European research on management and business economics 30 (2024) 100232

Contents lists available at ScienceDirect

European research on management and business economics

journal homepage: www.elsevier.es/ermbe

Impact of Industry 4.0 and circular economy on lean culture and leadership: Assessing digital green lean as a new concept

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ARTICLE INFO

JEL Classification:
M11
M14
M15
M12

Keywords:
Lean culture
Leadership
Industry 4.0
Circular economy

ABSTRACT

This paper aims to investigate the impact of Industry 4.0 and Circular Economy on Lean Leadership and Lean Culture, providing insights into how Lean Manufacturing companies can adapt their leadership and culture styles to succeed in the new business environment. We have conducted a systematic literature review focusing on the impact of Industry 4.0 and Circular Economy on Lean Leadership and Lean Culture, and our principal findings are that Implementing Industry 4.0 and Circular Economy requires changes in Lean Leadership and Culture styles to incorporate sustainability and digital transformation. This study identified ten Lean Culture characteristics classified in three groups values and principles (culture of respect, collectivism, power distance and authority distribution), customer centric (customer orientation and performance orientation) and operational excellence (receptiveness, working conditions, problem solving culture and continuous improvement and innovation) and nineteen Lean Leadership competences grouped in three categories customer oriented (customer focus, customer and supplier development and teamworking), personal development (personal stability, personal behavior, human centric, self-developing and learning, empowerment, self-transcendence and servant leadership), Lean principles (experimental, continuous improvement and innovation, zero-defects, process and lean expertise, problem solving and genchi genbutsu) and performance driven (targets settings, targets deployment and flow) that are necessary for successful implementation of Industry 4.0 and Circular Economy in Lean Manufacturing companies.

1. Introduction

The so-called fourth revolution comes from applying and integrating new digital technologies into industry. Industry 4.0 (I4.0) arose through a German government initiative (Kagermann et al., 2013). For the first time, an industrial revolution was evaluated a priori and not ex-post (Sato Duarte et al., 2018). The smart factory is expected to result from this revolution, with key technologies to help achieve productivity goals. These technologies will transform people's living and working conditions. The digital revolution could be a force for fair, sustainable development (Atasu et al., 2020).

I4.0 comprises a broad range of technologies and tools, including IoT devices and sensors, cloud computing, big data, artificial intelligence and machine learning, robotics and automation, digital twins, additive manufacturing (3D printing), augmented reality, and cybersecurity (Jankowska et al., 2021; Kagermann et al., 2013).

The adoption of I4.0 is still in its initial stages, but it is expected to impact the manufacturing industry in the coming years significantly. According to a report by the World Economic Forum, adopting I4.0 could lead to a 4.5 % increase in global GDP and a 15 % increase in productivity by 2030 (World Economic Forum, 2019).

I4.0 represents a significant shift in industries' operations, focusing on data-driven decision-making, automation, and optimization. Aspects of Industry 4.0 implementation are the development of I4.0-specific know-how, securing financial resources, integrating employees into the implementation process, and establishing an open-minded and flexible corporate culture (Veile et al., 2019). While there are challenges and uncertainties associated with this shift, the potential benefits are significant, including increased efficiency, productivity, and innovation (Ghobakhloo et al., 2021). As such, I4.0 will likely continue to be a key area of focus for businesses and governments worldwide in the coming years.

However, the adoption of I4.0 has challenges. One of the biggest is the need for workers with the skills and knowledge to use and keep innovative technologies. There is also the risk of job displacement as automation and robotics become more widespread.

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https://doi.org/10.1016/j.iedeen.2023.100232
Received 24 July 2023; Received in revised form 25 October 2023; Accepted 26 October 2023
Available online 25 November 2023
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Organizations are investing in training programs and other initiatives to address these challenges to help workers develop the required skills. Governments are also addressing the impact of automation on employment, with countries exploring the idea of a universal basic income to supply a safety net for workers displaced by automation (Au-Yong-Oliveira et al., 2019).

In sum, I4.0 is a significant shift in how goods are produced and is expected to impact the manufacturing industry in the coming years.

However, as we move towards a more technologically advanced society, it is essential to consider our actions' social and environmental implications.

Circular Economy (CE) is a relatively new concept that aims to optimize resource usage, reduce waste generation, and decouple economic growth from resource depletion (Kirchherr et al., 2017). The term "Circular Economy" was first coined by Turner and Pearce (1990), and it has since been further developed and popularized by academics, policymakers, and industry practitioners (Geissdoerfer et al., 2017).

CE is built on "Reduce, Reuse, and Recycle." It aims to keep products, components, and materials at their highest utility and continuously design out waste, pollution, and harmful practices from the start (Kirchherr et al., 2017). CE can be seen as a systemic approach that focuses on creating closed-loop material flows that are restorative and regenerative by design rather than linear and wasteful (Ellen MacArthur Foundation, 2013).

The CE concept (Ellen MacArthur Foundation, 2013) is an example of how we can balance economic growth with sustainability by reducing waste and maximizing the use of resources. Furthermore, the development of a super-smart society must prioritize the well-being of its citizens, ensuring that technology is used for the greater good.

CE has evolved from a niche concept to a mainstream movement, gaining increasing attention from governments, businesses, and consumers worldwide. In 2015, the European Commission adopted a comprehensive CE Action Plan, which includes ambitious targets (European Commission, 2015). Similarly, China has launched its CE Development Plan, which outlines a roadmap for resource conservation, eco-design, and green innovation (State Council of the People's Republic of China, 2021).

One of the technical features of CE is that it requires a system thinking approach. It involves collaboration and coordination between stakeholders, from design to disposal, along the value chain. It requires adopting innovative business models prioritizing product-service systems, leasing, sharing, and closed-loop supply chains (Geissdoerfer et al., 2017).

Despite the progress made, there are still challenges to overcome in implementing CE. One of the main challenges is the lack of market incentives and regulatory frameworks that support CE principles (Kirchherr et al., 2017). This includes issues related to intellectual property, taxation, and public procurement. There is also a need for better metrics and indicators to measure the impact of CE initiatives and show their benefits (Geissdoerfer et al., 2017). CE is gaining momentum despite the challenges and offers a compelling vision for a more sustainable future.

Summing up, we can say that the current market and countries' economic situation have significantly changed the global economy, causing a shift in the business landscape and highlighting the need for digital transformation and sustainable business practices. I4.0 and CE are two emerging trends reshaping the business environment, and companies adopting them will likely remain competitive. Combining I4.0 and CE can significantly impact production strategies by enabling a more efficient and sustainable manufacturing process. Integrating both models can lead to a circular production system that optimizes resource use, monitors the process and the efficiency, reduces waste, and ultimately creates a more sustainable production process (Moreira et al., 2010).

Besides, Lean Manufacturing (LM) –a term coined by Krafcik (1988) and popularized by Womack et al. (1990) based on the Toyota Production System (TPS)– has been a widely demonstrated production paradigm, proven to bring substantial improvements in efficiency, quality, delivery and flexibility, and customer satisfaction. With the rise of I4.0 and the need for more sustainable business practices, LM companies are also looking to incorporate CE principles and new technological advancements into their operations.

Lean Leadership (LL) and Lean Culture (LC) must effectively implement and manage these changes. Leaders in LM organizations must have the competencies and skills necessary to navigate the complexities of implementing I4.0 and CE practices.

By examining the literature on LL and LC, as well as the impact of I4.0 and CE on them, this study aims to shed light on the necessary adaptations that must be made to support the transition to a more sustainable and technologically advanced manufacturing paradigm.

Considering the theoretical and practical background posed, to the best of our knowledge, this study is among the first to investigate the impact of I4.0 and CE on LL and LC, contributing to covering the research gap identified in understanding how companies can succeed in the new business environment.

Therefore, we propose the following research questions:

- RQ1: "What is the impact of Industry 4.0 and Circular Economy on Lean Leadership and Lean Culture?"
- RQ2: "How can organizations effectively integrate these concepts to drive operational excellence and sustainable growth?"

2. Methodology

This paper follows a systematic literature review (SLR) approach. According to Seuring er al. (2020), SLR should limit bias in the assembly, critical appraisal, and synthesis of all relevant studies that address a specific question. The SLR was first used in 1995 in a medical document to find everything written about a specific topic for snowballing or pulling from references. Seuring et al. (2020) categorizes SLRs into four types: theory building (inductive), theory modification (abductive), theory refinement (deductive internal), and theory extension (deductive external). This paper follows an inductive (theory-building) approach, starting from a theoretical point of LC and LL, analyzing the impact of new concepts, and developing a new understanding. This method was developed by Kovács and Spens (2005).

The existing literature does not cover all the required aspects of the topics to the required level (Rusev & Salonitis, 2016). Therefore, this SLR will help find knowledge gaps and gather appropriate information to cover the intersection between the abovementioned four concepts.

Papers Selection Criteria and Analysis Methodology are as described below:

1 Gross Search: Search keywords in Web of Science and Scopus databases.
2 Refined Search: Filter articles by language (English or Spanish, the mother language of the authors). There is no publication time restriction.
3 Net: Total documents found.
4 Preliminary Analysis: Remove duplications on title/DOI.
5 Topic Related: Analyze titles and abstracts to remove articles unrelated to our research topic.
6 Relevance: By reading the full articles, we include relevant articles obtained from steps 4 and 5 and those found through narrative review. This includes papers related to the topic and connected with the keywords defined in the search.
7 Final Relevance: Read all remaining articles in-depth, capturing the required information for this paper. Remove articles that do not contain relevant information.

The last step of reading articles in-depth allows for a more comprehensive understanding of the information presented in each article. It ensures that only the most relevant information is included in the SLR.

Our SLR comprises four stages to comprehensively understand the interconnections between Lean Culture, Lean Leadership, Industry 4.0, and Circular Economy.

The first stage, performed on March 2, 2021, and shown in Table 1, aims to conduct an in-depth analysis of existing models for assessment, questionnaires, surveys, or evaluation from the literature regarding Lean Leadership and Lean Culture.

The second stage, performed on March 25, 2021, and shown in Table 2, identifies how Industry 4.0 can improve Lean Culture and Leadership practices.

In the third stage, done on March 30th, 2021, and shown in Table 3, we examine how the principles of Circular Economy can complement and enhance Lean Culture and Leadership practices.

The fourth stage, done on April 4th, 2021, and shown in Table 4, investigates how adopting Industry 4.0 and Circular Economy can impact Lean Leadership and Culture and explores any gaps in existing research.

The overall search generates a database composed of 139 initial relevant papers. 82 out of them have been deeply analyzed and support the responses to RQ1 and RQ2. Analyzing this literature background allowed us to understand better the relationship between Industry 4.0, Circular Economy, and Lean practices. This knowledge can then be used to develop new insights and recommendations for organizations looking to implement Lean principles in the context of Industry 4.0 and Circular Economy. It can then be used to guide further research and investigation.

3. Results and discussion

3.1. Lean culture

Organizational culture (OC) refers to a shared pattern of values, behaviors, and basic assumptions that guide how a group perceives, thinks, and feels (Urban, 2015). OC is not directly observable but can be identified through symptoms and symbols in an organization, classified as clan, adhocracy, market, and hierarchy cultures (Salma et al., 2019; Tortorella et al., 2016). These cultures involve different leadership roles, as shown in Table 5.

Lean Culture (LC) does not fit neatly into these cultural classifications. Companies practicing Lean Manufacturing tend to standardize processes, training, and leadership styles, fostering a unified culture.

LC was initially introduced by Liker (2004) through Toyota's 14 management principles, which are linked to OC. This research builds upon Liker's work and a previous SLR on LC conducted in 2018 by Dorval et al. (2019). A total of 13 definitions of LC were identified, encompassing aspects such as organizational behavior, philosophy, thinking, ideologies, decisions, and leadership style (Péczely & Liberona, 2017; Tortorella & Fogliatto, 2017). This indicates that LC is multi-dimensional.

The starting point for LC characteristics is based on Hofstede and the Globe Study (House et al., 2004). It includes the following Business Culture characteristics: (1) assertiveness, (2) future orientation, (3) human orientation, (4) in-group collectivism, (5) institutional collectivism, (6) performance orientation, (7) power distance, and (8) uncertainty avoidance.

Most LC papers in the literature align to varying degrees with these characteristics. Generally, lean organizations score higher than non-lean ones, except for assertiveness, which tends to be lower in lean organizations. In this paper, to align with LM literature, we will use "receptiveness" as the antonym for "assertiveness."

Wiengarten et al. (2015) explored the impact of collectivism at the national and OC levels on the effectiveness of lean practices. It was found that national and OC collectivism positively influences lean practice implementation and effectiveness, except in individualistic cultures. Studies like Netland (2016) empirically demonstrate the impact of Hofstede's dimensions on national culture, affecting rewards, benchmarking, and external support.

Bortolotti et al. (2015) examined the correlation between OC, soft lean practices, and the level of lean implementation. It was observed that companies with high lean performance exhibit higher collectivism, future orientation, human orientation, and receptiveness.

Furthermore, it is argued that an innovation culture should be an integral part of LC, as Solaimani et al. (2019) highlighted in the context of lean innovation management.

Situations characterized by unemotionality, depersonalization, subordination, conservatism, isolation, and antipathy can hinder transformation efforts, as discussed in Fadnavis et al. (2020). Table 6 shows a summary of the 10 final Lean Culture characteristics, grouped into three categories: (1) values and principles –a culture of respect, collectivism, power distance, and authority distribution–, (2) customer-centric –customer orientation and performance orientation– and (3) operational excellence –receptiveness, working conditions, problem-solving culture, and continuous improvement and innovation–.

3.2. Lean leadership

Recently, mainly after 2010, companies have realized the importance of LL for a successful lean implementation; however, they have not modified their leadership systems so far (Dombrowski & Mielke, 2013). The behavior and competences of the Leaders are a fundamental area of research to understand, model, and quantify individuals in a Lean context (Donohue et al., 2019). In his 4P model, Liker (2004) described a lean philosophy with long-term thinking as a vital part of the LL. Dombrowski and Mielke (2013, p. 570) define LL as: "Methodical system

Table 1
Stage 1 - Search and selection criteria.

AND →
OR ↓

Lean	Leader*	Assessment
	Cultur*	Survey
		Questionnaire
		Evaluation

Gross search:	Scopus 923 / WoS 861
Refined search:	Scopus 905 / WoS 777
Net:	1682 articles
Preliminary analysis:	1226 (456 duplications on title/DOI)
Topic related:	74 documents (1152 eliminated)
Total relevant:	81 relevant (including narrative literature review: 7)
Final relevant:	55 (1 from 2004, rest after 2011)

Table 2
Stage 2- Search and selection criteria.

AND →

OR ↓

Lean	Leader*	Industr* 4.0
	Cultur*	Fourth industrial revolution
		Cyber transformation
		Digitalization
		Cyber physical systems
		Digital transformation

Gross search:	Scopus 52 / WoS 40
Refined search:	Scopus 51 / WoS 39
Net:	90 articles
Preliminary analysis:	67 (23 duplications on title/DOI)
Topic related:	30 Documents (37 eliminated)
Total relevant:	34 relevant. (narrative literature review: 4)
Final relevant:	14 papers (all published after 2016)

Table 3
Stage 3- Search and selection criteria.

AND →

OR ↓

Lean	Leader*	Circular economy
	Cultur*	Circular manufacturing
		Green operations
		Green Manufacturing
		Sustainable manufacturing

Gross search:	Scopus 120 / WoS 84
Refined search:	Scopus 120 / WoS 83
Net:	203 articles
Preliminary analysis:	165 (38 duplications on title or DOI)
Topic related:	21 documents (144 eliminated)
Total relevant:	22 relevant (Narrative literature review: 1)
Final relevant:	11 papers (one published in 2005, rest after 2011)

Table 4
Stage 4-Search and selection criteria.

AND →

OR ↓

Lean	Leader*	Industry 4.0	Circular economy
	Cultur*	Fourth industrial revolution	Circular manufacturing
		Cyber transformation	Green operations
		Digitalization	Green Manufacturing
		Cyber physical systems	Sustainable manufacturing

Gross search:	Scopus 3 / WoS 5
Refined search:	Scopus 3 /WoS 5
Net:	8 articles
Preliminary analysis:	5 (3 duplications on title or DOI)
Topic related:	2 documents (3 eliminated)
Total relevant:	2 relevant
Final relevant:	2 papers

Table 5
Different organizational cultures (Source: Salma et al., 2019; Tortorella et al., 2016).

Organizational culture	Characteristic	Role of the leader
Clan / Group	Friendly work environment	Mentor / Father figure
Adhocracy / Development	Dynamic and creative	Innovator / Entrepreneur
Market / Rational	Get the job done	Hard driver / Competitor
Hierarchy	Structured work environment	Coordinator / Organizer

for the sustainable implementation and continuous improvement of lean production system. Describes the cooperation of employees and leaders in their mutual striving for perfection. This includes the customer focus of all processes and the long-term development of employees and leaders".

A common criticism is that no single model exists to develop and implement LL. Leadership at Toyota has been developed over the years and is not based on a specific recipe. When implementing an LL model, companies usually wait to be told specific practical steps to implement them (Trenkner, 2016) and what are the best performance indicators to follow implementation. These two questions are not answered, and the bibliography is very scarce. However, Seidel et al. (2017) surveyed 91 companies, showing that they understand and agree on the importance of LL but do not know how to apply it.

Lean leaders are the ones building and spreading the LC. Edgar Shein's model links the OC with the LL and proposes three levels: 1) basic assumptions, 2) norms and values, and 3) visible artifacts (Paro & Gerolamo, 2017). These categories are used as the first break-up classification to efficiently organize the concepts, followed by a detailed classification for LL competences, where a "competence" can be defined as the set of abilities which enables the leader to use behavioral strategies to solve complex problems (Dombrowski et al., 2019).

Laureani and Antony (2018) discussed the combination of the lean leader with the nine leadership styles from Northouse's book "Leadership: Theory and Practice" (Northouse, 1999) and arrived at the same conclusions: LL is not matching with any of the published leadership models ultimately. However, it has higher similarities with transformational and servant leadership styles (Toledo et al., 2019) and includes other competences from the other models; therefore, a new complete set of LL competences will be compiled.

Looking for a personality test to be done to lean leaders is not easy (Nielsen & Mathiasen, 2017). The studies show the low reliability of these tests because the personality traits are not well defined, and the framework where they fit may change inside companies, sectors, and locations. Tortorella et al. (2016) argue that lean is an evolutionary process; therefore, there is more than one best way to lead teams implementing lean. This leadership style, called "situational leadership, " ranges from directing to delegating through coaching and supporting, depending on the relationship intensity between the leader and the employee. It is moderated by contextual factors such as age, leader experience, and team size. Situational leadership is how the lean leaders use their competences, so the leaders will have to delegate, coach, or support differently according to the status of the operations. "Situational leadership" will be included with all its components in the different LL competences.

Tortorella et al. (2018) argue, surveying Brazilian plants, that the traditional thinking of lean leaders is more relation-oriented than task-oriented. Maroukian and Gulliver (2020) reach the same conclusion when analyzing the Toyota Production System (TPS), where the author supports that Toyota is looking for modest leaders, not charismatic ones. Open to learning and teamwork-oriented leaders. Task-oriented leaders are positively associated with just-in-time and total productive maintenance production processes. This finding supports our intention to define a baseline of LL and LC as a combination of earlier studies and

Table 6
Final lean culture characteristics.

Classification	Lean culture characteristic	Definition for lean organizations
Values and principles	**C1: Human orientation, culture of respect**	The degree to which organizations are human-centric and how policies to reward individuals for being fair, altruistic, friendly, generous, caring, and kind to others are in place and used.
	C2: Collectivism: In-group and institutional level of unionization	In group: the degree to which each individual expresses pride, loyalty, and cohesiveness in their organizations and collaborates for a better company. Institutional: the degree to which organizational policies and practices encourage and reward teamwork and collective action through teams, committees, or any other form of unionism.
	C3: Power distance	The way the organization is built, the spans of control, the easiness of communication, and the degree to which members expect and agree that power should be unequally shared.
	C4: Authority distribution & decision-making, uncertainty avoidance	The distribution of authority at all levels of the organization, how failure is tolerated, and the consequences of failure. The extent to which members of an organization strive to avoid uncertainty by relying on social norms, rituals, and bureaucratic practices to alleviate the unpredictability of future events.
Customer centric	**C5: Sustainable customer orientation**	The degree to which organizations focus their systems on sustainability and long-term relationships with customers and how they engage in future-oriented policies such as planning, investing in the future, and delaying gratification to achieve it.
	C6: Performance orientation	How the organization sets the vision, mission, and values and converts that into long-term and short-term strategies and the extent to which an organization encourages and rewards group members for performance improvement and excellence.
Operational excellence	**C7: Receptiveness**	The degree to which organizations are less assertive, less confrontational, and soft in social relationships.
	C8: Working conditions & EHS	The way the work is designed and standardized, the actual working conditions of the employees, and the human-centric EHS policies.
	C9: Problem solving culture (scientific method)	The way the organization creates the need and strives to eliminate non-value-added activities and the degree to which all employees participate are trained and coached by experienced leaders in problem-solving.
	C10: Continuous improvement & innovation	The extent to which the mindset that everything can be improved is set in the organizational policies and deployed to all employees. To what extent policies and systems are used in

(*continued on next page*)

Table 6 (*continued*)

Classification	Lean culture characteristic	Definition for lean organizations
		the organization for innovation through employee participation at all levels?

experience.

To understand how LL competences are defined in the bibliography and the methods to measure them, Dombrowski and Mielke (2014) depict 15 lean leader competences for sustaining lean implementation over time. Those 15 competences are the starting point for our paper: (1) leader stability in the position, (2) promoting continuous improvement, (3) zero defects approach, (4) self-reflection and awareness, (5) deep process knowledge, (6) customer focus, (7) successor development, (8) self-developing, (9) problem-solving, (10) fact-based decision making, (11) genchi genbutsu, (12) team working, (13) long term targets, (14) hoshin-kanri and (15) striving for perfection.

Dombrowski and Mielke (2013) propose that the basic principles of LL are improvement culture, self-development, qualification, Gemba, and hoshin kanri, and they develop the leader competences for lean sustainable development.

Seidel et al. (2019) analyze seven leadership theories and how they can help define LL competences, personal attributes, skills, and behaviors, contributing to a better definition of the previous competences. In his literature for LL attributes, focused on the healthcare sector, Aij and Teunissen (2017), starting from Dombrowski and Mielkeś (2013) analysis, add a few LL competences to the existing list, such as emotional intelligence, visualizing greatness, trust, and fairness.

Van Dun et al. (2017) analyze lean leaders' values and behaviors to evaluate them in a field case with effective lean middle managers. Starting from an SLR, refined using the Delphi method for consensus building, reaches 21 work values and 14 behaviors. All the values are already captured in our system. All behaviors are included except for experimenting, structuring, and controlling, which will be added to the final proposal. Another document from the same author (van Dun & Wilderom, 2016) elaborates further on the need for Leaders to reach a certain level of self-transcendent, being the leader that breaks free from OC and focuses on results, so they can work on a global scale realizing the impact of the company on other aspects of the life (social, environmental). Self-transcendence is added to the competences defined as "striving for perfection" and "visualizing greatness."

The role of high-level leadership in implementing LM was analyzed by Alefari et al. (2017) from UK manufacturing companies. Compared with the leader's competences, already included in the earlier papers, it is worth including the provision of adequate resources and the concept of time through the standardized work, takt time, and cycle times.

When reviewing the cause-effect relations of lean soft practices to foster sustainable improvement, Costa et al. (2019) research the critical success factors according to an SLR conducted in 2019 and classify them into three categories: cultural, organizational, and managerial. Out of the 24 factors identified, it is worth highlighting two of them: decentralized decision-making and working conditions evaluation and the level of unionized workforce. The same conclusion is reached when the relationship between lean leaders and healthy co-workers is analyzed (Bäckström & Ingelsson, 2015). They show that lean and healthy working conditions are moving in the same direction; however, other studies show that health conditions can be affected negatively by applying LM (Parker & Slaughter, 1990; Rampasso et al., 2017).

Seidel et al. (2017) conducted an SLR of lean competences, contrasted them with lean experts, and confirmed them with a survey of 91 companies from several sectors. It shows 16 LL competences. These competences are confirmed in terms of content and predictive validity. The survey shows that they positively correlate with the level of lean implementation and maturity of the leaders with lean systems. They introduced the concepts of "operations flow" and "safety of the employee" related to the human side (e.g., work stability, personal and professional). They reached the same conclusion with the concept of flow management and orientation.

Trenkner (2016) and van Assen (2018) add servant leadership and transformational leaders to the LL equation. Servant refers to the humble leader serving the team, finding ways to make employees work better, more successfully, and achieve better performance; transformational refers to the leader who detects the need, creates a vision, and guides the change. Nielsen and Mathiasen (2017) propose that the lean leader has two important traits for this research: physical and psychological strength.

One of the concepts, described initially by Liker (2004), and empirically assessed in small and medium enterprises (Timans et al., 2012), is developing customers and suppliers as a critical trait of the lean leader. This can be referred to by internal and external customers and suppliers, as also described in the paper of Spear (2004), "Learning to Lead at Toyota."

The leadership style differs for shopfloor leaders and top leaders. Tortorella et al. (2017) empirically analyze the leadership for various levels of the organization, arguing that from the team leader to the general manager, the preferred leadership style is moving from directing or coaching to supporting. When reviewing the LL competences so far, they match these leadership styles. Therefore, this study will not have the hierarchy as a moderator.

From this SLR, 19 final Lean Leadership competences are proposed, grouped into four categories as it is shown in Table 7: (1) customer oriented –customer focus, customer and supplier development, and teamwork–, (2) personal development –personal stability, personal behavior, human-centric, self-developing and learning, empowerment, self-transcendence, and servant leadership–, (3) Lean principles –experimental, continuous improvement and innovation, zero-defects, process, and lean expertise, problem-solving and genchi genbutsu– and (4) performance driven –targets settings, targets deployment, and flow–.

3.3. Lean culture and lean leadership impacted by Industry 4.0

SLR Stage 2 is used to analyze and understand the impact that applying I4.0 techniques could have on the LC and LL and helps answer RQ1.

There has been abundant bibliography on I4.0 since 2011, and there is an agreement that I4.0 may have a positive impact on the way shopfloors are managed and organized and influence an organization's business models, products, and services (Tortorella et al., 2019). However, the literature is scarce when understanding the impact of I4.0 on LC and LL. We try to understand the new or modified competences that the leaders in a lean organization need to adopt to effectively run areas where I4.0 is being implemented and the impact that I4.0 might have on the lean organization from a leadership and culture point of view. According to Pagliosa et al. (2021), 9 I4.0 technologies and 14 LM practices are identified and categorized according to different levels of value stream application and synergy between them; none are related to LL/LC.

Lean and I4.0 diverge into a few concepts but converge in others. Authors discuss technical correlation matrixes, but very few analyze how lean leaders could manage production lines with I4.0 implemented. Scholars agree that both systems must live together: I4.0 must be built on LM, and I4.0 improves the efficiency of LM (Bittencourt et al., 2019; Ciano et al., 2020; Rosin et al., 2020).

Companies are investing in I4.0 technologies nowadays. The money gets locked into production machinery, and therefore, it needs to be depreciated and amortized, bringing a financial risk if not managed properly. Only developing digital versions of LM tools will not make a significant impact if not utilized as a part of a learning process for leaders and employees (Saabye et al., 2020).

Considering the origin and the intent of I4.0, it is fair to say that the

Table 7
Final lean leadership competences.

Classification	Lean leadership competence	Definition for lean manufacturing organizations
Customer oriented	**L1: Customer focus**	Customer approach and focus on deliverables for internal and external customers. The need of the customer is above the need of the group.
	L2: Customer & supplier development	They are developing customers and suppliers (internal and external) into LM to achieve higher levels of efficiency for the organization through process improvement and waste elimination.
	L3: Teamworking	Leads teams with a span of control from 1:5 to 1:10. Develop proper communication and transparency. Teams are above individuals. Social ability to make contacts.
Personal development	**L4: Personal stability**	Leader stability in the position for expertise and proper coaching.
	L5: Personal behavior	Role model, hansei (self-reflection), self-awareness & assessment. Modesty & humility. Empathy. Credibility.
	L6: Human-centric	Respect for people: Constantly developing and coaching his successor and the team. Emotional Intelligence, Ethics, and Safety.
	L7: Self-developing and learning	Constant self-developing and learning in a structured way, guided by an experienced teacher.
	L8: Empowerment	Team empowerment and guidance and fact-based decisions after proper analysis.
	L9: Self-transcendence	Sets the true north. Always Striving for perfection and visualizing greatness (self-transcendence), Has physical and psychological strength and understands his contribution to the organization's future and influence on employees' personal and social lives.
	L10: Servant	Servant leadership: Humble, trustful, listens to others, respectful, and fair.
Lean principles	**L11: Experimental**	Uses constant experimentation, hypothesis testing, and trial (Kata): Standardizing the results, communicating the improvements, and recognizing the employees.
	L12: Continuous improvement and innovation	Enthusiastic and disciplined promotion of CI and Innovation through critical thinking, intellectual stimulation, and risk management.
	L13: Zero-defects	Zero-defects mindset approach but tolerance to mistakes and failure when it happens as an opportunity for improvement.
	L14: Process and lean expertise	Deep "Process and lean" knowledge and application. Uses and implements flow, takt time, and standardized work.
	L15: Problem-solving	Master quick problem-solving and root cause analysis as a standard way of thinking. Capable of teaching and guiding others.
	L16: Genchi genbutsu	Constant presence on the shop floor as a philosophy for gathering data, understanding the situation, and coaching. Visual management as a key facilitator.
Performance driven	**L17: Target setting**	Communicate Vision: Long-term targets setting (not modified by short-term ones) and Values follower.
	L18: Targets deployment	Consistent and transparent deployment and tracking of employees with challenging targets (Hoshin kanri) Reward and recognize success.
	L19: Flow	Understands the concept, importance, and value of flow, stability, leveling, and balancing. Manage with Emphasis on flow rather than on isolated operations.

intention was not to change LL or CC but to progress in the digital revolution and digitalization. This progression also changes the behavior and style of leading the shop floor and considerably influences how the teams are organized.

One of the principles of LM drafted by Toyota in their first document published in 1973 (Toyota Motor Co., 1973) is "automation with a human touch" (jidoka), the intent to reduce the interaction between the man and machine so employees can increase the time available problem-solving. We can assume that the technical tools on I4.0 can fall inside the autonomation technical part of lean (Sanders et al., 2016). We need to understand how those tools affect the competences of a lean leader and the aspects of the LC. The SLR is done to come up with the table below. The documents are focused on the technical part of lean and I4.0, and the management and culture part is not included. Since there is no agreed yet commonality of terms and definitions, all the articles have been read and interpreted to align the terms as shown in the table below.

The main I4.0 tools have been defined according to the original paper from Kagermann et al. (2013) on I4.0. The LL competences and LC aspects come from Sections 3.1 and 3.2. All the elements combined are shown in Table 8, which sheds the first light on the RQ1.

In the table, there are no references to any impact of digital twins on LC and LL; it is also interesting to see that there is a very scarce bibliography on the impact of the I4.0 in the LC. It mainly highlights how human orientation, performance orientation, working conditions, EHS and authority, and decision-making characteristics are affected by the introduction of new I4.0 technologies. This does not mean that the other LC characteristics cannot be affected by the introduction of I4.0, as there might be a lack of studies on the subject. Most of the documents are published only from 2017 onwards, which shows a new field of investigation.

On the impact of I4.0 tools on the LL competences, only 12 out of 19 competences are impacted by I4.0. IoT and big data have more citations due to 1) their high impact on the LL competences or 2) the fact that those two I4.0 tools are the most known and studied. They are followed by augmented reality and robots, which also makes sense, considering that lean is defined as a human-centric system, and these tools risk making jobs redundant or changing the content. The LL competences most impacted by I4.0 are flow, continuous improvement, innovation, problem-solving, team working, genchi genbutsu, and customer/supplier development.

3.4. Lean culture and lean leadership impacted by circular economy

Stage 3 is used to analyze and understand the impact that the application of CE principles could have on the LC and LL and contributes to answering RQ1.

The three starting statements on CE are: (1) the world's resources are finite, (2) the consumption of resources by human beings is above the possibility of generation of the planet Earth, and (3) the energy we are using for our development is scarce and based on fossil fuel. Could we do, as humanity, something different to preserve the planet and, at the

Table 8
Impact of Industry 4.0 on lean culture and lean leadership.

INDUSTRY 4.0 TOOL	IMPACT ON LEAN CULTURE CHARACTERISTICS	IMPACT ON LEAN LEADERSHIP COMPETENCES
Internet of things	Human orientation. Culture of respect (Saabye et al., 2020)	Zero-defects (Rosin et al., 2020) (Ciano et al., 2020) Problem-solving (Rosin et al., 2020) (Saabye et al., 2020) (Dombrowski et al., 2019) (Tortorella et al., 2019) Flow (Ciano et al., 2020) (Sanders et al., 2016) (Tortorella et al., 2019) (Satoglu et al., 2018) CI & innovation (Sanders et al., 2016) (Tortorella et al., 2019) (Satoglu et al., 2018) Teamworking (Saabye et al., 2020) Customer & supplier development (Satoglu et al., 2018)
Augmented reality		Genchi genbutsu (Rosin et al., 2020) (Ciano et al., 2020) Teamworking (Rosin et al., 2020) Self-developing & learning (Rosin et al., 2020) (Ciano et al., 2020) Flow (Satoglu et al., 2018) (Zhao et al., 2019) Process & lean expertise (Satoglu et al., 2018) Human-centric (Zhao et al., 2019)
Big data & analytics	Performance orientation (Saabye et al., 2020) (Rueb & Bahemia, 2020) Authority and decision-making (Saabye et al., 2020) Working conditions & EHS (Saabye et al., 2020)	Problem-solving (Rosin et al., 2020) (Saabye et al., 2020) CI & innovation (Rosin et al., 2020) (Dombrowski et al., 2019) (Satoglu et al., 2018) Process & lean expertise (Ciano et al., 2020) Empowerment (Ciano et al., 2020) (Saabye et al., 2020) Flow (Ciano et al., 2020) (Tortorella et al., 2019) (Satoglu et al., 2018) Customer focus (Sanders et al., 2016) Teamworking (Saabye et al., 2020) Experimental – Kata (Saabye et al., 2020) (Romero & Flores, 2019) Process and lean expertise (Dombrowski et al., 2019)
Autonomous robots	Human orientation, a culture of respect (Romero & Flores, 2019) Working conditions & EHS (Rueb & Bahemia, 2020)	Flow (Rosin et al., 2020) (Ciano et al., 2020) (Satoglu et al., 2018) Zero defects (Rosin et al., 2020) (Ciano et al., 2020) Problem-solving (Ciano et al., 2020) Servant (Ciano et al., 2020) Process and lean expertise (Dombrowski et al., 2019) CI & innovation (Satoglu et al., 2018)
Simulation		Problem-solving (Rosin et al., 2020) Genchi genbutsu (Rosin et al., 2020) Flow (Rosin et al., 2020) (Ciano et al., 2020) CI & innovation (Rosin et al., 2020) (Ciano et al., 2020) Self-developing & learning (Rosin et al., 2020)
System Integration	Sustainable customer orientation (Romero & Flores, 2019) (Rueb & Bahemia, 2020) Authority distribution & decision making (Rueb & Bahemia, 2020)	Flow (Rosin et al., 2020) (Ciano et al., 2020) (Tortorella et al., 2019) Customer/supplier development (Rosin et al., 2020) (Ciano et al., 2020) (Sanders et al., 2016) Teamworking (Sanders et al., 2016) Problem-solving (Saabye et al., 2020)
Cloud computing		Teamworking (Sanders et al., 2016) Flow (Tortorella et al., 2019)
Digital twins	None	None
Cyber-physical systems and security	CI and innovation (Romero & Flores, 2019) Performance orientation (Romero & Flores, 2019)	Problem solving ((Dombrowski et al., 2019) CI & innovation (Dombrowski et al., 2019) Teamworking (Dombrowski et al., 2019)
Additive manufacturing (3D Printing)		Flow (Ciano et al., 2020) Zero-defects (Ciano et al., 2020) CI & innovation (Tortorella et al., 2019) (Satoglu et al., 2018)
Deep learning		Empowerment (Schmidt et al., 2020) Flow (Schmidt et al., 2020) Target setting (Schmidt et al., 2020) Target deployment (Schmidt et al., 2020) Genchi genbutsu (Schmidt et al., 2020) Experimental (Villalba-Diez et al., 2019) Problem solving (Villalba-Diez et al., 2019)

same time, continue with the evolution and development of society?

CE brings a complete system redesign from linear economies "take-make-dispose" to "take-make-restore," through 1) converting the end-of-life concept to "restoration," 2) use of renewable energy, elimination of hazardous chemicals and waste materials, and 3) changing the consumer behavior from "owner" to "user" of the products. However, the elimination of non-added value activities is still critical as they consume energy, the minimization of any landfill material happens by design, and recyclability and refurbishment become part of the operations (Geissdoerfer et al., 2017; Ellen MacArthur Foundation, 2020).

CE also has some issues discussed, such as (Geissdoerfer et al., 2017): 1) complexity of closed circle in growing demand, 2) social or employment problems as there will be less processing required due to more extended use and elimination of the concept of obsolescence, 3) technical problems today as higher amount of energy required to recycle some materials compare with the new production, 4) customers preferring to own than lease will have an impact on the production lines and 5) the weak connection of sustainability with other economic aspects of the business.

Besides, CE, as a new management approach, could affect the lean leader competences and LC characteristics.

CE, at this stage, becomes more a modifier of the existing processes

than a business model. It lacks basic assumptions like productivity, employee social situation, economic balance, or transition from old production systems to new circular ones. Therefore, for this research, we would like to understand what impact CE has on the LL's competences and the organizational LC's characteristics.

Table 9 shows the three operational principles of the CE that will have an impact on lean companies (Ellen MacArthur Foundation, 2020).

While performing the SLR of these concepts, 22 documents were found with some connection with this research. However, only 11 documents connected well to the topic (Table 10). They are connected only with the environment or, more broadly, with sustainability, as LM is not green or sustainable per se (Chen et al., 2020; Lindskog et al., 2016). Table 10 sheds further light on the RQ1.

There is not much bibliography, and the existing one still has considerable confusion of terms between green, sustainability, and CE. In a brief analysis of the correlations, we can argue that the maximum impact happens on the topics related to manufacturing or customers.

The LC characteristics most impacted are continuous improvement, innovation, performance orientation, and collectivism. In lean leaders' competences, the maximum impact is found in flow management, customer focus, and zero defects or striving for perfection, which is also logical as they are the most connected with the operations, where the most significant change happens in CE.

3.5. Lean culture and lean leadership impacted by Industry 4.0 and circular economy

Stage 4 is used to analyze the overall combination of the concepts.

The articles covered the discussion's technical part, like tools and technical systems. They all argue that the companies using LM have a competitive advantage in implementing I4.0 (Varela et al., 2019) and that those with I4.0 tools and systems directly affect the implementation of sustainability as a triple-bottom-line approach.

The conjunction between the three concepts only triggers two papers. The first one, from Nascimento et al. (2019), describes how I4.0 can be integrated with CE and how quickly it can be integrated with existing production environments like LM. The second one from Salminen et al. (2016) defend how LM and I4.0 develop superior competitive power through the main principles of CE. None of the two papers touch on the leadership part of LM or the LC and how they can influence or be influenced by applying I4.0 technologies or the CE principles.

Consequently, it has been found that no articles cover I4.0 and CE impacting LL or LC. So, Tables 8 and 10 combined can provide an answer to RQ1 and derive the implications to answer RQ2.

Table 9
Operational principles of circular economy and its definition.

Principle	Definition
To increase material productivity: Power the inner circle	Minimize the usage of resources for production by improving the process, bringing the reuse, and recycling at all steps of the production line.
To Increase material productivity: Power of circling longer	Maximize the number of cycles a product can be reused, remanufactured, or recycled.
To increase material productivity: Power of cascade use	They are diversifying the reuse across the value chain. Lines should be ready to take recycling material from other products or manufacturing lines that could fit into your lines, which requires a higher amount of flexibility but, at the same time, robust processes to ensure the quality is obtained at a low cost.
To increase material productivity: Power of pure circles	Increase collection and redistribution efficiency by designing the use of uncontaminated material while keeping quality.
To improve customer interaction and loyalty	Promote the leasing of products and return them to the manufacturer at the end of the usage cycle with performance contracts in place.
Less product complexity and more manageable life cycles	Promoting manufacturing primary "skeleton" products and considering everything else as an add-on. Shorter cycle times and higher customization while keeping portfolio specs relatively low.

Table 10
Impact of circular economy on lean culture and lean leadership.

Circular economy principle	Lean culture characteristic	Lean leadership competence
Inner circles	Working conditions and EHS (Sorli et al., 2012) (Rothenberg, 2003) Performance orientation (Nadeem et al., 2019) (Ranky, 2010) CI & innovation (Rothenberg, 2003) (Ranky, 2010) Collectivism (Rothenberg, 2003)	Flow (Chen et al., 2020) (Sony & Naik, 2020) (Parmar & Desai, 2021) (Nadeem et al., 2019) Self-developing and learning (Chen et al., 2020) Target deployment (Chen et al., 2020) (Sony & Naik, 2020) (Rothenberg, 2003) Zero defects (Nadeem et al., 2019) (Ranky, 2010) Genchi genbutsu (Ranky, 2010)
Longer circles	Performance orientation (Nadeem et al., 2019) (Ranky, 2010)	Self-developing and learning (Chen et al., 2020) Flow (Sony & Naik, 2020) (Parmar & Desai, 2021) (Nadeem et al., 2019) Zero defects (Sony & Naik, 2020) (Nadeem et al., 2019) (Ranky, 2010)
Cascade use	Authority distribution and decision-making (Sorli et al., 2012) CI & innovation (Rothenberg, 2003) Collectivism (Rothenberg, 2003)	CI & innovation (Sorli et al., 2012) (Rothenberg, 2003) (Ranky, 2010) Target setting (Chen et al., 2020) Empowerment (Chen et al., 2020) Teamworking (Chen et al., 2020) (Ranky, 2010) Flow (Sony & Naik, 2020) (Parmar & Desai, 2021) (Nadeem et al., 2019) Process & lean expertise (Parmar & Desai, 2021)
Pure circles	None	None
Customer interaction & loyalty	Sustainable customer orientation (Sorli et al., 2012) (Parmar & Desai, 2021) (Nadeem et al., 2019) (Ranky, 2010)	Customer focus (Sorli et al., 2012) (Chen et al., 2020) (Sony & Naik, 2020) (Parmar & Desai, 2021) (Nadeem et al., 2019) (Ranky, 2010) Customer & supplier development (Parmar & Desai, 2021) (Ranky, 2010)
Product complexity & life cycles	CI & innovation (Nadeem et al., 2019)	

4. Conclusions and future research

In today's fiercely competitive landscape, manufacturing companies face productivity challenges and rely on efficiency, cost reduction, customer focus, and low-cost innovation, often driven by employee-centered systems.

Lean Manufacturing (LM, based on Toyota Production System-TPS), initially perceived as a toolkit for waste reduction, has evolved into a culture rooted in values, principles, and behaviors that foster continuous improvement and waste elimination across organizations. Lean Leadership plays a pivotal role in cultivating this culture.

The development of Lean Leadership emphasizes coaching, empowerment, and respect for people. It involves creating a culture of continuous improvement by supplying guidance and support to employees, encouraging experimentation and learning, and promoting a

shared sense of purpose and values. Lean Leadership is essential for the success of Lean Manufacturing, as it helps to create the conditions for continuous improvement and waste elimination.

Furthermore, due to the high cost of some techniques, the companies are moving resources and investments, initially dedicated to Industry 4.0, back to the operations line, trying to increase the circularity of their processes and reduce the impact on the planet Earth. Industry 4.0 and the Circular Economy have reshaped traditional Lean Manufacturing, emphasizing automated, circular processes for delivering customer value.

Our systematic literature review revealed that integrating Industry 4.0 and Circular Economy affects Lean Leadership and Culture. It requires a comprehensive approach tailored to an organization's unique needs and a culture of continuous improvement. We anticipate the emergence of a novel concept: "Digital Green Lean" (DGL), fusing Industry 4.0, Lean Manufacturing, and sustainability principles.

4.1. Theoretical contribution

This review, trying to answer RQ1 and RQ2, addresses a knowledge gap regarding how lean companies and leaders must adapt to Industry 4.0 and Circular Economy. We have identified ten critical Lean culture characteristics and nineteen Lean Leader competences that are most prevalent in the literature, providing an overarching view of Lean Leadership and Lean Culture. However, a significant knowledge gap exists at the intersection of Lean, Industry 4.0, and Circular Economy, requiring further exploration.

Responding to RQ1, Lean Leadership plays a pivotal role in implementing Industry 4.0 and Circular Economy while fostering a culture of continuous improvement. This leadership style prioritizes employee engagement, empowerment, and development, promoting collaboration and an environment where ideas are encouraged.

Regarding the RQ2 mentioned above, integrating Industry 4.0 and Circular Economy significantly impacts Lean Leadership and Lean Culture. To effectively integrate these concepts, organizations need to adopt a comprehensive approach that considers the unique needs of their business and engages employees in the process. This involves developing a strategic plan that defines the organization's vision and goals and finds the key initiatives that will help to achieve these objectives. It also involves creating a culture of continuous improvement that encourages employees to share their ideas and opinions and to take ownership of their work.

As of our knowledge cutoff in September 2021, there is no established framework to measure the impact of Industry 4.0 and Circular Economy on traditional lean companies, opening avenues for further research.

In summary, and answering RQ1 and RQ2, this review contributes to understanding the evolving concept of "Digital Green Lean" (DGL) and its potential in Lean Manufacturing. To the best of our knowledge, this concept has never been used in bibliography before. We can define it as a combination of the principles of Industry 4.0 and Lean Manufacturing with a focus on sustainability. It involves using digital technologies to check and optimize production processes, reduce waste, and minimize the environmental impact. Digital Green Lean builds upon the traditional understanding of Lean Manufacturing as a business culture and extends it to include newly developed digital technologies.

From the SLR, a value proposition for companies adopting DGL can be derived and summarized in the following benefits:

- Enhanced operational efficiency and cost savings: DGL harnesses the power of digital technologies to optimize processes, reduce waste, and eliminate inefficiencies. By leveraging real-time data and analytics, organizations can make better decisions, improve resource allocation, and streamline operations. Organizations can minimize operational expenses by reducing waste, energy consumption, and resource usage while increasing productivity.
- Flexibility and adaptability: The DGL approach fosters adaptability, enabling organizations to respond more effectively to changing market conditions, disruptions, and regulatory requirements. This resilience ensures long-term sustainability and growth, even in dynamic and uncertain environments.
- Environmental sustainability: Organizations can reduce their ecological footprint through resource conservation, responsible waste management, and eco-friendly production methods. This aligns with corporate social responsibility and responds to growing environmental concerns and regulations.
- Employee engagement: DGL promotes a culture of continuous improvement and innovation. Engaging employees in sustainability efforts and digital transformation fosters a sense of ownership and purpose among the workforce. This enhances morale and fuels a more collaborative and innovative corporate culture.
- Performance: DGL provides organizations with clear metrics and KPIs for tracking the impact of their initiatives. This data and fact-driven approach allows for transparent reporting, helping organizations demonstrate their commitment to sustainability to stakeholders, investors, and regulatory bodies.
- Strategic direction: DGL positions organizations to thrive in an evolving business landscape. It equips them with the digital capabilities and sustainability practices needed to remain relevant and thrive in a world where environmental concerns and technological advancements continue to shape industries.
- Competitive advantage: DGL equips organizations with a competitive edge in an increasingly environmentally conscious and technology-driven market. It allows them to meet consumer demand for sustainable products and processes while enhancing their reputation as socially responsible and forward-thinking companies.

4.2. Practical implications

Digital Green Lean (DGL) enables organizations to simultaneously achieve operational excellence and sustainable growth. Organizations can use digital technologies to collect real-time data on their production processes, identify inefficiencies and waste, and make data-driven decisions to optimize their operations. For example, sensors can be used to check energy consumption, water usage, and waste generation in real-time, allowing organizations to identify areas for improvement and reduce their environmental impact.

DGL also has a significant impact on Lean Leadership and Culture. Leaders who embrace DGL must be committed to sustainability and understand that it is no longer just a nice-to-have but a necessity for long-term success. Specifically, Digital Green Lean Culture and Leadership interconnect the core of lean, culture, and people, with state-of-the-art digital technologies and focus on circularity and protecting the planet Earth and its resources and inhabitants.

Organizations must assess their current digital maturity to effectively integrate DGL into their operations and show areas where digital technologies can be used to optimize their operations. They must also ensure they have the necessary skills and ability to implement and manage these technologies effectively. Finally, they must communicate the importance of Digital Green Lean to their employees and ensure that they are engaged and motivated to embrace this novel approach.

To effectively implement DGL, organizations must adopt a culture of continuous improvement, embrace change and innovation, and ensure that their employees are engaged and motivated to embrace this novel approach. Consequently, we propose the specific term "Digital Green Lean Culture" as part of Digital Green Lean.

The literature review findings can help companies using Lean to understand the impact of Industry 4.0 and Circular Economy on their leadership and culture styles and adapt them accordingly.

4.3. Limitations and future research

Theoretical and practical contributions notwithstanding, our study is not free of limitations. This literature review is limited to a theoretical analysis of the impact of Industry 4.0 and Circular Economy on Leadership and Culture in lean manufacturers. Further investigation could be done to apply this concept of Digital Green Lean (DGL) and DGL Culture to different companies, maybe from different industries and geographical locations, so it can be measured, calibrated, and improved. It will also help to evaluate the validity of the results and compare the impact to the effort needed to take the company to the next step.

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