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CE-oriented culture readiness: An assessment approach based on maturity models and fuzzy set theories

Ana Carolina Bertassini *, Lucas Daniel Del Rosso Calache, Luiz César Ribeiro Carpinetti, Aldo Roberto Ometto, Mateus Cecilio Gerolamo

Dep. of Production Engineering, São Carlos School of Engineering (EESC) - University of São Paulo (USP), Av. Trab. São Carlense, 400, São Carlos, SP 13562-190, Brazil

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ABSTRACT

Moving towards a Circular Economy (CE) requires systemic changes across organizations, technological and cultural changes. However, there is a lack of studies in the literature on guidelines and tools specifically focused on helping organizations to identify the aspects that could be improved to implement a CE-oriented culture. Thus, this paper aims to propose a fuzzy logic-based approach to assess the readiness of organizations to implement a CE-oriented culture. An in-depth literature review to identify the CE-oriented culture elements, a fuzzy Delphi methodology (FDM) to select the elements, a fuzzy inference system (FIS) to classify the organization in readiness levels, and an application to clarify the proposed approach were carried out. The main result of this study is an assessment approach that, based on analyzing a set of elements representing a CE-oriented culture: classifies an organization in six levels of readiness to implement a CE-oriented culture; provides a pairwise comparison of the performance of the organization between the building blocks; and a radar chart with the overall performance of the organization regarding CE-oriented culture. These three outcomes provide organizations with specific information and guidance for decision-making regarding the changes that should be made to adapt or change the existing culture to one that comprises the specificities of CE. This study found that organizations that focus on radical innovations and balance the efforts between technical and soft aspects are more oriented towards a CE culture. It was also identified that making a more in-depth analysis of the presence of CE-oriented culture elements in the organization may contribute by mitigating possible rebound effects that could be generated from implementing CE practices. Moreover, analyzing the culture orientation for CE of the organization might create in leaders and employees a sense of urgency to move towards CE as a way to obtain environmental, social and economic benefits.

1. Introduction

A fundamental shift in the purpose of business is currently occurring towards the transition to a sustainable society and business ecosystem. Circular Economy (CE) is a systemic model that can mitigate chronic problems caused by human economic activities and could be a way to accomplish the Sustainable Development Goals (SDGs) (Schroeder et al., 2018; Kristoffersen et al., 2021), depending on the business strategy. CE promotes a vision that decouples the consumption of non-renewable resources from value creation (EMF, 2014) contributing to organizations dealing with business challenges (e.g., global competition, environmental awareness, and limited resources) (Upadhyay et al., 2021a). CE is rooted in paradigms of waste minimization (Barón et al., 2020) and efficient use of resources (Ghisellini et al., 2016) mostly focused on the environmental and economic side of Sustainable Development (SD). However, CE is also a tool to address existing social needs. This is achieved by empowering workers, enabling social inclusion, and fostering sustainable lifestyles (e.g., applying practices and policies for long-lasting human-centered design) (Geissdoerfer et al., 2017).

CE is usually implemented through Business Model Innovation (BMI). BMI is considered a source of transformation within sociotechnical transitions (Sarasini and Langeland, 2021), representing the micro-foundation of the transition towards CE. The research area of transition towards more sustainable and circular societies is increasing in the literature (van Mossel et al., 2018; Kern et al., 2020; Hacker and Binz, 2021), however, transition aspects inherent in the internal context of organizations and people involved are not considered.

To be able to achieve ambitious targets regarding CE, companies are radically transforming their business models and strategic orientation. However, to support these disruptive changes and successfully

* Corresponding author.
E-mail address: anabertassini@usp.br (A.C. Bertassini).

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Nomenclature

AG	Aggregation operator
BMI	Business Model Innovation
CE	Circular Economy
CM	Centroid Method defuzzification technique
CMM	Capability Maturity Model
Eq	Equation
FDM	Fuzzy Delphi Methodology
FIS	Fuzzy Inference System
FST	Fuzzy Set Theory
MM	Maturity Models
n	Number of discrete points of the fuzzy set
OC	Organizational Culture
R	Implication operator to define the relationship between the input fuzzy numbers and the consequents
S	Fuzzy singleton used in the composition operation to obtain the output fuzzy number
SDGs	Sustainable Development Goals
SEI	Software Engineering Institute
$\mu_{\widetilde{A}}(x);\mu_{\widetilde{B}}(x)$	Membership function that associates the element x to a real value $\in [0,1]$ to represent the membership degree of x in the fuzzy sets $\widetilde{A}$ and $\widetilde{B}$
x_k	Discrete point of the fuzzy set

implement business strategies and BMI oriented to CE, companies need to realign their organizational culture (OC) as OC is the key to solidifying changes that need to be implemented (Sawe et al., 2021). Some previous studies highlighted the need to study the implications of OC in the CE transition (Bertassini et al., 2021a; Korhonen et al., 2018), but they did not discuss the complexity of such aspects. OC is complex and consists of different variables that should be well understood and developed to support the CE transition. These variables are reflected by different people's judgment and are usually intangible and subjective.

Fuzzy logic has the potential to deal with intangible and subjective variables, complex and uncertain problems, and the potential to deal with judgment from different people. Thus, this seems to be a suitable concept to deal with the complexity and subjectivity attached to OC.

Furthermore, a challenge in the transition to CE and changes in OC requires a broad view of the company's evolution, which makes Maturity Models (MMs) suitable. MM aims to guide organizations to assess and track their progress and/or readiness in a certain initiative or domain (Asdecker; Felch, 2018).

In the literature, there is a lack of documented studies regarding the use of MM or similar concepts applied in the CE context. MATChE is a tool to support companies in their transition to circularity. Its development was supported by the Danish Industry Foundation and carried out by the Technical University of Denmark (DTU) in partnership with Rambøll and Viegand & Maagøe consultancies. The tool aims to obtain a 'readiness profile' based on evaluating a set of skills and experience levels of different organizations considering eight different areas: organization; strategy & business model innovation; product & service innovation; take back & end-of-life strategies; use, support & maintenance; technology & data; manufacturing & value chain; and policy & market. This is a robust tool to understand how CE acts in different areas of an organization. However, OC aspects are superficially addressed. Standard BS 8001:2017 (The British Standard Institution, 2017) proposes a maturity level to guide organizations in the transition process by implementing CE principles. The standard addresses a culture of learning and innovation in some of its parts but it does not propose specific aspects that characterize a CE culture or actions that should be taken in the OC sense to foster the transition towards CE. Sehnem et al. (2019) propose an MM used to leverage and measure the implementation of CE in the wine production chain in Brazil but it is focused just on technical aspects of the production processes and its circularity. Other similar studies use MMs for sustainability implementation, but they are applied in specific areas, such as the sustainable supply chain (Salvadó et al., 2018; Okongwu et al., 2013; Chalmeta, Barqueros-Munoz, 2021); industry 4.0 (Benešova et al., 2021; Vásquez et al., 2021; Caiado et al., 2021); innovation (Baumgartner and Ebner, 2010) or strategy (Sari et al., 2020; Hynds et al., 2015).

To the best of the authors' knowledge, none of the previously studied models addresses OC cultural aspects for CE implementation. Moreover, most of the existing MMs applied to 'green contexts' lack a self-assessment tool to support decision-makers in assessing the readiness and/or maturity of fragmented building blocks and elements. Most models do not address CE-oriented culture requirements: do not have a well-defined structure with elements; do not consider the organizations' interests to define improvement actions; do not address the inherent uncertainty brought by intangible aspects of human judgment, and imprecision.

The limitations and weaknesses of previous studies are understood as a research opportunity when combined with the gap identified by Bertassini et al. (2021a) that pointed out the need for the proposal of quantitative methods and tools that support strategic decision-making focused on CE-oriented culture as a way of establishing overarching targets for business outcomes. Thus, this paper aims to propose a hybrid approach based on MMs, Fuzzy Delphi Methodology (FDM), and Fuzzy Inference System (FIS) to evaluate the readiness of organizations to move towards a sustainable CE-oriented culture. The term "readiness" was preferred to address organizations' needs for building a CE-oriented culture, rather than the maturity level of a specific element or building block (see Section 2.2, Maturity Model to understand the difference between them). Moreover, there is a huge variety of techniques, methods, and concepts that could be used to design this kind of tool, but in this study, we address the gap identified by Bertassini et al. (2021a) using fuzzy logic MM. The MM theory was chosen since it allows us to define levels to classify the organizations regarding their readiness to implement some concept. FMD is used to deal with consensus group decision-making in the selection of circular economy elements. FDM is adequate when it is desired to refine the criteria or elements based on the preference of a group of experts (Tseng et al., 2022). Fuzzy logic is suitable to be used to develop tools to assess the maturity of a company as it enables us to consider all the variables used in a problem (Caiado et al., 2021). It is a reliable and useful technique for measuring the level of CE-oriented culture through a readiness assessment approach.

To the best of the authors' knowledge, there is no previous study in the literature that presents an approach that combines MMs, fuzzy set theories, CE, and OC. Thus, this study brings a multidisciplinary theoretical contribution. Studies that combine concepts from different knowledge areas are important to deal with complex, new, and disruptive challenges. Moreover, it presents an adaptable methodology used to develop the approach that could inspire the solution of similar problems in different research areas. This tool is intended to be adaptable to remain applicable to any organization, irrespective of size, sector, location, and technology intensity. It helps managers to improve their journey towards CE as an organization scoring high in CE-oriented culture readiness suggests that strategy and culture are aligned to CE principles. The novelty of this paper lies in the integration of relevant topics from different areas that, when combined, create a powerful, usable, and modern approach to foster the transition towards a CE-oriented culture that has been understood as the key to achieving a sustainable society. Moreover, to the best of the authors' knowledge, it is the first time that decision-making techniques (FDM and FIS) are used to construct an MM that deals with subjective aspects as is the case of the OC oriented towards CE.

The remainder of the paper is structured as follows: Section 2 reviews the literature on relevant topics for this study. Section 3 presents the methods used for the development and testing approach. Section 4 presents the results. Section 5 presents the discussion of the results with a summary of theoretical and managerial contributions. Section 6 presents the main conclusions of the study.

2. Literature review

This section gives an overview regarding the essential concepts for the development of this study: CE-oriented culture (Section 2.1), maturity model theory (Section 2.2), and fuzzy decision-making techniques (Section 2.3).

2.1. Circular economy oriented culture

The CE presents the idea of creating interconnected systems that can be sustained in the long term (Xavier et al., 2021) aiming to optimize the value of products materials, and components (EMF, 2014; Kirchherr et al., 2017). CE aims to create a closed-loop economy by embracing a loop system connecting economy-environment collaborations (Mathews and Tan, 2011). CE can be defined as a new approach to address sustainability, paying particular attention to the social aspect (Upadhyay et al., 2021b). The transition towards CE requires new mindsets (Dufva et al., 2016) that drive organizations to implement radical innovations based on an ecosystem perspective (Konietzko et al., 2020) seeking to deliver value for a diversity of stakeholders (Bertassini et al., 2021b). Creating the right culture is essential for organizations to successfully implement CE strategies.

The OC reflects the values, norms, rules, procedures, organizational goals (Jones, 2013), and the sense of identity shared between the employees (Cameron and Quinn, 2011). OC reflects what an organization is (Smircich, 1983) and has the power to foster or hinder innovations (Schein, 1984). An OC focused on CE is an organization where all members have common and shared values, mindsets, and beliefs about the importance of creating and delivering positive values for all the ecosystem stakeholders.

OC for the CE is recent in the literature and according to Bertassini et al. (2021a), a CE-oriented culture is represented by five building blocks namely mindsets, values, behaviors, capabilities, and competences, that are dynamically linked. Mindsets are rooted in values. Values are translated into behaviors. Behaviors are executed when combined with the right capabilities. Capabilities become competences when they are supported by attitudes. These building blocks represent the soft and hard aspects that are relevant for organizations to promote changes. According to Bertassini et al. (2021a):

Values are criteria, patterns, or directional principles that are related to the future state of a circular organization.

Mindsets are beliefs or mental attitudes aligned with CE principles and values that determine how the organization will interpret and respond to situations.

Behaviors describe how people and organizations act in the CE transition.

Capabilities describe the right theoretical knowledge on CE concepts (qualification) with the ability to perform these concepts (know how to do).

Competences describe the combination of the capabilities implemented repeatedly with the attitudes to implement these capabilities (know how to behave).

To evaluate if an organization has a CE-oriented culture and what elements characterize the circularity of a certain organization, a tool or model is required. OC is passive of evolutions and transformation along time. On the other hand, organizations that are not thinking circular from the beginning need to pass through a journey to implement CE concepts. Thus, the MM theory seems to be a suitable theory to be used to propose a readiness assessment approach.

2.2. Maturity model

In 1979, Crosby developed a maturity framework for quality management (Crosby, 1979), and the Software Engineering Institute (SEI) launched the well-known Capability Maturity Model (CMM) (Paulk, 1993). These two models leveraged the use of MM by many organizations of all domains, and a wide range of models was created for different fields.

MMs are used to support the evolution from an initial state to the desired state following a defined path (Röglinger et al., 2012). The term maturity can be defined as "the state of being perfect, complete and ready, or as a measure used to evaluate the resources of an organization" (Reis et al., 2017, p. 644). MMs are designed to assess the evolution of a selected domain based on a set of criteria in a sequence of levels and used to describe, explain and evaluate growth cycles (Król and Zdonek, 2020). MM can be created for three purposes: be descriptive, prescriptive, or comparative. A descriptive MM is used to assess the as-is situation of an organization and is proposed in the form of a diagnostic tool (Okongwu et al., 2013; Reis et al., 2017; Röglinger et al., 2012). A prescriptive MM is an improvement path to higher maturity levels that provide guidelines and measures to an organization (Okongwu et al., 2013; Reis et al., 2017; Röglinger et al., 2012). A comparative one permits an organization to benchmark capabilities externally and internally based on historical data collected from other organization assessments (Okongwu et al., 2013; Reis et al., 2017; Röglinger et al., 2012).

In this study, the MM is used with a descriptive purpose, that is, to create a readiness assessment approach to identify the level of readiness in a CE-oriented culture. 'Readiness' and 'maturity' are used in the literature to represent the same set of concepts (Pirola et al., 2019) however they have relevant differences. Readiness Assessments are diagnostic tools to analyze and determine the level of preparedness, attitudes, and resources at all levels of a system, aiming to clarify whether the organization is ready or not to start the development process (Akdil et al., 2017; Mittal et al., 2018). On the other hand, MMs are models that help an organization to reach a more sophisticated maturity level in culture, processes, and/or technologies following a step-by-step continuous improvement process (Gökalp et al., 2017).

The implementation of MMs in organizations allows a better decision-making process, highlighting for managers and leaders their current maturity levels and indicating the paths that should be followed to improve in each domain. According to Caiado et al., (2021) and Röglinger et al., (2012), the MM theory should be used to develop ready-to-use instruments for evaluating and improving maturity, and that can adapt to the specific characteristics of the organization.

We analyzed the studies (see Table A in Section 1 of the supplementary material) existing in the literature that uses MM applied to 'green contexts', such as sustainability (Baumgartner and Ebner, 2010; Isaksson, 2019) and eco-design (Pigosso et al., 2013), and CE specifically (Sehnem et al., 2019). These models usually comprise 3 to 6 levels and most of them use 5 levels and are usually based on the CMM. Based on this analysis, the authors decided, as a development strategy, to consider heterogeneous and relevant contents from existing MMs in a new model structure by multiple dimensions. Thus, our approach proposes six levels in which an organization could be classified in its readiness to implement a CE-oriented culture. The levels, their nomenclature, and their descriptions are presented in Table 1.

2.3. Fuzzy decision-making techniques

Decision-making processes usually have to handle information resulting from imprecise and subjective judgments made by different decision-makers using linguistic variables. To deal with this type of information, the Fuzzy Set Theory (FST), proposed by Zadeh (1996), is widely applied in decision-making models (Kahraman et al., 2015). In FST, the linguistic variables are represented qualitatively using linguistic terms and quantitatively translated by fuzzy numbers in a discourse universe using pertinence functions (Abdullah, 2013). The triangular and trapezoidal membership functions (see Fig. A and B and Eqs. (1) and (2) in Section 2 of the supplementary material) are commonly used to represent the fuzzy numbers (Pedrycz and Gomide, 2007).

Table 1
CE-oriented culture readiness levels.

Level		Description
0	Rudimentary	Circular strategies are not part of the organization's interests, they only follow the legislation. They do not express any value, mindsets, behavior, capability, or competence oriented to CE.
1	Early stages	The organization has little experience or knowledge about circular business strategy. There are some actions related to CE, but environmental and social protection actions are seen as costs. There are a few values that are related to CE, but the current mindsets and behaviors are focused on economic gains.
2	Opportunist	The organization has some knowledge but lacks experience in CE. It believes that the implementation of circular strategies can create opportunities for cost reduction. It implements circular strategies focused on dealing with basic inefficiencies, and/or reaching some specific strategic goal. It shares in the mission and vision some values that are related to CE. It understands the need to implement circular strategies, but does not cultivate day-to-day behaviors that express this concern. It only develops specific projects on this thematic.
3	Integrated	It occasionally works with CE and has some knowledge and experience. It incorporates some circular principles in some of our products/services and processes. It captures some values regarding the implementation of circular strategies. CE strategies are formalized in documents and processes. The organization is engaged in the transition to a more circular economic model. It shares internal values that cultivate circular behaviors and mindsets.
4	Innovative	It frequently works with CE and has substantial knowledge and experience. It Incorporates CE principles in the innovation projects portfolio, including the development of new products, in the marketing of the brand, and in reports. The business model is circular and captures many circular values and even shares them with direct stakeholders. It engages with some groups that study and discuss CE. Most of the shared values are circular and cultivate day-to-day pro-circular behaviors and mindsets.
5	Leader	The organization has profound experience and in-depth practical knowledge. CE is in DNA and CE is the way to do business. It disseminates CE at the ecosystem level and brings together the stakeholders (direct and indirect). We are engaged in the proposition of public policies and legislation to foster the transition towards CE. It influences other organizations to engage in the transition journey. All shared values cultivate circular behaviors and mindsets. It seeks to improve circular performance measurement.

The FST stands out due to its ability to be combined with different decision-making techniques to address data imprecision (Dubois and Prade, 2012). Several studies in the context of CE have been using the FST combined with techniques to solve different decision-making problems (Sassanelli et al., 2019). However, the selection of a fuzzy decision-making technique depends on the characteristics of the problem being analyzed and its objectives. For the present study, the Fuzzy Delphi methodology and the Fuzzy Inference System technique were applied in the proposed decision-making model.

2.3.1. Fuzzy Delphi method

The Delphi Method was presented by Dalkey and Helmer (1963) and is an interactive consensus approach widely applied in many decision-making and prediction problems (Kannan, 2018). In the Delphi Method, a group of experts present their access to a given problem, and based on a feedback mechanism, the experts can modify their previous judgments to reach a consensus. However, the achievement of consensus through repetitive surveys can be difficult and time-consuming (Zhao and Li, 2015). Besides that, the traditional Delphi Method is not adequate to handle uncertainty and imprecise experts' judgments. Therefore, the FDM has been used to overcome the limitations of the traditional Delphi Method (Noori et al., 2020).

Initially proposed by Murray et al. (1985), the FDM has different operation approaches developed in several studies (Wang and Peng, 2020). A well-known method is presented by Ishikawa et al. (1993), which integrates the experts' judgments into fuzzy numbers (Hsu et al., 2017). Since its proposition, the FDM has been used in several decision-making models for the elicitation of criteria, definition of performance indicators, and selection of decision-makers (Liu et al., 2020; Noori et al., 2020; Zhao and Li, 2015). For this study, the operations approach presented in Kannan (2018) is used in the FDM (see Section 3 in supplementary materials for more details about the mathematical step-by-step for the FDM application).

2.3.2. Fuzzy inference system

The FIS is a non-linear approach widely used in decision-making models to model human reasoning through fuzzy if-then rules (Zanon et al., 2020). The main features of FIS are the ability to handle natural language using fuzzy linguistic variables, and it addresses non-linear relationships between inputs and outputs, making it an important tool for decision support systems and process control (Guillaume, 2001). The FIS proposed by Mamdani and Assilian (1975) is one of the most applied inference systems, in which the antecedent and consequence are defined as fuzzy sets, which are suitable for linguistic models (Pourjavad and Mayorga, 2019).

The Mamdani Inference method uses inference rules defined through experts' knowledge. The inference rule base is created using the logic connector "AND" to define the inference relation between the output and input fuzzy variables (Junior et al., 2013). To this end, the t-norm (minimum) operator, presented in Eq. (1) is usually applied because of the smaller computational effort required (Zanon et al., 2020).

$$\mu_{\widetilde{A}}(x)\ AND\ \mu_{\widetilde{B}}(x) = Min\left\{\mu_{\widetilde{A}}(x), \mu_{\widetilde{B}}(x)\right\} \tag{1}$$

For each activated rule, the Minimum (Mamdani) implication operator is represented in Eq. (2) and is commonly used by the fuzzy inference structure to define the relation R between the fuzzy numbers obtained from the logic operations and the consequent $\widetilde{B}$ (Osiro et al., 2014). Other options of implication operators that are frequently applied are the Max-Min (Zadeh) and the Multiplication (Larsen), presented respectively by Eqs. (3) and (4) (Pourjavad and Mayorga, 2019).

$$\mu_{R_{A\to B}}(x,y) = Min\{\mu_A(x), \mu_B(x)\} \tag{2}$$

$$\mu_{R_{A\to B}}(x,y) = Max\{1-\mu_A(x), Min(\mu_A(x), \mu_B(x))\} \tag{3}$$

$$\mu_{R_{A\to B}}(x,y) = \{\mu_A(x) * \mu_B(x)\} \tag{4}$$

The operation called composition is used to obtain the output fuzzy number of each activated rule. Composition operations are carried out between a fuzzy singleton and the implication relations. The most commonly used composition operators are Max-Min, Max-Prod, and Max-Media, respectively given by Eqs. (5) to (7) (Junior et al., 2013; Osiro et al., 2014).

$$S \circ R(x,y) = Max\{Min(\mu_S(x,y), \mu_R(y,z))\} \tag{5}$$

$$S \cdot R(x,y) = Max\{\mu_S(x,y) * \mu_R(y,z)\} \tag{6}$$

$$S \oplus R = Max\left[\frac{1}{2}(\mu_S(x,y) + \mu_R(y,z))\right] \tag{7}$$

The last step of the inference process is the aggregation of the resulting composition operations for each activated rule (Pourjavad and Mayorga, 2019). Different aggregation operators can be used in this step, such as arithmetic, geometric or harmonic means, Min and Max. However, when it is desired the compensation between input variables, the Max operator shown in Eq. (8) should be applied (Zanon et al., 2020).

$$AG(.) = Max\left(\mu_{R_1}(x), \mu_{R_2}(x), \ldots, \mu_{R_n}(x)\right) \tag{8}$$

The output fuzzy numbers resulting from the inference process are converted into a crisp number using a defuzzification technique. The Gravity Center or Centroid Method is the most used defuzzification technique because of its ability to consider all membership values in a given region, assuming a centralized position. Let n be the number of discrete points of the fuzzy set, and then the Centroid Method can be represented as in Eq. (9) (Martínez et al., 2020).

$$CM = \frac{\sum_{k=1}^{n} \mu_A(x_k) * x_k}{\sum_{k=1}^{n} \mu_A(x_k)} \quad (9)$$

After the defuzzification process, a classification procedure can be carried out considering all the individual contributions to each activated rule. The class to be provided as a response will be given by the linguistic term that produces the highest degree of activation concerning that defuzzified value (Osiro et al., 2014).

3. Methods

This study can be classified as quantitative axiomatic prescriptive model-based research as it proposes a quantitative model that analyzes the behavior of a system variable based on the behavior of other variables (Bertrand and Fransoo, 2016). It is axiomatic as the research uses the theoretical foundation consolidated through a literature review to construct the questionnaire and to define the readiness levels. It is prescriptive since we combine the literature with fuzzy techniques to propose an approach to evaluate the readiness of organizations to move towards a sustainable CE-oriented culture. The proposed approach was constructed and applied based on the problem presented in the introduction following four steps as shown in Fig. 1.

Step 1 – Theoretical background: consisted of a literature review to identify the elements that characterize a CE-oriented culture and a literature review to identify the existing MM or readiness tools applied to 'green context'. To identify the elements an exploratory review was

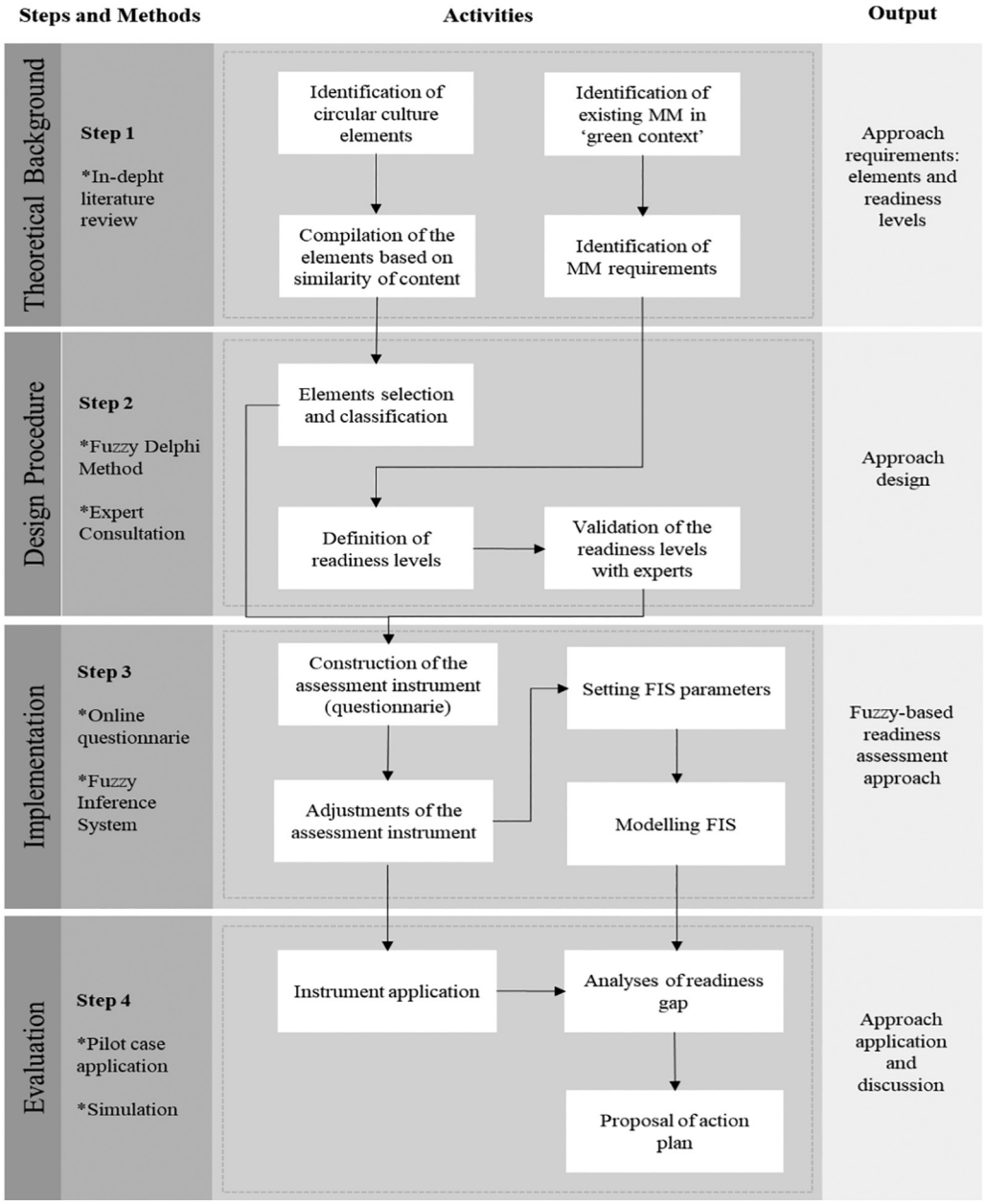

Fig. 1. Methodological steps.

conducted to increase the number of papers reached. 151 elements (see Table B in Section 4 of the supplementary material) were initially identified.

To identify the MM or the readiness tools, a keyword search of the article's title, abstract, and keywords was carried out in the Scopus and Web of Science databases. The search is limited to the string: *(((“maturity model” OR “readiness assessment”) AND (“sustainability” OR “circular economy” OR “closed-loop” OR “organizational culture”)))*. The studied articles went through a systematic review procedure: first, the title, abstract, and keywords were analyzed; then, the introduction and conclusion, and then the full paper. As inclusion criteria, we only selected articles that propose maturity levels or readiness assessments applied to ‘green contexts’ or that used fuzzy as a development methodology. In total, 19 articles were analyzed in-depth considering the number of levels, the description of each level, and the domains addressed by the MM. Based on the study of the existing MM, the authors decided, as a development strategy, to consider heterogeneous and relevant contents from existing MMs in a new model structured by multiple dimensions, linked with fuzzy logic. Thus, this first step was conceptual and derived the initial set of elements and the levels and characteristics that the readiness assessment approach should have.

Step 2 – Design procedure: in this step, the approach was designed. First, the initial set of elements was selected and classified using the FDM. Then, the number of readiness levels and description of each level were proposed and validated with experts.

Step 3 – Implementation: this step comprises the construction of the assessment instrument (questionnaire) and the definition of the FIS functions and rules. The first draft of the questionnaire was built and discussed with CE experts resulting in some adjustments on the questionnaire and the application platform, ensuring that professionals would have no difficulty in answering it.

Step 4 – Evaluation: this step embraces the application of the assessment instrument through a pilot case study application. Then, we analyzed the CE-oriented culture readiness gap of the case in the study and proposed an action plan for the organization to move towards a more circular culture.

3.1. Proposed assessment approach

Based on the methodological steps and in the literature review, we proposed an approach for assessing the CE culture readiness. Fig. 2 presents the phases followed to develop the approach using fuzzy logic.

3.1.1. Identification and classification of elements

The elements that compose a CE-oriented culture were identified through an exploratory literature review. 151 elements were identified. The most important elements of this list were selected and classified into the five CE-oriented culture building-blocks (value, mindsets, behavior, capability, and competence) proposed by Bertassini et al. (2021b) using the FDM applied through the steps below:

Define the experts and develop the questionnaire: the questionnaire was developed in a spreadsheet format to be sent to the CE experts to collect their perceptions, select and classify the elements. The experts judged them using a Likert scale from 1 to 5 (1 = unimportant; 2 = low importance; 3 medium importance; 4 high importance; 5 = essential), to classify the level of importance of each one of the elements for the maintenance of a CE-oriented culture related to each one of the proposed building blocks.

Determine the triangular fuzzy number for the evaluations of each element: with all the experts' answers, triangular fuzzy numbers are determined for each evaluated element (see Table C in Section 5 of the supplementary material) in each building block (Eqs. (1), (2), and (3) used are presented in Section 3 of the supplementary material).

Defuzzification of the defined fuzzy numbers for each element: with the triangular fuzzy number for each element in each building block the defuzzification operation (Eq. (4) presented in Section 3 of the supplementary materials used to obtain a score crisp number as the output (see Table D in Section 6 of the supplementary material).

Filter the elements in each building block: based on the defuzzified numbers, the elements were selected and classified into the building blocks. First, similar elements were aggregated following the experts' recommendations. Then, to be considered part of a building block, the element score should be bigger than 4. The elements defined for each building block are presented in Section 4.1.

3.1.2. Performance evaluation

The assessment instrument (questionnaire) was developed based on the elements identified in the previous phase. The questionnaire is divided into seven sections: an overview about the questionnaire and guidelines to answer it, five sections (values, mindsets, behaviors, capabilities, and competences) comprising the evaluation questions, and a section to collect generical data about the respondents (see the questionnaire in Section 7 of the supplementary material). The respondents followed a 1 to 5 scale (where 1- absent/understanding the potential; 2- planning/first

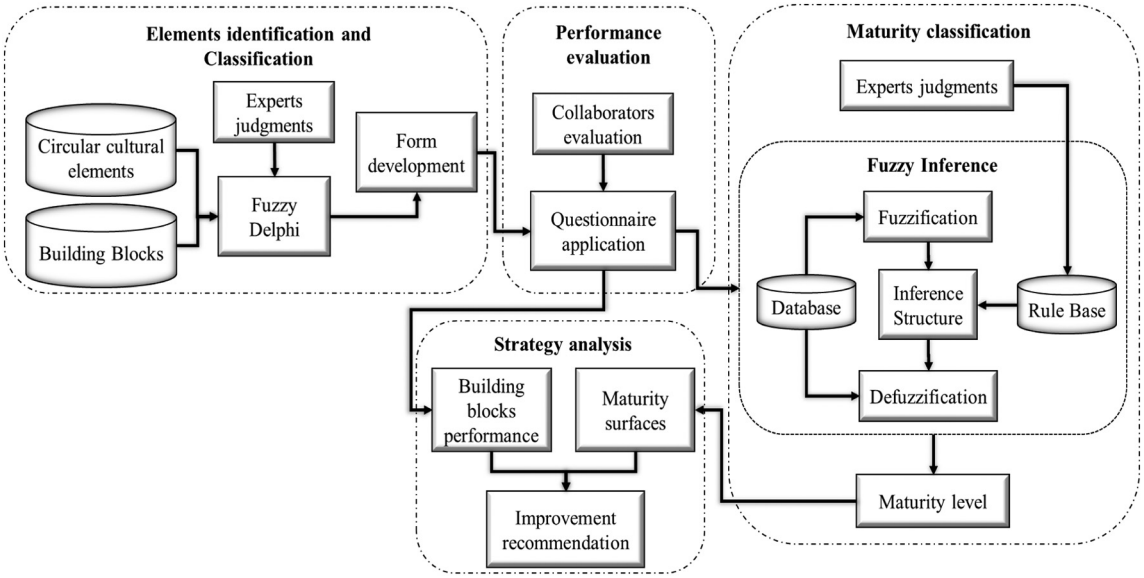

Fig. 2. A proposed approach for assessing circular economy readiness.

Table 2
Trapezoidal and triangular fuzzy numbers.

Antecedent variable building block	Linguistic term		
	Low	Medium	High
Values	(18, 18, 27, 54)	(27, 54, 81)	(54, 81, 90, 90)
Mindsets	(19, 19, 28.5, 57)	(28.5, 57, 85.5)	(57, 85.5, 95, 95)
Behaviors	(7, 7, 10.5, 21)	(10.5, 21, 31.5)	(21, 31.5, 35, 35)
Capabilities	(14, 14, 21, 42)	(21, 42, 63)	(42, 63, 70, 70)
Competences	(17, 17, 25.5, 51)	(25.5, 51, 76.5)	(51, 76.5, 85, 85)

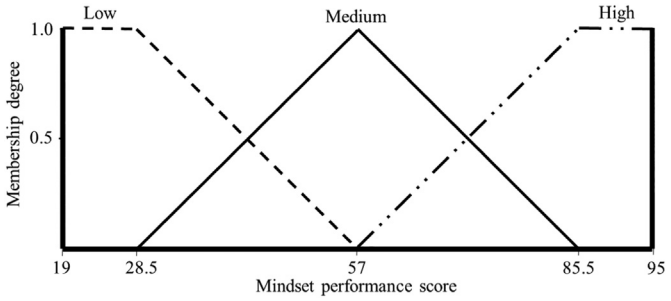

Fig. 3. Example of the fuzzy numbers used to represent the "Mindset" input variable.

Table 3
Triangular fuzzy numbers used to represent the readiness levels.

Maturity levels	Triangular fuzzy numbers
Rudimentary	(0, 0, 2)
Early stages	(0, 2, 4)
Opportunist	(2, 4, 6)
Integrated	(4, 6, 8)
Innovative	(6, 8, 10)
Leader	(8, 10, 10)

implementation initiative; 3- planning the dissemination; 4- giving scalability, 5- totally present) to answer the questionnaire.

The rating average of each element was used to compose the total performance of the building blocks. The answers collected through this questionnaire were used as input for the application of the FIS to evaluate and classify the cultural readiness of the organization to implement CE.

A pilot application of the proposed approach was conducted in a multinational mining and steel company operating in Brazil, whose defined fictitious name is the Alpha Company. Brazil is the 9th producer in the world ranking of steel production and this sector has greater importance for economic development since steel is used in a variety of products and industry sectors. In Brazil, the Alpha Company has an installed capacity of more than 12.5 million tons/year and employs around 17,000 people. Steel is the most recycled material in the world and is a versatile and permanent material with infinity potential of transformation. Thus, the Alpha Company takes advantage of such characteristics of steel and is involved with CE projects. We chose the Alpha Company for our application due to their potential to leverage the implementation of CE in Brazil.

3.1.3. Readiness classification in maturity levels

The answers collected by the questionnaire are used to classify the readiness of the studied organization to implement a CE-oriented culture in maturity levels. To do this, three linguistic terms are proposed to represent the performance of each building block (antecedent linguistic variable). The linguistic variables are represented by trapezoidal and triangular fuzzy numbers as shown in Table 2. Fig. 3 presents an example of the fuzzy numbers used to represent the "Mindset" input variable. It should be noted that the universe of discourse of each building block depends on the number of elements present in it (The quantity of elements is not the same for all the five building blocks).

To define in which level of readiness an organization is classified, six linguistic terms are used as consequents variables, based on the CE-oriented Culture Readiness Levels presented in Table 1. The Triangular fuzzy numbers are used to represent these terms, as shown in Table 3 and detailed in Fig. 4.

The rule base used in the model consists of 243 if-then rules (see Table E in Section 8 of the supplementary material). The consequent linguistic term for each rule was defined by a panel of 6 experts in the field and with in-depth knowledge of the interactions between the antecedents. The Mamdani Inference method is applied as presented in Section 2.3.2. After defuzzification, the organization is classified in the readiness level for which the defuzzified output has the highest membership degree.

Using the results of this phase, response surfaces, and the result of the questionnaire application, radar chart, it is possible to define strategical improvement recommendations to achieve a CE-oriented culture.

4. Results

This section comprises the presentation of the results, which are: the elements that characterize a CE-oriented culture (Section 4.1), the performance evaluation and readiness classification of the studied organization (Section 4.2), and sensitivity analysis (Section 4.3).

4.1. Elements of a circular economy-oriented culture

The questionnaire, proposed in Section 3.1.1, was sent to eight professionals that are dedicated to studying and working in the field of CE for at least three years. The FDM application resulted in the classification

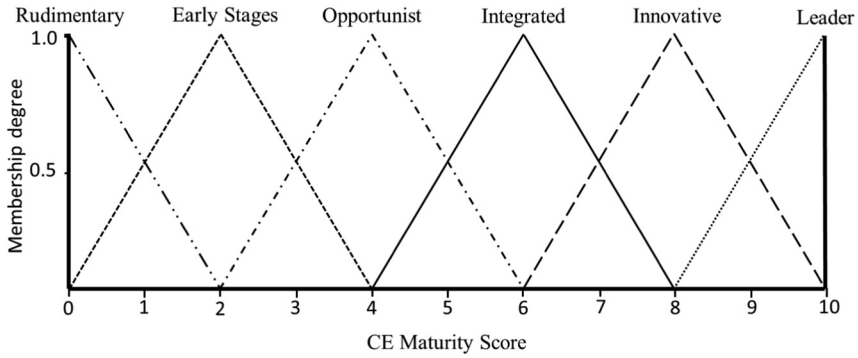

Fig. 4. Triangular fuzzy numbers used to represent the readiness levels.

Table 4
Circular values.

	Value	Description
V1	Adaptability	It has the ability to adjust or adapt to local circumstances
V2	Audacity	It is bold to innovate and opposes the current standards
V3	Collaboration	It cooperates with stakeholders to create joint value, achieve common goals, and create a sustainable system. It is close to its stakeholders. It builds strong relationships and interactions with stakeholders, based on trust and sharing.
V4	Commitment	It is dedicated to the cause of CE and making efforts to achieve the organization's CE goals and values should be part of every employee
V5	Creativity	It is able to produce original and unusual ideas, or to do something new or imaginative
V6	Diversity	It prioritizes the value creation and delivery for diverse stakeholders. Diversity is good. Different sources of inputs, suppliers, sources of income, and workforce are better than only one source. It promotes a plurality of perspectives and solutions for CE and a culture of knowledge exchange and learning across society, generates a global knowledge base supporting local, context-dependent implementation, to build-in resilience against the uncertainty that accompanies transition processes with sufficient backup solutions.
V7	Effectiveness	Effective use of resources. It uses resources intelligently to achieve the objectives set
V8	Environmental-friendly	It uses recycled/reused/renewable material where possible. It embraces the use of environmental-friendly/sustainable materials
V9	Ethic	It has the fundamental assumption about what is morally right and wrong
V10	Impact	It creates a positive influence in a situation, person, organization, society, or the environment. It minimizes resource consumption and environmental impact. It focuses on generating global positive impacts when the organization has global dimensions. It is able to reduce emissions and environmental footprint.
V11	Innovation	It creates and implements new ideas that can be applied in products/services, processes, business models, and value chains. Circular/sustainable-oriented innovation rather than profitability. The proposition of an interconnected set of innovation, where each one influences the other, with innovation both in parts of the system and in how they interconnect.
V12	Longevity	It focuses on the longevity of things. It extends the service life of products, materials, and components
V13	Regeneration	It prioritizes regenerative resources
V14	Sharing	It shares information, ideas, and resources with stakeholders. Open communication, mutual understanding, and the exchange of information, news, ideas, feelings, and the sharing of meaning are essential to support CE transition.
V15	Simplicity	It focuses on the simple, it produces in a simple, intuitive way, and with a visual layout; it makes it easier to use, understandable and easier to update
V16	Sustainability	It aims to provide economic, environmental, and social benefits simultaneously, and values the well-being of the current and future generations. Using resources within planetary boundaries, enhancing natural capital within and across generations. It creates a collective organization of fair access to resources within and across generations to enable social and environmental quality
V17	Transparency	It carries out activities openly, so that people can trust in your fairness and honesty.
V18	Waste Reduction	It focuses on eliminating/minimizing residues at the source to minimize the amount needed to be treated and discarded

of the elements for each CE-oriented culture building-block. 76 elements were selected and classified in 18 values; 19 mindsets; 7 behaviors; 14 capabilities; and 17 competences.

Table 4 shows the 18 selected circular values. Those values determine the criteria, patterns, or directional principles that demonstrate the things that are most important to achieve a circular organization. These values could be explicit and communicated or they could be tacit and showed through actions but not communicated. They are the basis for mindset construction and translated into daily behaviors.

Table 5 shows the 19 selected circular mindsets. Those mindsets are the beliefs of the organization and its members that are aligned with CE principles and values and that determine how the organization interprets and responds to situations regarding the implementation of the CE.

Table 6 shows the 7 selected circular behaviors. Those behaviors describe how people and organizations are acting in the cause of CE implementation. Behaviors are daily actions carried out through appropriate capabilities.

Table 5
Circular mindsets.

	Mindset
M1	It makes all the stakeholders aware of the importance of inclusion and respect for ethical values, the preservation of the environment, sustainable development, and the guarantee of an adequate quality of life.
M2	Willingness to accept and embrace change as part of daily interactions and activities.
M3	It is concerned and perceives negative impacts of activities on the environment and society and pays attention to implementing of mechanisms that encourage sustainable development.
M4	It is able to change easily and adapt to different conditions and circumstances.
M5	It focuses on the future, that is, plan actions to anticipate future consequences. It has a long-term view. It embeds strong sustainability in political-economic systems, seeking a GDP growth to long-term multi-dimensional prosperity in environmental, social, and economic terms.
M6	It is humanitarian and wants good for humanity and improve the environment and social condition of a place and/or a community. It creates conditions that offer equity in achieving a quality of life that meets human rights standards for all.
M7	Inspired by people, especially leadership, to come up with new and creative ideas.
M8	It leads the transition. Intentionally influences stakeholders to move towards CE.
M9	It listens to comments, feedback, concerns, and new ideas, receives criticism and dialogue.
M10	It is proactive and anticipates future problems and/or needs, to change behaviors and situations in search of effective consumption and production results.
M11	Resilience is a state of life and gives us the ability to adapt business models and strategies according to continuous changes, adjusting trends capable of altering the business' profit generation. It is able to return to its original or improved state after being disturbed by some condition.
M12	It considers systems thinking and understands the interdependent relationships between various components that are part of the organization and its business ecosystem. It takes a whole system approach to understand challenges and the potential of proposed solutions in a precautionary way through a continuous improvement process.
M13	Learning about sustainability should not be restricted to leaders and senior managers
M14	Every unmet request of a customer is a potential new solution
M15	It nurtures a culture of civic responsibility and awareness surrounding resource efficiency. Move away from producer-driven consumerism and towards systems-of-provision that enable responsibly, reduce, demand-driven resource use and more sharing, service, and experience-based consumption.
M16	It refreshes one's mind, seeing existing things differently
M17	It is comfortable with complexity and systems thinking
M18	It empowers the employees to come up with new ideas and opportunities to improve the product, business, and system circularity, and raises employees' awareness to contribute to the journey towards the CE
M19	Communicate and share know-how and experience across functions

Table 6
Circular behaviors.

	Behavior
B1	It influences, motivates, modifies the thinking or behavior of stakeholders to include the concepts of circular economy
B2	It establishes synergic relationships to be more successful and/or productive
B3	It communicates, commits and educates consumers about products issues and the merits of the circular economy
B4	It performs reverse logistics and establishes a system for recovering/remanufacturing/refurbishing/recycling the used and defective products and parts
B5	It promotes the local market and local producers
B6	It trains ecosystem partners to make them aware of circular economy issues and to establish a closer relationship
B7	It manages an open ecosystem with new forms of collaboration and engages in open innovation

Table 7 shows the 14 selected circular capabilities. These capabilities describe the proper theoretical knowledge on CE concepts (qualification) with the ability to perform these concepts (know how to do). These capabilities become competences when they are supported by attitudes.

Table 8 shows the 17 selected circular competences. These competences describe the combination of the capabilities implemented repeatedly with the attitudes to implement these capabilities (know how to behave) to be successful in CE implementation.

4.2. Performance evaluation and readiness classification

The questionnaire, proposed in Section 3.1.2, was answered by 19 employees from the Alpha Company in the areas of sustainability & environment; innovation & product development; culture & innovation competences; governance, risk & compliance; and research & development. Moreover, 15 of the 19 respondents play the role of innovation agents within the company. As it is a large company, the sample of respondents was selected so that some representatives from the main areas of the company would participate in the assessment. This sample is sufficient to understand the cultural orientation of these areas towards CE. Information about the respondents is presented in Table 9.

The results obtained from the questionnaire were used as input data (see Tables F to J in Section 9 of the supplementary material to consult the answers obtained through the questionnaire application), and it is summarized in Table 10. The parameters used to define the fuzzy numbers applied in the fuzzy inference system were previously presented in Section 3.1.3. Table 2 presents the input parameters, while Table 3 presents the output parameters for CE maturity classification. The FIS used the "Minimum implication operator" represented in Eq. (6), and the "Max-Min composition operator" presented in Eq. (3). The "Max operator" shown in Eq. (8) was used for the aggregation of the composition operations. Finally, the resulting "crisp" defuzzified number was obtained through Eq. (9). All the operations were carried out using the fuzzy MATLAB© toolbox.

Table 7
Circular capabilities.

	Capability
C1	Ability to sell outcomes and lifecycle services. It is able to develop new offers and pricing models focused on outcome-oriented solutions
C2	It is able to understand, coordinate, engage and manage the ecosystem partners and different stakeholders to share resources, operations, close the loop and co-innovate
C3	It is able to design effective and dynamic systems; business models and intelligent products for longer and multiple life cycles.
C4	It is able to integrate circular economy principles into product design
C5	It is able to understand dependencies, risks, and opportunities through a sustainable and circular lens
C6	It is able to give guidance on how to use the product throughout its life cycle
C7	It is able to establish return systems to add value to products and facilitate the disposal of end-of-life products
C8	It is able to integrate technologies to monitor, track and sort materials and product flows
C9	It is able to attract new talents with circular values and motivate old employees
C10	It is able to enable a culture shift to embrace cross-functional collaboration, system thinking, and customer-centricity
C11	It is able to develop and implement metrics to measure the performance over time and to incentivize the development of circular capabilities
C12	It is able to transform the linear supply chain into a circular one
C13	It is able to collect data, develop and initiate circular programs and communicate outcomes
C14	It is able to optimize values from products and increase the use of capacity

Table 8
Circular competences.

	Competence
Co1	Embedding sustainability should include technical and action learning opportunities
Co2	Working close to the consumers, including them in the product design, and understanding their user journeys and needs
Co3	Establishing a proper system to recover materials at end-of-life and reuse them in their production or share with ecosystem partners
Co4	Training employees in circular economy issues to educating them and to bring in concrete projects to work on
Co5	Establishing effective and transparent communication with stakeholders to share information and opportunities about circular and environmental initiatives
Co6	Ability to design products for circularity. Design, select and transform industrial systems, supply chains, materials, and products, using "R-ladders" and whole-system assessments of solutions.
Co7	Ability to create synergies, define and map out the ecosystem stakeholders
Co8	Ability to source and use recycled or recyclable materials
Co9	Ability to deploy technologies and data for delivering outcomes
Co10	Ability to develop, transform and motivate circular competences, outcomes, and jobs
Co11	Ability to understand product functions, maintenance procedure, failure mode, and wear by using
Co12	Able to negotiate new types of contracts considering the diverse roles that each stakeholder can perform
Co13	Able to put the customer at the center of product design and delivery value-adding solutions
Co14	Able to map out the customer stakeholders, understand their needs, engage them in the sales process and the product lifecycles
Co15	Able to prolong the life of products, components, and materials developing services and after-sales offering
Co16	Able to eliminate the use of a hazardous substance and access materials that can easily be regenerated and recycled
Co17	Able to build, maintain and expand CE understanding among ecosystem partners (including workers and customers) to train and support the organization and identify new opportunities and improvements

The output value of 5.54, on a 0 to 10 scale, was obtained as the organization's current performance in terms of readiness to implement a CE-oriented culture. Thus, the Alpha Company is classified at the "Integrated" level, which means that Alpha has some knowledge and experience in CE concepts and practice. It incorporates CE principles in some of its products/services and processes. It already captured some values regarding the implementation of circular strategies, and these strategies are formalized in documents and processes. It is engaged in the transition to a more circular model and it shares values that cultivate circular behaviors and mindsets. However, as was confirmed by the Alpha Company Sustainability Report and by some interviews with the questionnaire respondents, Alpha has a long way to go in the transition journey towards CE. Despite Alpha having many actions and projects oriented to the CE implementation, they are just incremental circular innovations and mostly focused only on recycling.

FIS application results in the surfaces are presented in Figs. 4 to 13. From the evidence, it can be compared how a building block behaves concerning another. The surfaces present 3 dimensions: the organization's current performance in one dimension and one building block in each one of the other two dimensions. In general, the surfaces demonstrate that not one factor has a major impact on the others in the context of the Alpha Company. In each one of the surfaces, two building

Table 9
Respondents' information.

Respondents	Area	Innovation agent	Level of knowledge in CE
R1	Environmental management	Yes	Some knowledge in CE
R2	Research & development	Yes	Some knowledge in CE
R3	Research & development	No	High level of knowledge in CE
R4	Research & development	Yes	Some knowledge in CE
R5	Research & development	No	Some knowledge in CE
R6	Research & development	No	Some knowledge in CE
R7	Research & development	Yes	High level of knowledge in CE
R8	Research & development	Yes	Some knowledge in CE
R9	Research & development	Yes	High level of knowledge in CE
R10	Research & development	Yes	Some knowledge in CE
R11	Research & development	Yes	Some knowledge in CE
R12	Research & development	Yes	High level of knowledge in CE
R13	Research & development	No	High level of knowledge in CE
R14	Innovation & product development	Yes	Some knowledge in CE
R15	Governance, risk & compliance	Yes	High level of knowledge in CE
R16	Sustainability & environment	Yes	Some knowledge in CE
R17	Culture & innovation competences	Yes	High level of knowledge in CE
R18	Innovation & product development	Yes	Some knowledge in CE
R19	Sustainability & environment	Yes	High level of knowledge in CE

Table 10
Results obtained from the questionnaire and used in the FIS.

Antecedent variable building block	Input data used in the FIS
Values	61
Mindsets	62
Behaviors	22
Capabilities	44
Competences	57

blocks can be compared and it can be analyzed which one should be more developed for the company to achieve CE maturity.

By observing the current point in which the organization finds itself, some elements that were not yet implemented can be prioritized to increase the level of maturity more quickly. As can be observed in Figs. 5, 7, 10, and 13 the compared building blocks show that there are not just one of them that should be chosen to put effort. Their comparison shows that the shorter path to a CE-oriented culture, in this case, is to simultaneously improve: the mindset combined with the value (Fig. 5); capability combined with the value (Fig. 7); capability combined with the mindset (Fig. 10); or competence combined with behavior (Fig. 13). In Fig. 6, moving towards the development of 'values' over 'behaviors' may bring better results. On the other hand, Fig. 8 shows that moving in the direction of 'competence' may be a better option when compared to 'values'. Meanwhile, Figs. 9 and 11 show that prioritizing 'mindset' over 'behavior' and 'competence' may be a more effective

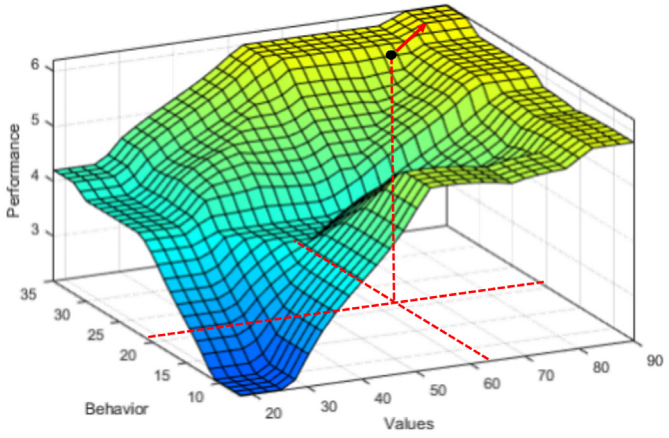

Fig. 6. Behaviors × values.

path. Similarly, Figs. 12 and 14 show that 'capability' should be prioritized when compared with 'behavior' and 'competence'.

The analyses inferred by the surfaces are complemented by the results of the radar chart presented in Fig. 15. It portrays the company's performance in each CE-oriented culture building block compared to the best case that a company could achieve. Radar charts are used for representing multidimensional data. They are best for determining

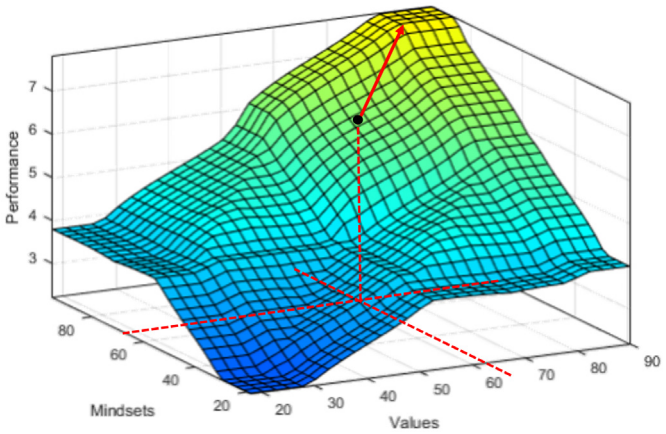

Fig. 5. Mindsets × values.

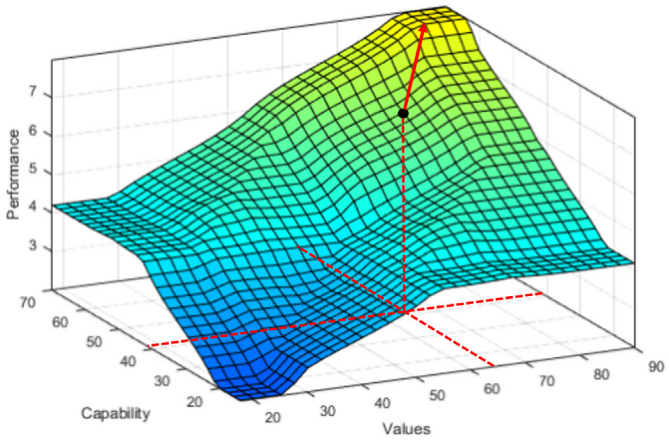

Fig. 7. Capabilities × values.

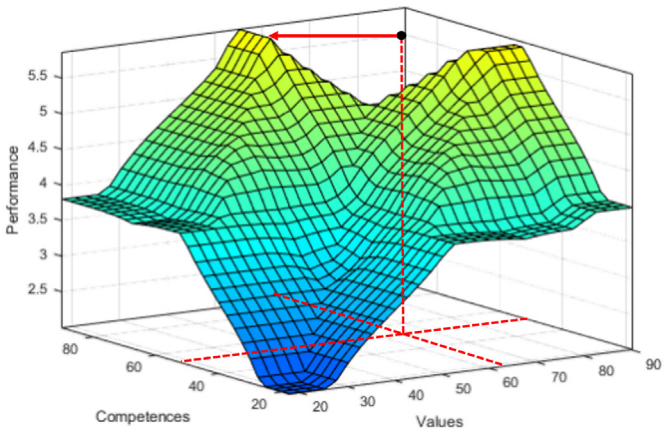

Fig. 8. Competences × values.

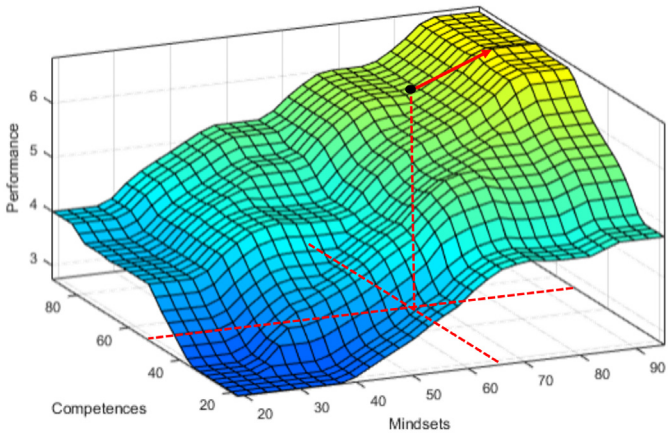

Fig. 11. Competences × mindsets.

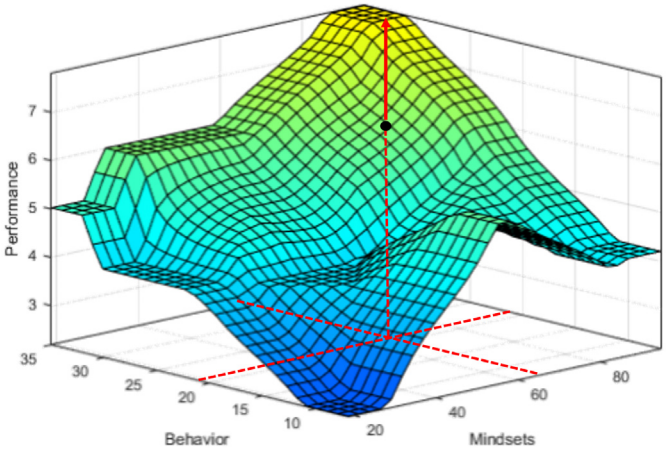

Fig. 9. Behaviors × mindsets.

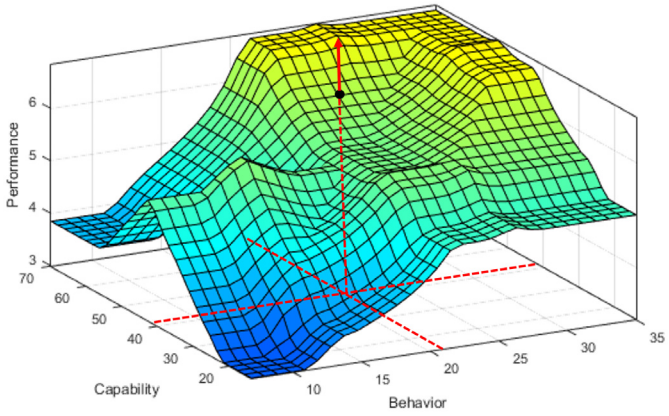

Fig. 12. Capabilities × behaviors.

which variable in a data is doing better than the rest and are mostly used for performance analysis. As can be observed, the Alpha Company has a long way to go to improve its readiness in a CE-oriented culture. The building block in which they performed better is in 'behavior' (21 points from a maximum of 35), however, in the other building blocks the organization should make an effort to perform better.

We propose that the Alpha Company Alpha should make an effort to improve their mindsets and capabilities oriented towards CE. Bertassini et al. (2021b) affirm that is easier to conduct changes in the building block values, behaviors and capabilities because they are more tangible than mindset and competences. In the case of the Alpha company, they will need to analyze this in more depth and improve their capabilities (tangible and technical) they need to improve their mindsets (intangible and soft) to achieve a better CE-oriented culture performance. Focusing first on implementing the elements that comprise these two building blocks, the Alpha Company has the potential to improve its readiness level to have a CE-oriented culture. After improving the mindset and capabilities, they could focus on improving values, and

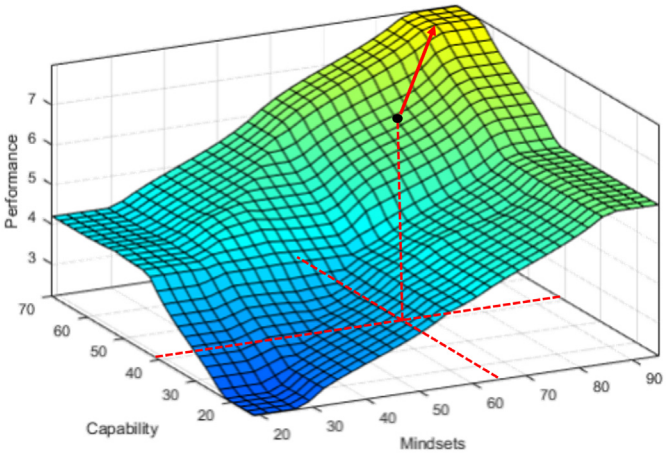

Fig. 10. Capabilities × mindsets.

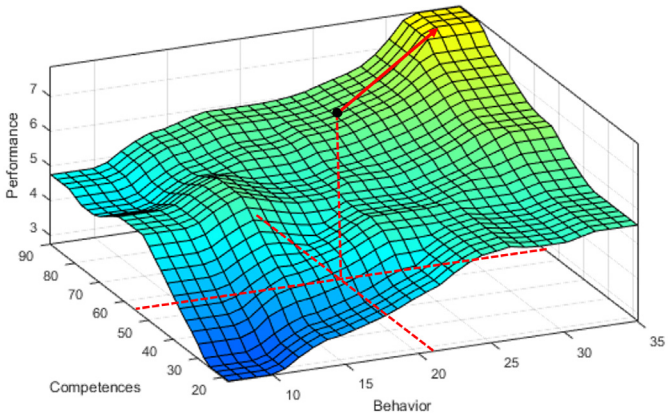

Fig. 13. Competences × behaviors.

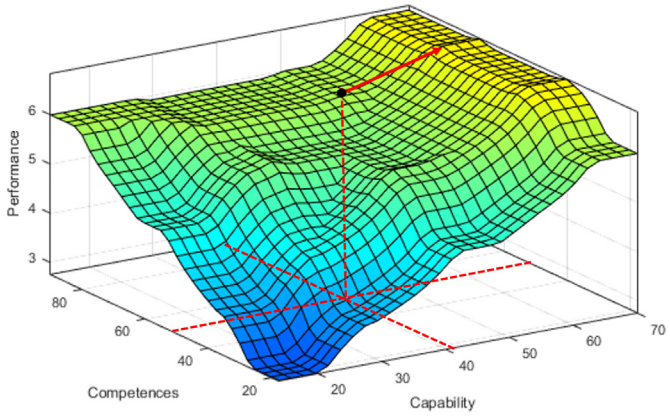

Fig. 14. Competences × capabilities.

improving behaviors and competences. It should be noted that the proposed approach is cyclical, so it should be continuously applied to monitor the evolution of the organization in the readiness levels.

4.3. Sensitivity analysis

Sensitivity analyses are used to validate decision models (Delgado and Sendra, 2004). The full factorial design technique (Montgomery, 2017) is commonly applied used to assess the effect on the response of interactions between input variables and to assess the relative importance of input variables based on the FIS rule bases (Zanon et al., 2020; Osiro et al., 2014; Lima-Junior et al., 2013). Thus, to analyze the consistency and sensitivity of the applied inference systems, a full 3^k factorial design technique was carried out using the Minitab 17® software.

As described in the previous sections, the FIS applied in the proposed tool has 5 input variables, which are the building blocks of a CE-oriented culture. These 5 factors were evaluated considering the 3 possible levels represented by the linguistic variables "low", "medium" and "high", which generates a combination of 3 (243) input variables. The values related to the highest membership degree for each criterion concerning each linguistic term were used as input data for the factor analysis. Table K in Section 10 of the supplementary material presents the

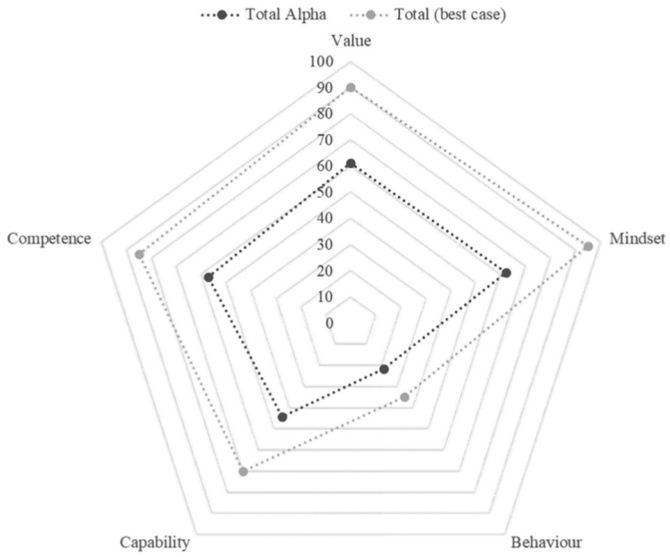

Fig. 15. The Alpha Company's performance in the building blocks.

randomized experimental design performed and the respective defuzzified results for the tested dataset.

Fig. 16 presents the interaction effect graphs of the input variables. The x-axis of the graphs presents the values referring to the tested linguistic terms, and the y-axis represents the output of the FIS according to the interacting input variables. In the graphs in Fig. 15, if the lines are not parallel at all, it indicates a strong interaction between the variables. On the other hand, if the lines are parallel (or close to parallel), it indicates that there is no interaction between the variables. By analyzing the graphs resulting from this analysis, it can be concluded that there is no trade-off relationship between the input variables. Therefore, the graphs and response surfaces show that the input variables (building blocks) do not differ greatly in their impact on CE maturity. Furthermore, it reinforces that the theoretical supposition of the factors (building blocks) complements each other in the development of a CE-oriented culture.

5. Discussion

CE is perceived as a promising approach to SD and as a framework to implement the SDGs. At local and national levels, governments are developing action plans to include CE in development goals (Ogunmakinde et al., 2022) as they emphasize the regeneration of products rather than their disposal (Ghisellini et al., 2016) and guarantee the circularity of products in the system (Ogunmakinde et al., 2022), resource efficiency and waste minimization (Barón et al., 2020). Sustainable CE innovations applied in business models, supply chains, and business ecosystems, and the implementations of new technologies are considered key aspects for the transition towards CE (Konietzko et al., 2020; Pollard et al., 2021). However, due to cultural/behavioral aspects, companies do not understand the positive outcomes that sustainable CE innovations could generate, which makes companies struggle to adopt circular business models (Salvador et al., 2020).

Cultural and behavioral aspects must be directed towards a sustainable CE; thus, organizations can have the required basis and support to propose such innovation so that they can transmit long-lasting CE concepts (Bertassini et al., 2021a). Therefore, mapping the CE elements is essential to allow organizations to improve their performance in the transition towards a CE-oriented culture and carefully consider and mitigate the rebound effects that could be generated from implementing CE practices.

The rebound effects are mostly related to operational 'errors' when implementing practices (Salvador et al., 2020) that do not fit with the adopted culture/strategy. Therefore, developing a CE-oriented culture might create awareness in the organization that a circular system needs to be thoughtfully designed aiming to prevent all the possible rebound effects. Not considering the rebound effects from the beginning may lead to an overstatement of the benefits of certain innovations, which can lead to increases in emissions targets, preference for recycling (Siderius and Poldner, 2020), overuse of products in solution-based models, insufficient secondary materials or products and price effects (Salvador et al., 2020). Thus, developing the CE-oriented culture elements means that organizations must have their culture properly focused on the design of the circular system from the beginning and focused on the ecosystem to build a strategic partnership that is the key for CE transition and rebound effect control.

The culture of organizations that seek circularity should enable the explicit value proposition of circular business models with a broader and long-term orientation. The CE-oriented culture must shift from interaction based on transactions to one based on shared values, which in the long run will help achieve sustainability. A CE-oriented culture must involve social innovations driven by transformative use of resources, connecting grassroots initiatives, ideas, and opinions to local, national, and supranational policy development and decision-making.

The readiness assessment approach proposed based on the CE-oriented culture building blocks and its elements allow organizations

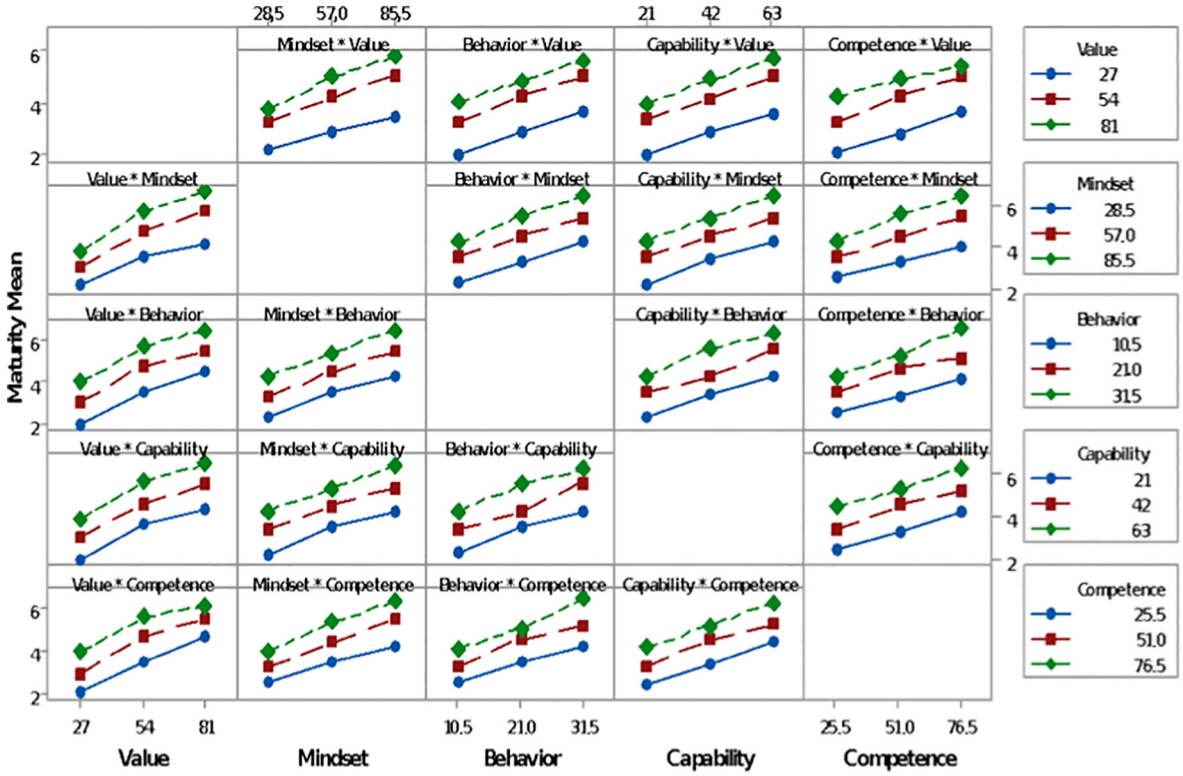

Fig. 16. Interaction effect graphs of the input variables.

to see how well they are performing on each one of the building blocks and identify which ones they should develop actions to go further in their journey towards the CE. Having a CE-oriented cultural awareness and knowing the cultural readiness to move towards CE might guide companies in the achievement of SDG 12 (sustainable production and consumption) (Belmonte-Ureña et al., 2021). Performing the CE-oriented culture readiness assessment might encourage companies to adopt sustainable and circular practices (SDG 12.6); disseminate CE and sustainable knowledge through the business ecosystem and ensure that people have the relevant information and awareness for SD (SDG 12.8); and through implementing the CE-oriented elements, support government and developing countries to strengthen their scientific and technological capacity to move towards sustainable production and consumption (SDG 12.A) (United Nations, 2022; UNEP, 2022).

Using the readiness assessment approach gives a clearer vision of the cultural performance of companies about CE implementation and can create a sense of urgency in implementing CE-oriented culture elements and CE practices. This can lead to positive impacts in the environment (e.g., reducing greenhouse gas emissions, reducing de use of virgin materials, resource efficiency, and reuse), economical (e.g., resource productivity, lower production costs, creation of jobs), and social (e.g., creating avenues from mutual trust and partnership between communities and industries, boosting community well-being, resolving economic disparities and fostering social equality) spheres (Ogunmakinde et al., 2022).

Moreover, using the readiness assessment approach is a way to move away from the techno-centric CE narrative and puts the human aspect at the center of the CE transition. According to Schröder et al. (2020), putting humans at the center of CE will encourage the development of solutions to structural unemployment; adoption of business models that align business values with social impact that engage Bottom of Pyramid populations; strengthening community resilience and belonging; and promoting sustainable lifestyles. In the Global South, as is the case of Brazil, populations that are not part of any business ecosystem, with CE implementation, have the opportunity to become part of the solution.

Both theoretical and managerial implications are offered herein.

5.1. Theoretical implications

To the best of the authors' knowledge, there is no previous study that combines MM, fuzzy set theories, CE and OC to propose an assessment approach. In this sense, this research has a multidisciplinary theoretical contribution as it combines divergent topics in a single proposition. It can be observed that the number of multidisciplinary studies in the CE field is increasing, showing the relevance and importance of this study. This study presents an adaptable methodology used to develop the approach that could inspire the solution of similar problems in different research areas.

The approach uses a quantitative approach based on fuzzy sets that allow modeling readiness to CE transition from qualitative, inaccurate, and vague data. This is a valuable way to analyze the culture orientation, as decision-makers opinions can be more accurately processed and the knowledge of the problem domain captured and maintained in the system. Moreover, to the best of the authors' knowledge, this is the first time that fuzzy logic is used to develop an assessment model for a CE-oriented culture context.

The results of the pilot application showed that using the fuzzy techniques combined with MM theory allows the development of a quantitative model capable of capturing inaccuracies of human reasoning (Caiado et al., 2021; Zadeh, 1965), and provides a useful way to deal with vague and uncertain data and estimates a global maturity score based on the readiness level dimensions (Aqlan and Lam, 2015) and considering non-linear relationships between input and output variables (Zanon et al., 2020). Thus, the application of FIS for the development of this readiness assessment is an appropriate tool.

Adding to the existing MM, the assessment approach presented here brings additional information using the elements that characterize the CE-oriented culture. It can be applied independently by any company

and it shows measurable results. Regarding the development, the proposed approach and techniques were tested through a pilot application and sensitivity analysis showed that the effects on the responses of interactions between input variables used in the approach are consistent. Moreover, the paper presented a detailed description of the construction process and offered guidelines for its application, ensuring reproducibility.

5.2. Managerial implications

From a managerial perspective, this paper presents a scientific approach intended to help companies achieve CE, providing guidance that enables them to gain awareness regarding the true level of readiness towards a CE-oriented culture. In general, companies struggle to identify their actual CE-oriented culture level, and it is unclear to them what actions they should take to obtain improved results. Thus, companies could use the result from the assessment to choose the building blocks that they should prioritize and, based on the building block, select the elements that they will implement to achieve a CE-oriented culture. The evidence collected in the testing phase showed that the proposed approach is of great help to give managers insights and guidance about which path the organization should follow to achieve a CE-oriented culture quickly. This approach is adaptable to remain applicable to any organization, irrespective of size, sector, location, and technology intensity. It helps managers to improve their journey towards CE and give support for more precise decision-making regarding CE transition. Moreover, the proposed approach can be integrated into toolboxes used by companies for internal benchmarking and road mapping for circularity.

5.3. Limitations

As with every study, our study has some limitations. First, in the pilot application, an overview of the CE-oriented culture was obtained from only a few areas of the organization. To have a systemic vision that represents the entire organization, a bigger sample should be defined to answer the questionnaire. Second, only one company from a specific industrial sector with its characteristics was evaluated.

6. Conclusions

This study proposed a novel approach to assess the readiness of companies to implement a CE-oriented culture based on the application of fuzzy techniques to overcome the complexity, inaccuracy, and uncertainty inherent in the study of OC combined with CE. The main results are: classification of an organization into six levels of readiness to implement a CE-oriented culture; a pairwise comparison of the performance of the organization between the building blocks; and a radar chart with the overall performance of the organization regarding CE-oriented culture. The results provide organizations with specific information and guidance for decision-making regarding the changes that should be made to adapt or change the existing culture to one that comprises the specificities of CE. Organizations that focus on radical innovations and balance the efforts between technical and soft aspects are more oriented towards a CE culture. It was also identified that making a more in-depth analysis of the presence of CE-oriented culture elements in the organization may contribute by mitigating possible rebound effects that could be generated from implementing CE practices. The application of the proposed approach might be a way to create sustainable and circular awareness in the organizations that see sustainability-related action as obligations showing them the power that a CE has to generate value in all its forms.

As future research, the tool may be applied to a bigger sample of respondents in studies on organization to have a systemic view, as this organization is in the process of disseminating CE concepts and projects to the entire organization. Another opportunity is to apply the assessment instrument with different organizations (different sectors, sizes, countries), to further validate the proposal as well as to analyze if there are significant discrepancies regarding the readiness in different contexts. Further research could also evaluate readiness at different times by applying a roadmap with periodic goals. The creation of a digital platform to apply the readiness assessment approach with different organizations and using the results as benchmarking for the companies is understood as a future research opportunity. It should be noted that the importance of the elements evaluated may change depending on the panel of experts involved and the types of resources available to the organization's context. In addition, future work can apply other MDCA (Multi-Criteria Decision Analysis) techniques to rank and select the elements that will be used in the maturity assessment. Furthermore, different fuzzy information representations can be applied, such as hesitant fuzzy, intuitionistic fuzzy, and dual hesitant fuzzy to deal with hesitations in the subjective judgments of the experts.

Declaration of competing 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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.spc.2022.03.018.

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