EFFECT OF THE APPLICATION OF CIRCULARITY REQUIREMENTS AS GUIDED QUESTIONS ON THE CREATIVITY AND THE CIRCULARITY OF THE DESIGN OUTCOMES

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Abstract:

Implementation of the circular economy is beginning to become a reality and the early stages of product design are crucial for a proper adoption of the circular model. However, several studies claim that when designers have many restrictions concerning sustainability imposed upon them, the creativity of the design outcome decreases. Therefore, it is necessary to help designers to think in a more circular manner and at the same time to increase creativity. In this research, we study whether creativity and circularity of the design outcomes change depending on how circular requirements are applied. For this purpose, an experiment has been carried out with 20 teams of three or four Engineering Design students. The teams were asked to propose a novel idea for a product design problem taking circular economy into account. All the teams had requirements concerning circularity expressed as selection criteria. They applied a modified "6-3-5 Method", in which four people sketched and wrote three ideas during a period of time and then exchanged the ideas with the next person. Half of them received some circular economy requirements in the form of explicit guided questions during the creative generation of ideas, while the other half did not. The results indicate that explicitly introducing guided questions leads to no significant differences in creativity or circularity. However, using guided questions about circular requirements does lead to more dispersed circularity and creativity results. The practical implications of this are interesting, since circularity requirements do not decrease creativity when applied as explicit questions during the generation of ideas.

Keywords:

Circular design; circular economy; conceptual design; creative products

1. INTRODUCTION

1.1. Introduction

Sustainability is the satisfaction of the needs of human society without compromising the resources given by the ecosystems (Morelli, 2011) and maintaining it over a very long time (Heijungs et al., 2010). Human activity poses a threat for the future because nature's resources are finite and we need to face a number of sustainability challenges. According to d'Orville (2019), achieving long-term sustainability requires coming up with new solutions and therefore creativity is closely linked to sustainability. This author claims that to attain the Sustainable Development Goals (SDGs) adopted by the United Nations creativity is necessary. This idea is defended in other studies. For example, Lozano (2014) indicates that creativity, and creative thinking in particular, is crucial to question reductionist mental models and build more sustainable societies. Mitchell and Walinga (2017) maintain that sustainability requires creative ways of thinking and new ideas. More recent studies also suggest that firms should make the effort to promote creative thinking initiatives (Awan et al., 2019).

Taking into account that circular economy and sustainability are closed related terms, although with some differences (Geissdoerfer et al., 2017), this work focuses on how to generate more creative and circular products during idea generation. Following the linear model of extract–produce–use–discard has created fundamental challenges (Rockström et al., 2009), many of which can be addressed during product design (Buchanan, 2001). The circular economy, as opposed to the linear economy, is a "system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impairs reuse, and aims for the elimination of waste through the superior design of materials, products, systems and within this, business models" (The Ellen MacArthur Foundation, 2012: 7).

The circular economy can be introduced during the earlier phases of design as a list of design requirements. However, previous findings show that considering environmental-related requirements may lead to less creative results. For instance, when young designers are expected to implement very strict design requirements which may give way to an understanding of "what is" instead of "what can be", the creativity of their results decreases (Cucuzzella, 2016). It also decreases when the requirements are so open that it is too challenging to reimagine a different future (Cucuzzella, 2016). Interestingly, using the terms "requirements" and "shall" for a concept generation task, leads the designer to focus on satisfying these explicit requirements and inhibits creativity (Mohanani et al., 2014). The same study reveals that if a list of ideas is provided during the concept generation task without explicitly using the word "requirement", creativity increases. Another study highlights that when designers use detailed environmental information, the solutions generated are more conservative and less creative. This makes it necessary for methods and tools in the future to deliver relevant information avoiding this fixation effect (Collado-Ruiz and Ostad-Ahmad-Ghorabi, 2010). The three studies agree that, when strict requirements exist, designers' creativity decreases. So, tension arises between creativity and satisfying requirements.

It is therefore necessary to analyse how to encourage circularity without compromising creativity in order to design both more circular and more creative products. There is a gap between how to introduce the circular economy approach/requirements in product design without compromising the creativity of the products.

The aim of this work is to gain knowledge about how applying circular requirements in the form of guided questions (GQ) influences the creativity and the circularity. Accordingly, the following research question is posed:

Does applying a creative method introducing circular requirements as guided questions improve creativity and circularity?

To address this objective, this paper considers circularity requirements implicitly and compares the results of applying the 6-3-5 Method to generate ideas with the results when some circularity requirements are used in the form of guided questions during the generation of ideas.

2. LITERATURE REVIEW

2.1. Circularity

In the circular economy approach, resources are retained as much as possible by preserving and recirculating them instead of discarding them (Milios, 2018). The different actions that can be performed to introduce circularity are classified in three main groups, according to Bocken et al. (2016):

- Slowing loops: designing long-life goods and product-life extension services to extend and/or intensify a product's life. This results in a slowdown of the flow of resources.
- Narrowing loops: using as few resources as possible per product.
- Closing loops: recirculating the materials again through recycling or reuse, among others, after the use phase.

Nowadays, this change of model is starting to become a reality (European Commission, 2015). However, although awareness is more widespread, it is necessary to implement strategies to reduce the use of resources by humans (Bocken et al., 2016). Companies also have to develop business models that fit the circular consumption, thereby acting as an exchange agent while also allowing and facilitating the highest possible number of uses for their products (Selvefors et al., 2019). For firms it is also important to manage the pressure from stakeholders to increase the implementation of sustainability or circularity (Awan et al., 2017).

In Andrews' words "designers have to change their design thinking and practice and lead the development of the Circular Economy by creating products and services that match all inherent criteria of this model" (Andrews, 2015). Design thinking is understood as the collaborative process by which the designer's sensibilities and methods are employed to match people's needs with what is technically feasible and a viable business strategy (Brown, 2009). Design thinking skills can help designers to solve complex problems and to be able to adapt to changes (Razzouk and Shute, 2012). It can be achieved by understanding the user's needs and the social and economic context (Melles et al., 2011).

Therefore, industrial designers play a key role in circular design (Lofthouse, 2004). For designers, this implies the challenge of creating robust products that, in turn, follow circularity principles and remain with users for as long as possible without jeopardising the product's functionality, while also considering the consumer behaviour and attitudes and the social context (Lofthouse and Prendeville, 2018). The circular economy context must be considered right from the start of the design process (Bakker et al., 2019) by correctly using resources to optimise the product in terms of both its function and the resources employed to make it. Following this, Moreno et al. (2017) define a taxonomy of strategies that guide product designers to introduce circular economy into product design from the earlier stages of the design process. In their taxonomy, they focus on five main categories: resource conservation, life cycles, whole system design, the customer and development. Another example of an approach to circular design is the "Circular Design Guide" developed by IDEO (2017). This consists of a set of online tools that allow designers to have a guide on how to design in a more circular way with several design methods adapted to the principles of circular economy.

The Ellen MacArthur Foundation (2013), Van der Berg and Bakker (2015) or Mulder et al. (2014), among many others, have established strategies and guidelines to introduce circularity into product design. These design guidelines can guide designers to achieve more circular solutions. It is essential that design strategies and business models are related in order to encourage the transition from a linear to a circular economy (Camacho-Otero, 2015; Moreno et al., 2016). For instance, Bocken et al. (2016) propose a series of strategies for slow and closed loops:

- Design strategies to slow loops.

Designing long-life products

- Design for attachment and trust
- Design for reliability and durability

Design for product-life extension.

- Design for ease of maintenance and repair
- Design for upgradability and adaptability
- Design for standardisation and compatibility
- Design for dis- and reassembly

- Design strategies to close loops.

- Design for a technological cycle
- Design for a biological cycle
- Design for dis- and reassembly

Some metrics also exist to assess circularity in products and evaluate their improvement potential. However, no standard method is currently available (The Ellen MacArthur Foundation, 2015; European Environment Agency, 2016). In order to apply these metrics, it is often necessary to know product details that are not defined in the conceptual phase: materials, weights, etc. Moreover, these metrics do not usually cover all the aspects contemplated under the circular economy umbrella. The metrics or methods available partially evaluate the circularity, but there are deficiencies in the assessment of circularity in concepts (Ruiz-Pastor et al., 2019). Circularity should thus be incorporated into product design. Consequently, it is necessary to adapt present methods to measure circularity in order to assess it globally and coherently (Mesa et al., 2018).

2.2. Creativity in Engineering Design

The design process is basically a problem-solving process. The initial phase of this process is the conceptual design stage (Pahl and Beitz, 1996), where the most important decisions are made (Cross, 1999). This stage starts from the problem to be solved, which is translated into requirements and design specifications that the product to be designed must achieve. The designer has to solve the problem in a creative way.

Creativity is an innate human characteristic and a very important factor when facing new design engineering challenges (Amabile, 1996). This is why an individual's creativity has been well studied from the field of psychology (Guildford, 1968; Torrance, 1969; López-Martínez and Navarro-Lozano, 2008). Nevertheless, in the field of Design Engineering, creative results also depend on the creative process (Csikszentmihalyi, 1998). In a real product design situation, the solution-seeking phase is the one in which a designer's creativity is witnessed to a greater extent. Many design methods exist to help synthesise solutions. Numerous studies have been published about creative problem-solving methods, as seen in the collections of methods by Jones (1970), VanGundy (1988) and Higgins (1994), and in the extensive literature in many different journals.

One of the most widely used methods is brainstorming and its variants. Brainstorming methods, in which stimulation is achieved by using the stimuli generated in the group, are extensively used in industry (López-Mesa, 2003). The "6-3-5 Method", also known as a brainwriting method (Rhorbach, 1969), is an intuitive idea-generation method that is subclassified into progressive methods in which ideas are generated by repeating the same set of steps a number of times to generate ideas in discrete progressive steps (Shah, 2000). It is a creative method for generating many ideas in a short time that is a variation of brainstorming and complements the individual work obtained by this technique.

Another kind of method to help introduce new elements into a product is to introduce guided questions (GQ) during the design process. During the design process, a question is a statement that requests the design actions that designers need to answer (Eris, 2004), which could act as a guide to lead designers to find a solution for the problem under consideration. Questions are used both implicitly and explicitly to help designers move away from their usual problem-solving routine (Cardoso et al., 2016).

A product's creativity is generally defined as the combination of its novelty and usefulness for most of the metrics that evaluate it (Chulvi et al., 2012). In other words, creativity in a product comes about when a stakeholder uses his or her capacity to produce novel and valid solutions for design purposes (Sarkar and Chakrabarti, 2008). This definition encompasses the three above-cited concepts that refer to creativity in design: the stakeholder, the solution-generating process, and the novelty and validity of the solutions that are generated.

2.3. Creativity in circular design

However, apart from the validity referring to the solution's usefulness, creativity may also involve seeking new characteristics that are to be included in the product design, such as circularity. In this sense, Charter (2018) states that designing for the Circular Economy requires thinking about how to enable product circularity in the early creative stages of design. Jawahir and Bradley (2016) claim that value creation through circularity requires, among other things, the use of visionary thinking, which combines creativity with an established technical basis to create implementable solutions to "real-world" problems.

These new characteristics or demands of the client or society can, in turn, be interpreted as a restriction by designers and as such, as mentioned in the introduction section, could be an obstacle for creativity (Cucuzzella, 2016; Mohanani et al., 2014; Collado-Ruiz and Ostad-Ahmad-Ghorabi, 2010). Nevertheless, circularity needs to be introduced into product design. This means that we face the problem of how to guide designers to introduce circularity into product design in a creative innovative fashion.

3. METHODOLOGY

This section describes the research methodology. A practical experiment has been carried out, in order to validate the research questions with empirical data.

3.1. Design Experiment

The experiment was performed with 72 year-3 Industrial Design students, 35 males and 37 females. First, all the participants attended a preparation session about circular economy. In this session, circular economy and design strategies to obtain circular designs were explained using examples. The following week a two-hour workshop was carried out to analyse four items of school furniture in terms of circular economy requirements. In this workshop the participants were distributed in four different sessions due to space and organisation restraints. The workshop was carried out in 20 work groups with three or four members in each one. These two sessions served as a preparation for the empirical study. The setting and the materials were the same in the four sessions: a room with tables and seats to allow participants to work in groups.

A week later the same teams that worked together were asked to generate a novel proposal for an item of school furniture. They were provided with the description of a design problem, in this case, a new piece of school furniture that should:

- be novel
- respond to some educational trends in which furnishings play a key role
- take circular economy into account

Before starting the generation of ideas, each team was provided with written instructions. In these instructions they were told that they should apply a creative method to come up with ideas. In addition, a set of criteria were established as those that would guide the selection of the final idea. Seven criteria concerned circular economy and four were related to other issues, such as novelty, playfulness and diversity. In order to avoid the decrease in creativity produced by very strict requirements, these circular requirements are considered in an implicit way, in this case, as selection criteria. The design problem with the instructions delivered is shown in (Fig. 1).

CREATIVE SESSION – Week 3

Objective: to generate a new design of school furniture that:

- Is creative.
- Respond to the trends in education described in the articles and examples shown, where furniture plays a key role.
- Consider the circular economy.

Material:

Markers, colours, pencils, post-its and the presentation of the topic to work on.

Steps:

1. Brain Warming Exercises
2. Apply the creative method that has been explained to you
3. Choose the design solution you see as the best. In order to do so, you will point out each one of its strong and weak points, according to the aspects already analysed in Practical 1 and any other criteria that you consider:

1. Facilitates **reparation** and replacement of parts
2. Parts could be **reused** again in the same design or in another product
3. It **takes advantage** of **waste** to use them as raw material of the product.
4. When it is no longer used, **waste is NOT generated**
5. Extends lifetime through **versatility**
6. Covers a need in a **poor environment**
7. It can be used or **interacted** with in **several ways**
8. It is designed to make the user **enjoy** using it
9. It is original and **innovative**
10. Moves away from the concept of linear economy: extracting, manufacturing and assembling, using and throwing away
11. It is designed for users with **diversity** (reduced mobility, reduced sensoriality, etc.).

4. Describe the solution chosen, using an A3 format sheet showing the following information:
   - The largest space will be occupied by a main drawing that shows the best possible design.
   - Smaller secondary drawings showing other views, other forms of interaction, or other design details. The use of silhouettes is recommend to show the interaction.
   - Description of key design features and user benefits.
   - Description of how the design considers the circular economy

Fig. 1. Design problem and instructions

To perform this task, the participants were informed that they had to apply the idea-generation “6-3-5 Method” (Rohrbach, 1969). In this method, six participants are told they have five minutes to each write down three ideas. It can also be applied with four, five or seven members. For the experiment that was carried out, describing the ideas with sketches is important, so, instead of five minutes, the first turn had up to 15 minutes and the subsequent steps lasted eight minutes each. Therefore, the objective was to obtain 48 ideas (27 in teams with three members) per work group as proposals to solve the problem set out in the description. One of the authors moderated the method in the four sessions. Nine of the 20 teams applied this method with the requirements implicitly delivered in the instructions as selection criteria.

The other 11 groups applied this method including guided questions (GQ) about circularity. The following questions were verbally and explicitly introduced in each eight-minute round:

- (GQ1) How can this product be made to be more adaptable or modular (and used for different activities, in various places, with varying numbers of children, by children of different ages, etc.)?
- (GQ2) Where can this product's raw materials and components be obtained, so as to not extract new materials from our planet to manufacture it?
- (GQ3) What can be done with this product when it is no longer used in schools so as not to produce waste?

That is, during each methodology round, they were asked a question when they received the sheet with solutions from the person next to them.

Fig. 2. Experiment development

Finally, each group selected one of the proposals generated, or a combination of several, as the final solution. As a result of the experiment, each work group came up with a conceptual design proposal, which was then assessed for its creativity and circularity. The steps followed in the experiment are shown in Fig. 3.

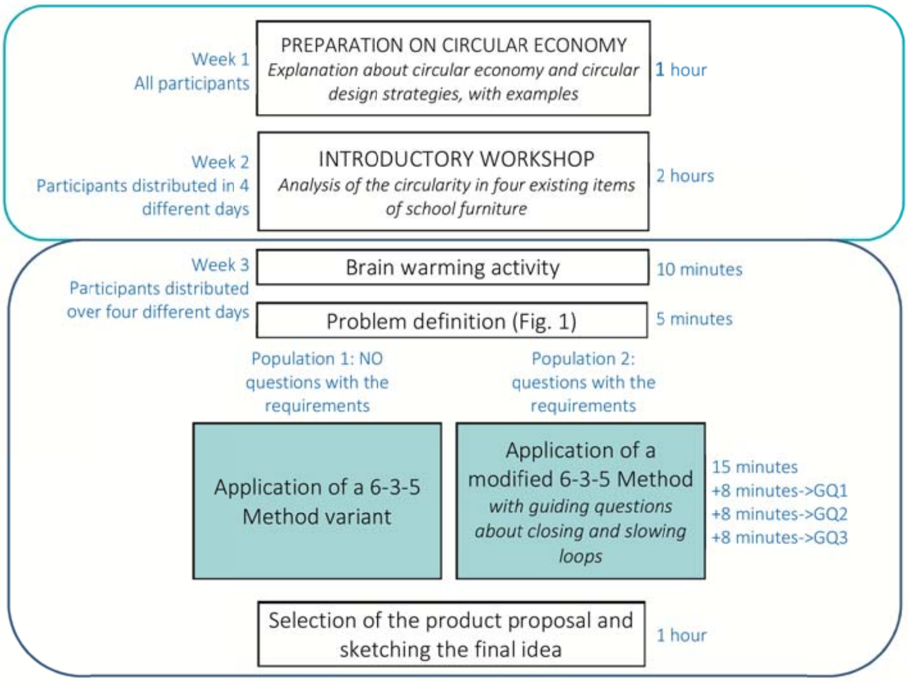


Fig. 3. Experiment steps

At the end of the experiment, the participants were asked to individually complete a questionnaire to assess their satisfaction with the method followed to generate ideas. It asked them how much they liked the method, if they thought it was easy, and if they believed it had helped them to obtain more novel and circular ideas or not.

3.2. Creativity assessment

The creativity (C) of the proposals obtained was assessed according to the method proposed by López-Forniés et al. (2017) to specifically assess concepts according to the scale proposed to collectively measure novelty (N), usefulness (U) and technical feasibility (F). In this way, all three of the above-mentioned aspects were assessed by following the criteria set out in Table 1. The final score was then calculated for each concept by combining the three values (eq. 1).

$$C = N \times U \times F \quad \text{(eq. 1)}$$

The creativity score ranged between 1 (more creativity) and 0.001 (less creativity).

Scale	Explanation	Rate
Much novelty	The concept will be new and cannot be compared	1
Much usefulness	The concept solves the problem	
Much feasibility	The concept is easy to achieve without any technical changes	
Average novelty	The concept exists but with considerable differences	0.7
Average usefulness	The concept only solves part of the problem	
Average feasibility	Some investment is required to implement the concept	
Little novelty	The concept already exists but for other applications	0.3
Little usefulness	The concept solves part of the problem under specific circumstances	
Little feasibility	The changes are relevant and considerable investment is required	
No novelty	The concept already exists for the same application	0.1
No usefulness	The problem has already been solved in a simpler way	
No feasibility	The changes required are difficult to achieve and very high investment is needed	

Table 1. Assessing creativity (López-Forniés et al., 2017)

Next, the creativity score obtained during the experiment for each school furniture concept is shown. The product proposal (Fig. 4) is a rotating table with adjustable height, lighting and various modules to configure it to suit users' preferences.

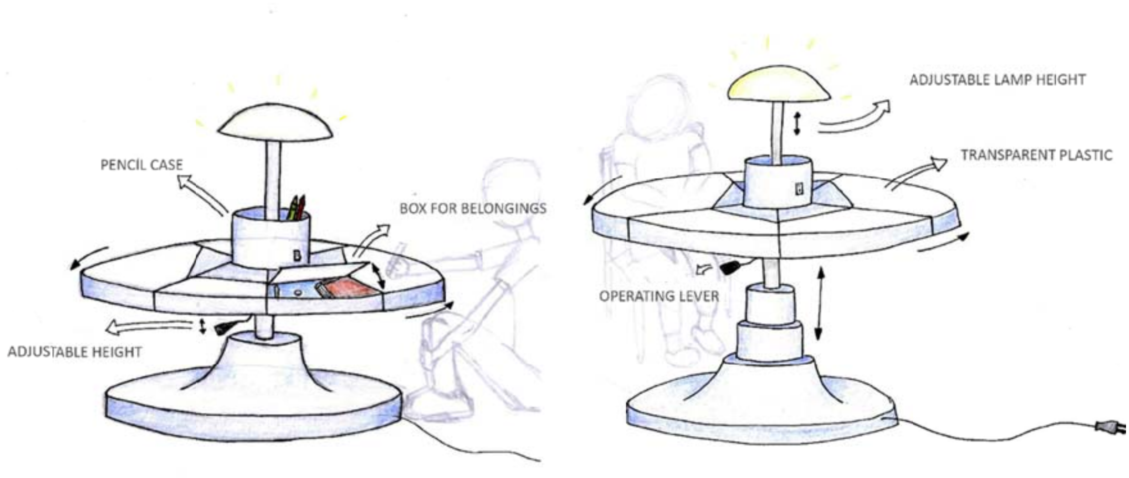


Fig. 4. An example of creativity results

Novelty = 0.3 – The product already exists, but it is proposed for a new use

Usefulness = 1 – It proposes a solution for a new application and solves the problem

Feasibility = 0.7 – The design needs changing or adjusting to be completely feasible

$C=0.3 \times 1 \times 0.7=0.21$

Total creativity score → 0.21

Fig. 5 shows the creativity results for the 20 design outcomes of the experiment.

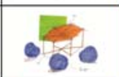
	GROUP	Solution description	Novelty punctuation	Usefulness punctuation	Feasibility punctuation	Creativity score
method applied with guided questions	L1 - 1		0.300	0.700	1.000	0.210
	L1 - 2		0.100	0.100	0.300	0.003
	L1 - 3		0.100	0.300	1.000	0.030
	L1 - 4		0.300	0.300	0.300	0.027
	L1 - 5		0.100	0.700	1.000	0.070
	L7 - 1		0.300	0.700	1.000	0.210
	L7 - 2		0.700	0.700	1.000	0.490
	L7 - 3		0.300	0.700	1.000	0.210
	L7 - 4		0.100	0.300	1.000	0.030
	L7 - 5		0.100	0.300	1.000	0.030
	L7 - 6		0.300	0.300	0.700	0.063
method applied without guided questions	L3 - 1		0.300	1.000	0.700	0.210
	L3 - 2		0.300	0.700	1.000	0.210
	L3 - 3		0.300	0.700	1.000	0.210
	L3 - 4		0.300	0.100	0.700	0.021
	L5 - 1		0.100	0.700	0.700	0.049
	L5 - 2		0.300	0.300	1.000	0.090
	L5 - 3		0.700	0.700	0.300	0.147
	L5 - 4		0.300	0.700	1.000	0.210
	L5 - 5		0.300	0.100	0.100	0.003

Fig. 5. Creativity scores (L1 and L7: method applied with guided questions; L3 and L5: method applied without guided questions)

3.3. Circularity assessment

The circularity of each proposal was assessed in terms of the number of aspects that enhanced the product's circularity included in the proposal. To obtain a score, all the characteristics present in the proposals were classified according to whether they all followed the design guidelines that focused on slow, narrow or closed loops (Bocken et al., 2016; Mesa et al., 2018).

This was achieved by applying the weighted sum of all the characteristics that referred to the slow loops, closed loops and narrow loops of each of them. Since there is no semi-quantitative standard method to measure circularity in concepts, the weighting values of the method used for the creativity assessment were adopted. The values of the ratios were then established following the same weighting used to assess creativity in the metric proposed by López-Forniés et al. (2017). Consequently, ratios of 0.3, 0.7 and 1 were considered, depending on each type of action. According to The Ellen MacArthur Foundation (2013), the closer the product approaches the user, i.e. the more closed the loop is, the more favourable the action being performed in this loop will be for circularity. Therefore, the characteristics that favoured slow loops were assessed by multiplying the number of characteristics by 1, those favouring narrow loops were assessed by multiplying the number of characteristics by 0.7, while those favouring closed loops were assessed by multiplying the number of characteristics by 0.3. The characteristics set out in the solution proposals that did not refer to circularity were not taken into account. This meant that the higher the obtained score was (eq. 2), the more circular the proposal was. Table 2 shows the values to score the circularity of the ideas. Hence:

$$C = Is \times 1 + In \times 0.7 + Ic \times 0.3 \quad \text{(eq. 2)}$$

C = Circularity
Is= Number of ideas for slow loops
In = Number of ideas for narrow loops
Ic = Number of ideas for close loops

Type of action in the loop	**Rate**
Ideas for slow loops	1
Ideas for narrow loops	0.7
Ideas for closed loops	0.3
Other ideas that did not show slow, narrow or closed loops	0

Table 2. Rating of the type of ideas for an accountability of the circularity of conceptual designs

Some of the characteristics obtained that did not refer to circularity included making the best of space, fun furniture, promoting creativity or being comfortable for children, etc. Fig. 6 shows one of the design outcomes with the characteristics to evaluate the circularity.

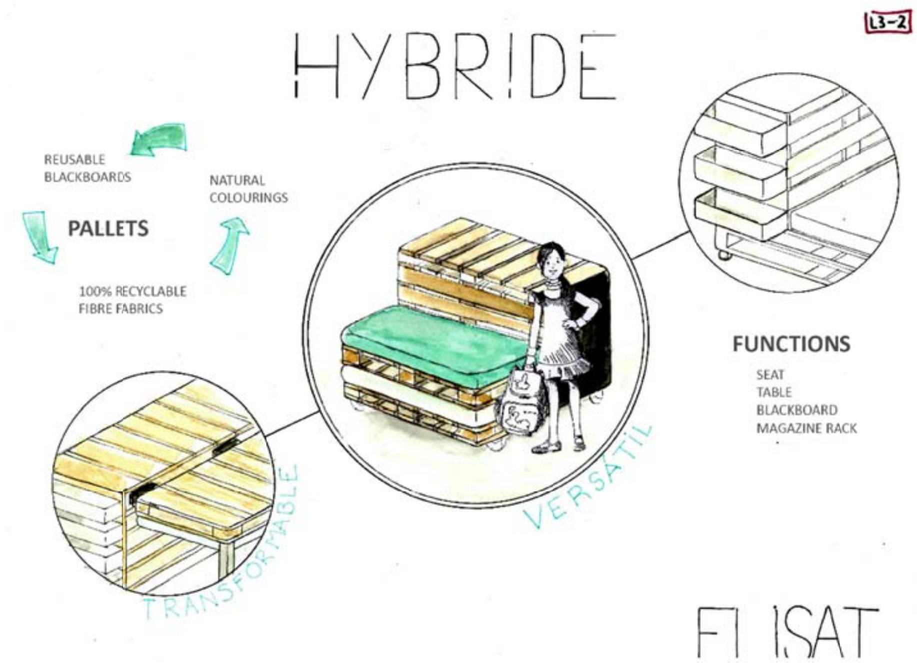


Fig. 6. Example of the circularity outcome

The proposal was for modular multifunctional furniture made from wooden pallets, which offered the following characteristics:

> Ideas for slow loops → Transformable, versatile, several functions (3)
>
> Ideas for closed loops → Reusable blackboards, 100% recyclable fibre fabrics, made from reused pallets (3)
>
> Ideas for narrow loops → Natural colourings (1)
>
> Total circularity = 3 × 1+1 × 0.7+3 × 0.3 = 4.6

Fig. 7 shows the ideas to slow, close and narrow loops and the circularity score for the 20 design outcomes of the experiment.

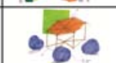
GROUP	Solution description	Ideas for slowing loops	Ideas for closing loops	Ideas for narrowing loops	TOTAL ideas	Circularity score
L1 - 1		Convertible Color palette	Easy joining and assembly		3	2.30
L1 - 2					0	0.00
L1 - 3		Enjoyable to enlarge the use. You can interact with it in several ways Versatile Foldable to use as a table or as a chair Height adjustable	Possibility of repairing Possibility of reusing		7	6.60
L1 - 4		Versatile You can interact with it in several ways	Materials can be recycled Part of its components are made of recycled materials	Take advantage of waste	5	3.30
L1 - 5					0	0.00
L7 - 1		The board has two positions: table and blackboard Height adjustable Long life time	Easy interchangeability of parts Easy repair The board comes from recycled materials	The board comes from pieces of another one of greater dimensions in disuse	7	4.60
L7 - 2		Several functions Versatile	Reused materials Reusable materials The components come from others reused Possibility of reusing components		6	3.20
L7 - 3		Three positions of use Neutral aesthetics Versatile Heavy duty components	Component parts facilitation service Component repair Materials are reused for new components Recyclable materials		8	5.20
L7 - 4		Several functions Aesthetics: primary colors	MDF board (recycled wood) Easy assembly and disassembly		4	2.60
L7 - 5		Multifunction Various colors Versatility One of the components can be replaced	Made of recyclable material		5	4.30
L7 - 6		Evolutionary Versatility You can interact with it in different ways		It is made with a sustainable material (cardboard) The raw material is waste Does not generate waste (biodegradable)	6	5.10
L3 - 1		Several functions Versatile Height adjustable Rotary movement	Easy interchangeability of parts		5	4.30
L3 - 2		Transformable Versatile 4 functions	Reusable blackboards Fabrics made with 100% recyclable fibers Made from reused pallets	Natural colors	7	4.60
L3 - 3		Modular Several functions	Easy assembly between components		3	2.30
L3 - 4		Versatile Height adjustable			2	2.00
L5 - 1		Customizable Several functions		Bioplastic	3	2.70
L5 - 2		Versatile	Reusable Made of 100% biodegradable material Seat fabric from reused clothes	It does not generate waste It is made with a sustainable material (cardboard)	6	3.30
L5 - 3		Versatile			1	1.00
L5 - 4		Modular Versatile Adaptable to the child's growth Variety of accessories		Made of wood	5	4.70
L5 - 5		Height adjustable	Recycled wood Legs remanufactured from cans Use for combustion at end-of-life		4	1.90

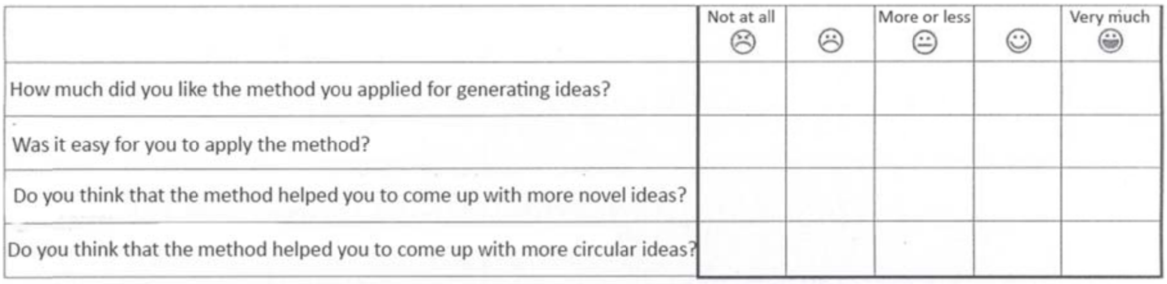
Fig. 7. Circularity scores (L1 and L7: method applied with guided questions; L3 and L5: method applied without guided questions)

3.4. Perception questionnaire

At the end of the experiment, the participants were provided with a perception questionnaire that they filled in to assess the following questions on a 5-point Likert scale (Fig. 8):

- How much did you like the method you applied for generating ideas?
- Was it easy for you to apply the method?
- Do you think that the method helped you to come up with more novel ideas?

- Do you think that the method helped you to come up with more circular ideas?



	Not at all		More or less		Very much
How much did you like the method you applied for generating ideas?					
Was it easy for you to apply the method?					
Do you think that the method helped you to come up with more novel ideas?					
Do you think that the method helped you to come up with more circular ideas?					

Fig. 8. Perception questionnaire

4. RESULTS AND DISCUSSION

4.1. Creativity results

The creativity results were analysed to see if there were any marked differences between the proposals obtained with the implicit circularity requirements and those obtained by including circular requirements in the form of GQ while the creative "6-3-5 Method" was being applied. The creativity values obtained were as follows (Table 3):

	Creativity results											M	SD
With implicit requirements	0.21	0.21	0.21	0.021	0.049	0.09	0.147	0.21	0.003			2.70	1.323
Adding explicit GQ	0.21	0.003	0.03	0.027	0.07	0.21	0.49	0.21	0.03	0.03	0.063	3.30	2.088

Table 3. Creativity results

First of all, the normality of the series of scores obtained was checked using the statistical Kolmogorov-Smirnov test, which resulted in a series of data that did not follow a normal distribution.

$D(20) = 0.193$, p=0.049

In order to compare the results of the groups that used explicit GQ as opposed to those that followed the creative method with implicit guidelines in the description, the statistical Kruskal Wallis test was used.

$H(1) = 0.151$, p=0.697

So, the results show no significant difference between the creativity of the proposals obtained with the implicit circular design indications and those obtained with the method to which GQ were added. As shown in Fig. 9, the creativity results were similar during the sessions in which GQ were added during the creative method and when guided questions were not used. When circularity requirements were implicit and not applied as guided questions, slightly more creative results were obtained, although the difference between the two groups of results was non-significant. The results showed that 95% of the design outcomes score "little" creativity or "no" creativity and only 5%

of the outcomes score between the average and "much" creativity (Table 3). Hence, overall, the method has not helped much to generate highly creative outcomes, regardless of whether requirements were used implicitly or as guided questions. The most relevant finding is that using requirements explicitly as guided questions does not decrease creativity.

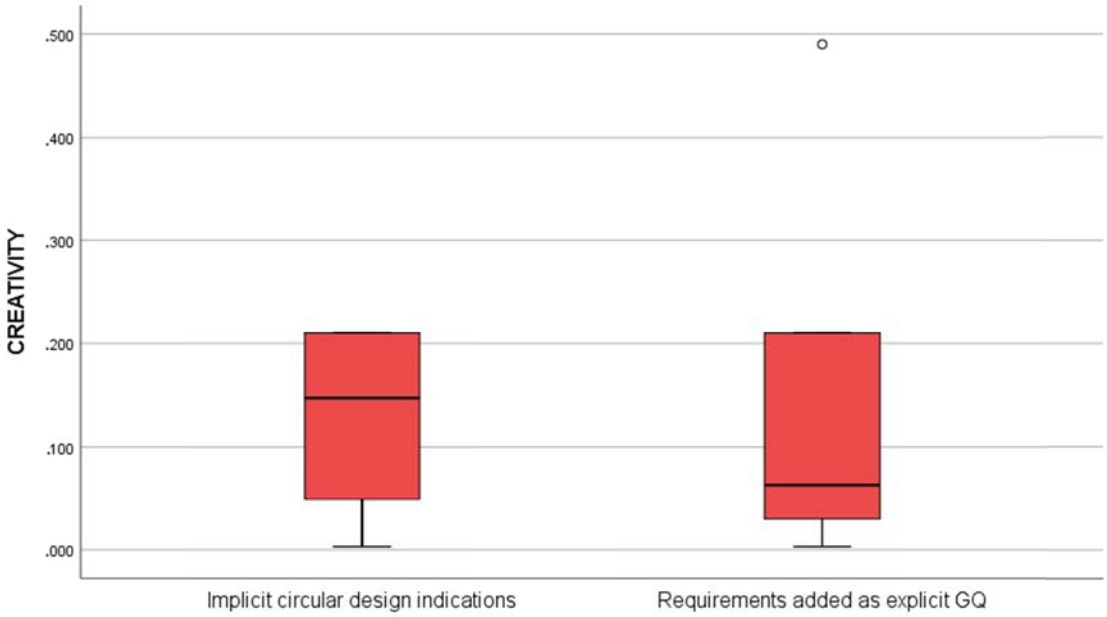


Fig. 9. Creativity results

4.2. Circularity results

The circularity results obtained are presented in Table 4. They were analysed to see whether any relevant differences appeared between the proposals obtained using the implicit guidelines in the description and those achieved by adding explicit GQ when applying the adapted 6-3-5 creative method. Each design outcome of the experiment has been analysed and every characteristic related to circularity accounted and scored as explained in subsection 3.4.

	Circularity results											M	SD
With implicit requirements	4.3	4.6	2.3	2	2.7	3.3	1	4.7	1.9			0.147	0.088
Adding explicit GQ	2.3	0	6.6	3.3	0	4.6	3.2	5.2	2.6	4.3	5.1	0.063	0.146

Table 4. Circularity results

As in the previous case, the normality of the series of scores obtained was checked using the Kolmogorov-Smirnov test, which resulted in a series of data that followed a normal distribution.

$D(20) = 0.135$, p=0.200

After checking the normality of the data obtained, the two groups were compared by an analysis of variance (ANOVA), which revealed that the result was non-significant. Thus, no difference appeared in the circularity results between using and not using explicit GQ while applying the creative method.

$F(1,18) = 0.252$, $p=0.622$

Fig. 10 shows that the results obtained during the sessions in which the circularity indications were introduced as GQ during the creative method are slightly higher. The range of scores goes from 1 to 4.6 for when requirements are not introduced as GQ, and from 0 and 6.6 when they were introduced by means of GQ. Thus, the results are far more dispersed for the case when GQ were introduced. This might indicate that not all the designers dealt with the methodology applied with explicit GQ in the same way despite the requirements being theoretically the same. The dispersion may lie in the creative stimulus provided when formulating them as GQ. Sentential stimuli, such as questions, have a different effect on the results depending on the innovative or adaptive problem-solving style of the designers (López-Mesa et al., 2011).

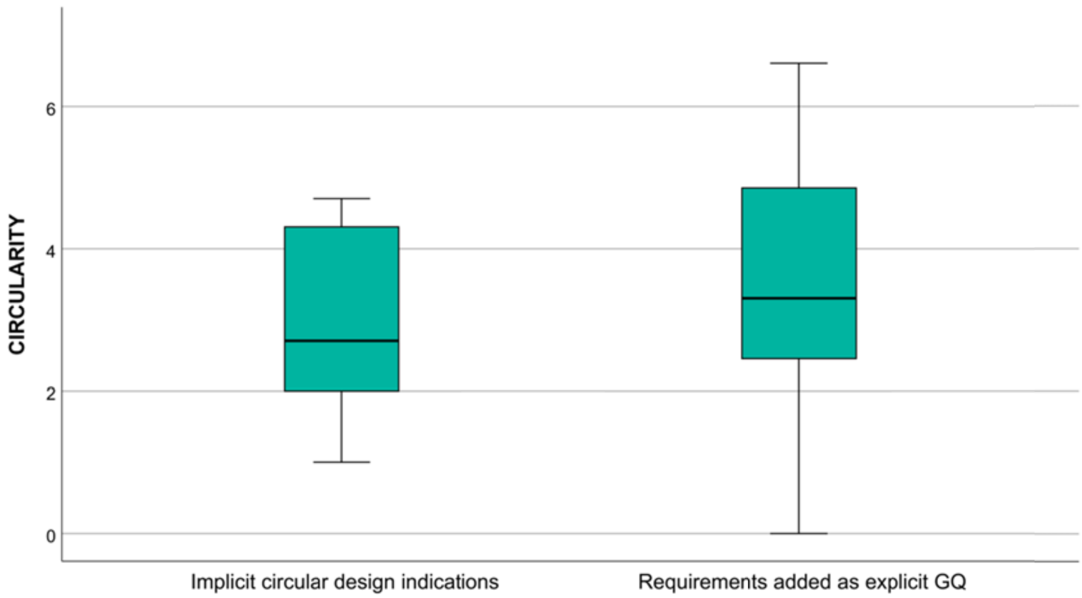


Fig. 10. Circularity results

4.3. Results for number of solutions

Regarding how many circular features are obtained in the design proposals, studies have been conducted on how their number varies depending on whether they were obtained in the groups working with the implicit circular design guidelines on the instruction sheet or, in contrast, if these work groups were working with the adapted 6-3-5 method with guided questions (Table 5).

	Number of circular attributes											M	SD
With implicit requirements	5	7	3	2	3	6	1	5	4			4	1.936
Adding explicit GQ	3	0	8	5	0	7	6	8	4	5	6	5	2.796

Table 5. Number of circular attributes obtained in the design solutions

Firstly, the normality of the results was checked by the Kolmogorov-Smirnov test and the result is, also in this case, that the data follow a normal distribution.

$D(20) = 0.148$, p=0.200

After checking the normality of the results, an ANOVA test was carried out in order to compare how these results vary, depending on whether the creative method applied provides the circularity requirements in the form of guided questions or not, as noted above. Although Fig. 11 shows that the results with explicit guided questions are more dispersed and have the highest scores, the result of the analysis shows that there is no difference between the results for the two groups.

$F(1,18) = 0.436$, p=0.512

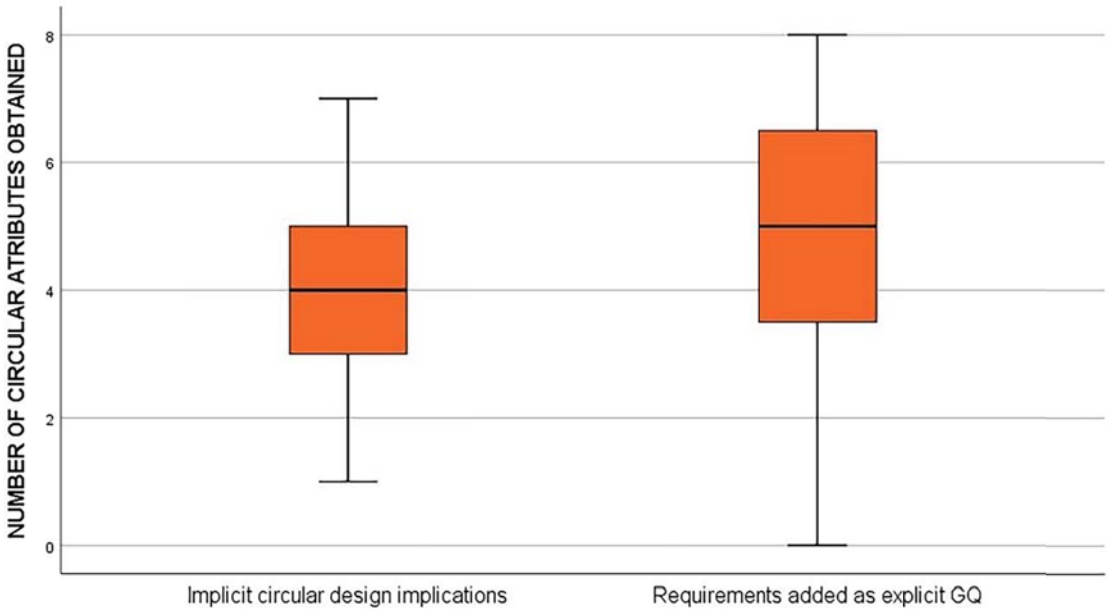


Fig. 11. Results for the number of circular features

4.4. Results for perception questionnaire

In relation to the perception mentioned in the previous section, the four questions formulated in the perception questionnaire were analysed to determine whether their respective results varied according to how the circularity requirements were indicated to the designers (implicitly as selection criteria or by explicit GQ when applying the creative method).

Fig. 12-15 show the results obtained in the perception questionnaire, where 1=not at all and 5=very much in all the sections.

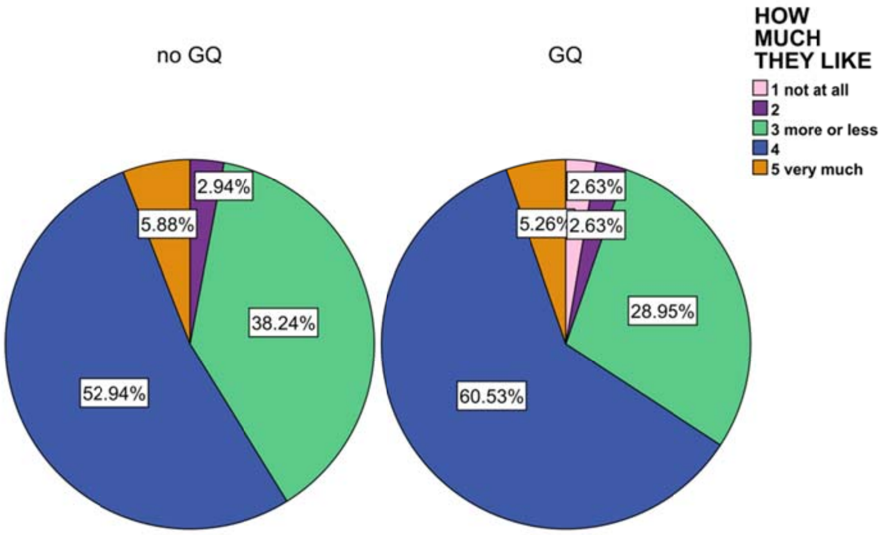


Fig. 12. Results concerning how much the designers liked the method

The questionnaire results revealed that the participants liked the method to a similar extent regardless of whether GQ were added to the method or not. Some participants gave a lower score for the requirements that were given in the form of GQ.

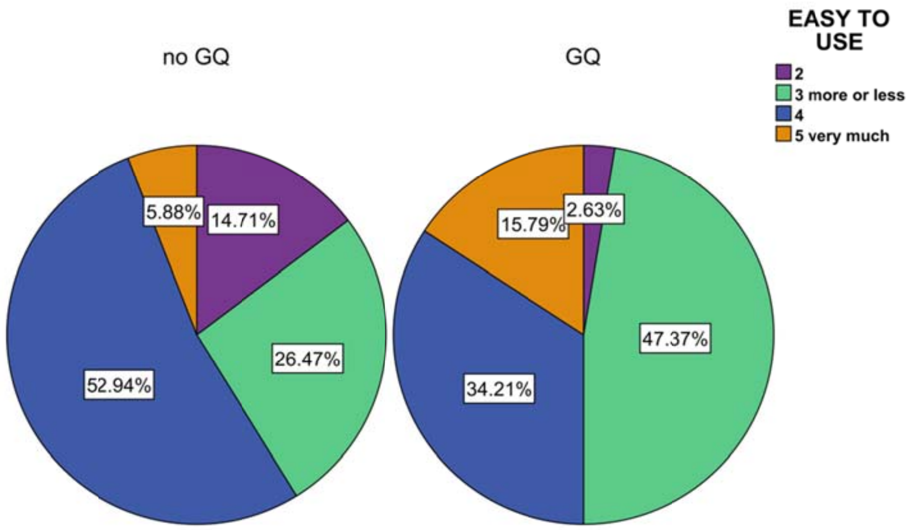


Fig. 13. The results concerning the method being easy to use

None of the participants thought that the method was very hard to use (regardless of adding GQ or not) as no low score was obtained. Nonetheless, for the circularity requirements that were given as explicit GQ, the scores were slightly higher. This could indicate that explicit GQ did not initially affect how at ease the designers felt when using the method because introducing GQ slightly increased their perception about it being easy to use.

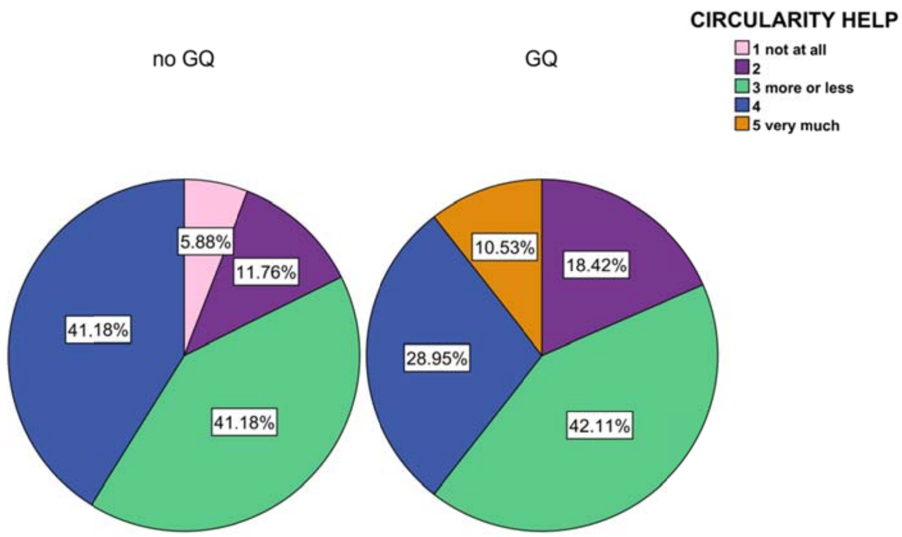


Fig. 14. Results of the extent to which the participants thought the method had helped them to obtain circular ideas

Regarding the participants' thoughts about the method helping them to obtain more circular ideas, Fig. 14 shows how the number of positive scores was similar. However, when requirements are not introduced as guided questions, 5.88% of the participants thought that the method did not help them at all with the circularity of the solutions. This difference was not significant according to the statistical results.

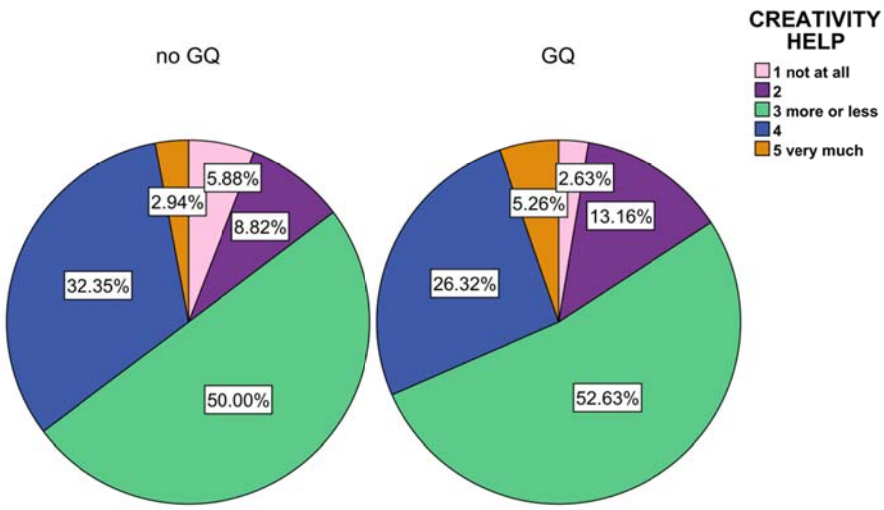


Fig. 15. Results of the extent to which the participants thought the method had helped them to obtain creative ideas

As for their perception about how much the method helped to obtain more creative results, no relevant differences were found between introducing circular design requirements as explicit GQ during the creative method or just describing them implicitly as selection criteria. This coincides with the non-significant difference found between the results about the method being used in one way or the other.

4.5. Circularity and creativity connection

The relation between the creativity results and the circularity results for both study cases was also checked, depending on whether the circularity requirements were implicit in the problem description or if they were included as explicit GQ during the creative process. A poor positive correlation was found (Pearson's correlation coefficient = 0.203) for the relation between the circularity and creativity obtained (Fig. 16). A moderate positive correlation was obtained (Pearson's correlation coefficient = 0.578) for the implicit circularity requirements in the description, while a very poor positive correlation was found (Pearson's correlation coefficient = 0.092) when the method was modified with GQ.

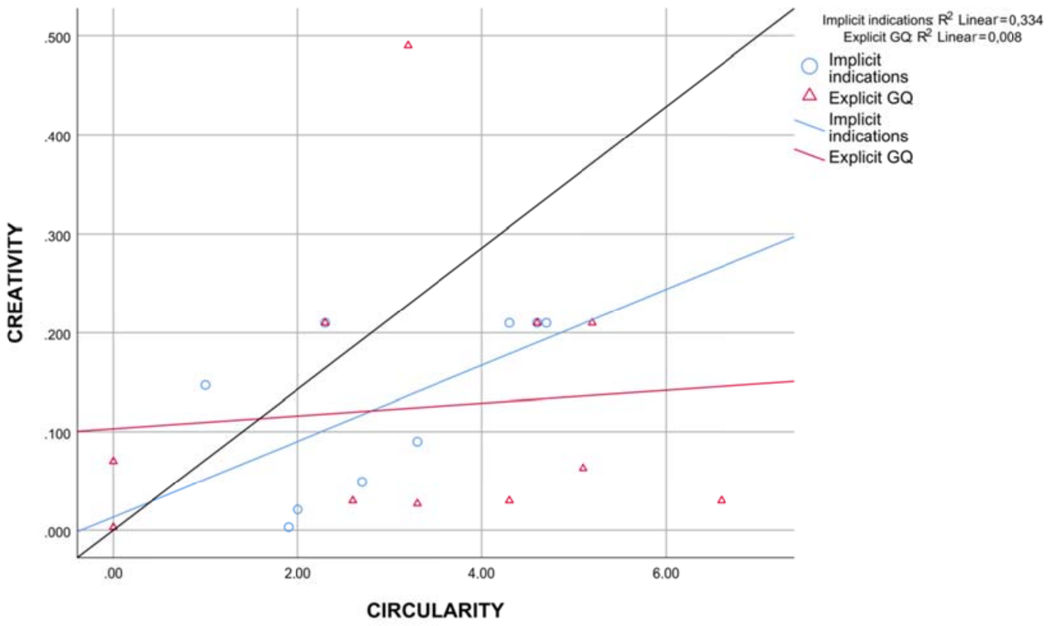


Fig. 16. Correlation between creativity and circularity

The comparison of the circularity and novelty results showed that, although the correlation index was low with implicit requirements, the correlation was higher than when introducing GQ. For the cases when circularity requirements were implicit, data dispersion was narrower than when explicit GQ were introduced to produce circular results.

This dispersion of the results may be due to the designer's personality. Thus, presenting questions explicitly and one by one at each change in the "6-3-5 Method" may be an encouraging measure or an obstacle, depending on the designer's personality. This would be in line with other studies, like that by Chulvi and González-Cruz (2016), who stated that, depending on the designer's personality type, emotionally speaking, they react differently to the design method they use; or those by Mulet et al. (2016) and García-García et al. (2019), who demonstrated that designers' personality interacts with variables related to the creativity of results. This is not the case for all methodologies. For instance, designers with a rational judgement and sensorial perception produce similar creative results to those with an emotional judgement and intuitive perception (Chulvi et al., 2015) using the SCAMPER method. In our case, it was demonstrated that when the methodology was modified by directly introducing GQ, the design results were more dispersed for circularity and creativity, possibly as a result of how designers' different personality profiles react. This would agree with Eris (2004), who says that introducing questions during the design process has an influence on the design outcomes.

Previous findings showed that very strict requirements decrease creativity. In this study, we contribute with new findings about how the use of circular requirements as guided questions during the creative method increases circularity and creativity in some designers and decreases them in others.

5. CONCLUSION

The empirical data obtained showed that introducing GQ explicitly caused no difference in the creativity of the results as opposed to them being introduced implicitly into the description. That is, design requirements affect creativity in a similar way regardless of how they are introduced, i.e. implicitly as selection criteria or as explicit guided questions while solving the problem.

As regards how this affects the circularity of the proposed solutions, initially no significant difference was found in the results obtained by the two groups. Moreover, there are no significant differences between the numbers of circularity aspects. Differences did appear, however, in the dispersion of the results insofar as the participants with implicit requirements presented similar circularity results to one another, while wider dispersion was noted for those who were given GQ. In other words, one part of the study population obtained better results, while the other part achieved poorer results. This indicates that using requirements in the form of explicit GQ might have different effects on the designers who participated in our experiment.

When analysing this difference in terms of perception, a slight preference for using GQ was shown because GQ were also perceived to help the designers generate more circular ideas. Despite a greater number of participants stating that they liked the method without GQ more, there was also a higher percentage of participants who stated that they did not like the method, while the percentage of those people who used GQ and did not like the method was practically zero. Therefore, the preference for using GQ is because by using them they avoid discomfort, not because they provide comfort.

These findings have both practical and educational implications. Introducing circular requirements explicitly during the "6-3-5 Method" would affect the range of the circularity of the design outcomes. At a practical level, this finding can help in the management of design teams in companies in order to generate more creative and circular results. This can also have effects at an educational level. So, this study is a starting point from which to delve deeper into the interaction between the creative method, the questions about circular requirements and the designers.

The fact that the results do not show any differences regarding creativity supports the idea that there is still a need for research on how to foster creativity when designers are required to design more circular products. As dispersion was much wider when explicitly using GQ, the notion that using this methodology affects designers differently is reinforced, but in exactly what way was not studied. Verifying this would be very important to optimise the design results according to each individual by allowing the optimum methodology to be selected according to the designer's personality profile. It would be very interesting to distinguish those methodologies affected by the designer's personality or thinking style from those that are not. Future research lines in the design methodologies field thus indicate that it is worth studying the human-method interaction in order to optimise the design process by selecting optimum methodologies for each type of person. The advantage of having conducted a practical experiment is that the study has used real data but, in order to make up for the limited results, it would be a good idea to enlarge the number of participants in future experiments, to obtain more extensive and diverse data and to verify the results obtained in this work.

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