



How the type of methodology used, when working in a natural environment, affects the designer's creativity

Vicente Chulvi¹ · Marta Royo¹ · María-Jesús Agost¹ · Francisco Felip² · Carlos García-García²

Received: 16 April 2021 / Revised: 8 March 2022 / Accepted: 25 March 2022
© The Author(s) 2022

Abstract

The study of the mechanisms linked to creativity has become a topic of great interest in various scientific fields in recent decades. One area in which a particularly large amount of research has been conducted is on the positive effect of natural environments on creativity. Yet, none of these studies have focused on the interaction that may arise with the design method used. That is, they consider the empowering effect of nature on creativity to be something general, without taking into account other factors that may influence it, such as the type of methodology used. This paper therefore aims to go a step further and investigate how the type of design methodology used—intuitive or logical—in a simulated natural environment affects the designer's creativity. The analysis of both the design process and its outcomes shows that the main differences in the way of working with design methodologies occur mainly in the case of intuitive methodologies, helping designers to improve the quality of their outcomes.

Keywords Design methodology · Conceptual design · Creativity and concept generation · Natural environments

1 Introduction

One of the characteristics that define human beings is their ability to solve problems by integrating different kinds of knowledge acquired through their experiences, which allows them to quickly come up with original and effective solutions. This creativity, which is innate in people (Amabile 1996) and driven by the flexibility of thinking, is nowadays fundamental to be able to undertake the everyday tasks in

any job, ensure they are resolved satisfactorily and improve competitiveness. Studying the mechanisms linked to creativity has thus become an activity of increasing relevance in recent decades, the aim of which is to find ways to direct and enhance it. As Gero (2011) pointed, creativity in design is still a relatively under-researched field, so there are numerous research questions that need to be asked and responded to develop an understanding of creativity in design.

There are several definitions of creativity in the literature, and most of them sharing common elements, like Sternberg and Lubart (1999), who point that creativity is the ability to produce work that is both novel and appropriate; Shah et al. (2003), who claim that creativity in engineering design is achieved by the intersection of novelty and utility; or Sarkar and Chakrabarti (2007), who claim that the main components of creativity are novelty and usefulness. One of the most generally accepted definitions maintains that: “Creativity happens through a process by which a subject uses his skills to generate ideas, solutions, and products that turn out to be novel and useful” (Chulvi and González-Cruz 2016). Therefore, the main components when assessing the creativity of a product are those related to the novelty and the usefulness of the product, but creativity is also closely related to the individual and to the design process (Gero 2011).

✉ Vicente Chulvi
chulvi@uji.es

Marta Royo
royo@uji.es

María-Jesús Agost
magost@uji.es

Francisco Felip
ffelip@uji.es

Carlos García-García
cgarciag@uji.es

¹ Department of Enginyeria Mecànica i Construcció,
Universitat Jaume I, Av. Vicent Sos Baynat, s/n,
12071 Castellón de la Plana, Spain

² Department of Enginyeria de Sistemes Automàtics i Disseny,
Universitat Jaume I, Castellón de la Plana, Spain

There is a need for continuous innovation and competitive advantage in product design. Designers are therefore asked to be creative, going beyond existing solutions to come up with original designs (Yilmaz et al, 2010). Thus, designers need to be able to maximize their creative potential to achieve this level of competitiveness in their designs. To improve the creative design process, many methodologies have been developed through the years (Csikszentmihalyi 1998). Several empirical and experimental studies have demonstrated the advantages of applying these design methods to foster creative thinking (Mulet and Vidal 2001; Bilda and Gero 2005). From the most open and intuitive ones, like brainstorming (Osborn 1963), to the more structured and logical ones, like the Forward Steps of Pahl and Beitz (2013). Despite the differences between them, there is not a typology of methodology that has been demonstrated as better to achieve creative products.

Lastly, the creativity related to the individual has been said previously to be innate on the human being. From the psychological point of view, there are several tests driven to rate the individual's creative potential (Guilford 1959; Torrance et al. 1977; Corbalán et al. 2006). Creativity, however, can be influenced by various factors related to the individual and to his or her environment that make its study a complex matter.

Some of this research has focused on analyzing certain variables related to people that can affect their creativity, so they can optimize their creative capacity. In this regard, García-García et al. (2019) showed that a person's psychological profile influences the way in which a stressful or relaxing work environment affects their creativity during the conceptual design phase. In this same line, Paige et al. (2021) relate the mood of the designers with creativity parameters of their design outcomes, and Ruiz-Pastor et al. (2021) relate them with the personal intrinsic factors. The influence that the presence of other people in the workplace can have on creativity has also been studied, either when interacting in a team (Alves et al. 2007), when there are other people present but we do not interact with them (Aiello et al. 1977; Alencar and Bruno-Faria 1997; Stokols et al. 2002) or when we are aware of the existence of competitors working on the same task (Shalley and Oldham 1997). Other research focuses on studying the influence of new technologies on people, by analyzing the impact of using computers on the creative process (Ceylan et al. 2008), when computers are used as a medium during collaborative work carried out at a distance (Chulvi et al. 2017) or even when the interaction is performed through virtual dynamic personas (Bonnardel and Pichot 2020).

Other research has analyzed the sensory variables of the environment and the physical or structural characteristics of the workspace that can affect people's creativity, and has quantified their impact. As regards sensory variables,

several studies show that sound in the workplace can be a factor that enhances creativity, depending on whether it is perceived positively or not (Kasof 1997; Alencar and Bruno-Faria 1997; Mehta et al. 2012). Other studies have focused on analyzing the influence of smells (Knasko 1992), temperature (Alencar and Bruno-Faria 1997) or colors (Stone and English 1998; McCoy and Evans 2002; Ceylan et al. 2008) on creativity. Furthermore, among the studies focused on analyzing the influence of the physical and structural characteristics of the workspace, we find the contributions of (McCoy and Evans 2002) on how the way furniture is arranged in a room can affect users' creativity. Other studies have analyzed the influence of the type, intensity, and temperature of the light that illuminates the workspace (Knez 1995; Ceylan et al. 2008), the presence or absence of windows that allow natural light to enter the room (Stone 1998; Ceylan et al. 2008) and the effect of ventilation, whether natural or artificial (Alencar and Bruno-Faria 1997).

These four aspects of creativity correspond to those already postulated by Rhodes (1961) in his 4Ps model: Product, Press, Process and Person. The works presented in this section have been organized under this structure. However, the study presented in this article aims to analyze the possible interaction between these factors. Specifically, to analyze the effect of the variation of the Process for a specific Press, previously studied, on the creativity of the results (Product) and, if it is the case, to study why. The aim would be to optimize the way of working in this type of environment to obtain more creative results.

2 Research background

Among the studies conducted on variables related to physical aspects of the workplace, we are especially interested in those related to the influence of nature. For "natural environment" we are referring to those that cause the perception of not created by the human being (Kaplan and Kaplan 1989). That is, vegetation and plants, sunlight, sound of birds, etc. Numerous studies have shown that nature has a positive impact on people's physical and psychological well-being, helping to alleviate stress levels and improving their effectiveness when performing a task (Kaplan et al. 1998; Herzog et al. 2002; Immordino-Yang et al. 2012; Tyrväinen et al. 2014; Korpela et al. 2017; Breda et al. 2018; Barakat et al. 2019). Direct contact with nature has also proved to have a positive influence on creativity, especially when carrying out physical activity (Ferraro 2015) or dispensing with technological devices (e.g., avoiding the use of smartphones) (Atchley et al. 2012), through more flexible thinking (Plambech and Konijnendijk van den Bosch 2015) and improved association of ideas (Williams et al. 2018). Creativity is also enhanced by the presence of these natural elements in closed

spaces, as evidenced in different works (Shibata and Suzuki 2004; Ceylan et al. 2008; Studente et al. 2016; Van Rompay and Jol 2016).

Other studies have shown that these positive effects that nature has on people can also be achieved through simulated natural environments. Thus, de Kort et al. (2006) showed that significant levels of stress reduction could be achieved when people were subjected to immersive simulated natural environments and, similarly, (Kjellgren and Buhrkall 2010) showed that the same effect could be achieved with both natural environments and other settings in which the natural elements were simulated. Fewer works have studied the effect that real or simulated natural environments can have on designers' creativity, specifically during the process of designing new products, although some very recent studies offer clues that also point in a similar direction to the works mentioned above (Chulvi et al. 2020; Batey et al. 2021).

However, none of these studies have taken into account the interaction that may arise with the design method that is used. The above experiments were conducted without following any prescribed methodology. Therefore, it would be of interest to know whether this enhancement of creativity is affected by the type of method used. This can be of interest when planning creative activities in design studios, optimizing results by selecting the right working method, and making the best use of creative workspaces, either individual, used for co-working or even at the educational level. Thus, the hypothesis considered here is that the type of methodology used for the conceptual design phase will manifest some type of interaction with the effect on creativity caused by the natural environment.

The present study is built mainly, but not exclusively, upon the results of three previous research experiments:

- A. Both natural and artificial environments enhance creativity during the design phase, compared with a neutral environment, but it has not been tested with a specific design method (Chulvi et al. 2020).
- B. Both intuitive and logical methods boost the creativity of the results, but in a different way, since intuitive methods improve the novelty and logical methods the utility (Chulvi et al. 2012a).
- C. Intuitive and logical methods present differences between times devoted to each phase of the design process, and this distribution seems to be related with the creativity parameters of the results: more percentage of time devoted to PS drives to better novelty but worse utility results (Chulvi et al. 2012b).

Chulvi et al. (2020) showed that environments that include natural elements, whether real or simulated, encourage creativity in conceptual proposals for new products to a greater extent than environments that contain no natural

elements. In this work, an experience was performed in which the participants must solve different conceptual design problems in three different environments: real nature, simulated nature and neutral environment. Creativity of the results was rated using the metric proposed by Shah et al. (2003), considering the parameters of quantity, variety, novelty, and quality. The results show that the participants achieve better results in all the creativity parameters in both real and simulated nature, compared with the neutral environment, but there were no significant differences between the real and the simulated nature.

Chulvi et al. (2012a) showed differences between the two types of methodology, intuitive and logical, in terms of both their application and the results. They used several metrics that combine the parameters novelty and usefulness for evaluating the creativity. The main results point that the solutions obtained using intuitive methods present higher values for novelty, while those obtained with logical methods score higher on usefulness. Nonetheless, when the two parameters were combined to obtain a creativity value, this differences compensated, so the results in terms of creativity were on the same level regardless of the type of methodology used. These results are also in line with the findings of Shealy et al (2020), who used neurosensors to analyze the level of brain activity when design activities were performed using different methods. Their results pointed to significantly different patterns of cognitive activation depending on the structuredness of each method.

In this same line of work, Chulvi et al. (2012b) also identified differences in the distribution of the time spent on each conceptual design phase according to the type of method used, according to Chakrabarti (2003) definition of design phases. This definition was established after a review of the major theories and models of design problem-solving (Gero and Mc Neill 1998). They establish two main phases in the conceptual design process, Problem Understanding (PU) and Problem Solving (PS). Problem Understanding comprises the early stages of the design process and involves comprehension of the design requirements, as well as acquisition of the necessary knowledge to address the problem and the decision making on how to deal with it. It has been divided in three sub-phases, which are Problem Interpretation (PI), which involves the interpretation of the problem and identification of the main requirements, Problem Analysis (PA), where there is an inner seek of knowledge to improve the comprehension of the problem identified, and Problem Choice (PC), where the designer takes the decision of how to address the problem. Problem Solving (PS) is usually carried out in the last part of the design process, and is characterized by the generation of solutions that will be seriously considered for further development. The sub-phases that comprise it are Solution Generation (SG), that is the stage where the designer produces the solution alternatives based

on their previous interpretation of the problem, Solution Evaluation (SE), where the previous proposals are analyzed to see how they fit with the requirements identified, and the Solution Selection (SS), that ends the conceptual phase with the decision of choosing the concept that better solves the interpreted problem.

In their work, Chulvi et al. (2012b) analyzed the distribution of time devoted to each of the design phases when using logical and intuitive design methods. In addition, they analyzed the creativity of the results as the combination of novelty and utility, using the CPSS (O'Quin and Besemer 1989). As a result of this research, they demonstrated that when logical methodologies were used, the time was distributed equally between the Problem Understanding (50.3%) and the Problem Solving (49.7%) phases, but while using intuitive methodologies considerably less time was spent on Problem Understanding (9.3%) than on Problem Solving (90.7%). In addition, this research point that the most time devoted to problem analysis drives to more useful solutions, while the most time devoted to problem-solving provides with solutions that are more novel.

It remains to be verified, therefore, whether the type of methodology used when working in a natural environment affects the designer's creativity, and in what sense. First, it would be necessary to find out whether it affects the enhancement of creativity differently between methods, assuming that it is already known that it is effective when working with a non-prescribed method (Chulvi et al. 2020). It would also be necessary to study whether the time distributions devoted to each design phase vary according to the type of methodology (Chulvi et al. 2012b). And, if it does vary, whether it affects the creative parameters as expected for previous research (Chulvi et al. 2012a).

For this purpose, an experiment was carried out in which the participants were asked to solve a design problem in a space with simulated natural elements, using two different design methodologies: one intuitive (SCAMPER) and the other logical (TRIZ), according to the definition by Shah et al. (2003). In their work, Shah and colleagues classify the formal idea generation methods into two major blocks: intuitive, which use mechanisms to overcome mental blocks, and logical, which involve a systematic analysis of the problem, relying on technical and scientific data to find solutions to it. Intuitive methods are focused to generate many solutions from self-knowledge, like brainstorming (Osborn 1963), where logical methods force to previous analysis or knowledge search before starting with the idea generation, like the functional analysis (Jones 1970). Intuitive methods are in turn classified as germinal, transformational, progressive, organizational and hybrid, SCAMPER being considered transformational, while logical methods are divided into history based and analytical, TRIZ being considered history based.

3 Research question

Thus, the main research question this article aims to answer is, based on the assumption that an artificial nature environment enhances creativity compared to a neutral environment, as has already been demonstrated in previous work (Chulvi et al. 2020), whether this enhancement presents differences when using a logical or intuitive type of methodology. The differences between these two types of methodology have also been analyzed in previous studies (Chulvi et al. 2012b), but in a neutral environment. In the same way, it has been previously proven that both are capable of enhancing the achievement of creative design results, compared to when no design method is used (Chulvi et al. 2012a).

Therefore, the present work is limited to the comparison of two design methods of different typologies in the same artificial nature environment. Since the creativity-enhancing effect of both nature and the use of design methodologies have been previously demonstrated, it was not considered necessary to demonstrate it again in the present work, and therefore both a neutral environment and the resolution of the problems without the use of design methodologies were omitted in the preparation of the experiment.

4 Materials and methods

As previously indicated, the present work is built upon previous research. Therefore, the research methodology is strongly linked to that previous work. Following the principle of reflexive practice (PRP) of Reich (2017), it could be interpreted that we are assuming a type III role, since we are designing a method which we are the users of. However, from another perspective, we are moving in a type I role, since both the experimentation and the methods used in them have already been elaborated and tested previously. In this case, it would coincide with the definition of "knowledge developer". On the other hand, within the concepts of PRP it can also be seen that it represents the two forms "strong" and "weak". It is "weak" from the point of view of using design knowledge and methods to design the research. And at the same time it is "strong" because having been used previously, early feedback has been obtained that leads to improving the research.

4.1 Design of the experience

A total of 16 volunteers, 6 females and 10 males, took part in the experiment. The profile of all the participants was that of junior designer. The sample consisted of undergraduates in the final year of their Engineering Design studies or

recent graduates who were studying for the Master's Degree in Design and Manufacturing in the same university. Consequently, all of them have received the same formation in creativity regarding Design Engineering, including definition and parameters used to evaluate it. Ages ranged between 20 and 24 years.

Each participant would later be asked to solve two different design problems, each with a different methodology, in a room endowed with a natural environment (Fig. 1), using the same setting used in Chulvi et al. (2020). The room measured 3 × 3 m and the entire floor surface was covered with artificial lawn. One of the walls was taken up almost entirely by a large window facing out and southwards to allow sufficient natural light to enter the room. On another wall, there was a floor-to-ceiling mural with a full-scale image of an outdoor garden area. Participants could sit on the lawn, on a chair or on a bean bag chair. They were also provided with an A2-sized wooden board on which to rest the sheets



Fig. 1 Room with simulated nature where the experiment took place

of paper and the drawing material needed to carry out the experiment, together with several bulldog clips to keep the paper still.

The experiment was conducted in the following way:

On the first day, all the participants met for a 1-hour training session on the methodologies to be used in the experiment. They were already familiar with the two methodologies, since they are included in the syllabus of the bachelor's degree in Engineering Design that all of them had studied. The purpose of the training session is mainly to ensure that all participants remember the methodologies well and will be able to use them without difficulties during the experiment.

Appointments were made to carry out the next phase of the experience, the experimental session, with each of the participants over the days following the training session. In this experimental session, each participant was asked to solve a conceptual design problem with each of the previously explained methodologies. For each participant, both the combination of problem and methodology and the order in which they solved each problem or used each methodology were alternated, so that neither the problem itself nor the order of resolution affected the overall results of the study. To ensure this combination was respected, the participants were distributed in the four settings defined as shown in Table 1.

The practical experiment was divided into different steps to facilitate the measurement of the time devoted to each of the design phases. These steps are also intended to standardize the design process followed by the participants, and to ensure that none of the steps outlined in the prescribed methodologies are overlooked. The experience was performed as follows:

- Step 1. Place the participant in the room, provide them with the necessary drawing material, along with the board and clips. Tell them they have 45 min to do the entire experiment, including understanding the problem, applying the methodology, coming up with ideas and setting the most creative one down on paper.
- Step 2. Give the problem statements to the participant for them to read and comprehend. In this step, they were allowed to ask questions to the facilitators to clarify doubts regarding design requirements.

Table 1 Organization of groups according to the combination of methodology and problem

Participants	Session 1		Session 2	
	Problem	Methodology	Problem	Methodology
1, 5, 9, 13	P1	TRIZ (evolutionary potential)	P2	SCAMPER
2, 6, 10, 14	P1	SCAMPER	P2	TRIZ (evolutionary potential)
3, 7, 11, 15	P2	TRIZ (evolutionary potential)	P1	SCAMPER
4, 8, 12, 16	P2	SCAMPER	P1	TRIZ (evolutionary potential)

- Step 3. When the participant indicates that the problem has been understood, give them the method application template (see Figs. 2 and 3).
- Step 4. When they signal that they have finished applying the methodology, give them the sheets on which to produce their solutions. They must sketch each proposal in a different sheet. Tell them how long they have left, so that they can organize their time, and remind them that they must put their final sketch on a template. They should also be told when they have only 10 min left before the experiment ends.
- Step 5. When they indicate that they have developed enough ideas, give them the template on which to develop their final idea.

At the beginning of each of steps 2–5, and at the end of step 5, the time is recorded by the researchers. These recordings will be used later for analyzing the time devoted to each design phase.

After a 15-min break, the same process is repeated with the other problem and the other methodology.

The problem statements were set at the same level of detail and extent as the previous studies on which this paper is built. The statements are deliberately open-ended to avoid causing fixation in the participants, since the loss of

creativity in the conceptual design phase is usually caused by fixation (Helms et al. 2009). Specifically, they have not been provided with an initial or example concept to use in the methods because this has a strong influence on the design fixation (Vasconcelos et al. 2017). Each participant will work from his or her own initial mental concept to apply the prescribed methodologies. So, fixation is not a factor to be taken into account in the creative results. In any case, this will not be considered a disadvantage for the participants, as they have been trained in the use of the methods in this way during their degree studies. The statements were presented as follows:

Problem 1:

Applying the corresponding methodology, develop as many ideas as possible regarding novel creative concepts for a SMALL RECYCLING STATION.

Use a separate sheet of paper to express each of the different ideas. You can use sketches or words to explain the idea.

When you have finished, choose the one you feel is the most creative and develop it on the final template.

Problem 2:

Applying the corresponding methodology, develop as many ideas as possible regarding novel creative concepts for URBAN TRANSPORTATION FOR 2 PEOPLE.

Use a separate sheet of paper to express each of the different ideas. You can use sketches or words to explain the idea.

When you have finished, choose the one you feel is the most creative and develop it on the final template.

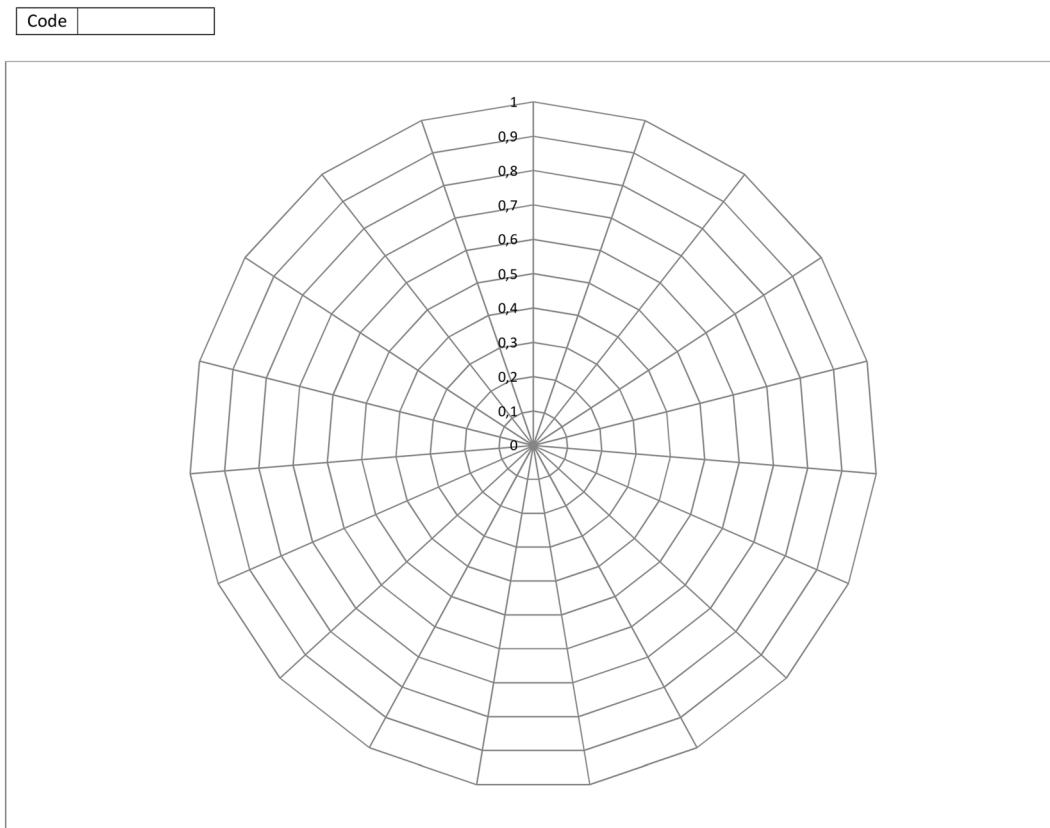
4.2 SCAMPER

The SCAMPER method (Eberle 1971) is an intuitive method of external stimulation that has its origin in the rearrangement of Osborn's "73 idea-spurring questions" (Osborn 1963). SCAMPER allows the problem to be reframed and increases creativity through the use of analogies and metaphors that expand the design space. This method aids the designer in generating ideas using questions that help solve a problem. SCAMPER is an acronym for seven categories and actions, namely (S) Substitute, (C) Combine, (A) Adapt, (M) Modify/Magnify/Minimize, (P) Put to other uses, (E) Eliminate, and (R) Reverse/Rearrange.

Thus, for example, the category (S) Substitute could include questions, such as: Which elements can be substituted? Is it possible to change one material for another with better properties? What function could be substituted? This would lead to new concepts that would help generate a different design solution.

Code	
S Substitute	
C Combine	
A Adapt	
M Modify	
P Put to another use	
E Eliminate	
R Reverse	

Fig. 2 Template for applying the SCAMPER methodology



	Line of evolution	A	Value
1	Smart materials		
2	Space Segmentation		
3	Surface Segmentation		
4	Object Segmentation		
5	Macro-to nano scale		
6	Webs and fibres		
7	Density decrease		
8	Increasing asymmetry		
9	Boundary Breakdown		
10	Geometric linear evolution		
11	Geometric volumetric evolution		
12	Dynamization		
13	Action Coordination		
14	Rhythm coordination		

	Line of evolution	A	Value
15	Non-linearity		
16	Mono-bi-poly similar objects		
17	Mono-bi-poly various objects		
18	Mono-bi-poly increase of differences		
19	Damping		
20	Increasing use of the senses		
21	Increasing use of colours		
22	Increasing transparency		
23	Customer Purchase Focus		
24	Market evolution		
26	Degrees of freedom		
27	Reduce system complexity		
28	Controllability		
29	Reduction of human Involvement		

Steps:

- 1) For each line of evolution:
 - a. See if the line can be applied to the product studied (mark it in column A)
 - b. See where the standard product is in the evolutionary line
 - c. Put this value with respect to its maximum on this line on a scale of 0 to 1, so that it can be compared
- 2) Draw the graph with the values obtained in 1c

Fig. 3 Template for applying the evolutionary potential analysis tool

For the experiment, participants were given a template like the one in Fig. 2, showing the seven categories marked with their corresponding initials and a space for writing the questions related to the design problem arising from each of them.

4.3 TRIZ (evolutionary potential)

The analysis of evolutionary potential is one of the tools from the Theory of Inventive Problem Solving (TRIZ), originally developed by Altshuller (1984). This tool identifies

the level of evolution of a particular product with respect to a given trend line, and positions it as a value on a radar plot. By analyzing the product with respect to each of the 35 trends of evolution proposed by Mann and Dewulf (2002), a graphic representation of the level of technological evolution of a given product is obtained, and possible improvement alternatives can be seen in each of the less evolved lines. Within Shah et al. (2003) classification, this structured tool fits perfectly with the definition of a "story-based method". In this case, it is based on the analysis of patents to define 35 lines of evolution, on which the designer must carry out the analysis. An example of a line of evolution would be:

Geometric evolution of volumetric constructions:

Plane → 2D - curve → Axi - symmetric → 3D - curve
→ Axi - symmetric → 3D - curve → Fully 3D

For the experiment they were provided with a template like the one shown in Fig. 3, together with the lines of evolution according to Mann and Dewulf (2002). The template has a radar plot, and the list of lines of evolution with space to write down their values. To speed up the process, six of the lines on the original list were removed as they were deemed not applicable to the two problems being proposed.

4.4 Design process phases

For the present research, the definition of design phases of Chakrabarti (2003) has been used for analyzing the design process used by the participants:

- Problem Understanding (PU), which comprises Problem Interpretation (PI), Problem Analysis (PA) and Problem Choice (PC)
- Problem Solving (PS), which comprises Solution Generation (SG), Solution Evaluation (SE) and Solution Selection (SS).

4.5 Evaluation of the solutions

The activities performed for the evaluation are as follows:

Formation of the team of experts. The experts selected were two of the researchers, one man and one woman, both with more than 15 years of experience combining researching and product design working. Experts are very familiar with the evaluation method, and with product design.

Determination of functional criteria to evaluate the creativity parameters. The two experts together decided the functions that will be used for concept evaluation by means of the decomposition of the main objective in sub-criteria, based on hierarchical models.

Determination of the weights for each criterion defined. AHP multi-criteria analysis technique (Saaty 1980) was

used for this proposal. This involves a pairwise comparison against the relative importance of the criteria. The functions selected and the weights assigned can be seen on Fig. 4.

Evaluation of creativity parameters. To compare the performance of the design methods during the design process phases, not only the final solution is going to be evaluated in terms of creativity, but also the design process, in terms of capacity to provide with good and varied ideas. The method used to evaluate the effectiveness of the design process is Shah et al. (2003) metric, which takes four parameters into account: quantity, variety, novelty, and quality. These metrics have been extensively applied to assess the effectiveness of the ideation process since they were first published (Oman et al. 2013; Jagtap et al. 2015). Their different parameters are defined as follows:

Quantity is the total number of ideas generated.

Figure 5 shows the proposed concepts of the participant 1 to solve the problem 2. As it is a direct count, the value of quantity is 4.

Variety measures how different concepts are from each other. It is measured based on a genealogy similar to that of the tree structure which has branches at various levels of physical abstraction: Physical Principle (PP), Working Principle (WP), Embodiment (E) and Detail (D). The value of variety is established as the total sum of the products of the number of different ideas at each level of abstraction multiplied by a coefficient according to that level. This parameter was calculated using the refinement of Nelson et al. (2009), that points that the number of different ideas at each level of abstraction will be determined as the number of branches at this level minus one, and the coefficients are $PP=10$, $WP=5$, $E=2$, $D=1$. Following the example of Fig. 5, the variety of the solutions elaborated has been calculated according to the level of abstraction in which they solve the main functions expected for the product. If we observe the tree related to the function "mode of travel", at PP level proposal A goes floating, B and D pending from a railway, and proposal C by wheels, so the tree divides in 3 branches. The next division remaining is only between B and D, and it produces at detail level, since one consists in a cabin pending from two cables, and the other one is a pole pending from one cable. So, according to Nelson et al. (2009), its value for F1 is calculated as $(N_{pp} - 1) \times 10 + (N_{wp} - 1) \times 5 + (N_E - 1) \times 2 + (N_D - 1) \times 1 = (3-1) \times 10 + (1-1) \times 5 + (1-1) \times 2 + (2-1) \times 1 = 21$. For the function "way of two persons use it", the first division is at PP level, where proposals A and D are on feet, and proposals B and C are seated. B and C achieve their next difference at embodiment level, since B is a consists of one semi-seat, which allows support but keeps the legs straight, while C is a full seat, with the legs bent. The difference between solutions A and D are at detail level, since the difference is in that D has a handle, and proposal A does not. So, the value for F2 is

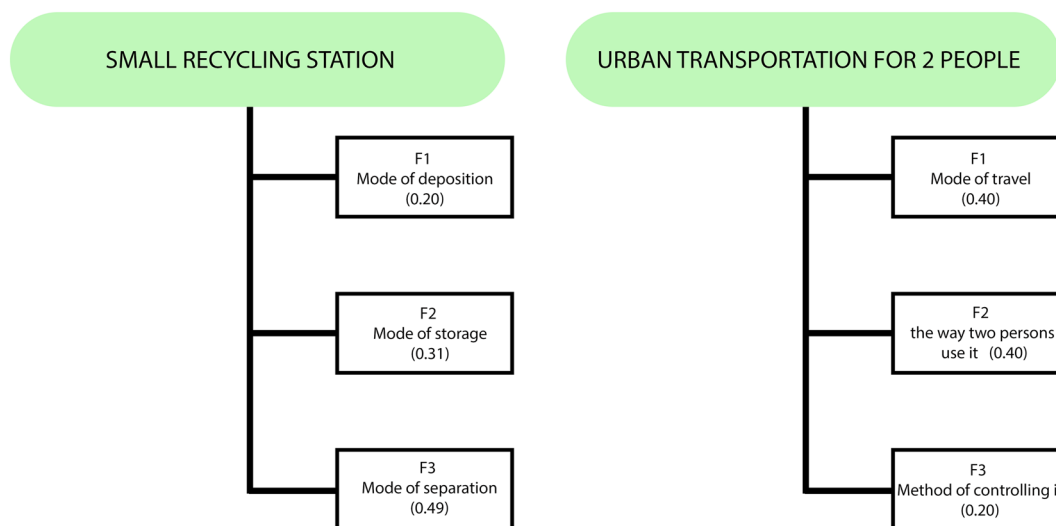


Fig. 4 Hierarchical diagram with the weights obtained for the evaluation of creativity

calculated as $(2-1) \times 10 + (2-1) \times 5 + (3-1) \times 2 + (2-1) \times 1 = 20$. Lastly, regarding the function “method of controlling it”, the difference at PP level is that A and C are directly human-controlled, but B and D are guided by railways, so no control by the user is allowed. A and C present differences at embodiment level, since C is controlled by one of the two original users, while A is controlled by a third user on a bicycle. So, the value for F3 is calculated as $(2-1) \times 10 + (2 \times 1) \times 5 + (3-1) \times 2 = 19$. The resultant value after the weighing is $0.4 \times 21 + 0.4 \times 20 + 0.2 \times 19 = 20.2$ (weights can be seen in Table 2). Finally, to homogenize results, Nelson et al. (2009) indicate that results of the evaluations must be divided by $(n - 1)$, where n is the maximum number of concepts achieved. As in this case $n = 10$, the final value for variety is $20.2 / (10 - 1) = 2.24$.

Quality measures the feasibility of ideas and the extent to which they comply with the design specifications. Each of them is analyzed and assigned a value on a scale from 0 to 10, where 0 indicates that the solution is incapable of performing the desired function, 5 indicates that it performs the function in a basic but satisfactory way, and 10 indicates that the function is performed in the best possible way. The final result for quality will be the weighted sum of the ratings of each of the functions associated with the design specifications considered, weighting them according to the importance of that function in the product. Table 2 shows the functions and weightings taken into account to evaluate the proposed alternatives.

Following the example in Fig. 5, the concept selected by the participant as the final solution was the B. In this case, and continuing with the evaluation considerations of Table 2, the “mode of travel” function performs in a better way than the considered minimum efficient level (on

wheels), although being guided by rails is not considered the best possible solution. Therefore, it is given a rating of 7 for the performance of this function. For the function “the way two persons use it”, the seat shown in the concept is considered to be very basic, just enough to be considered “not uncomfortable”, but no further. Therefore, it is the exact definition of the score 5. Finally, for the function “Method of controlling it”, in the concept it is written that the users mark on a map the destination and the driving is automatic. It is thus the definition of the value 10 for this function. Therefore, the final value for the quality of the proposal would be $0.4 \times 7 + 0.4 \times 5 + 0.2 \times 10 = 6.8$.

Novelty is the measure of how unusual or unexpected the idea is compared to other ideas that solve the same problem. To measure novelty, the problem is divided into its main functions or characteristics and they are weighted according to their importance. Each idea obtained is classified on a scale from 1 to 10 depending on how unexpected or rare the solution obtained is for each of the main functions. Table 3 shows the functions and weights, together with the level of novelty considered according to the way the solution is solved. A value of 0 is taken into account if the function is not fulfilled.

Continuing with the concept B in Fig. 5 as an example, and with the evaluation considerations in Table 3, the first function “mode of travel” is not performed in a land mode, with or without wheels, as it moves by hanging from rails. Therefore, its novelty rating is 10 for this function. On the other hand, the function “the way two persons use it” is solved with a basic seat, which has been defined as not very novel, and it corresponds to a value of 3. Finally, for the function “Method of controlling it”, it is not only independent, but it also automatically takes the users to the

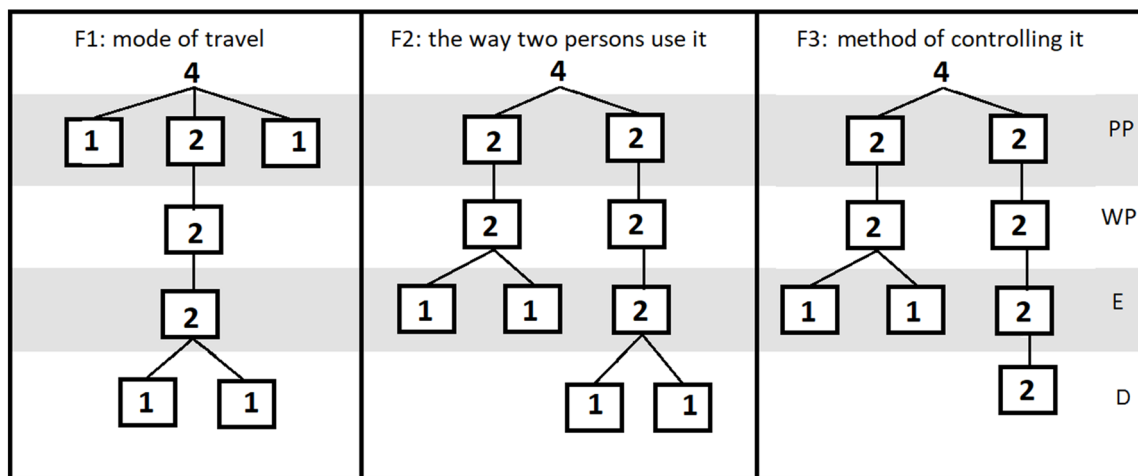
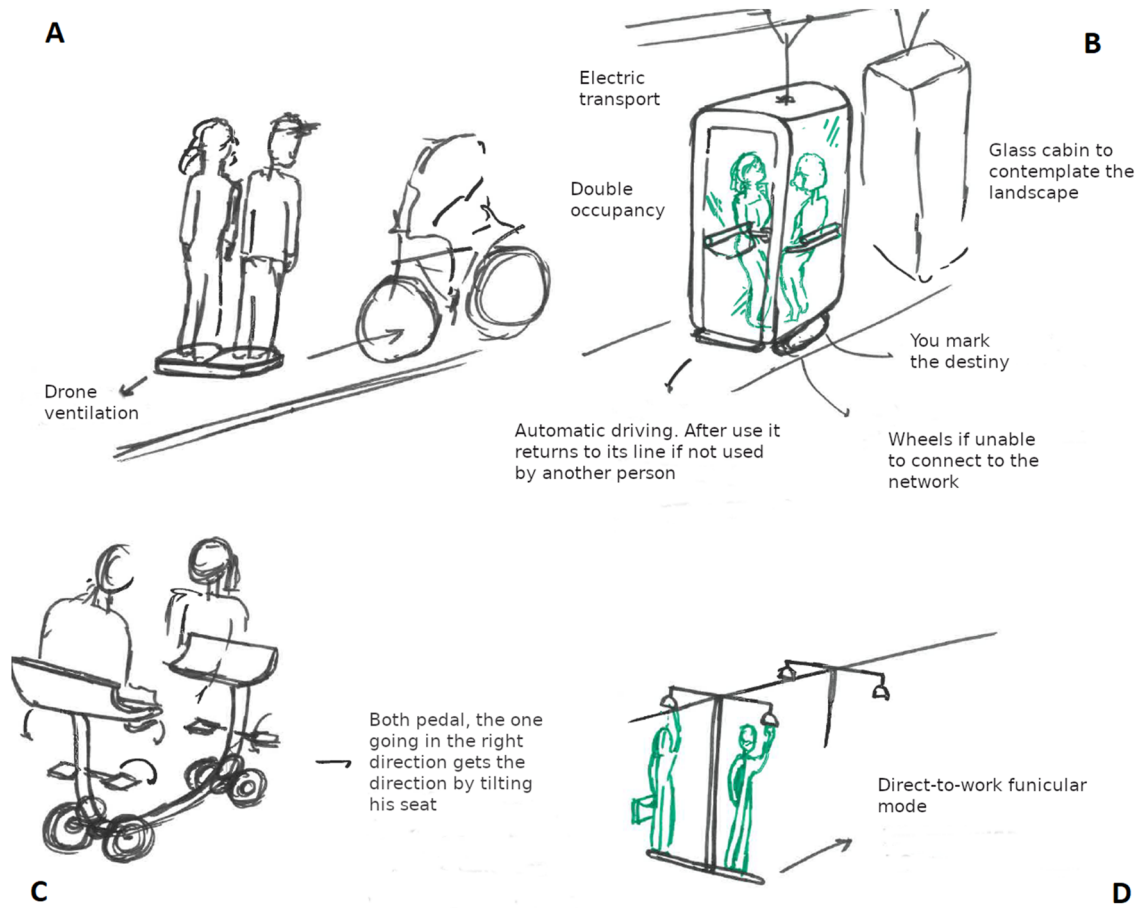


Fig. 5 Concepts developed by participant 1 to solve problem 2, and the analysis of variety of these proposals

destination they have marked on the map. Therefore, its rating would be 10 for this function. Hence, the final value of the novelty of the proposal is $0.4 \times 10 + 0.4 \times 3 + 0.2 \times 10 = 7.2$.

All the evaluations were carried out by two different raters, both experts in the field, as defined previously. The

reliability of the agreement was calculated with a Fleiss Kappa assessment, with a value of 0.951. The data for this assessment can be consulted in the appendix. The use of validated creativity metrics, as Shah et al. (2003), helps to reduce the subjectivity of the evaluations, so the high level

Table 2 Functions and scores for quality assessment with Shah et al. (2003) metric

Product	Functional requirement	Weight	Quality scores													
			0	1	2	3	4	5	6	7	8	9	10			
Small recycling station	Mode of deposition	0.2	Does not allow it						Deposited with ease							Assisted
	Mode of storage	0.3	Does not allow it						Sufficient and adequate containment							Holds a lot, saves space
Urban transportation for two	Mode of separation	0.5	Does not separate						Possible to see where each type of waste goes							Assisted
	Mode of travel	0.4	Not very effective						Effective (wheels, etc.)							Optimised
	The way two persons use it	0.4	Tiring or not very comfortable (standing)						Seated (not uncomfortable)							Comfortable seats or similar
	Method of controlling it	0.2	Difficult to handle						Easy control (steering wheel, handlebars)							Semi-autonomous

of agreement is not unexpected. On the other hand, the two evaluators have many years of joint experience in the use of creativity assessment metrics, and this may also have led to a more unified criterion, resulting in a better agreement.

4.6 Statistical analyses

The statistical analyses were performed with IBM SPSS Statistics, Version 23 (IBM Corporation). Variables were defined to analyse the parameters quantity, variety, novelty and quality, based on the rater's appraisals of the solutions chosen by the participants. The total creativity of a concept is considered to be the average of its novelty and quality. The maximum novelty, quality, and creativity scores for the proposals provided by each participant were also considered variables, regardless of whether or not it was the chosen proposal.

Bivariate correlation analysis was applied between the variables, Pearson coefficient in general, except for the variable quantity, for which the Spearman Rho coefficient was applied, since its distribution cannot be considered normal, according to the Kolmogorov–Smirnov test.

Repeated measures analyses of variance (RM ANOVAs) were conducted to compare the effect of the methodology used on the variables of creativity, and also on the variables representing the time devoted to each phase.

RM ANOVAs were also applied to check that no effect is detected on results (times invested in each phase and ratings of creativity factors), due to neither the order of the sessions nor the problem solved.

5 Results

The Kolmogorov–Smirnov test indicated that the distributions of the variables of the parameters on creativity and the times employed, for each of the methodologies used, could be considered normal. If no distinction is made between methodologies, again all variables show a normal distribution, except for the variable quantity. The summary of results for all participants can be consulted in Online Appendix 1. Figure 6 shows the box and whiskers diagram of each of the variables that define creativity according to Shah et al. (2003), according to the method employed, and the creativity of the selected solutions. In the diagrams of novelty, quality and creativity, it also appears the box and whiskers plot of the maximum values of the novelty, quality, and creativity variables from among the proposals generated by each individual (including those discarded as the selected one). Table 4 shows the percentage of time dedicated to each of the design phases and sub-phases described by Chakrabarti (2003), with PI corresponding to stage 2, PA_PC to stage 3, SG to stage 4 and SE_SS to

Table 3 Functions and scores for novelty assessment with Shah et al. (2003) metric

Functions			Weight	Novelty grades for each function		
				3	7	10
Small recycling station	F1	Mode of deposition	0.2	Thrown (e.g. through a hole)	Assisted	Others
	F2	Mode of storage	0.3	Differentiated containers	Segmentation	Others
	F3	Mode of separation	0.5	Visually (the users themselves)	Assisted	Others
Urban transportation for two	F1	Mode of travel	0.4	Wheels	On the ground (no wheels)	Others
	F2	The way two persons use it	0.4	Standing, sitting or with a standard seat	Lying down, non-standard seats	Others
	F3	Method of controlling it	0.2	Direct (steering wheel, handlebars)	Independent (rails, track, etc.)	Others

stage 5. PU corresponds to the sum of PI and PA_PC, and PS to the sum of SG and SE_SS.

Figure 7 shows how, in the logical methodology TRIZ, a greater percentage of the time available is invested in the PU phase and also in its sub-phases PI (to a lesser extent) and PA_PC. The statistical study detects significant effect of the methodology applied on the time used in each phase of the process. For the PU phase, Wilks' Lambda = 0.584, $F(1, 15) = 10.703$, $p = 0.005$. For the PA_PC phase, Wilks' Lambda = 0.598, $F(1, 15) = 10.093$, $p = 0.006$. In contrast, in the PS phase (and its sub-phases SG and SE_SS), the percentage of time spent is higher when using the intuitive SCAMPER methodology. In this case, significant effect of the methodology on the time was found in phases PS, Wilks' Lambda = 0.584, $F(1, 15) = 10.703$, $p = 0.005$, and SE_SS, Wilks' Lambda = 0.706, $F(1, 15) = 6.256$, $p = 0.0024$.

Among the creativity parameters, Fig. 8 shows how using SCAMPER has yielded higher values in terms of quantity and variety of ideas. The final solution selected by the participants presented slightly higher values for novelty in the case of SCAMPER, although as regards quality, the results achieved using TRIZ were rated slightly better. A significant effect of the methodology used was only detected on the variable variety, Wilks' Lambda = 0.625, $F(1, 15) = 8.987$, $p = 0.009$.

In addition, a significant negative correlation was detected between the variable variety and the percentages of time (Pearson's coefficient), PU, $r(30) = -0.462$, $p < 0.01$, and PA_PC, $r(30) = -0.449$, $p = 0.01$, and a significant positive correlation between this variable and the percentages of time, PS, $r(30) = 0.462$, $p < 0.01$, and SE_SS, $r(30) = 0.567$, $p < 0.01$. Similar relations were detected for the variable quantity (Spearman Rho coefficient), with PU, $r(30) = -0.387$, $p < 0.05$, and PA_PC, $r(30) = -0.365$, $p = 0.05$, and with PS $r(30) = 0.387$, $p < 0.05$, and SE_SS, $r(30) = 0.408$, $p < 0.05$.

The appropriateness in the choice of the final solution among the proposals generated is used to assess the design

sub-phases SE and SS. The better the designers made their selection of the most creative concept will indicate that they have performed these sub-phases more correctly. In this case, no significant difference is detected in the quality, novelty, and creativity of the selected solution, with respect to the rest, in relation to the methodology applied. A summary of this selection of proposed solutions is shown in Table 5. In this table, "wise choice" means that the designers selected the best-rated choice among the solutions they proposed, while "wrong choice" means that they selected an alternative that is not the best-rated by the evaluators. Of the total $N = 32$, in 3 cases the value of Quantity = 1, so no final solution is selected.

A significant positive correlation was detected between the percentage of time spent on the phase SE_SS and the variable representing the appropriateness in the choice of the final solution, in terms of quality (calculated as the difference between the quality score obtained by the chosen solution, and that of the next best-rated solution generated by the same participant) $r(29) = 0.488$, $p < 0.01$. Besides, a significant positive correlation was also detected between this percentage of time spent in the SE_SS phase and the appropriateness in the choice of the final solution, regarding creativity (calculated as the difference between the creativity score for the chosen solution and that of the next best-rated solution generated by the same participant. The score in creativity is calculated from novelty and quality), $r(29) = 0.402$, $p < 0.05$.

6 Discussion

This research was based on the hypothesis defended by Chulvi et al. (2020), who showed that environments that include natural elements, whether real or artificial, favor the designer's creativity during the conceptual phase. In the present study, this work has been extended by analyzing whether the type of methodology used for the conceptual

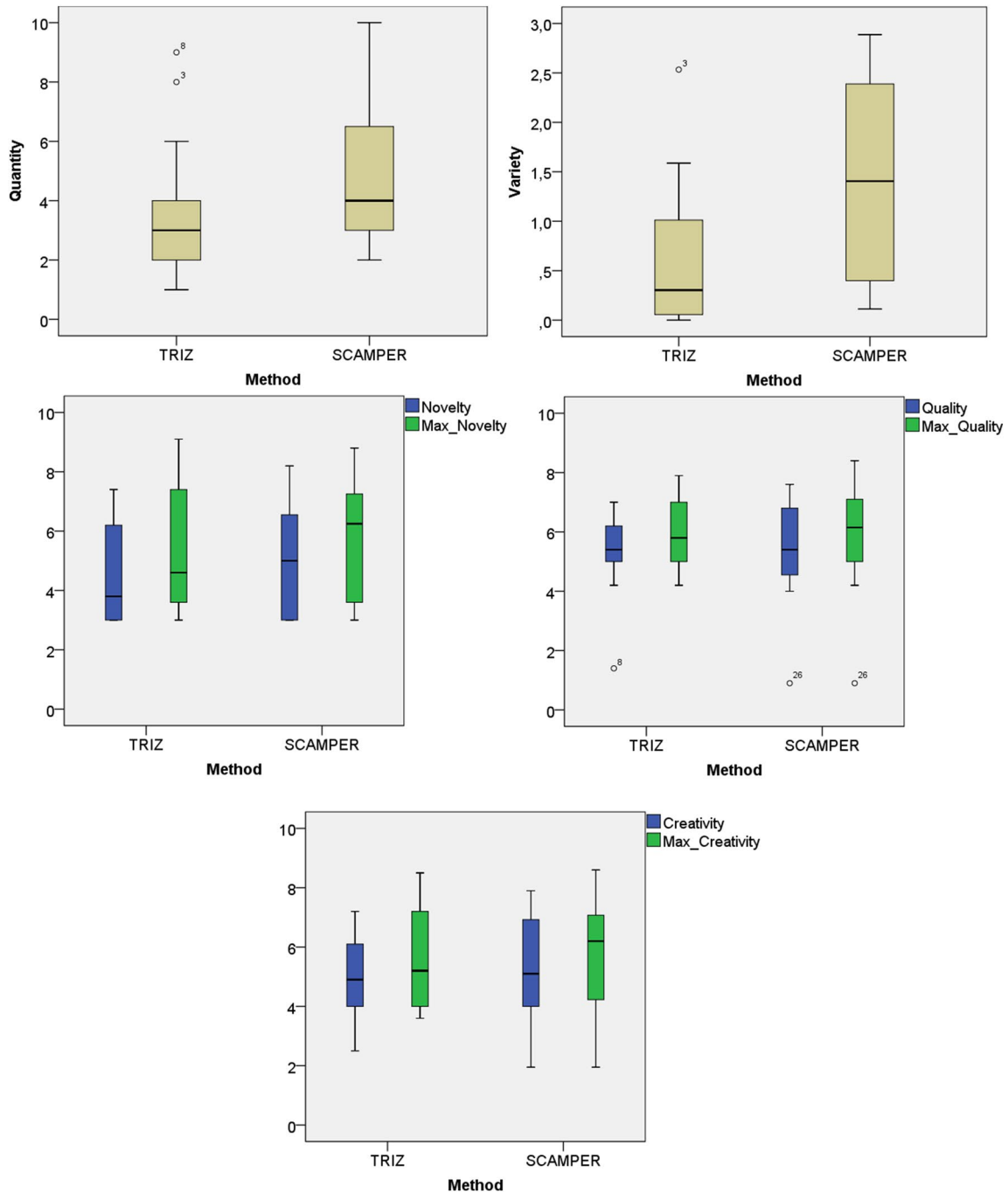


Fig. 6 Box and whisker plot of creativity parameters

design phase presents some kind of interaction with the effect on creativity caused by the natural environment.

The first analysis carried out on the results is devoted to the time spent on each of the phases of the conceptual design described by Chakrabarti (2003). In this study, it was found that the percentage of time dedicated to the Problem Understanding phase is significantly higher when using the logical method (TRIZ) and that the

percentage of time dedicated to the Problem Solving phase is significantly higher when using the intuitive method (SCAMPER). This result is initially to be expected, in line with previous research in this field (Chulvi et al. 2012b), in which there were identified differences in the distribution of the time spent on each conceptual design phase according to the type of method used. However, if we compare the average percentages of time devoted to each

Table 4 Percentages of time dedicated to each of the design phases and sub-phases

	TRIZ		SCAMPER	
	Mean	Std. dev	Mean	Std. dev
Problem Understanding (PU)	49.58%	12.74%	40.46%	11.91%
Problem Interpretation (PI)	1.56%	1.35%	1.26%	0.84%
Problem Analysis and Problem Choice (PA_PC)	48.02%	12.40%	39.20%	11.56%
Problem Solving (PS)	50.42%	12.74%	59.54%	11.91%
Solution Generation (SG)	33.95%	14.61%	35.48%	10.60%
Solution Evaluation and Solution Selection (SE_SS)	16.47%	10.14%	24.06%	6.98%

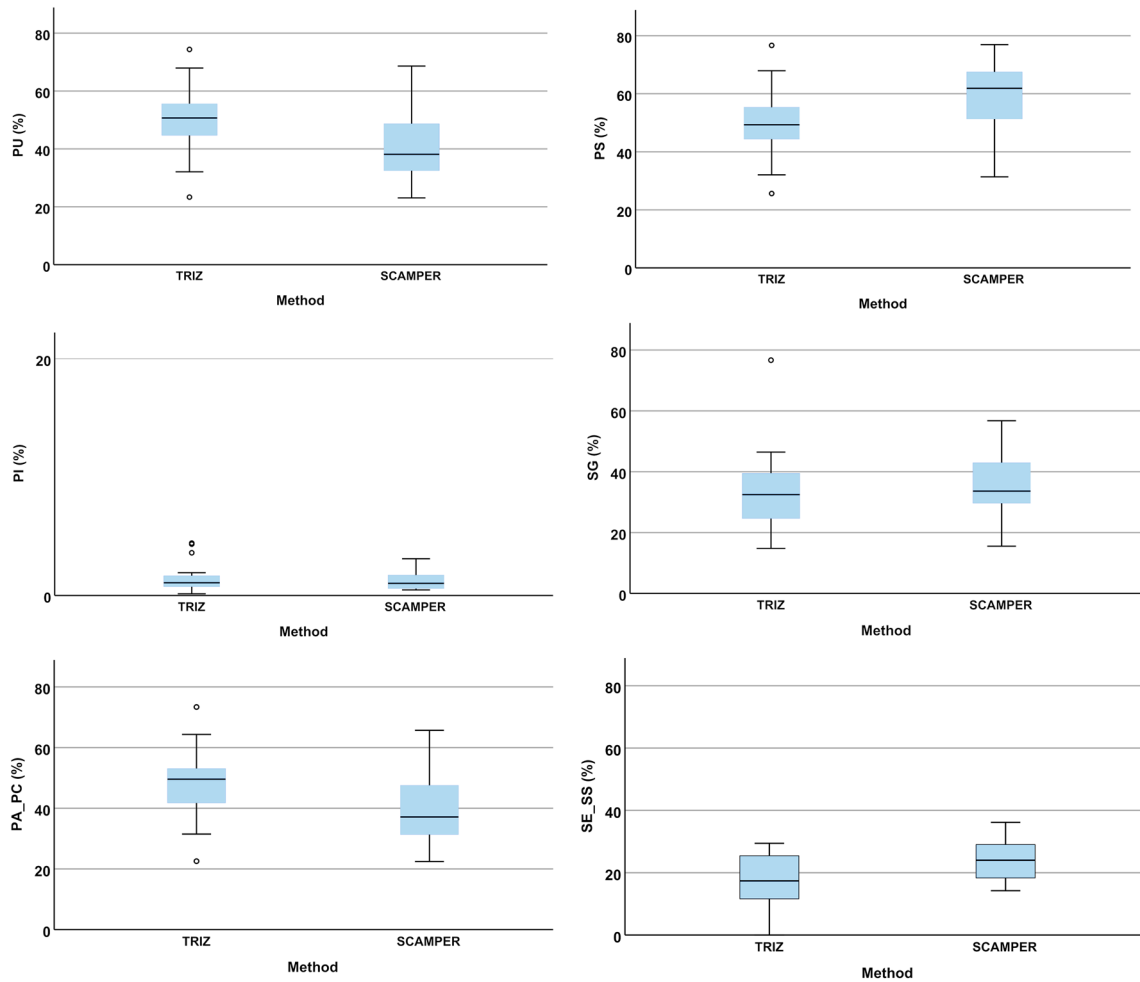


Fig. 7 Box and whisker plot of time distribution by phases

of the phases with previous research, we can see a clear difference in the time distributions depending on the type of methodology used. While in the case of the structured methodology analyzed this percentage remains quite similar, in the case of the intuitive methodology they are quite different (Table 6). Despite the fact that the two studies have not carried out identical tasks, although they are very similar regarding typology, the differences between the percentages of time devoted to each activity in the

case of the intuitive methodologies is clearly noteworthy. From this, it could be deduced that the simulated natural environment is acting on the designer when they use the intuitive methodology, causing them to spend more time thinking in the PU phase than when they carry out the same activity in a neutral setting.

The second analysis was performed on the results of the conceptual phase. On the one hand, it was seen that the use of the intuitive methodology provides a greater quantity and

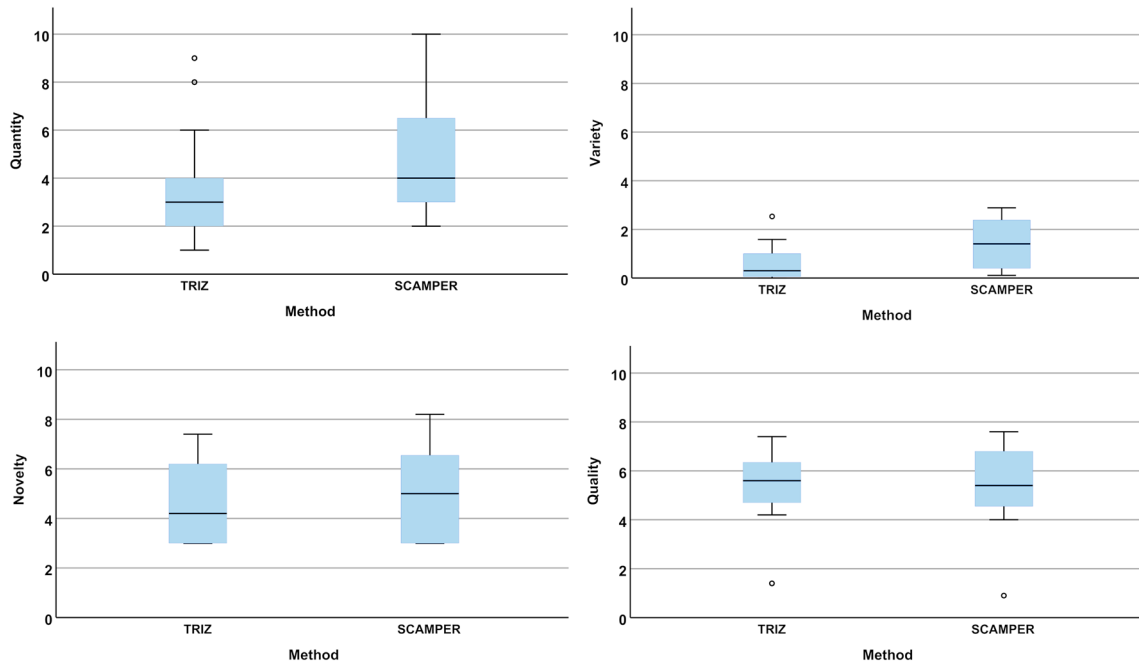


Fig. 8 Box and whisker plots of the results for quantity, variety and novelty and the quality of the final solutions

Table 5 Correct selections according to the methodology used

	Quality		Novelty		Creativity	
	Wise choice	Wrong choice	Wise choice	Wrong choice	Wise choice	Wrong choice
TRIZ	6	7	7	6	7	6
SCAMPER	6	10	6	10	7	9

Table 6 Comparison of times in PU and PS in a neutral environment and in a simulated natural environment

	Logical methodology		Intuitive methodology	
	Mean PU (%)	Mean PS (%)	Mean PU (%)	Mean PS (%)
Neutral setting (Chulvi et al. 2012b)	50.25	49.75	9	91
Simulated nature (present research)	49.58	50.42	40.46	59.54

variety of results than when the structured methodology is used, as can be seen in the diagrams of Fig. 6, although in the present study a significant relationship was only seen in terms of variety. This finding seems logical because, as more time is spent on the solution generation phase, more

solutions can be expected. Similarly, intuitive methodologies expand the design space in which ideas are sought, while logical methodologies further define the design space in which to seek ideas (Hernandez et al. 2010). On the other hand, although the use of SCAMPER provides more novel results and the use of TRIZ yields higher quality values, in neither case was this difference significant. This contrasts with the results from previous works (Chulvi et al. 2012b), where there is a significant difference in novelty and quality when using intuitive or logical methods. There, the highest novelty was obtained when using the former and the highest quality with the latter, although these differences in terms of novelty and usefulness were compensated in terms of creativity, since creativity is by definition the combination of both factors. The explanation in this case could be justified if we combine the results of the two above-mentioned studies by Chulvi et al. (2012a, b), from which it can be deduced that the more time is dedicated to the PS phase, the higher the results will be in terms of novelty, whereas more time dedicated to the PU phase will lead to better results in terms of quality. Hence, we have seen that when using the design

methodologies in a simulated natural environment, the differences in the amount of time spent on each design phase according to the methodology used are smaller. Therefore, this implies that the differences among the results in terms of novelty and quality decrease.

Finally, the selection of the best alternative from among the solutions generated is performed during the SE and SS sub-phases. In Table 5, it can be seen that on using the SCAMPER methodology, there is a greater number of participants who have not selected the best-rated solution, although not significantly. This can be caused due to the fact that using SCAMPER results in a greater number and variety of solutions from which to make the selection. In this case, we have seen a direct relationship between more time dedicated to the SE + SS sub-phases and the correct selection of the results.

7 Conclusion

In the present work, we have studied how the type of methodology used, when working in a natural environment, affects the designer's creativity. In particular, differences have been identified when using intuitive methodologies. In this case, the environment leads designers to spend more time in the PU phase, in relation to the results of previous work (Table 6), which helps them to improve the quality of their outcomes. At the same time, however, it does not have a negative effect on the number and variety of the solutions, which are still greater than when the logical methodologies are applied (Fig. 6). Conversely, when a logical methodology is used, the percentages of time dedicated to each design phase do not differ from other studies in which participants worked in a neutral room (without any natural elements).

It can therefore be concluded, as a main research result, that employing an intuitive design methodology in a simulated natural work environment has a positive effect on the conceptual proposals. This answer the research question raised previously. Creating such working environments and applying intuitive methodologies in professional design studios could help them to improve their efficiency. In addition, the use of natural indoor spaces in companies for relaxed tasks, such as intuitive meditation, could be considered to promote the creativity of their employees. It may also be useful to reconsider the type of educational environment in which creative teaching can take place, especially when it has a high intuitive and less structured dimension (Chulvi et al, 2019).

This study has been carried out with the collaboration of 16 junior designers working individually. This sample size was selected for being similar to those used in related studies, like Kjellgren and Buhrkall (2010), Plambech and Konijnendijk van den Bosch (2015), García-García et al. (2019)

or Chulvi et al. (2020). However, it is intended to extend the sample size with further studies. Future work would therefore include checking whether there are any differences between junior and experienced designers when working in these conditions, since the latter have a professional experience that can influence the way they use the methodologies, while the former are more associated with less elaborate but more novel ideas (Stacey et al. 2002). And it would also be necessary to determine whether there are any differences when working individually or in groups, since teamwork can also cause variations in the design phases, as discussion takes place among the members of the group (Kim et al. 2010). Moreover, it may be worthwhile to replicate the experiment with other intuitive and logical methodologies, to confirm that the conclusions derived from the present study are generalizable. Despite Shah's classification, there is not such a clear dichotomy between these two types of methodology. This differentiation between intuitive and logical methods could be established in a more scalar way. That is, there can be methods more or less intuitive and methods more or less logical (Gero et al. 2013). This encourages to this intention to replicate the experiment with other methods. Specifically, looking for methods that are strongly intuitive and strongly logical, and even trying with some method in an intermediate point, so that it could act as a control method.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s00163-022-00387-y>.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This work was supported by the Generalitat Valenciana Government (project ref. GV/2017/098).

Declarations

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

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Aiello JR, Derisi DT, Epstein YM, Karlin RA (1977) Crowding and the role of interpersonal distance preference. *Sociometry* 40:271–282. <https://doi.org/10.2307/3033534>
- Alencar EMLS, Bruno-Faria MF (1997) Characteristics of an organizational environment which stimulate and inhibit creativity. *J Creat Behav* 31:271–281. <https://doi.org/10.1002/j.2162-6057.1997.tb00799.x>
- Altshuller G (1984) *Creativity as an exact science: the theory of the solution of inventive problems*. Gordon and Breach Science Publishers, Luxembourg
- Alves J, Marques MJ, Saur I, Marques P (2007) Creativity and innovation through multidisciplinary and multisectoral cooperation. *Creat Innov Manag* 16:27–34. <https://doi.org/10.1111/j.1467-8691.2007.00417.x>
- Amabile TM (1996) *Creativity in context: update to the social psychology of creativity*. Hachette
- Atchley RA, Strayer DL, Atchley P (2012) Creativity in the wild: improving creative reasoning through immersion in natural settings. *PLoS ONE*. <https://doi.org/10.1371/journal.pone.0051474>
- Barakat HAER, Bakr A, El-Sayad Z (2019) Nature as a healer for autistic children. *Alex Eng J* 58:353–366. <https://doi.org/10.1016/j.aej.2018.10.014>
- Batey M, Hughes DJ, Crick L, Toader A (2021) Designing creative spaces: an experimental examination of the effect of a nature poster on divergent thinking. *Ergonomics* 64(1):139–146
- Bilda Z, Gero JS (2005) Key centre of design computing and cognition In: Gero JS & Bonnardel N (eds) *Studying Designers '05*, University of Sydney, pp 145–159
- Bonnardel N, Pichot N (2020) Enhancing collaborative creativity with virtual dynamic personas. *Appl Ergon* 82:102949. <https://doi.org/10.1016/j.apergo.2019.102949>
- Breda J, Jakovljevic J, Rathmes G, Mendes R, Fontaine O, Hollmann S, Rütten A, Gelius P, Kahlmeier S, Galea G (2018) Promoting health-enhancing physical activity in Europe: Current state of surveillance, policy development and implementation. *Health Policy (new York)* 122:519–527. <https://doi.org/10.1016/j.healthpol.2018.01.015>
- Ceylan C, Dul J, Aytac S (2008) Can the office environment stimulate a manager's creativity? *Hum Factors Ergon Manuf* 18:589–602. <https://doi.org/10.1002/hfm.20128>
- Chakrabarti A (2003) Towards a measure for assessing creative influences of a creativity technique. In DS 31 (eds) *Proceedings of ICED 03, the 14th International Conference on Engineering Design*. Stockholm, pp 1–10
- Chulvi V, González-Cruz C (2016) Influencia de la metodología de diseño en los parámetros emocionales del diseñador y en los resultados del diseño. *DYNA* 83:106–112. <https://doi.org/10.15446/dyna.v83n196.49783>
- Chulvi V, Mulet E, Chakrabarti A, López-Mesa B, González-Cruz MC (2012a) Comparison of the degree of creativity in the design outcomes using different design methods. *J Eng Des* 23:241–269. <https://doi.org/10.1080/09544828.2011.624501>
- Chulvi V, Sonseca Á, Mulet E, Chakrabarti A (2012b) Assessment of the relationships among design methods, design activities, and creativity. *J Mech Des Trans ASME*. <https://doi.org/10.1115/1.4007362>
- Chulvi V, Mulet E, Felip F, García-García C (2017) The effect of information and communication technologies on creativity in collaborative design. *Res Eng Des* 28:7–23. <https://doi.org/10.1007/s00163-016-0227-2>
- Chulvi V, Royo M, García-García C, Felip F, Gual J (2019) Does a creative environment help the acquisition of creative skills? In AEIPRO (d): 23rd International Congress on Project Management and Engineering, Málaga (Spain), pp 1885–1894
- Chulvi V, Agost MJ, Felip F, Gual J (2020) Natural elements in the designer's work environment influence the creativity of their results. *J Build Eng* 28:101033. <https://doi.org/10.1016/j.jobbe.2019.101033>
- Corbalán F, Martínez F, Donolo D (2006) *Crea, inteligencia creativa: una medida cognitiva de la creatividad*. TEA Ediciones Madrid, Madrid
- Csikszentmihalyi M (1998) *Creatividad: el flujo y la psicología del descubrimiento y la invención*. Paidós, Barcelona
- de Kort YAW, Meijnders AL, Sponselee AAG, IJsselstein WA (2006) What's wrong with virtual trees? Restoring from stress in a mediated environment. *J Environ Psychol* 26:309–320. <https://doi.org/10.1016/j.jenvp.2006.09.001>
- Eberle RF (1971) *Scamper games for imagination development*. DOK, New York
- Ferraro FM (2015) Enhancement of convergent creativity following a multiday wilderness experience. *Ecopsychology* 7:7–11. <https://doi.org/10.1089/eco.2014.0043>
- García-García C, Chulvi V, Royo M, Gual J, Felip F (2019) Does the work environment affect designers' creativity during the creative phase depending on their personality profile? *Think Ski Creat* 33:1–14. <https://doi.org/10.1016/j.tsc.2019.100578>
- Gero JS (2011) Future directions for design creativity research. *Des Creat*. https://doi.org/10.1007/978-0-85729-224-7_3
- Gero JS, Mc Neill T (1998) An approach to the analysis of design protocols. *Des Stud* 19:21–61. [https://doi.org/10.1016/s0142-694x\(97\)00015-x](https://doi.org/10.1016/s0142-694x(97)00015-x)
- Gero JS, Jiang H, Williams CB (2013) Design cognition differences when using unstructured, partially structured, and structured concept generation creativity techniques. *Int J Des Creat* 1(4):196–214. <https://doi.org/10.1080/21650349.2013.801760>
- Guilford J (1959) *Personality*. McGraw-Hill, New York
- Helms M, Vattam SS, Goel AK (2009) Biologically inspired design: process and products. *Des Stud* 30(5):606–622. <https://doi.org/10.1016/j.destud.2009.04.003>
- Hernandez NV, Shah JJ, Smith SM (2010) Understanding design ideation mechanisms through multilevel aligned empirical studies. *Des Stud* 31:382–410. <https://doi.org/10.1016/j.destud.2010.04.001>
- Herzog TR, Chen HC, Primeau JS (2002) Perception of the restorative potential of natural and other settings. *J Environ Psychol* 22:295–306. <https://doi.org/10.1006/jevp.2002.0235>
- Immordino-Yang MH, Christodoulou JA, Singh V (2012) Rest is not idleness: implications of the brain's default mode for human development and education. *Perspect Psychol Sci* 7:352–364. <https://doi.org/10.1177/1745691612447308>
- Jagtap S, Larsson A, Hiort V, Olander E, Warell A (2015) Interdependency between average novelty, individual average novelty, and variety. *Int J Des Creat Innov* 3:43–60. <https://doi.org/10.1080/21650349.2014.887987>
- Jones J (1970) *Design methods: Seeds of human futures*. Wiley-Interscience, New York
- Kaplan R, Kaplan S (1989) *The experience of nature: a psychological perspective*. CUP Archives
- Kaplan R, Kaplan S, Ryan R (1998) *With people in mind: design and management of everyday nature*. Island Press, Washington, DC
- Kasof J (1997) Creativity and breadth of attention. *Creat Res J* 10:303–315. https://doi.org/10.1207/s15326934crj1004_2
- Kim YS, Kim MS, Wilde DJ (2010) Toward the management of design creativity: personal creativity modes, design activity, and team interaction. *Des Manag J* 3:45–52. <https://doi.org/10.1111/j.1948-7177.2008.tb00013.x>
- Kjellgren A, Buhrkall H (2010) A comparison of the restorative effect of a natural environment with that of a simulated natural

- environment. *J Environ Psychol* 30:464–472. <https://doi.org/10.1016/j.jenvp.2010.01.011>
- Knasko SC (1992) Ambient odor's effect on creativity, mood, and perceived health. *Chem Senses* 17:27–35. <https://doi.org/10.1093/chemse/17.1.27>
- Knez I (1995) Effects of indoor lighting on mood and cognition. *J Environ Psychol* 15:39–51. [https://doi.org/10.1016/0272-4944\(95\)90013-6](https://doi.org/10.1016/0272-4944(95)90013-6)
- Korpela K, De Bloom J, Sianoja M, Pasanen T, Kinnunen U (2017) Nature at home and at work: naturally good? Links between window views, indoor plants, outdoor activities and employee well-being over one year. *Landsc Urban Plan* 160:38–47. <https://doi.org/10.1016/j.landurbplan.2016.12.005>
- Mann D, Dewulf S (2002) Evolutionary-potential in technical and business systems. *TRIZ J* 6:1–15
- McCoy JM, Evans GW (2002) The potential role of the physical environment in fostering creativity. *Creat Res J* 14:409–426. https://doi.org/10.1207/S15326934CRJ1434_11
- Mehta R, Zhu R, Cheema A (2012) Is noise always bad? Exploring the effects of ambient noise on creative cognition. *J Consum Res* 39:784–799. <https://doi.org/10.1086/665048>
- Mulet E, Vidal R (2001) Classification and effectiveness of different creative methods in design problems. In: Publishing PE (ed) 13 Th International Conference on Engineering Design. Glasgow (Escocia, UK), pp 363–370
- Nelson BA, Wilson JO, Rosen D, Yen J (2009) Refined metrics for measuring ideation effectiveness. *Des Stud* 30:737–743. <https://doi.org/10.1016/j.destud.2009.07.002>
- O'Quin K, Besemer SP (1989) The Development, reliability, and validity of the revised creative product semantic scale. *Creat Res J* 2:267–278. <https://doi.org/10.1080/10400418909534323>
- Oman SK, Tumer IY, Wood K, Seepersad C (2013) A comparison of creativity and innovation metrics and sample validation through in-class design projects. *Res Eng Des* 24:65–92. <https://doi.org/10.1007/s00163-012-0138-9>
- Osborn AF (1963) *Applied imagination*. Scribner, New York
- Pahl G, Beitz W (2013) *Engineering design: a systematic approach*. Springer Science & Business Media
- Paige MA, Fillingim KB, Murphy AR, Song H, Reichling CJ, Fu K (2021) Examining the effects of mood on quality and feasibility of design outcomes. *Int J Des Creat Innov*. <https://doi.org/10.1080/21650349.2021.1890228>
- Plambech T, Konijnendijk van den Bosch CC (2015) The impact of nature on creativity—a study among Danish creative professionals. *Urban for Urban Green* 14:255–263. <https://doi.org/10.1016/j.ufug.2015.02.006>
- Reich Y (2017) The principle of reflexive practice. *Des Sc*. <https://doi.org/10.1017/dsj.2017.3>
- Rhodes M (1961) An analysis of creativity. *Phi Delta Kappan* 42:305–310
- Ruiz-Pastor L, Chulvi V, Mulet E, Royo M (2021) The relationship between personal intrinsic factors towards a design problem and the degree of novelty and circularity. *Res Eng Des* 1:1–24. <https://doi.org/10.1007/S00163-021-00374-9>
- Saaty T (1980) *The analytic hierarchy process*. McGraw-Hill, New York
- Sarkar P, Chakrabarti A (2007) Development of a method for assessing design creativity. *Int Conf Eng Des ICED* 07:349–350
- Shah JJ, Vargas-Hernandez N, Smith SM (2003) Metrics for measuring ideation effectiveness. *Des Stud* 24:111–134. [https://doi.org/10.1016/S0142-694X\(02\)00034-0](https://doi.org/10.1016/S0142-694X(02)00034-0)
- Shalley CE, Oldham GR (1997) Competition and creative performance: effects of competitor presence and visibility. *Creat Res J* 10:337–345. https://doi.org/10.1207/s15326934crj1004_5
- Shealy T, Gero J, Hu M, Milovanovic J (2020) Concept generation techniques change patterns of brain activation during engineering design. *Des Sci*. <https://doi.org/10.1017/dsj.2020.30>
- Shibata S, Suzuki N (2004) Effects of an indoor plant on creative task performance and mood. *Scand J Psychol* 45:373–381. <https://doi.org/10.1111/j.1467-9450.2004.00419.x>
- Stacey MK, Eckert CM, Wiley J (2002) Expertise and creativity in knitwear design. *Int J New Prod Dev Innov Manag* 4:49–64
- Stenberg RJ, Lubart TI (1999) The concept of creativity: prospects and paradigms. In: Sternberg RJ (ed) *Handbook of Creativity*, Cambridge University Press, Cambridge, pp 3–15
- Stokols D, Clitheroe C, Zmuidzinas M (2002) Qualities of work environments that promote perceived support for creativity. *Creat Res J* 14:137–147. https://doi.org/10.1207/S15326934CRJ1402_1
- Stone NJ (1998) Windows and environmental cues on performance and mood. *Environ Behav* 30:306–321. <https://doi.org/10.1177/001391659803000303>
- Stone NJ, English AJ (1998) Task type, poster, and workspace color on mood, satisfaction, and performance. *J Environ Psychol* 18:175–185. <https://doi.org/10.1006/jev.1998.0084>
- Studente S, Seppala N, Sadowska N (2016) Facilitating creative thinking in the classroom: Investigating the effects of plants and the colour green on visual and verbal creativity. *Think Ski Creat* 19:1–8. <https://doi.org/10.1016/j.tsc.2015.09.001>
- Torrance EP, Reynolds CR, Riegel T (1977) Your Style of Learning and Thinking, Forms A and B preliminary norms, Abbreviated technical notes, scoring keys, and selected references. *Gift Child Q* 21:563–573. <https://doi.org/10.1177/001698627702100417>
- Tyrväinen L, Ojala A, Korpela K, Lanki T, Tsunetsugu Y, Kagawa T (2014) The influence of urban green environments on stress relief measures: A field experiment. *J Environ Psychol* 38:1–9. <https://doi.org/10.1016/j.jenvp.2013.12.005>
- Van Rompay TJL, Jol T (2016) Wild and free: Unpredictability and spaciousness as predictors of creative performance. *J Environ Psychol* 48:140–148. <https://doi.org/10.1016/j.jenvp.2016.10.001>
- Vasconcelos LA, Chen CC, Taysom E, Crilly N (2017) To copy or not to copy: the influence of instructions in design fixation experiments. In: JS Gero (ed) *Design computing and Cognition'16*. Springer, Cham, pp 359–375
- Williams KJH, Lee KE, Hartig T, Sargent LD, Williams NSG, Johnson KA (2018) Conceptualising creativity benefits of nature experience: attention restoration and mind wandering as complementary processes. *J Environ Psychol* 59:36–45. <https://doi.org/10.1016/j.jenvp.2018.08.005>
- Yilmaz S, Seifert CM, Gonzalez R (2010) Cognitive heuristics in design: instructional strategies to increase creativity in idea generation. *Ai Edam* 24(3):335–355. <https://doi.org/10.1017/S0890060410000235>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.