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Review

Lean and Industry 4.0: A Review of the Relationship, Its Limitations, and the Path Ahead with Industry 5.0

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Abstract: This article aims to analyze the relationship between Lean and Industry 4.0, further exploring the opportunities for integration with the new concept of Industry 5.0. Departing from a literature review, it shows how the relationship between Industry 4.0 and Lean is—while unanimously positive—clearly orientated towards the more technological aspects. In this scenario, most studies on this relationship highlight the technological side of organizations, emphasizing the integration of Industry 4.0 technology to augment Lean methodologies and tools. As such, most of the apparent value of this relationship derives from the use of technology, and relatively limited inputs input are found on issues related to the human and social factors of organizations—such as leadership, people, integration, and training for new roles and new tasks. In the face of this reality, we evaluate the potential for integration between Lean and Industry 5.0, arguing how Lean may offer a proper perspective to support sustainability, resilience, and human orientation in Industrial contexts.

Keywords: lean manufacturing; quality management; Industry 4.0; Industry 5.0

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1. Introduction

The move to Industry 4.0 led to a creation of context-specific variations for multiple philosophies, tools and approaches came to carry the same neologism “X 4.0” [1]. A few examples include Excellence 4.0 [2], Quality 4.0 [3], or Supply Chain Management 4.0 [4]). In most cases, these neologisms signify the application of technology to continuous improvement and operational management practices, and Lean was another common example of this trend [5,6]. As such, the relationship between Lean Management and Industry 4.0 has been frequently explored, to a point were several hundred articles and dozens of literature reviews are available [7]. However, a quick review of the most cited results quickly seems to indicate a reality where the relationship is mostly analyzed from a technological perspective [8–11].

Considering that a similar critique—the overshadowing of operational and social aspects of continuous improvement efforts in favor of technological adoption—has been made to, for example, Quality Management [12,13], we set out to identify if this trend is observable also in the literature on the relationship between Lean and Industry 4.0—and if so, to identify opportunities and risks for expanding this relation beyond its technological facet.

In order to validate this hypothesis, we set out to analyze the most recent reviews on this relationship. Still today, the literature shows a growing number of papers concerning “Lean and I4.0” [14], and in the first half of 2022 alone, eight literature reviews have been published on this relationship. In this paper, we analyze these reviews (and further literature), seeking to understand whether they are aligned and if their results support a common understanding, aiming to identify gaps and future research paths.

Based on this analysis, this article aims to comprehend whether this scientific production has converged to a single understanding, or if the debate is still active regarding the integration between Lean and Industry 4.0, its benefits, and its limitations. Furthermore, this work seeks to identify research gaps around this very same topic.

As a result, it is shown that most studies on this relationship highlight the technological side of organizations, emphasizing the integration of Industry 4.0 technology to augment Lean methodologies and tools. However, research on how Lean and Industry 4.0 contributes to social, environmental, and business continuity and sustainability are more limited. In the face of this finding, we then explore the opportunities for the integration of Lean and Industry 5.0 to overcome the existing limitations and support the acceleration of sustainability, resilience, and human-centered strategies.

This article aims to analyze the relationship between Lean and Industry 4.0, further exploring the opportunities for integration with the new concept of Industry 5.0. To this end, the article has five sections. To identify the necessary elements for the proper understanding of the potential additional value Lean Manufacturing can add to Industry 4.0, Section 2 offers a conceptual introduction to the topics of Lean and Industry 4.0. After this theoretical introduction, in Section 3, the relationship between Lean and Industry 4.0 is analyzed, departing from the eight most recent reviews at the date of the development of this article (September 2022). An analysis is conducted whereby the most frequent points of contact between Industry 4.0 and Lean are summarized, and the existing gaps in the literature about this relationship are identified. Next, Section 4 discusses the opportunities and challenges for Lean Manufacturing in Industry 5.0. A conclusion and perspectives for future work are presented in Section 5.

2. Conceptual Review

2.1. Industry 4.0

Industrial Revolutions are marked by a paradigm shift of the production process [15]. However, they further install themselves into society, to the point where their effects are clearly recognized outside industrial and business forums [16]. The 4th Industrial Revolution, also called Industry (I4.0), was declared as an opportunity for the transformation of the previous paradigm (born with the 3rd Industrial Revolution) at the Hannover Fair in 2011. This was followed by the launch of the Strategic Development Report for German Industry, published in April 2013 with the aim of allowing it to achieve a strategic global differential [17]. Based on the premise established in that work, the *Industrie 4.0* Program sought to give direction to companies not only on production process change but also at the level of investment, training, and technological development necessary for those industries to lead markets and supply products [17]. It is important to highlight that the concept "4.0" has taken dimensions for several business areas not limited to the industrial environment itself, and that it has become an icon ("4.0")—an identity sometimes greater than its original idea, even defining its evolution ("5.0") [1].

While it can be traced back to Germany [18], the concept quickly grew beyond the country, across the European Union, and beyond it. Each of the Union's members have a national agency working to improve the block's industrial competitiveness [19]. In Japan, the term Industry 4.0 has also gained attention, and inspired even broader societal approaches to a technologically-driven future, where the benefits of Industry 4.0 are exploited to serve society at large and create a "technology-based, human-centered society" [20]. In America and Asia, the terms "Smart Manufacturing" or "Smart Industry" are used frequently to signify a similar industrial and societal transition [21–23].

Smart Factories (SF) are considered as an essential component for the expression of I4.0, and, in them, the information transfer flows between people, machines, and resources are key. SF have internalized the data of origin and the date of manufacture; of the processing parameters to be applied and applied; how, where, when, and to whom they are to be delivered; and several others [17]. In this sense, interdisciplinary actions are strongly suggested, both in terms of technologies, processes, and the development of personal skills, and the creation of an Industry in the I4.0 paradigm requires multidimensional work [18] and not just a selection of technologies. However, Industry 4.0 has been studied predominantly from a technological point of view [24,25]. Earlier works in Industry 4.0 focused on understanding and framing the forces that influenced this paradigm shift, as well as its relevance [26]. Normally, they list a wide variety of technologies that will help improve performance and organization [27]. Nevertheless, strategies or initiatives deployed in the context of this transition tend to have a vast focus, often showing a disconnection between the advancements proposed by area experts and those derived from the technological push.

Another important aspect is the fact that Industry 4.0, from the perspective of a "revolution", undoubtedly represents the expected lasting and comprehensive economic impact; however, from the perspective of "innovation", Industry 4.0 is positioned more as a driving force of innovations than the result of innovations [28].

The transformation towards Industry 4.0 offers many opportunities in the way organizations integrate their processes and their production, and how their systems evolve [13]. In the face of this reality, several organizations are on the lookout for new and innovative approaches to help them navigate the transition towards Industry 4.0. For many, Lean is central for mastering such a transition [29].

2.2. Lean Manufacturing

Since the 1970s, the high performance of the Japanese automobile industry has created a standard of operations that industries should seek to maintain competitiveness and survival [30,31]. As a result, the term "Lean" gained increased attention [32], and the development of Lean models and tools for companies began to emerge to ensure competitiveness. Drivers were the elimination of waste from the value chain, stakeholder satisfaction, and continuous improvement [33–35]. The use of techniques and tools for process improvement were key for the achievement of the objectives of Lean, allowing performance to be maintained and improved in the long term; and a focus on the Culture and People was reinforced as a central aspect of industrial management [30]. Lean is thus supported by guiding principles and a strong culture aimed at innovation, permanent development, and respect for people and society [36].

The central goals of Lean are to eliminate any activities that represent waste, to ensure a fluid operation, to achieve minimum set-up times and eliminate downtime due to breakage and defects, to level stocks and production quantities, or to maintain and develop standardized operations [33,37]. From these core perspectives, there are several methods and tools—Jidoka, Kaisen, pull system, Value Stream Mapping (VSM), Just-in-Time (JIT), Andon, Gemba, Kanban, Hoshin Kanri, Kata, etc.—that support it, reinforced by a culture where trust, respect, and empowerment of employees and partners is constant [38,39].

Lean Manufacturing was an adaptation to the mass production management model advocated in the 3rd Industrial Revolution. Differently, Industry 4.0 is a set of technological principles and tools that guides production to automation, integration, and connectivity to their highest levels. Therefore, Lean and I4.0 are different things, but complementary to each other—in spite of the imminent conflict between them, since in I4.0, production seems to promote a reduction of the dependence on employees, while Lean considers the human factor as a competitive differential and a valuable asset [30,33,37,40,41].

Because of these factors, for years major global consultancies [18,42,43] and academic contributions [44–49] have been trying to explore the relationship between Lean and Industry 4.0, and to understand it at both the theoretical and empirical levels—most often, with the hope of demonstrating the capacity that Lean can add competencies to I4.0. While there seems to be a wide agreement in relation to some aspects of this relationship, such as the benefit of technology for improved performance, improved data collection and analysis, and reduced human error [50], practical results are most often tied to increased automation [8]. Integration between Lean and Industry 4.0 concerning the social and environmental aspects remains mostly at the theoretical level [11,51].

3. Literature Review

3.1. Methodology

There are many articles on the numerous aspects of the relationship between Lean Manufacturing and Industry 4.0. A search using the Scopus database produced 764 results on the query "Lean AND Industry 4.0", all between 2014 and 2022. A quick analysis of the results showed a variety of themes, with a total of 104 different keywords occurring 10 or more times.

The purpose of this work, however, is not to dive into specific topics within the relationships between Industry 4.0 and Lean, but rather to gain an overall perspective of the state of the art. Our goal is to understand if, after almost a decade of research on this topic, there is a clear, common perspective on how Lean and Industry 4.0 interact. As such, a review of reviews methodology was followed [52,53]. 42 reviews relating to the topics of Lean and Industry 4.0 were identified. However, after excluding those unrelated to our research, only 12 articles remained—all ranging between 2021 and 2022. Amongst the exclusion criteria were a focus in narrow or specific trade or industry, research agendas, or narrow perspectives on the relationship between Lean and Industry 4.0. Exclusion criteria removed neighboring topics such as Lean Six Sigma, or particular aspects such as "Lean-Green" or "Sustainability".

In order to use the most recent works as our base, we selected the literature reviews written in 2022. From there, we moved on to older works. Departing from the most recent literature reviews, we explored the main trends, opportunities, and limitations in this relationship.

The following literature reviews on the subject of "Lean" and "Industry 4.0", published this year (2022), were identified (Table 1).

Table 1. Articles published in 2022—"Lean" and "Industry 4.0" literature review.

Authors	Title
Tailise, M.M.; Mergulhão, R.C.; Mano, A.P.; Silva, A.A.A.	The integration of technologies Industry 4.0 technology and Lean Manufacturing: A systematic literature review.
Rajaba, S.; Afy-Shararaha, M.; Salonitisa, K.	Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes.
Lucantoni, L.; Antomarioni, S.; Ciarapica, F.E.; Bevilacqua, M.	Implementation of Industry 4.0 Techniques in Lean Production Technology: A Literature Review.
Terra, J.D.R.; de Melo, C.C.; Berssaneti, F.T.	Are Lean, World Class Manufacturing and Industry 4.0 are related?
Nedjwa, E.; Bertrand, R.; Boudemagh, S.S.	Impacts of Industry 4.0 technologies on Lean management tools: a bibliometric analysis.
Yürekli, S.; Schulz, C.	Compatibility, opportunities and challenges in the combination of Industry 4.0 and Lean Production
Komkowski, T.; Antony, J.; Garza-Reyes, J.A.; Tortorella, G.L.; Pongboonchai-Empl, T.	The integration of Industry 4.0 and Lean Management: a systematic review and constituting elements perspective
Rossi, A. H. G.; Marcondes, G. B.; Pontes, J.; Leitão, P.; Treinta, F. T.; de Resende, L. M. M.; Mosconi, E.; Yoshino, R.T.	Lean Tools in the Context of Industry 4.0: Literature Review, Implementation and Trends

In most articles, the results focused on the contribution of different technologies of Industry 4.0 to Lean. Since different names were used for similar technologies, and in order to avoid confusion, we have grouped the different technologies into seven broader technological areas: (1) Cybernetics, (2) Connectivity and Integration, (3) Big Data, (4) Industrial Automation, (5) Administrative Process Automation, (6) Simulation and Augmented Reality, and (7) Additive Manufacturing. The correlation table of the technologies presented in the articles in Table 1 and the "Seven broader technological areas" are indicated in Appendix A.

3.2. The Relationship between Lean Manufacturing and Industry 4.0: Review of Reviews

From the above listed articles, it was possible to validate the connection between Lean and I4.0 in distinct dimensions. In "The integration of Industry 4.0 technologies and Lean Manufacturing: A systematic literature review" [54], we find an analysis of nine articles published between 2017 and 2021, seven of which demonstrate empirical examples of the joint use of I4.0 technologies and Lean tools. This result is presented in Table 2, adapting the original dimensions to the dimensions of Cybernetics, Connectivity, and Integration, Big Data, Industrial Automation, Administrative Process, Automation, Simulation and Augmented Reality, Additive Manufacturing. The intensive use of Connectivity and Integration, Big Data, Simulation, and Virtual and Augmented Reality are the most adopted dimensions in the empirical cases observed in conjunction with Lean. In addition to the integration between I4.0 technologies and Lean practices and tools, this article highlights other important topics within its review results. Other topics are (1) the extent to which I4.0 design principles are supporting Lean Manufacturing tools and (2) environmental factors in the integration of Industry 4.0 and Lean manufacturing.

Table 2. Analysis of the article "The integration of technologies Industry 4.0 technology and Lean Manufacturing: A systematic literature review" [54].

Industry 4.0 Technology	**Cybernetics**	**Connectivity and Integration**	**Big Data**	**Industrial Automation**	**Administrative Process Automation**	**Simulation and Augmented Reality**	**Additive Manufacturing**
Article							
Continuous Improvement Programs and Industry 4.0: Descriptive Bibliometric Analysis		X	X	X	X	X	
How Industry 4.0 Can Enhance Lean Practices	X	X	X	X	X	X	X
Impact of Industry 4.0 Concept on the Levers of Lean Manufacturing Approach in Manufacturing Industries	X	X	X	X	X	X	X
Impacts of Industry 4.0 technologies on Lean principle	X	X	X			X	X
Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies		X	X	X		X	X
Industry 4.0 and Lean Manufacturing: A systematic literature review and future research directions	X	X	X		X	X	X
The Relationship between Lean and Industry 4.0: Literature Review		X	X		X	X	X

The next review, "Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes" [55], presents several examples of the integration between I4.0 technologies and the elimination of inherent waste from production processes, based on the 7 + 1 classical waste perspective. Based on the literature review between 2008 and 2021, 53 articles were analyzed, with the results showing a greater contribution to the elimination of classic Lean waste in the Big Data dimension, followed by Administrative Process Automation and Simulation and Augmented Reality (Table 3).

Table 3. Analysis of the article "Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes" [55].

Technology	**Cybernetics**	**Connectivity and Integration**	**Big Data**	**Industrial Automation**	**Administrative Process Automation**	**Simulation and Augmented Reality**	**Additive Manufacturing**
Lean wastes and Industry 4.0							
Defects				X	X		
Overproduction					X		
Waiting			X				
Transportation	X		X				X
Over-processing			X				
Inventory		X					
Underutilized Skills						X	
Motion						X	X

The review "Implementation of Industry 4.0 Techniques in Lean Production Technology: A Literature Review" [56] was conducted on articles published between 2018 and 2021. This review sought to identify combinations of Lean practices and I4.0 technologies. The result is presented in Table 4, and shows the intensive use of Lean tools in conjunction with I4.0 technologies. In this work, the strong contribution of the I4.0 technologies to the analyzed Lean tools is observed—including the areas of Industrial Automation and Additive Manufacturing, which have a smaller but no less relevant contribution.

Table 4. Analysis of the article "Implementation of Industry 4.0 Techniques in Lean Production Technology: A Literature Review" [56].

Technology	**Cybernetics**	**Connectivity and Integration**	**Big Data**	**Industrial Automation**	**Administrative Process Automation**	**Simulation and Augmented Reality**	**Additive Manufacturing**
Lean Tools							
Value Stream Mapping	X	X	X	X	X	X	X
Cellular Manufacturing	X	X	X		X	X	X
Kanban	X	X	X		X	X	
Jidoca	X	X	X		X	X	
5S		X	X		X	X	
Total Productive Maintenance	X	X	X	X			X
Just In Time	X	X		X	X		
Poka Yoke	X		X		X	X	

The review "Are Lean, World Class Manufacturing and Industry 4.0 related?" [14] looked at 165 articles published between 1984 and 2021. By analyzing its results, it was verified that the relationship between Lean and Industry 4.0 is yet limited if looking at the overall publishing scenario on these topics. The results (shown in Table 5) demonstrate, among other things, high academic interest in the topics themselves, but still some limitation when it comes to the relationship of Lean and I4.0 (15.5% of the articles reviewed show a focus on the two concepts) (Table 5). Even focusing on a shorter time range, from 2016 to 2021, it is observed that the articles in this subset that have a focus on I4.0 and Lean still represent less than 20% of the total. In addition to these findings, the article provided little contribution regarding how different Industry 4.0 areas interact with Lean Manufacturing (Table 6).

Table 5. Analysis of the article "Are Lean, World Class Manufacturing and Industry 4.0 related?" [14].

Main Themes Covered in Sample (1984–2021)	N	%	Ac.%
Industry 4.0	34	20.61%	20.61%
Lean and Industry 4.0	25	15.15%	35.76%
Lean	24	14.55%	50.30%
World Class Manufacturing	22	13.33%	63.64%
Structure Process	17	10.30%	73.94%
Lean and World Class Manufacturing	8	4.85%	78.79%
Manufacturing	7	4.24%	83.03%
Business Process Mapping	6	3.64%	86.67%
Lean and Manufacturing	6	3.64%	90.30%
World Class Manufacturing and Industry 4.0	5	3.03%	93.33%
Semi-structure Process	4	2.42%	95.76%
Multi-Criteria Decision Analysis	2	1.21%	96.97%
Lean and Agile	1	0.61%	97.58%
Lean and Information Technology	1	0.61%	98.18%
Lean and Six sigma	1	0.61%	98.79%
Lean and Value Stream Mapping	1	0.61%	99.39%
Process Structure	1	0.61%	100.00%

Table 6. Analysis of the article "Are Lean, World Class Manufacturing and Industry 4.0 related?" [14]—subset 2016–2021.

Main Themes Covered in Sample (2016–2021)	N	%	Ac.%
Industry 4.0	34	28.10%	28.10%
Lean and Industry 4.0	23	19.01%	47.11%
Lean	21	17.36%	64.46%
Structure Process	8	6.61%	71.07%
World Class Manufacturing	8	6.61%	77.69%
Lean and World Class Manufacturing	7	5.79%	83.47%
Lean and Manufacturing	6	4.96%	88.43%
World Class Manufacturing and Industry 4.0	5	4.13%	92.56%
Business Process Mapping	2	1.65%	94.21%
Manufacturing	2	1.65%	95.87%
Lean and Agile	1	0.83%	96.69%
Lean and Information Technology	1	0.83%	97.52%
Lean and Six sigma	1	0.83%	98.35%
Lean and Value Stream Mapping	1	0.83%	99.17%
Process Structure	1	0.83%	100.00%
Multi-Criteria Decision Analysis	0	0.00%	100.00%
Semi-structure Process	0	0.00%	100.00%

In "Impacts of Industry 4.0 technologies on Lean management tools: a bibliometric analysis" [57], a review is made considering articles from 2011 to 2020. As a result, the relationship between Lean methodologies and techniques and I4.0 technologies are presented in Table 7. The article is different from the results presented before, since it expands the scope of the analysis to include other Lean tools and methodologies, and presents similar results. As in the previous work, the dimensions that promote the greatest impact on Lean are Big Data and Connectivity and Integration at the top, and Industrial Automation as the one that, although impactful, has the least contribution in relation to the other dimensions. The other tools, despite not being at the top, have a relevant contribution, being basically equivalent to each other. In this last group, Additive Manufacturing has a slightly lower impact than the others.

Table 7. Analysis of the article "Impacts of Industry 4.0 technologies on Lean management tools: a bibliometric analysis" [57].

Technology	Cybernetics	Connectivity and Integration	Big Data	Industrial Automation	Administrative Process Automation	Simulation and Aug. Reality	Additive Manufacturing
Methodology & Tools							
Continuous improvement	X	X	X	X	X	X	X
Heijunka	X	X	X		X	X	
TPM (Total Productive Maintenance)	X	X	X		X	X	X
Communication and Information sharing	X	X	X	X	X		
Jidoka	X	X	X	X	X	X	
JIT	X	X	X			X	X
5S		X	X			X	X
Andon	X	X	X		X	X	
Kanban	X	X	X			X	X
Poka-yoke	X	X	X			X	X
Pull flow	X	X	X	X		X	X
Standardization work	X	X	X	X			
VSM		X	X		X	X	
Waste reduction		X	X		X	X	
CIM (Computer Integrated Manufacturing)		X	X		X		X
Decreased operation and waiting times	X	X	X	X			X
Decreased stocks and inventory management	X	X	X			X	X
Problems solving	X	X	X		X	X	
Quality control		X	X		X	X	
Standardization		X	X		X	X	
Increased flexibility	X		X	X		X	
KPI	X		X			X	
Statistical control process	X	X	X		X		
Cellular manufacturing		X	X				X
Empowerment and involvement of workers		X	X		X		
Improved human resources			X			X	X
Set up reduction used (SMED)		X				X	X
Supermarket	X	X	X				
WIP reduction		X					X
Automation					X		
Machine and human separation							X
Production Smooth					X		
Supplier development					X		
Takt time						X	

The article "Compatibility, opportunities and challenges in the combination of Industry 4.0 and Lean Production" [58] analyzed 15 articles published between 2015–2020, and among the results, it presented a correlation between I4.0 principles with some Lean tools. The compatibility is presented on a Likert scale from 0 to 3, with "0" being no compatibility and "3" being high compatibility, and the result is presented in Table 8. Strong overall compatibility is perceived, with Kanban and Total Productive Maintenance (TPM) being present in all I4.0 principles.

Table 8. Analysis of the article "Compatibility, opportunities and challenges in the combination of Industry 4.0 and Lean Production" [58].

Lean Tools vs. Industry 4.0 Principles	Real-Time Capability	Interoperability	Decentralization	Virtualization	Modularity
Kanban	3	3	3	2	3
TPM	3	3	3	2	1
Just-in-time-production	3	0	2	3	3
One-piece-flow	3	3	2	0	3
SMED	2	3	2	1	3
Andon	3	3	2	3	0
Kaizen	3	3	1	2	0
Poka Yoke	1	1	3	3	0

Two more literature reviews were analyzed. In line with the broader goals of this work, their focus was less on the relationship between Industry 4.0 technologies and Lean Manufacturing practices and methods, and more focused on the integration between the two within an organization. These reviews provided different results. "The integration of Industry 4.0 and Lean Management: a systematic review and constituting elements perspective" [59] sought, through analysis of 111 articles published between 2015 and 2021, to identify the key components for the integration process between Lean and I4.0. This article draws a link between 'what' elements of Lean and I4.0 organizations should integrate and 'how' they may do it. The findings indicate that integrations cover the essential constituting elements of LM. However, serious gaps were identified concerning the operational level. The authors identify as major constraints the lack of enabling processes, routines, and implementation pathways. It further identifies Change Management as the key component of the integration process, given the transformational nature that both Lean and I4.0 represent for the organization.

Finally, in "Lean Tools in the Context of Industry 4.0: Literature Review, Implementation and Trends" [51], a different analysis was identified. While still approaching the relationship between I4.0 and Lean, this article is focused on the implementation of a lean philosophy for the digital environment, where it may be used to tackle problems related to inefficient digitalization within organizations. Through the analysis of 53 articles, a proposed framework for the implementation of Lean to the digital environment is elaborated. While the work presents the phases and objectives to be achieved, a strong technological perspective is present, emphasizing automation, including at the administrative level. In this proposition, not only does Lean become Lean 4.0, but its tools and methodologies are also adapted to this digital environment.

3.3. Lean Manufacturing and Industry 4.0: Review, Analysis, and Discussion

The articles reviewed presented visions of Lean and I4.0 from different dimensions and perspectives, but always demonstrating added value in the relationship between them. Most articles are focused on the technological side of the relationship between Lean and

Industry 4.0. Nevertheless, some connections to other factors—especially at the human and social level—were identified.

To better understand the relationship, in this section we first dive into the contributions of the different I4.0 technologies to Lean. Looking at these reviews, we must highlight the relationship between specific Industry 4.0 technologies and Lean methods and tools. In fact, these were the most frequent associations between the literature reviews analyzed, with six of the reviews presenting this perspective. Amongst the technological areas most prone to support Lean Manufacturing, the most frequently indicated in the literature are: Big Data (27), Connectivity and Integration (26), Administrative Process Automation (21), Cybernetics (18), and Augmented Reality (17). Regarding these technologies, in Appendix B we indicate the main contributions. Although the presentation is by I4.0 technology, the contribution is considered systemically—the more tools applied, the more iterations, the more value.

These results show the central aspect of technology in the relationship between Lean and Industry 4.0. They demonstrate that technology offers performance improvement opportunities when integrated with traditional industrial control and management practices [60], often in such a way that new approaches and tools are created [61,62]. Digital Lean Manufacturing (DLM) is one example of such "new" analytics applications where Connectivity and Integration are central. A DLM system relies on new data acquisition, integration, processing, and visualization capabilities to detect, fix, predict, and prevent ambiguous parameters and avoid quality issues inside defined tolerance ranges. These capabilities lead to fostering substantial feedback loops for quality assurance and quality management digitalization [63]—allowing the reliable functioning of several of the technologies presented above. Highly reliable, secure, and clean data ensure quality is guaranteed in the use of machine learning, high-performance computing, predictive modeling, correlations, and pattern recognition, neural networks, and others [64–66]. Similarly, Closed-loop Manufacturing (CLM) also allows the use of Big data, gathered during manufacturing in the production machine, to be shared across the different systems along the product lifecycle [67]. This allows increased connectivity, with immediate information sharing with product development activities, reducing variability and the risk of defects in the process [68].

The performance and stability of processes may also be improved using increased Administrative Process Automation—such as Robotic Process Automation (RPA). RPA allows the elimination of operational risk and brings companies the opportunity to better manage their resources, attaining savings in time and cost [69]. RPA will deliver a higher quality by standardizing operations and processes and reducing human errors by diminishing or eliminating the possibility of a process being performed in the wrong way or by an operator without proper knowledge [70,71].

Taking advantage of Cybernetics, organizations may create interconnected systems, where technologies are integrated in a collaborative way. They allow information to be closely monitored and synchronized between the physical factory floor and the cyber computational space, allowing for enhanced equipment efficiency, reliability, and quality [72].

Another area that gains interest from a systems perspective is that of extended digital support systems [73,74]. Technologies supporting such systems include collaborative robots (COBOTs), Augmented Reality (AR), and Smart Human Interfaces (SHI), and a number of smart technologies such as screens, 3D glasses, or exoskeletons. Such systems allow companies to achieve standardization, attain superior performance, and avoid human errors [75,76].

Despite this strong technological partiality, the relationship between Lean and Industry 4.0 is not encapsulated by the adaptation of technology to Lean, or vice versa. While results are more limited in terms of absolute numbers, there are important takes in the Literature about the importance of other aspects in this relationship—such as social, environmental, and business sustainability and continuity. In fact, some authors argue that even technology should not be regarded only to the extent of its technical applications, being instead used as catalysts of people, products, processes' efficiency, performance, and innovation [77]. In this sense, technology, processes, and people must be integrated in the I4.0 transition [78]. Looking back at our review of reviews, very little input is perceived in issues such as leadership, people, and cultural management, integration (downstream and upstream) in the value chain, innovation and design, and problem solving. At most, we found important points that indicate that issues of leadership and people management and culture are keys to the success of a Lean to I4.0 integration model. Along these lines, we selected a few excerpts from "The integration of Industry 4.0 and Lean Management: a systematic review and constituting elements perspective" and from "Lean Tools in the Context of Industry 4.0: Literature Review, Implementation and Trends":

- Lean Management "maturity introduces success factors" supporting the integration of Lean Management with I4.0: "a learning culture, senior management leadership, cross-functional team development, change governance frameworks, and training activities" [59];
- "Concerning elements of change" management, a series of factors were "identified [as] essential issues to be covered in integrating I4.0: transformation strategy, design, delivery, governance, and leadership" [59].
- "Processes only focused on digital technologies tend to be less efficient than processes based on Lean and that are rethought by people. In this way, workers are the center of innovation in a sustainable way, it is from them that comes the ability to improve processes and develop specific improvements for organizations, and it is up to them to focus on improving their skills and training them to deal with digital technologies" [51].
- "As in the past, without thinking people there is no Lean, and without Lean, there is no waste control, whether digital or not. This has the potential to impact the transition from the fourth industrial revolution to a new bias of Industry 5.0 or Society 5.0, in which, in addition to machines, employees are also a fundamental part of the industrial process, and Lean 4.0 converges along this same line of thought. Thus, there is a need for further research to understand what impacts Lean 4.0 has on the new way of thinking about Society 5.0 and if they can go together and what their intersection points are (. . .)" [51].

Moving on to environmental sustainability, a similar scenario is observed. The relationship between Lean and Sustainability has been explored from multiple perspectives [79]—including the use of technology to improve green production [80–82]. A significant part of these studies is focused on the supply chain [83,84]. The search for "Corporate Sustainability" has led multiple frameworks and instrumental studies on the causality between sustainability and performance, and on managerial practices and on tools to manage them [85,86]. However, these efforts have seen mixed results. While theoretical studies were able to pinpoint both the synergies and trade-offs between environment and performance, instrumental studies failed to provide convincing evidence, either because of inaccurate measurement systems or because they were often representative of a single company or sector, and they failed to provide a cross-industry perspective [85,87].

However, the impact of the relationship between Lean and Industry 4.0 has been more limited, and better integration between Industry 4.0 business models and performance management frameworks is still necessary [88]. Examples of limited approaches abound, and include the listing of paperless organizations as a benefit of the sustainability-productivity link, or claiming sustainability as a result of predictive analytics in production and operations management, resulting in less waste. However, these perspectives create a false sense integration, a feeble solution instead of the larger promotion of a structural change in the management practices and methods of organizations.

Business continuity is another topic with limited mentions across the literature, with the topic being absent even from the most recent reviews. Nevertheless, some important notes exist on how Lean supports long-term success and the transition to Industry 4.0. It has been identified that organizations that have been implementing lean productions extensively are more likely to concurrently adopt Industry 4.0 technologies [89], demonstrating that Lean may be critical for the resilience of organizations, including in helping to navigate large industrial transitions [13]. However, the contribution of the relationship between Lean and Industry 4.0 towards resilience has only had limited mention in the literature [90,91].

4. The Path Ahead with Industry 5.0

4.1. A New Strategic Era: Industry 5.0

While Industry 4.0 is a recent technological and societal transformation—affecting not only our industries but society at large—other more ambitious initiatives have been proposed since its inception. In 2015, the "2030 Agenda for Sustainable Development", adopted by UN member countries, defined 17 Sustainable Development Goals (SDGs) to improve health, education, and inequality that stimulate economic development, without losing focus on combating climate change and preserving oceans and forests [92]. In the same year, Michael Rada [93] posted his reflection on the lack of a man-machine perspective in a synergistic way of Industry 4.0 and coined this evolutionary vision as "Industry 5.0". In 2016, Japan, in the "5th Science and Technology Basic Plan", presented the concept of Society 5.0 (S 5.0), which started from the hunter/gatherer evolving to the partisan/farmer, and then to the industrial and later to the information ages [94,95]. This proposition of S5.0 that has as its foundation the SDGs and represents a society that keeps humanity as the central actor, promoting happiness and a sense of value to them, through the use of technology, which is the instrument for the promotion of these actions [94]. From there, the proposed definition of Industry 5.0 as it is known today begins [96,97].

In the unfolding of the S5.0 concept, there is the proposal of Industry 5.0 (I5.0). Proposed by the European Union [98], the definition of I5.0 [99] presents industry as an active element in the societal change process towards a more sustainable, resilient, and human-centered perspective [99]. In this new concept, industries take an active role in the achievement of targets beyond employment and growth, coming to consider also the productive limits of the planet, supporting research and innovation at the service of sustainability, and promoting a human-centered digitalization and a resilient society [100,101]. The key activators for I.5.0 and their relation with the SDGs are presented in Table 9 [101].

Since I5.0 is conceptually oriented towards an innovative, resilient, and human-centric industry, new points of attention regarding problems that are reflected in the technological, social, and governance spheres tend to arise. This is one of the areas where understanding the relationship between I4.0 and I5.0 becomes critical, as we need to identify the key technologies that facilitate the transition. Examples are [101]:

- Human-centric solutions and human-machine interaction technologies that connect and combine the strengths of humans and machines.
- Bio-inspired technologies and smart materials using recyclable materials with embedded sensors and enhanced features.
- Simulation and real-time digital twins for modeling systems.
- Cyber-secure data analysis, transmission, and storage technologies that can manage the interoperability of systems and data.
- Artificial intelligence, such as the ability to find causal relationships in complicated dynamic systems and produce useful information.

Reliable, energy-efficient autonomy technologies are also needed because key technology enablers will use a lot of energy.

A point of attention is the fact that despite the fact that the Industry 5.0 theme is incipient and, as a result, there is little literature on the subject, the growth of research in this regard has grown significantly. This requires converging understanding on the subject in order to avoid neologisms and derivations that tend to create confusion and conceptual failure on the subject [102].

Table 9. Sustainable Development Goals link with Industry 5.0 & Society 5.0 Key Enables.

Technologies vs. Sustainable Development Goals	**1 No Poverty**	**2 Zero Hunger**	**3 Good Health & Well-Being**	**4 Quality Education**	**5 Gender Equality**	**6 Clean Water & Sanitation**	**7 Affordable & Clean Energy**	**8 Decent Work & Economic Growth**	**9 Industry, Innovation & Infrastructure**	**10 Reduce Inequalities**	**11 Sustainable Cities & Communities**	**12 Responsible Consumption & Production**	**13 Climate Action**	**14 Life below Water**	**15 Life Land**	**16 Peace, Justice & Strong Institutions**	**17 Partnerships for the Goals**
Advanced Materials	X			X	X	X	X						X				
Artificial Intelligence		X	X		X				X		X	X		X	X	X	X
Augmented Reality				X							X				X		
Big Data & Analytics			X									X	X			X	
Blockchain	X						X			X						X	
Cloud											X						
Cybersecurity					X			X									X
Data Democratization				X												X	X
Digital Twin												X					
Drones			X											X	X		
E-Governance							X										X
Electric Vehicles													X	X			
Innovation strategies				X			X								X		
Internet of Things		X								X			X		X		X
IoT enabled supply chain process optimization & automation	X						X	X	X	X							X
Maintenance		X				X	X				X	X		X	X		
Robotics		X				X		X	X					X			
Smart Sensors						X											
Virtual Reality				X							X						
Wearables			X														

The three dimensions of I5.0 [103]—Sustainable, Resilience, and Human-centric—need further detailed description in order to identify the impact of their implementation. In this regard, Table 10 [104] presents a proposed framework for I5.0. These are exactly the characteristics that make Industry 5.0 a different type from previous Industrial Revolutions, to the point that it prevents the consideration of it as a natural "chronological evolution" resulting from the previous Revolution—as happened from Industry 1.0 to Industrial 4.0. When dealing, for example, with the question of the productive process centered on the human being, where man and machine "co-labor" and "co-exist", it is something far out of the context of the previous Industrial Revolutions, and there is a great opportunity for studies and projects in the construction of this path [103,105].

Table 10. Industry 5.0 Framework.

Industry 5.0 Dimensions	Society Level	Network Level	Plant Level	Organization—Level and Dimensions
Resilience	Viability of intertwined supply networks	Supply chain, resilience Reconfigurable supply chain	Resilience of manufacturing and logistics facilities Reconfigurable plants.	Resilient Value Creation and Usage
Sustainability	Sustainable usage of resources and energy on the earth	Supply chain sustainability Life cycle assessment of value-adding chains	Reduction of CO_2 emissions Energy-efficient manufacturing and logistics.	Sustainable Manufacturing and Society
Human-Centricity	Viability of human-centric ecosystems	Cyber-physical supply chains Digital supply chains	Human-machine collaboration Health protection standard and layouts	Human Well-Being

Table 11 presents the enablers that support the transition between I4.0 and I5.0 [101].

Although I5.0 seems to still be at a theoretical level—since its ability to deliver its results is yet to be proved—studies have shown that it has the ability to support the development of the proposed values to promote sustainable development [100]. An unplanned "trial run" of the benefits that I5.0 can bring to society as a whole was the critical pandemic scenario that plagued society between 2020 and 2021 [106]. The contingency scenario that nations and companies required accelerated the virtualization of work activities in a way not previously imaginable—-in the form of remote work and meetings and in virtual rooms, intensive use of corporate networks, etc. These activities, which hitherto depended on travel, were now performed virtually. The reduction in the use of cars in general in the cities, the use of airplanes, etc. changed the appearance of the big centers. The reason for this action was to ensure sanitary conditions and preserve the health of employees, customers, and partners—a vision focused on man as the center of society. This generated learning and developed knowledge and skills previously unused or unknown—that is, resilience. Because of the low consumption/production promoted by the general activity level of society, it promoted the reduction of pollution in general (air and water) [107]. Some fruits of this transformation have altered how we work beyond the pandemic scenario.

Table 11. Key Enabling Technologies—transition from Industry 4.0 to the concept of Industry 5.0.

Authors	Impact
Edge Computing	Low latency Ensure cybersecurity Expanded interoperability Reduce storage cost
Artificial Intelligence	Intelligent automation Greater efficiency Quality control Quick decision making
Cobots	Increased productivity Robustness Enhanced dexterity More consistent and accurate

Table 11. *Cont.*

Authors	Impact
5G & Boyond	Knowledge discovery Smart resource management Low latency Ultra-high reliability
Digital Twins	Reduce cost Predicting future errors Design customization Predictive maintenance
Blockchain	Decentralized management Operational transparency Create digital identities Compartmentalized approach
Internet of Everything	Asset Productivity Cost reduction Supply-chain and logistics Reflect intelligence in network
Big Data Analytics	Customization Faster, better decision making Foster competitive pricing Real-time forecasting

4.2. Opportunities and Challenges for Lean Manufacturing in Industry 5.0

Lean, as a set of methodologies and tools with a strong cultural basis, is a production management model oriented to the elimination of waste, focusing on value for the customer, honoring and respecting its employees, partners, and society [30,36]. This is different from the I4.0 the I5.0 models, which are not a production management model and not even fully implemented—given the high degree of "economy of scale" required for full adoption. As such, they end up representing, at most, a vision of the future supported by actions or processes more or less fragmented in relation to the integrated, fully-tested perspective of Lean. Despite these differences, Lean may serve as a bridge between the I5.0 vision and the reality of the productive system management of a company.

The number of works that integrate I5.0 to Lean is appreciably low. However, in these few articles it is possible to see the correlation potential between both. Compared to the scenario of I4.0, in which the focus of technology overshadows Lean and tends to integrate it mostly in the use of methodologies and tools, Lean may find its real value I5.0, as in the case of the analysis, which demonstrates that Lean, due to its people/partner-oriented perspective, is a facilitator in the implementation of I5.0 [108]. In this context, the Lean principles orbit among the "core" elements of I5.0 by cause-effect relationships.

In "Industry 4.0 and Industry 5.0 from the Lean Perspective", of the 13 articles analyzed regarding I5.0 and Lean, 12 of them indicate the "Human-centric" perspective as that most related to Lean. This is in line with the principles of Lean [30,32,39,40] where people—not only employees, but customers, partners, suppliers, and society in general—are relevant to the success of an organization and should be strongly considered.

Regarding "Sustainability", "Lean Green" (and its variations, such as "Sustainability & Lean", "Eco-Efficiency and Lean", "Sustainability & Eco-Efficiency & Lean"), the link between Industry 5.0 and Lean may help tackle the limitations still standing in the integration of Lean and a more ambitious sustainability policy. The literature demonstrates the benefits related to environmental performance in several dimensions, highlighting emissions (air), energy use, solid disposal, reduction in water pollution, reduction of toxic chemicals, and improvement in water and material use, among others. These results are strong opportunities for setting impactful Lean Green practices [109].

As for "Resilience", research conducted in 2022 regarding the impact of the COVID-19 pandemic in three different companies in the construction industry showed that the companies that were better qualified in relation to Lean principles were also better rated in relation to the dimensions of "Resilience", and, moreover, they had less impact on business and sometimes performed better during the critical period [110]. This result corroborates previous findings (from 2016), which demonstrated the positive synergy between Lean and resilience, and concluded that a company with a high level in implementing the dimensions of resilience and a high breadth in Lean implementation will be more likely to perform better after disruption or a contingency situation [110,111].

5. Conclusions

5.1. Lean, Industry 4.0 and Industry 5.0

In this article, we set out to analyze the relationship between Lean Management and Industry 4.0, exploring how Lean is framed within the so-called 4th Industrial Revolution, and uncovering any remaining opportunities and limitations. As a departure point, we analyzed the most recent reviews on the relationship between Lean and Industry 4.0. The eight literature reviews analyzed here unanimously highlighted the positive aspects of the relationship between Industry 4.0 and Lean. However, a clear orientation towards the integration of Industry 4.0 technologies with Lean methods and tools was shown. A common trend was uncovered in the different articles reviewed: the relationship between Lean and Industry 4.0 gains most of its apparent value based on the use of technology, and the increase oin such value is considered systemically—the more tools and technology are integrated, the more iterations, and consequently the most value. In opposition, very little or no input is perceived on issues related to the human and social factors of organizations—such as leadership, people, integration, and training for new roles and new tasks [112]. Similar gaps were observed regarding sustainability—whether in its social, financial/operational, or environmental aspects. Concerning business sustainability and resilience—paying special attention to the long-term success of the business—no reference was identified. As for environmental sustainability, the single reference to the topic across the most recent reviews is precisely the identification of the topic as a limitation of the literature on the relationship between Lean and Industry 4.0. The social focus, as mentioned above, is most often lacking.

These gaps became more obvious in the current *zeitgeist*. In fact, they have all pointed to Industry 4.0 itself, to the point of giving rise to a new concept, Industry 5.0., which aims to attack the limitations and missed integration opportunities in Industry 4.0 regarding human orientation, resilience, and environmental sustainability. Unlike the three previous Industrial Revolutions, I4.0 and I5.0 are not only the result of a disruptive reality in the production management model but also the product of technical and/or political decisions with the intention of adopting, in a targeted manner, larger societal strategies [103,113]. In the case of Industry 4.0, the clear intention was that of raising the level of the automation of industry—virtually to the limit of having a "lights out" production system, where decisions and production stages would be integrated and autonomous, and with very limited need for people. Naturally, this model has some particular restrictions in its integration with Lean, as people are central in this philosophy. Furthermore, the fact that I.4.0 is not a production management model but a technological vision creates limitations to its integration with Lean. The so-called I4.0 implementations are also often limited to a few areas or productive segments, a step away from the value chain perspective that is promoted in Lean.

Industry 5.0, unlike the former, has a broader perspective. It supports the vision of a more sustainable and balanced society, where environmental, societal, and governance challenges are further shared by all societal agents, including industrial companies. Lean Manufacturing, when implemented in a broad and sustainable way in an organization, yields the basic components of I5.0: Human-orientation, Resilience, and Sustainability [98]. By applying the Lean Management model, this broader vision enables the promotion of a more sustained digital transition—one where the leadership sees people, the environment, and society as elements that must be considered in the long term as a condition for the business itself to prosper. Continuous improvement will promote that people and machines, without conflicting roles, can operate in a complementary way. These synergies will improve the business process, developing the competence of people and creating a strong culture to support this management model permanently [114].

Attempts to implement a I4.0 without considering Lean were a way to speed up and automate industries [115]. However, such improvements are achieved in a way that better integrates the social and sustainability aspects of continuous improvement. As shown in this article, most references in the relationship between Lean and Industry 4.0 verge towards technology implementation and integration—an issue that has already been discussed by researchers in related areas, such as Quality Management and Operational Excellence [12,13]. As a result, the perspectives on this relationship are heavily skewed towards the technical aspects, diminishing the comprehensiveness of Lean Management. It is in the face of this reality that we argue for the strong potential of aligning Lean Management with Industry 5.0. By taking the ongoing shift in attention from I4.0 to I5.0, there is a clear opportunity to renew the role of Lean Management in today's industries, promoting, at the same time, an acceleration of sustainability, resilience, and human-centered strategies.

5.2. Considerations and Future Work

This work is one of the first efforts to explore the relationship between Industry 5.0 and Lean as a way to address the limitations of the integration of Lean and Industry 4.0. In our effort to summarize the relationship between Industry 4.0 and Lean, we have opted to center our work on the most recent reviews around this relationship. While we understand that this may be seen as a limitation, we would like to highlight that it is not the purpose of this article to offer another review—even of it is a review of reviews—on this relationship, describing in detail its many perspectives. As argued in this article, there have been many such works, including those reviewed in this document. Instead, our goal is to efficiently digest the different perspectives on this relationship, identifying and explaining them, uncovering their limitations, and setting the path ahead.

We believe we were able to successfully meet our goals. We have dissected the main trend in the relationship between Lean and Industry 4.0—that related to technological integration—by pointing which technologies are the most cited and how they relate to different Lean tools, methods, and practices. Furthermore, we have highlighted the uncovered topics—such as social, environmental, and business sustainability—that are the most lacking in terms of past research. Finally, this article points towards Industry 5.0 as a way of further integrating Technology and Lean, but by assuming a broader perspective where people are the central focus of the transition, and where the single focus on productivity is replaced by a joint perspective of sustainability, resilience, and productivity.

In terms of future work, the next steps are to deepen the study on the integration between Lean and Industry 5.0. Our goal is to create a framework where the triple perspective sustainability-resilience-productivity may be easily followed by organizations, helping them set goals and anticipate tradeoffs as they seek further (sustained) development.

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Appendix A

Technologies (Articles Table 1)/Broader Technological Areas	Cybernetics	Connectivity and Integration	Big Data	Industrial Automation	Administrative Process Automation	Simulation and Aug. Reality	Additive Manufacturing
The integration of technologies Industry 4.0 technology and Lean Manufacturing: A systematic literature review	"Cyber Physical System"	"Cloud" "Vertical/Horizontal Integration" Machine-to-machine communications" "Radio Frequency"	"Big Data"	"Autonomous Robotics"	"Internet of Things"	"Simulation" "Virtual and augmented reality"	"3D Printing"
Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes	"Cyber Physical System"	"Cloud"	"Big Data"	"Autonomous Robotics"	"Internet of Things"	"Simulation" "Virtual and augmented reality"	"3D Printing"
Implementation of Industry 4.0 Techniques in Lean Production Technology: A Literature Review	"Cyber Physical System"	"Cloud"	"Big Data"	"Autonomous Robotics"	"Internet of Things"	"Virtual Simulation" "Virtual and augmented reality"	"Additive manufacturing"
Impacts of Industry 4.0 technologies on Lean management tools: a bibliometric analysis	"Cyber Physical System"	"Cloud" "Sensors"	"Big Data"	"Robotics"	"Internet of Things" "Internet of Services"	"Simulation" "Augmented reality and Virtual reality"	"3D Printing"

Appendix B. Contribution of Different Technologies to Lean Manufacturing—Summary of the Articles Listed in Table 1

Technology	Contributions	Articles
Cybernetics	• Help Lean correct failures through interconnected systems and employ self-optimizing manufacturing systems aiming at zero defects, ensuring process security.	[54]
	• System integration refers to the increased connectivity and linking of cyber-physical systems in the manufacturing operation.	[55]
	• Cyber Physical System for a flexible Kanban production scheduling.	[56]
	• Lean tools most related to 4.0 technologies in the industry are Heijunka, Continuous Improvement, Just in Time and Jidoka, Communication Information Sharing and Waste Reduction. Among these categories, the technologies most used to improve Lean Management tools are: Big Data, Cyber Physical System, Sensors, Augmented Reality, Data Analytics and 3D Printing with, Cloud, Internet of Things. • Lean Manufacturing Automation (Jidoka) using Cyber Physical Systems is considered a cost- effective and efficient approach to improve system flexibility in increasingly challenging global economic conditions. This is the reason for intelligent Lean manufacturing automation powered by Cyber Physical Systems technologies, which is also based on Jidoka's analysis and the intelligence capability of Cyber Physical Systems technologies. • Able to collect real-time data on service needs and automatically send signals to the service (e.g., automatic notifications) of the machines when errors or defects are detected. • Can be used in combination with CPS networks providing real-time data to establish a virtual VSM. Intended to improve work processes and conditions, as well as to enable faster decision making. VR	[57]
Connectivity and Integration	• Help Lean with integrating and sharing with different sectors of the plant, perform remote maintenance management of complex equipment, reduce the space for data storage, stores, and share data between different companies (data warehouse), share company's data and information with the internal and external public, and establish communication between ERP systems of different companies.	[54]
	• Guarantees better estimates for product and predicted inventory amounts compared to traditional software downloads on personalized computers. • Increases the cost-effectiveness of inventory handling by eliminating the need for servers, as well as human-related services rendered in inventory management on-site. • Inventory amounts could be accessed anytime, anywhere, and from any device with a high degree of accuracy. • All processes relevant to inventory organization, arrangement, and ordering could be handled in one location, the Cloud, where every stakeholder has access to the needed information.	[55]
	• Bring more benefits in product design and development, and how condition monitoring and Cloud computing contribute to enhancing TPM in electric drives production.	[56]
	• Lean tools most related to 4.0 technologies in the industry are Heijunka, Continuous Improvement, Just in Time and Jidoka, Communication Information Sharing, and Waste Reduction. Among these categories, the technologies most used to improve Lean Management tools are: Big Data, Cyber Physical System, Sensors, Augmented Reality, Data Analytics and 3D Printing with, Cloud, Internet of Things. • Allows the collection of data on resources, ensuring the configuration, implementation, and flexibility of the Jidoka performance system. Enables an autonomous global supply chain with improved process, efficiency, and zero defects.	[57]

Technology	Contributions	Articles
Big Data	• Helps to manage data to optimize the maintenance of complex equipment; reduces the time to make decisions based on history; helps in the creation of new products based on customer relationship management (CRM) and their preferences, in addition to performing market analysis and monitoring different degrees of customer satisfaction in relation to horizontal/vertical integration; helps to integrate different sectors of the company such as engineering and production; integrates information technology systems horizontally and vertically to obtain productivity, cost and quality gains and shares data within the entire value stream.	[54]
	• Decrease lead time in the manufacturing process. • Manufacturing time at each phase of the batch input manufacturing decreased. • Consumers may channel their preferences along the manufacturing process allowed by intelligent data systems that integrate consumers' desires in the manufacturing process of products. • Big data analytics decreased waiting time in tracking products, their locations, and features. • Positive relationship between the implementation of big data and sustainable supply chain practice—big data applications improve real-time knowledge about problematic routes, equipment, vehicles, personnel, and suppliers making manufacturers correct their choices to guarantee smooth transportation quickly. • Big data tools could be linked with machines to autonomously correct any deviations from standardized processes using the information generated and recommended by the intelligent data-based systems.	[55]
	• Provides support to Lean, increasing productivity. • Big Data and 5S integration with only a few practical applications. • Few researchers have developed robust and sustainable Cellular Manufacturing.	[56]
	• Lean tools most related to 4.0 technologies in the industry are Heijunka, Continuous Improvement, Just in Time and Jidoka, Communication Information Sharing and Waste Reduction. • Cited in some publications as facilitating problem solving and promoting accountability to improve services, reducing waste of human activities and material resources, while improving the quality of the patient experience and reducing costs. • Can be attributed to waste disposal.	[57]
Simulation and Virtual and augmented Reality	• Helps in solving workstation problems through the use of devices such as tablets, smart glasses, or smartphones; supports carrying out maintenance remotely through knowledge sharing and technical guidance, and simulation; facilitates the construction of prototypes and samples; and also simulates projects and processes in different production and programming scenarios.	[54]
	• Additive manufacturing refers to the creation of high-dimensional objects by the disposition of materials such as 3D printing. Eliminate wastes in the production planning phase by the evaluation of alternative planning strategies to determine the optimal course of action. • Allows manufacturers to integrate siloed operations within the general system by eliminating excess resources, people, or equipment additive manufacturing saves large amounts of resources and minimizes the waste of operator motion, resources, costs, and energy used in production. Virtual and augmented reality application in Jidoka principle. • Few case studies have been implemented, focusing mainly on JIT, TPM, and VSM	[55]
	• Bring more benefits in product design and development.	[56]
	• Lean tools most related to 4.0 technologies in the industry are Heijunka, Continuous Improvement, Just in Time and Jidoka, Communication Information Sharing and Waste Reduction. Among these categories, the technologies most used to improve Lean Management tools are: Big Data, Cyber Physical System, Sensors, Augmented Reality, Data Analytics and 3D Printing with, Cloud, Internet of Things.	[57]

Technology	Contributions	Articles
Administrative Process Automation	• Strong impact on real-time tracking of customer demand and Work in progress and finished product inventory. Solution difficulties, such as inadequate management and poorly organized manufacturing systems, and, in addition to collaborating with data storage correctly, it reduces the time between failure notification and failure occurrence, makes systematic management of the supply chain more efficient, and supplies and improves the supply chain. • Help Lean to perform inventory control and material traceability and data sharing with the network to optimize preventive maintenance, and provides real-time information to support management decision making.	[54]
	• Reduces information defects and increases product traceability. Tested the use of a blockchain platform that allows producers, logistics services providers, and consumers to participate in information certification on improving products' information integrity and traceability. • Advanced sensors that read many variables and act autonomously can reduce risks of gas leaks or unexpected overflows. Increases the real-time data collection of customer needs, making the manufacturing of only desired products realized. Enhancement of machine-to-machine communication increases optimal production generating only needed amounts requested by customers. Enhances the implementation of Just-in-Time manufacturing, and thus avoids overproduction. Reduces excessive communication among varying departments in the enterprise. • Lean tools most related to 4.0 technologies in the industry are Heijunka, Continuous Improvement, Just in Time and Jidoka, Communication Information Sharing, and Waste Reduction.	[55]
	• Bring more benefits in product design and development. Management system is considering Agile–Kanban.	[56]
	• Enables an autonomous global supply chain with improved processes, efficiency, and zero defects. • Supported by networked communication between production and supply by providing real-time data on operations and machines. Using the available information, we are able to optimize processes, reduce costs, and minimize resource consumption. • Offers enormous possibilities for providing real-time data for analysis, eliminating waste and the need for human intervention.	[57]

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