, or both are altered. As an example, the performance of the above-mentioned cutting function can be improved by using alternative geometries, placements, or motions of the cutting element or supportive elongated metal object, or by relying on other appropriate means of support, and so on.

4.5 Possible limitations

Despite the encouraging results, the potential of the EIDeM has been demonstrated only a few times (in a couple of real-life and in two artificial design scenarios) by a single person. Without further evidence, the wider reproducibility of the EIDeM's potential is speculative. And because the scope of this research is divergent thinking, the EIDeM-generated ideas have not yet been exposed to more critical convergent assessment or practical testing, excluding the closing mechanism for the door which performed well in practice (figure 7).

When the requirement-level scenario was primed, the different approaches were unbalanced as the author was much more familiar with the personal tactic than the chosen third-party software. The virtual designs also represented quite different categories of tools that can be used to aid the project management, such as a general-purpose voice assistant and more specific project-management software (supplementary notes). Thus, more weight was given for the priming of the design scenario, rather than trying to follow all the recommendations for using the Pugh matrix (Pugh 1981). However, no reasons are known why this arrangement would not be suitable for setting up the artificial design scenario for the planned demonstrative purposes.

The EIDeM has not yet been tested in group working. To avoid possible collaborative-fixation effect, one possibility to secure the breadth of ideas is to work as a group until the underlying forms of the function and problematic factor of interest are validated and agreed upon, after which the group members can withdraw to work alone (Kohn and Smith 2011). After the idea-generation phase, the group can come back together to aggregate and asses the ideas. To limit possible anxiety about too-wild or badly-performing ideas, the results could be gathered anonymously, yet some sort of a tracking and identification method should be arranged to enable acknowledgements for the contributors of eventually successful ideas. According to the aggregated results, the group can decide whether to continue the divergent thinking or move on to the convergent phase.

The performance parameters (figures 4 and 6) provide mostly demonstrative value. As such, they do not lay foundations for analyzing whether the EIDeM can produce more or less ideas than other divergent-thinking methods could generate outside the EIDeM framework in similar settings, and what are the exact qualitative differences between the ideas originating from different sources. More research is needed to draw such further conclusions, requiring repetitive controlled experiments done with different types divergent-thinking methods, and careful (multilevel) statistical analysis.

A few topics were purposely excluded from the current research to keep the project reasonable and limit conclusions on reliable foundations. The novelty of the EIDeM-generated ideas was assessed only superficially, as it does not have intrinsic value from the point of view of a designer whose primary goal is to try to establish a working design. For the same reason, the quality how the ideas effect on the problems was not assessed comprehensively, for instance, were the problematic factors excluded in conventional sense or not. Furthermore, it was left for the readers to judge the overall balance of the results, whether the EIDeM generated novel ideas or merely reminded to consider more usual approaches, for example missed during the priming phases. Finally, no hypothesis tests about the feasibility, compatibility, superiority, profitability, secondary-problem inducement, or similar features of the EIDeM-generated ideas alone or as part of any design were conducted. Examining embodiments of the designs was not feasible, and solely abstract assessment could cause misleading conclusions due to the complex nature of design processes in practice. The only exclusion to these is the new closing mechanism for the door (figure 7).

5 Conclusions

In this paper, a new general-purpose brainstorming method named EIDeM is presented. The method can be used for solving a variety of design conflicts between functions of interest and complementary problematic factors, using organized and probabilistically favorable problem-positive divergent thinking. The EIDeM concerns the observed problematic factors as partial glints of bigger structures of opportunities, a substantial phenomenon governed by the laws of probability (chapters 4.1 and 4.4), from which the frequency can be extracted and combined with the desired technical effect (figure 2A).

Using two artificial design scenarios, the EIDeM was demonstrated for generating a number (figures 4 and 6) of diverse ideas for starting materials ranging from concrete technical implementations to digital software (supplementary notes). The EIDeM helped to navigate the relevant parts of the infinitely large parameter space of designs, enabling reminders about more usual approaches and exposing surprising new opportunities. It was also shown how the mere observation of the repeating problematic factors can induce significant new insights on the designs when the systematic problem-positive EIDeM mindset was used. The EIDeM integrated well with design projects structured by morphological charts (Zwicky 1967; figure 3) and Pugh matrices (Pugh 1981; figure 5). Other schemes are also possible to use as starting points, such as unstructured design experience (figure 7). The EIDeM also provides an open framework for other divergent-thinking methods to approach the design problems in organized and probabilistically favorable manner, and to generate further ideas when the initial idea resources become depleted during the use of the EIDeM. In addition regarding the primary functions of interest, in some scenarios the designer's prior knowledge about the dealt concepts lead to spontaneous idea generation also for the other relevant yet incomplete areas of the designs. Real-life applications of the EIDeM are also reported, such as the prompt invention of a viable design that was immediately embodied to solve an unexpected urgent problem (figure 7).

The overall experience of using the EIDeM has been fascinating, and the benefits for the divergent thinking were strong and clear from many points of views. The sudden and fast emergence of relevant yet divergent ideas felt surprising, and this intriguing phenomenon was experienced repeatedly in different design scenarios. The EIDeM could also be beneficial outside the field of engineering design, such as adapting it to solve issues met in medicine, economy, society, and geopolitics. The EIDeM was primarily developed on tentative inspiration aroused from natural phenomena (chapter 4.1), and a further attempt to formalize the underlying hypothetical mechanism the EIDeM utilizes for the divergent navigation is also described (chapter 4.4). Afterwards, the thinking process reminds an agent exposing the patterns of opportunities within and outside the primary design focuses by following the underlying elemental mechanisms in probabilistically favorable manner. In addition of running this imaginary agent in the circuits of biological brains, the results could be unimaginable if the principles of the EIDeM could be harnessed by the powers of artificial intelligence.

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