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Lean and industry 4.0 principles toward industry 5.0: a conceptual framework and empirical insights from fashion industry

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Abstract

Purpose – Examining synergies between Lean, Industry 4.0, and Industry 5.0 principles, the aim is to showcase how Lean's focus on people enhances Industry 5.0 implementations, leading to the development of the Lean 5.0 paradigm. In addition, insights from artisanal industries, like the fashion one, are specifically collected.

Design/methodology/approach – First, a literature review was conducted to define a comprehensive framework to understand how Lean fits into the Human-Centric (HC) paradigm of Industry 5.0. Second, a case study was employed to give empirical insights and identify practical initiatives that brands can pursue, involving two best-in-class leather goods brands located in Italy.

Findings – A conceptual framework to pave the way for new paradigm Lean 5.0 was defined and validated through a case study. To path the way for a case study in the fashion industry, the Lean HC paradigm is detailed into domains and related categories to group practices. The empirical insights demonstrate that Lean HC actions can be effectively supported by Industry 4.0 technologies in traditional sectors like the fashion industry, shifting towards Industry 5.0.

Practical implications – The proposed framework and related practices can be used by companies to facilitate their transition towards Industry 5.0, leveraging on Lean Manufacturing.

Originality/value – The innovative contribution of the present work mainly refers to the proposed conceptual framework, encompassing Lean, HC and Industry 4.0 and introducing Lean 5.0 paradigm. The case study enriches the empirical contributions in the fashion industry.

Keywords Lean manufacturing, Industry 5.0, Human-centric manufacturing, Luxury fashion industry, Made in Italy, Lean 5.0

Paper type Research paper

Quick value overview

Interesting because: The Industry 5.0 paradigm is disruptive in manufacturing, shifting the focus from Industry 4.0's technology-centric approach to a human-centric model. Studies showed the relevance of Industry 5.0, but mostly focused on its high-level conceptualization. Our research offers a roadmap for effectively moving towards Industry 5.0 and provides

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actionable insights applicable across various sectors. Depending on the peculiarities of the industry, we emphasize that the transition to Industry 5.0 can begin from various starting points. For instance, artisanal companies will mostly start from already applied Human-Centric (HC) initiatives, while more automated sector from implemented Industry 4.0 technologies.

Theoretical value: The study found that Industry 5.0 principles can be effectively achieved by starting with paradigms that are already extensively used in industries, thereby narrowing the gap to the shift. The novel concept of Lean 5.0 is therefore introduced as a result of the synergies between the well-known paradigms of Lean, Industry 4.0 and HC, illustrating how each can serve as a starting point for effectively moving towards Industry 5.0.

Practical value: This research provides practical guidelines for adopting the Lean 5.0 paradigm, addressing one of the main challenges for companies facing disrupting paradigms: how to concretely evolve from their status quo. The proposed case study in the fashion luxury industry demonstrates that the application of Lean HC actions, combined with Industry 4.0 technologies such as Cloud Manufacturing and Business Data Analytics, represents a concrete way to move towards Industry 5.0. It also provides an initial list of replicable Lean 5.0 practices.

1. Introduction

Industry 5.0 (I5.0) paradigm is replacing the well-known Industry 4.0 (I4.0), switching the industrial perspective towards a HC approach (Ghobakhloo *et al.*, 2023). I4.0 paradigm is heavily centered on technology (Cimini *et al.*, 2021), facilitating instantaneous interconnection and communication among individuals, machinery and goods (Pagliosa *et al.*, 2021), and resulting in an exponential increase in the volume of data generated across various business and industry sectors (Saad *et al.*, 2023). Technologies and innovative solutions, indeed, represent the enablers to readapt production processes to workers' needs, so to get them engaged and empowered (Leng *et al.*, 2022). In the current competitive business landscape, all sectors strive for continuous performance improvement, involving relentless waste elimination to consistently add value (Alves, 2022). The promotion of a bottom-up philosophy covers a key role in Lean (Angelis *et al.*, 2011), where process improvements are based on workers' commitment and active involvement (Ainul Azyan *et al.*, 2017). It comes naturally to wonder which crucial role Lean will play for I5.0, after beneficial effects of Lean 4.0 have been proposed already (Rossini *et al.*, 2021; Tortorella *et al.*, 2021). Despite Lean, I4.0, and I5.0 are concepts more and more frequently investigated in the academic literature and considered across all sectors (Souza *et al.*, 2022), there is a literature gap in their interrelation, especially considering the connection and synergies between Lean and HC aspect of I5.0.

Accordingly, the first research question is:

RQ1. How does Lean fit within the HC paradigm of Industry 5.0?

Sectors where human involvement is crucial, such as the artisanal luxury fashion industry noted for the "Made in Italy" brand, are highly significant for research due to the expected substantial benefits of adopting a HC approach. Among them, luxury fashion industry is particularly promising since the role of the operator is central to this type of production process (Fani *et al.*, 2023a). Despite industry's reliance on human skills, the integration of digital technologies enhances these capabilities and drives innovation in the fashion industry. Considering the presence of Lean and I4.0 applications in a less automated sector such as fashion, investigating the implications of Lean 5.0 in this context can provide valuable insights. Additionally, case studies are scarce in this specific industry.

Therefore, the second research question is:

RQ2. : Which Lean HC best practices can be implemented in fashion luxury industry to move towards the I5.0 paradigm?

To answer the research questions, a conceptual framework has been proposed and applied through an in-depth case study in two luxury leather goods realities in Italy, to initiate a scientific debate on the role of Lean in the post-I4.0 era by showing how powerful is to promote I5.0 within companies. The selection of a traditionally crafty sector shows the possibility of establishing a successful I5.0 environment even in certain contexts where I4.0 is less eradicated than in other industries, such as automotive.

The paper is structured as follows: Section 2 presents the theoretical background, and outlines the proposed framework; Section 3 resumes the methodology; the findings from the case study are presented in Section 4; Section 5 discusses the evidences and conclusions are presented in the final section.

2. Theoretical background

2.1 Lean and I4.0

Lean and I4.0 are two paradigms that guide the manufacturing industry in tackling the challenges presented by the growing complexity of the market (Kassem *et al.*, 2024). Lean 4.0 has been studied by researchers and practitioners to understand how both approaches, when implemented together, can raise operational and financial performance levels to a different pattern (Rossini *et al.*, 2019). In fact, many studies have demonstrated that I4.0 supports Lean practices adoption, through technology and digitalization, allowing an improvement of the practices already in use. Vice versa, Lean is considered fundamental for a better implementation of I4.0 (Sanders *et al.*, 2017; Wagner *et al.*, 2017). Throughout the years, this vision has completely overcome the first one, making the integration between Lean and I4.0 even more realistic and necessitating the adoption of Lean practices to facilitate digitalization (Ciano *et al.*, 2021). It is worth mentioning that the relationship sheds the light on an important touchpoint between Lean and I4.0: the learning process, which is considered necessary for the proper implementation of Lean 4.0 (Prinz *et al.*, 2018). Many authors have agreed on the fact that, in order to properly train the workers to use smart technologies in solving production problems, it is necessary to resort to the learning factory approach (Bauer *et al.*, 2018). This solution, in fact, can gradually establish a connection between the two aspects – Lean and I4.0 – and make people aware of which are the improvements that can be achieved using them both.

2.2 Lean, HC manufacturing and I5.0

In Lean processes, communication with employees is the key to getting everyone on board (Bashar *et al.*, 2022). Placing people at the center, focusing on their well-being, development and involvement, refers to the HC manufacturing approach (Hines, 2021). It recognizes the importance of engaging employees at all levels and emphasizes the development of their skills (Vilda *et al.*, 2019). It is based on the principles of respect for people, which involves creating a working environment that guarantees employee satisfaction and well-being (Zhang *et al.*, 2023), not only focusing on efficiency and productivity (Lu *et al.*, 2022). HC is one of the three pillar of the I5.0 paradigm, as defined by European Commission (2021) and widely accepted by researchers (Alves *et al.*, 2023). Besides Sustainability and Resilience, the HC approach focuses on prioritizing the requirements and concerns of individuals (Destouet *et al.*, 2023), emphasizing the need for integrating human factors into I4.0 solutions and preparing for the transition to Operator 5.0 (Gladysz *et al.*, 2023). Fundamental human rights

are safeguarded, ensuring inclusive work environments (Coronado *et al.*, 2022) and considering the overall well-being of individuals as a key driver of sustainable and resilient industrial practices (Li *et al.*, 2023). Considering the "Human Needs Pyramid" (Lu *et al.*, 2022), traditional system-centric manufacturing delivered only the first two levels, leaving the last three for HC manufacturing to create a "comfortable, motivating and rewarding environment for growth".

2.3 Lean, I4.0 and I5.0 in fashion industry

Several applications of Lean principle in the fashion industry can be found. For instance, some of them refer to the successful implementation of the value stream map to identify inefficiency in garment (Kumar *et al.*, 2020), textile (Hussain and Figueiredo, 2023) and leather shoe (Reda and Dvivedi, 2022) industries. Others focus on the combination of Lean tools with autonomous maintenance to provide continuous improvement in the field, with case studies in textile companies (Kose *et al.*, 2022) or combining them with deep learning to guide companies towards their effective implementation in real context, such as clothing companies (Elboq *et al.*, 2023). Also, several contributions of I4.0 applications can be found. For instance, Fani *et al.* (2023b) proposes a framework to combine data mining and augmented reality to improve quality defect detection, demonstrating its successful application in a leather goods company. A digital twin model composed of discrete event simulation, artificial intelligence and decision dashboard is proposed by Lorenzon dos Santos *et al.* (2019) to support decision-makers in line balancing. Data-driven discrete event simulation has been also combined with association rule mining to introduce stochasticity in the scenario analysis (Fani *et al.*, 2023a). On the other side, literature about I5.0 in the fashion industry is quite scarce, considering only one focused contribution as far as authors' knowledge, related to the identification of indicators to evaluate elements of I5.0 in textile micro and small enterprise (Flores-Siguenza *et al.*, 2022).

2.4 Proposed framework

To gain a more comprehensive understanding of synergies between Lean, HC in I5.0, and I4.0, a literature review is performed using the following query on the research engine Scopus: TITLE-ABS-KEY (("industry 4.0" OR "industry 5.0") AND "Lean" AND "manufacturing" AND ("human centered" OR "human-centric" OR "human centered" OR "people centric" OR "human factor")). The resulting 22 published documents are filtered according to the following exclusion criteria: documents not written in English (one), conference proceedings (six), irrelevant abstracts (five), lacking full-text availability (three). Additionally, seven documents were incorporated through snowballing.

Evidences of the synergy among these concepts can be found, particularly with regards to the principles of Lean and I5.0, and how Lean can catalyze the progression from an I4.0 context to I5.0 (Alves, 2022; Mladineo *et al.*, 2021). Even if with a lack of conceptualization, there are some specific examples of the implementation of tools such as the HC SMED (Fonda and Meneghetti, 2022), and human–robot collaboration (Gervasi *et al.*, 2020; Hosseinian-Far *et al.*, 2023; Pizoń *et al.*, 2022). Highlighting the HC dimension of I5.0, linked to Lean, examples of utilizing Serious Games (Brauner and Ziefle, 2022), Microlearning (Roth *et al.*, 2022), a collaborative platform for work instruction (Stacchio *et al.*, 2023) and a prototype system for employee suggestions (Salvadorinho *et al.*, 2024) can be observed. However, a void remains with respect to an all-encompassing framework. On the other hand, frameworks are developed, but not investigating all the three aspects and intersections. Ciccarelli *et al.* (2022) experiment a methodology for relevant benefits in terms of ergonomics, process standardization and efficiency focusing on HC manufacturing, the ergonomic design is also investigated by Singh and Karmakar (2021). Wang *et al.* (2022) propose a Human centered Lean Six Sigma framework that considered Lean in terms of build operational

excellence, removal of waste and streamline of value-added processes and Human Centered approach considering leverage interpersonal experiences and improve human well-being, accessibility and sustainability but focusing on value stream map tool and without considering I4.0 dimension. Margherita and Zabudkina (2023) aim to understand the organizational aspects at the individual (micro) and organizational (meso) levels for building a HC organization with I4.0 technologies, in line with the I5.0 policy. Table 1 is presented to elucidate the proposed framework in relation to existing literature.

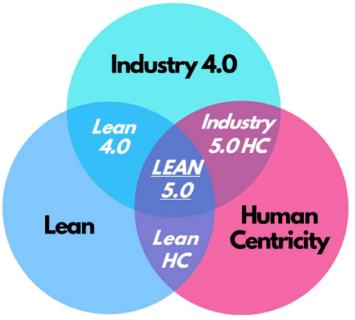
As discussed, the concepts of Lean, I4.0 and I5.0 have garnered widespread recognition, but a conceptual framework to highlight their interrelations is missing. To fill this gap, the proposed conceptual framework integrates three fundamental paradigms in modern era: Lean, HC and I4.0. This model, depicted in Figure 1, explores the synergies and intersections between these schools of thought to outline the evolution toward a new productive horizon, which is Lean 5.0.

The real innovation of this framework manifests at the convergence points of the three paradigms. Besides, another important contribution refers to the possible path to move towards Lean 5.0 starting from the existing intersections. First, Lean merges with I4.0 giving life to the concept of "Lean 4.0", which captures the opportunities offered by digitalization to

Concept	Proposed framework	Definition	Reference
Lean and I4.0	*Lean 4.0*	*Lean 4.0* integrates Lean principles with I4.0 technology-driven capabilities. It aims to enhance operational performance and optimize manufacturing processes through synergies	Bauer *et al.* (2018), Ciano *et al.* (2021), Prinz *et al.* (2018), Rossini *et al.* (2019), Sanders *et al.* (2017), Wagner *et al.* (2017)
Lean and HC	*Lean HC*	*Lean HC* combines Lean with emphasis on respect, well-being, and needs of employees. It aims to boost operational performance by improving empowerment and engagement, rather than solely focusing on efficiency	Alves (2022), Bashar *et al.* (2022), Brauner and Ziefle (2022), Fonda and Meneghetti (2022), Hines (2021), Mladineo *et al.* (2021), Roth *et al.* (2022), Stacchio *et al.* (2023), Vilda *et al.* (2019), Wang *et al.* (2022), Zhang *et al.* (2023)
HC and I4.0	*I5.0 HC*	*I5.0 HC* represents a progression from I4.0 by emphasizing integration of human elements into advanced manufacturing systems. It aims to foster environments that prioritize human well-being, enhance productivity through collaboration, and ensure the sustainability of production systems	Alves *et al.* (2023), Ciccarelli *et al.* (2022), Coronado *et al.* (2022), Destouet *et al.* (2023), Gervasi *et al.* (2020), Hosseinian-Far *et al.* (2023), Lu *et al.* (2022), Margherita and Zabudkina (2023), Pizoń *et al.* (2022), Singh and Karmakar (2021)
Lean 4.0, Lean HC and I5.0 HC	*Lean 5.0*	*Lean 5.0* is an emerging paradigm that integrate Lean methodologies with advanced human-centric and digital principles. It combines the efficiency and waste-reduction focus of Lean practices with the technology-driven enhancements of I4.0, and further enriches this integration by prioritizing human aspects	Authors' proposal

Table 1.
Literature to build proposed framework

Source(s): Authors' work



Source(s): Authors' work

Figure 1. Conceptual Framework

further enhance Lean operational efficiency. Second, in the intersection "Lean HC", HC meets Lean in terms of focusing on involvement of workers as an indispensable component of an organization's triumph. At the same time, when HC meets I4.0, the concept of "Industry 5.0 HC" emerges, promoting a HC ambition in the digital age, recognizing and valuing the unique and irreplaceable contribution of human within the industrial value chain.

2.4.1 Lean HC domains and categories. According to the conceptual framework, some industries that already benefit the synergies between these paradigms could move towards Lean 5.0 starting from one specific intersection. For instance, in the fashion industry, progressions to Lean 5.0 could originate from Lean HC, as manual labor is predominant and many lean tool applications could be found. Potential domains within this intersection area have been explored to prepare the case study, identifying as employee *Empowerment* and employee *Engagement* (Subramanian and Suresh, 2024).

Empowerment can be defined as the capability of an employee to make independent decisions without the need to consult their superiors (Shuck *et al.*, 2011), referring to the transfer or enablement of power from one individual to another (Shuck and Rose, 2013). Empowered employees exhibit heightened proficiency in making appropriate decisions to solve specific problems independently (Andrew and Sofian, 2012). Comprehensive training aims at transitioning the entire organization towards an empowered model, where employees are entrusted and more responsible (Taneja *et al.*, 2015). Within the concept of empowerment, two aspects are taken into consideration: *Training* and *Job Enrichment*. The provision of *Training* to employees is essential to equip them with the necessary skills and knowledge to perform their jobs competently and independently. Training has the potential to increase understanding of company obligations and procedures and foster an environment of continuous learning. *Job Enrichment* augments the motivating factors within a job, such as accomplishment, acknowledgment, and individual development, rather than concentrating solely on hygiene factors like remuneration and working conditions (Cimini *et al.*, 2022). Job Enrichment is a tactic employed to cultivate dynamic and efficient work atmosphere in an ever-evolving business landscape (Siengthai and Pila-Ngarm, 2016). By encouraging employees to fully leverage their capabilities and competencies in carrying out their responsibilities, it fosters a sense of loyalty to the organization (Marta *et al.*, 2021).

The other area identified, employee *Engagement*, describes employees' emotional commitment with their job, which urges them to work at their highest level of ability and to be more outcome oriented (Kossyva *et al.*, 2023). Saks (2006) outlined two different approaches to characterizing and quantifying the concept of engagement (Saks, 2006). Specifically, the work posited that is composed of *Job Engagement*, which pertains to the individual's involvement in the job itself, and *Organizational Engagement*. The term

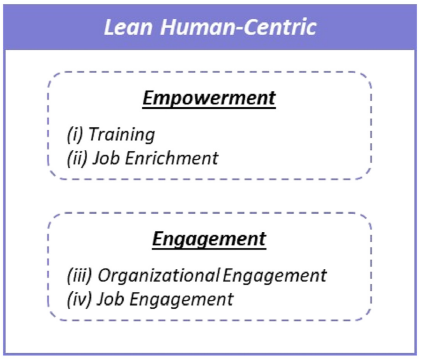
Organizational Engagement can refer to all the actions taken by the team to increase the individual's sense of belonging to the organization and to place him or her at the center of all processes.

As a result, four main categories within the two domains of *Empowerment* and *Engagement* were identified from literature to classify Lean HC practices: (1) *Training* and (2) *Job Enrichment* (*Empowerment*); and (3) *Organizational Engagement* and (4) *Job Engagement* (*Engagement*) (see Figure 2).

3. Methodology

The developed conceptual framework paths the way to deep dive into a real manufacturing context within the fashion industry. To answer RQ2, a case study in the leather goods market is performed, investigating the implemented Lean HC best practices to move towards the I5.0 paradigm.

To explore the emergent Lean 5.0 paradigm, which integrates Lean Manufacturing and Industry 4.0 principles within a HC framework, our study adopted an exploratory case study approach, recognized for its effectiveness in new research areas where multiple variables interact (Yin, 2014). This approach is particularly suited for developing and extending theories in operational management (Netland and Ferdows, 2015). The theoretical convenience sampling strategy has been followed for the case selection (Voss *et al.*, 2002). According with Ünal *et al.* (2019) our case study is selected after a deeper investigation based on secondary sources and comparing other alternatives. The luxury group selected stands out as a unique case for the exemplary integration of Lean and Industry 4.0 principles, with a particular emphasis on HC processes, which strengthens the rigor of our methodological approach. Several contributions can be found from the literature using this methodology to deeper investigate the impact of new paradigms in industrial scenarios such as the I4.0 transformation for automotive sector (Hermann *et al.*, 2019) and circular economy for Italian SME in the office supply industry (Ünal *et al.*, 2019). While a single case study may have constraints in terms of the generalizability of its outcomes, the authors express confidence that the conclusions drawn from their study could be extrapolated to a certain degree and implemented in comparable scenarios (Yin, 2014). In addition, to partially overcome this limitation, two fashion brands belonging to the selected luxury group were identified that are renowned for their craftsmanship and innovative manufacturing practices. Both brands are situated within the same industrial district in Tuscany, Italy, offering a unique geographical proximity that allows for comparative analysis under similar regional manufacturing



Source(s): Authors' work

Figure 2.
Lean Human-Centric Domains and Categories

conditions (Eisenhardt, 1989). Moreover, these brands belong to the same prestigious luxury group, providing a unified corporate philosophy while maintaining distinct product lines – one specializes in leather bags and the other in footwear. This distinction in product focus enriches the diversity of our case study, enabling a broader evaluation of Lean HC practices across different segments of the fashion industry. More specifically, the first brand (i.e. Brand A) in 2021 opened in Tuscany its first production plant totally based on those principles for bags production, requalifying a dismissed building located in a low-employment area following a sustainable and responsible approach. The second brand (i.e. Brand B) is a footwear manufacturing plant, also located in Tuscany. Further, Brand A represents a nascent plant launched less than 24 months ago, founded upon the principles of Lean and HC logics. Conversely, Brand B represents an established entity, having adopted the Lean methodology internally and prioritized the enhancement of operator performance.

Data were collected through multiple sources, enhancing the reliability of our findings (Barratt *et al.*, 2011; Bryman, 2012), primary and secondary data are included.

First, primary data sources included in-depth one to one semi-structured interviews with key personnel (Creswell and Poth, 2018). Specifically, for Brand A, the investigation involved four Team leaders and three Lean specialists, while for Brand B, three Team leaders and two Lean specialists were interviewed. Furthermore, it is important to emphasize that the positions of the individuals involved reflect a variety of responsibilities within their respective organizations. The role of the Team leader is defined as that of the operator overseeing operations on their production line. In the case of the Lean specialist, this is a role involving process engineering activities with a strong orientation towards Lean principles. Therefore, through these interviews, perspectives from different organizational levels were considered, providing a comprehensive overview of the gathered opinions. These interviews were structured around predetermined topics with open-ended questions to capture detailed insights while allowing respondents the flexibility to introduce new, relevant themes (Tzeng *et al.*, 2008). An outline was developed consisting of three distinct sections (see Appendix). The first section aims to identify the Lean HC practices implemented while the second part focuses on validating the concepts of *Empowerment* and *Engagement*, which were identified as the key domains of interest, and the categories related to them. The third part of the interviews, on the other hand, focused on specific operational practices, examining the I4.0 technologies supporting them within the two brands under study. Each initial interview session lasted between 60 and 90 min, with a follow-up session lasting around 60 min to deepen the understanding of specific issues.

Secondary data were gathered from official company documents, observations during site visits, and analyses of content from company websites, the on-field observation. This methodological approach ensured a robust "between-method triangulation," improving the validity of our data by comparing information from various sources and perspectives (Jick, 1979). In analyzing the data, content was coded independently by three researchers to minimize bias (Campbell *et al.*, 2013). Reliability was achieved through a rigorous case study protocol and the creation of a comprehensive case study database that includes all notes, documents, and analyses performed during the study.

During the on-field observation, the operational sites of both brands were visited to directly examine implemented activities. This approach facilitated the comprehension of how the strategies discussed during the interviews were transformed into concrete actions in the routine operations. For further enhancement of the comprehension, direct engagement with frontline workers responsible for carrying out daily tasks was undertaken. This level of involvement helped identify any disparities between corporate theory and actual practice.

After collecting and analyzing data from interviews, field observations and discussions with frontline workers, the findings were aggregated. The results were then presented to representatives of the brands analyzed. This sharing process provided direct insight into their reactions and confirmed the validity of the results interpretations.

In summary, the methodology of our case study embraced a holistic approach that combined semi-structured interviews, field observations, involvement of frontline workers and results sharing with the involved companies and spanned a duration of six months (i.e. March to September 2022). The first month was dedicated to semi-structured interviews, a more extensive period of three months was allocated for on-field observation, following that, a month was devoted to the comprehensive analysis of the collected data, and the final month encompassed the synthesis and presentation of the obtained results.

4. Findings

To address RQ2, detailed Lean HC practices grouped according to the proposed classification are identified from empirical evidence collected from best-in-class brands. As previously depicted, the case study focused on two brands belonging to a famous luxury group, both excelling in Lean principles and applying I4.0 technologies. Main characteristics are summed up in Table 2.

The establishment owned by Brand A specializes in manufacturing bags that bear the "Made in Italy" label, and it is situated in the leather goods district of Florence. The factory has a workforce of 120 individuals who yield an estimated 950 handbags/week. The plant contains six main departments, namely: Warehouse, Cutting, Shoulder Strap, Kitting, Preparation and Production Lines. This leather goods plant is regarded as one of the most contemporary and evolved establishments in the vicinity, as evidenced by the visits of several other brands within the same group, who have utilized it as a benchmark. Indeed, the entirety of the facility was meticulously planned and constructed in accordance with the principles of Lean and I4.0. The plant owned by Brand B, has been identified as the reference plant, and is specialized in the production of both sporty and elegant footwear with the "Made in Italy" label and is in Tuscany. Currently, the plant under consideration employs a workforce of 270 individuals manufacturing approximately 10,000 pairs of shoes/week. The facility consists of seven production lines, with six dedicated to creating sneakers and one designed to produce elegant footwear. Additionally, the industrial complex includes a warehouse and a department dedicated to material cutting. While the facility of Brand A has recently opened and was custom-designed from the outset to embody the lean philosophy and a HC approach, the ones of Brand B is an existing plant that has embraced this philosophy in recent years, with a particular focus on HC practices as a strategic decision made by the brand. Therefore, the case study focuses on two best-in-class within the same group, both excelling in lean principles, but with two production facilities of different origins, one being newly established and the other pre-existing.

In Table 3, Lean HC actions that have been implemented in the plants are presented as an application case study. In addition, the use of I4.0 technologies supporting them is investigated. The methodology employed for structuring the table involves a systematic subdivision of techniques, in accordance with its respective domain and category depicted in Figure 2. Lean HC actions are practices implemented by the brands, explicitly declared or directly observed by the authors during the empirical investigation.

Table 2. Characteristics of brands involved in the case study

	Turnover	Employees	Plant daily production
Brand A	> € 1 bn	>1,000 (global) 120 (plant)	950 bags/week
Brand B	> € 10 bn	>15,000 (global) 270 (plant)	10,000 pairs of shoe/week

Source(s): Authors' work

Domain	Category	Lean HC practices	Brands A	Brands B	I4.0 techniques supporting lean HC
Empowerment	Training	Induction training	X	X	CM (A)
		Quality and Lean training courses	X	X	CM (A, B)
		SOPs	X	X	CM (A)
	Job Enrichment	MES and Monitor real-time Andon	X	X	CM (A, B), IoT (A), BDA (A, B)
		OPL	X	X	CM (A)
		Job Rotation	X	X	–
		Vertical Loading	X	X	–
		Quality Master	X	X	CM (A, B), BDA (A, B)
		Bag Maker Master	X		–
		Safety Cross	X		CM (A), BDA (A)
		Ohno Circle		X	–
Engagement	Organizational Engagement	Employee Satisfaction Survey	X	X	BDA (A, B)
		Obeya Meeting	X	X	CM (A, B)
		Continuous Action Report	X		–
		Motivation Meeting	X		–
		Problem Solving Session	X		CM (A)
		Serious Game Session	X		–
	Job Engagement	5S Audit	X	X	CM (A), BDA (A)
		Employee Recognition Program	X	X	–
		Standard Work Audit	X		CM (A), BDA (A)

Note(s): CM = Cloud Manufacturing; BDA = Big Data Analytics; IoT = Internet of Things
Source(s): Authors' work

Table 3. Lean Human-Centric actions implemented in the analyzed brands

In the realm of *Empowerment*, particularly in the *Training* category, it is evident that both organizations employ Lean HC practices encompassing Induction Training, Quality and Lean training courses, along with Standard Operating Procedures (SOPs). In Brand A, a noteworthy six-week Induction Training period is mandatory for all newly recruited operators, irrespective of their prior experience, aimed at fostering a consistent proficiency level. This training regimen involves hands-on experience with materials, constructive feedback from experienced trainers and is fortified by Cloud Manufacturing (CM) technologies. Conversely, Brand B administers a preliminary four-week induction training, focusing on foundational practical and theoretical knowledge. Notably, direct production line instruction is deferred during this training period, concentrating instead on a designated area of the line. Both Brand A and B extend training courses to new production line entrants, encompassing Lean and quality topics, and supported by CM technologies. In the *Training* category, other implemented actions include SOPs. Brand A employs SOPs through a tablet and a cloud platform, allowing multimedia integration, such as videos displaying proper operations ("beau geste") and visuals of non-compliant bags. In contrast, Brand B relies on a paper-based approach. SOPs enhances operator involvement, aided by video tools for micro-learning and establishes valuable resources for less experienced operators, fostering confidence and independence.

Persisting within the *Empowerment* domain but shifting to the *Job Enrichment* category, both brands have adopted diverse techniques. The Manufacturing Execution System (MES), integrated with Internet of Things (IoT) sensors in Brand A, offers the potential to assess standard durations and recommend enhancements based on measured processing times at different stations. Real-time monitoring, facilitated by the Andon system supported by Big Data Analytics (BDA) technologies, is strategically positioned throughout the plants. This tool not only enables remote assessment of production line performance by Team leaders and supervisors but also incentivizes line operators to autonomously enhance and adapt their activities. The utilization of the One Point Lesson (OPL) form is a shared strategy across both brands for documenting solutions. The OPL provides comprehensive outlines of corrective actions, potentially incorporating visual examples or physical samples. In Brand A, this

process is supported by a CM platform, while Brand B utilizes a paper-based approach. Aligned with the HC approach embraced by both brands, job rotation is employed to enhance operator versatility. Operators interchange workstations at adjacent positions on the production lines after the lunch break, aiming to mitigate the monotony associated with repetitive tasks, thereby preventing disinterest and lack of concentration. Both Brand A and B have successfully implemented the "Quality Master" tool, equipping each operator with a tablet integrated with a CM and data analytics system. This technology allows meticulous recording of product non-conformities and introduces a tolerance system, granting operators autonomy and responsibility for decisions impacting the line gate. The "Bag Maker Master" program, exclusive to Brand A, represents a three-year training initiative for a group of five permanent employees aspiring to become proficient bag makers. Participants undergo rigorous practical and theoretical examinations, enhancing their skills and achieving a profound level of specialization within the fashion industry. In Brand A, each production line possesses a Safety Cross, updated daily by the Team leader and integrated into the cloud platform for data analysis. This visual tool highlights safety concerns, near misses, and accidents, emphasizing operator safety through documentation and corrective measures. Brand B employs the Ohno Circle technique, involving line operators and Team leaders trained in process engineering to observe production, identify waste and propose improvements. This approach culminates in cost-benefit analyses and action plans based on direct input from operators, typically completed within a month.

Transitioning to the *Engagement* domain, specific actions classified as *Organizational Engagement* were implemented in the analyzed production plants of both brands. Notably, Employee Satisfaction Surveys and Obeya Meetings are common practices. These surveys, conducted periodically at the group level, elicit evaluations of respective managers from all employees, with data analysis utilizing BDA.

Obeya Meetings, a daily gathering of top and middle management equipped with a digital blackboard connected to a cloud system, facilitate transparent information exchange, fostering a collaborative environment and enhancing cross-area alignment and overall productivity. Brand A utilizes the Continuous Action Report, completed by leather workers, as a motivational tool for proposing workplace modifications and improvements. This includes alterations to work procedures, with endorsement by supervisors and action plans devised to implement enhancements, involving other plant departments if necessary. The "Monday Motivation" meeting, overseen by the plant manager, serves as a weekly forum for presenting the previous week's progress and outcomes. Objectives for the current week are discussed, with opportunities for employee suggestions and inquiries. Problem Solving Sessions, executed by Brand A in response to recurring defects, engage the entire production line or department along with Team leaders, quality managers and supervisors. An online form, integrated with a cloud platform, guides the session through problem definition, analysis using the 5 Whys technique and Ishikawa fishbone diagram, and the planning of prioritized actions and solutions. To instill dedication and loyalty during the preliminary phase of employee training, Serious Game Sessions are organized, including the "Desk Assembly Challenge" and the "Paper Bag Creation Challenge". These sessions, promoting team spirit and organizational values, involve teamwork and problem-solving scenarios.

In the *Job Engagement* category, referring to individual commitment to the job, both brands implemented actions such as the 5S Audit and Employee Recognition Program. Lean specialists organize 5S audits, planning them strategically across various factory lines for effective implementation. Brand A integrates these audits with I4.0 technologies, including cloud platform and BDA, while B relies on paper-based methods. Employee Recognition Programs acknowledge commendable performances and accomplishments through various approaches such as production bonuses, wellness packages, gift cards and professional development courses. Notably, both brands implement Standard Work Audits, wherein the

Lean team organizes "audit" moments for operators, encouraging suggestions on workstation and operation sequence improvements. This approach ensures attention to operator needs and the logic of continuous improvement across all levels of the plant.

5. Discussion

Looking at the Lean HC, the findings from the case study reveal that the implementation of such practices enhances employee satisfaction. For instance, involvement in cross-functional teams and participation in decision-making processes were frequently mentioned as factors that increased their investment and contentment in their roles. Brand B Team leader affirms "Job rotation has been a game changer for me. Switching roles not only breaks the monotony. It's empowering to know several aspects of the work process, and it keeps the job interesting and me motivated". "During our Problem Solving Sessions, I feel more valued and involved in addressing the issues we face on the production line," commented Brand A Team leader. "These sessions are not about top-down decisions; we all work together to define the solutions, which enhances our commitment to the process and the overall outcomes". Same evidence has emerged from on-field observations. Observers noted increased interactions among team members and proactive engagement in problem-solving sessions, as employees expressed a higher sense of fulfillment and morale. Brand A emerges as a frontrunner, incorporating a comprehensive suite of 19 Lean HC best practices, well balanced between *Empowerment* and *Engagement* domains. In contrast, Brand B, while demonstrating a commendable effort, implements a slightly more modest count of 13 Lean HC practices, mostly related to the *Empowerment* domain. The implementation of Lean HC practices in both domains suggests driving employee retention, as demonstrated by a higher employee turnover for Brand B than A as well as employee interviews. "Compared to my previous job experiences where training was the sole focus, I feel more connected to this company because it truly listens to my needs and suggestions, allowing me to make a real contribution," shared a Brand A employee during the interview. "This approach not only enhances my skills but also deepens my commitment to the organization".

The application of technology in these practices demonstrates a successful blend of Lean principles with I4.0 technologies. This study, through the detailed case study in the fashion industry, confirms the assumption theorized in Table 1 that Lean 5.0 represents an advanced production environment where the centrality of the human element, integrated with digital technologies, enables a process of operational excellence free of waste. This finding underscores that Lean 5.0 is about creating a production environment where technology and human capabilities are not just aligned but are synergistically integrated to enhance both operational efficiency and worker satisfaction. Among all Lean HC practices, only a subset is supported by I4.0 technologies. Specifically, the *Training* category is particularly well-integrated with CM. "Training with the CM system is extremely useful because it allows us to instantly update and disseminate best practices across the entire line," noted a Brand A lean specialist. "This capability not only ensures that all employees are up-to-speed with the latest operational techniques but also facilitates immediate application and troubleshooting, significantly enhancing our efficiency and adaptability on the factory floor". Furthermore, the most significant aspect in which I4.0 supports Lean HC practices appears to be data tracking. As the case study results show, the Lean HC practices supported by I4.0 in this area include for instance MES and real-time Andon monitoring, Quality Master and Safety Cross. It is evident that of all the I4.0 technologies compatible with lean, taking for referment (Narula *et al.*, 2023), only three – CM, BDA and IoT (with a single occurrence) – are utilized in the case study. These needs – for always available and updated training and for integrated and tracked data – are aligned with the listed I4.0 technologies used in support. Some Lean HC practices supported by I4.0 are aligned with existing literature while others enlarge the

discussion around them. For example, Rojas and Huamanchahua (2022) discussed "Andon 4.0" defined as Andon integrated with real time data, which we observed in our case studies. Additionally, Brand A has integrated CM into their SOPs to facilitate process standardization and to digitize training manuals. This integration involves using digital tools to streamline workflows and ensure that training materials are both accessible and up-to-date, reflecting the principles of Poka Yoke – a method ensuring error prevention – and the broader trend of digital transformation in manufacturing, as detailed by Rossi *et al.* (2022). While the selective integration demonstrates effectiveness and alignment with Lean HC practices, it also points to the potential for further exploration and adoption of other I4.0 technologies. Accordingly, there remains space for improvement in integrating other innovative technologies, as suggested by the Lean specialists of Brand A, such as Augmented Reality/Virtual Reality for training and Artificial Intelligence for data tracking. A different adoption level of Industry 4.0 technologies between Brand A and B resulted from the case study. Brand A, with its higher integration of digital technologies, demonstrates a more robust alignment with the principles of Industry 5.0. Out of the 19 Lean HC practices embraced by Brand A, an impressive 12 are supported by I4.0 technologies. This integration is characterized by improved error reduction through real-time feedback, and greater employee engagement owing to more interactive and technologically supported training methods. On the other hand, Brand B, while demonstrating commendable Lean HC practices, relies on I4.0 technologies to support 5 out of its 13 implemented practices. While this represents a substantial utilization of technological support, it also suggests potential avenues for further integration and optimization within the framework of I4.0.

Summing up, the results indicate that Brand A, by leveraging I4.0 technologies, is closer to achieving the ideals of Lean 5.0. This environment supports a more engaged and empowered workforce, leading to higher job satisfaction and retention. Brand B's slower adoption of digital technologies suggests a more cautious approach to I5.0 demonstrating a lower maturity. Our contribution to the field has been to detail the specific practices that effectively move our theoretical framework from an abstract concept to a central, actionable strategy within Lean 5.0 operations. As demonstrated by the practices listed in Table 4.

6. Conclusions

The three paradigms of Lean, I4.0, and I5.0 have been extensively explored and recognized in both academic and industrial domains. Despite the comprehensive literature on each of these paradigms, and the existing contributions about some interrelations, a gap has emerged regarding their full integration and intersection, particularly in artisanal sectors where case studies are still scarce. To answer RQ1, a conceptual framework has been developed. This research introduces and delves into the emerging concept of Lean 5.0, a paradigm aiming to bridge this gap by proposing innovative pathways toward an industrial production that values efficiency, technology and the humanization of the manufacturing process alike. In highly automated sectors, Lean 4.0 may naturally serve as a starting point. However, to fully realize the potential of Lean 5.0, it is imperative to integrate a HC perspective in these contexts as well, underscoring the aspiration towards an industrial production that is not only Lean and technologically advanced but also deeply respectful and appreciative of the human contribution. Besides, in the traditionally artisanal fashion industry, the transition towards Lean 5.0 seems more intuitive from the Lean HC intersection.

To answer RQ2, a case study is performed in the fashion luxury industry involving two best-in-class brands. The empirical insights are grouped according to the identified domains and categories for Lean HC practices. The case study presented demonstrates how, in some exemplary realities, Lean practices have been effectively integrated with HC approaches, facilitating the transition to Lean 5.0 with the support of I4.0 technologies. The example of

Domain	Category	Lean 5.0 practice	Description of lean 5.0 practice
Empowerment	Training	Induction training supported by CM	Comprehensive training for new employees via a cloud platform supporting shared best practices and rapid onboarding processes
		Quality and Lean courses supported by CM	Ongoing education of employees via cloud-based technologies, ensuring up-to-date knowledge dissemination and skill enhancement
		SOPs supported by CM	Cloud-based platforms to provide SOPs with multimedia integration, enhancing the clarity and adherence to operational guidelines
	Job Enrichment	MES and Monitor real-time Andon supported by CM, IoT and BDA	Real-time feedback on production provided through MES and Andon, enabling proactive problem-solving and decision-making
		OPL supported by CM	Quick, focused lessons distributed updated through cloud systems
		Quality Master supported by CM and BDA	A system to record product non-conformities and use BDA to identify and implement improvements
		Safety Cross supported by CM and BDA	Safety monitoring and reporting with cloud-based platforms to track incidents and near-misses effectively
Engagement	Organizational Engagement	Employee Satisfaction Survey supported by BDA	Regular analysis of employee feedback via surveys using big data tools to improve management practices and workplace conditions
		Obeya Meeting supported by CM	Regular meetings with digital tools to facilitate real-time, transparent communication, fostering collaborative environment
		Problem Solving Session supported by CM	Structured sessions using cloud platforms to address production issues collaboratively
	Job Engagement	5S Audit supported by CM and BDA	Regular audits on 5S using digital tools to maintain workplace organization and efficiency
		Standard Work Audit supported by CM and BDA	Practices involving regular SOPs checks and updates, ensuring continuous improvement through digital tools

Note(s):CM = Cloud Manufacturing; BDA = Big Data Analytics; IoT = Internet of Things
Source(s): Authors' work

Table 4.
Lean 5.0 practices

Brand A is clear, with 63% of its Lean HC actions supported by I4.0 technologies, positioning itself at the forefront of the transition. Brand B has implemented a lower percentage (38%) of Lean HC practices supported by I4.0 technologies, indicating a positive movement towards the new paradigm, even if its progress is more cautious.

Accordingly, to fill the theoretical gap, this research proposes a conceptual framework to navigate the transition towards Lean 5.0 and offers a significant contribution by providing empirical evidence on the application of Lean HC actions in a traditionally artisanal sector, such as the luxury fashion industry. The practical implications stemming from this study offer companies guidelines to adopt the Lean 5.0 paradigm, defining it as the emerging

paradigm that effectively synergizes human centrality and digital technologies to create an environment that optimizes both operational efficiency and worker satisfaction and for those in fashion industry, presenting replicable best practices that pave the way for an industrial future where technological innovation and human well-being progress hand in hand. Brands can promote the well-being and skills development of their employees, while improving overall operational efficiency and staying at the forefront of the evolving I5.0 paradigm.

As a limitation, this paper does not go in depth into the lower levels of the Human Needs Pyramid. The focus of the HC approach though, could be extended and Inclusivity and Safety could be embedded from both literature and practical perspectives. Indeed, the analyzed brands do not ignore the concepts of diversity and integration for example (e.g. optional online classes on inclusivity and people equity were al arranged as well as weekly Italian Class for non-mother language operators) and of course lots of initiatives are also carried out in terms of safety.

In addition, future research should assess the possibility to investigate a broader spectrum of industrial contexts, in terms of I4.0 maturity and context peculiarity (i.e. automated industry) to investigate the other path for transition to Lean 5.0, starting from Lean 4.0. Surely the proposed framework represents a first example of Lean 5.0 conceptualization, that leverages the HC and collaborative nature of both Lean and I5.0 fields, bringing concrete hopes for bright implementations that will be beneficial for the entire society.

References

Ainul Azyan, Z.H., Pulakanam, V. and Pons, D. (2017), "Success factors and barriers to implementing lean in the printing industry: a case study and theoretical framework", *Journal of Manufacturing Technology Management*, Vol. 28 No. 4, pp. 458-484, doi: 10.1108/jmtm-05-2016-0067.

Alves, A.C. (2022), "Lean thinking: an essential mindset", *IEEE Engineering Management Review*, Vol. 50 No. 4, pp. 127-133, doi: 10.1109/emr.2022.3215062.

Alves, J., Lima, T.M. and Gaspar, P.D. (2023), "Is industry 5.0 a human-centred approach? A systematic review", *Processes*, Vol. 11 No. 1, p. 193, doi: 10.3390/pr11010193.

Andrew, O.C. and Sofian, S. (2012), "Individual factors and work outcomes of employee engagement", *Procedia - Social and Behavioral Sciences*, Vol. 40, pp. 498-508, doi: 10.1016/j.sbspro.2012.03.222.

Angelis, J., Conti, R., Cooper, C. and Gill, C. (2011), "Building a high-commitment lean culture", *Journal of Manufacturing Technology Management*, Vol. 22 No. 5, pp. 569-586, doi: 10.1108/17410381111134446.

Barratt, M., Choi, T. and Li, M. (2011), "Qualitative case studies in operations management: trends, research outcomes, and future research implications", *Journal of Operations Management*, Vol. 29 No. 4, pp. 329-342, doi: 10.1016/j.jom.2010.06.002.

Bashar, A., Hasin, A.A. and Jahangir, N. (2022), "Linkage between TPM, people management and organizational performance", *Journal of Quality in Maintenance Engineering*, Vol. 28 No. 2, pp. 350-366, doi: 10.1108/jqme-11-2019-0105.

Bauer, H., Brandl, F., Lock, C. and Reinhart, G. (2018), "Integration of industrie 4.0 in lean manufacturing learning factories", *Procedia Manufacturing*, Vol. 23, pp. 147-152, doi: 10.1016/j.promfg.2018.04.008.

Brauner, P. and Ziefle, M. (2022), "Beyond playful learning – Serious games for the human-centric digital transformation of production and a design process model", *Technology in Society*, Vol. 71, p. 102140, doi: 10.1016/j.techsoc.2022.102140.

Bryman, A. (2012), *Social Research Methods*, OUP, Oxford.

Campbell, J.L., Quincy, C., Osserman, J. and Pedersen, O.K. (2013), "Coding in-depth semistructured interviews: problems of unitization and intercoder reliability and agreement", *Sociological Methods and Research*, Vol. 42 No. 3, pp. 294-320, doi: 10.1177/0049124113500475.

Ciano, M.P., Dallasega, P., Orzes, G. and Rossi, T. (2021), "One-to-one relationships between Industry 4.0 technologies and Lean Production techniques: a multiple case study", *International Journal of Production Research*, Vol. 59 No. 5, pp. 1386-1410, doi: 10.1080/00207543.2020.1821119.

Ciccarelli, M., Papetti, A., Cappelletti, F., Brunzini, A. and Germani, M. (2022), "Combining World Class Manufacturing system and Industry 4.0 technologies to design ergonomic manufacturing equipment", *International Journal on Interactive Design and Manufacturing*, Vol. 16 No. 1, pp. 263-279, doi: 10.1007/s12008-021-00832-7.

Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M. and Pinto, R. (2021), "How do industry 4.0 technologies influence organisational change? An empirical analysis of Italian SMEs", *Journal of Manufacturing Technology Management*, Vol. 32 No. 3, pp. 695-721, doi: 10.1108/jmtm-04-2019-0135.

Cimini, C., Lagorio, A. and Gaiardelli, P. (2022), "The evolution of operators' role in production: how lean manufacturing and industry 4.0 affect job enlargement and job enrichment", *International Journal of Production Research*, Vol. 61 No. 24, pp. 8493-8511, doi: 10.1080/00207543.2022.2152894.

Coronado, E., Kiyokawa, T., Ricardez, G.A.G., Ramirez-Alpizar, I.G., Venture, G. and Yamanobe, N. (2022), "Evaluating quality in human-robot interaction: a systematic search and classification of performance and human-centered factors, measures and metrics towards an industry 5.0", *Journal of Manufacturing Systems*, Vol. 63, pp. 392-410, doi: 10.1016/j.jmsy.2022.04.007.

Creswell, J.W. and Poth, C.N. (2018), *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*, Sage Publications, Los Angeles, CA.

Destouet, C., Tlahig, H., Bettayeb, B. and Mazari, B. (2023), "Flexible job shop scheduling problem under Industry 5.0: a survey on human reintegration, environmental consideration and resilience improvement", *Journal of Manufacturing Systems*, Vol. 67, pp. 155-173, doi: 10.1016/j.jmsy.2023.01.004.

Directorate-General for Research and Innovation (European Commission) Breque, M., De Nul, L. and Petridis, A. (2021), *Industry 5.0: Towards a Sustainable, Human Centric and Resilient European Industry*, Publications Office of the European Union, LU.

Eisenhardt, K.M. (1989), "Building theories from case study research", *The Academy of Management Review*, Vol. 14 No. 4, pp. 532-550, doi: 10.5465/amr.1989.4308385.

Elboq, R., Fri, M., Hlyal, M. and El Alami, J. (2023), "Modeling lean and six Sigma integration using deep learning: applied to a clothing company", *Autex Research Journal*, Vol. 23, pp. 1-10, doi: 10.2478/aut-2021-0043.

Fani, V., Antomarioni, S., Bandinelli, R. and Bevilacqua, M. (2023a), "Data-driven decision support tool for production planning: a framework combining association rules and simulation", *Computers in Industry*, Vol. 144, p. 103800, doi: 10.1016/j.compind.2022.103800.

Fani, V., Antomarioni, S., Bandinelli, R. and Ciarapica, F.E. (2023b), "Data mining and augmented reality: an application to the fashion industry", *Applied Sciences*, Vol. 13 No. 4, p. 2317, doi: 10.3390/app13042317.

Flores-Siguenza, P., Vásquez-Salinas, B., Siguenza-Guzman, L., Arcentales-Carrion, R. and Sucozhañay, D. (2022), "Indicators to evaluate elements of industry 5.0 in the textile production of MSMEs", *Communications in Conference on Information and Communication Technologies of Ecuador*, Springer International Publishing, Cham, pp. 85-100, doi: 10.1007/978-3-031-18272-3_7.

Fonda, E. and Meneghetti, A. (2022), "The human-centric SMED", *Sustainability*, Vol. 14 No. 1, p. 514, doi: 10.3390/su14010514.

Gervasi, R., Mastrogiacomo, L. and Franceschini, F. (2020), "A conceptual framework to evaluate human-robot collaboration", *International Journal of Advanced Manufacturing Technology*, Vol. 108 No. 3, pp. 841-865, doi: 10.1007/s00170-020-05363-1.

Ghobakhloo, M., Iranmanesh, M., Foroughi, B., Babaee Tirkolaee, E., Asadi, S. and Amran, A. (2023), "Industry 5.0 implications for inclusive sustainable manufacturing: an evidence-knowledge-based strategic roadmap", *Journal of Cleaner Production*, Vol. 417, p. 138023, doi: 10.1016/j.jclepro.2023.138023.

Gladysz, B., Tran, T.-A., Romero, D., van Erp, T., Abonyi, J. and Ruppert, T. (2023), "Current development on the Operator 4.0 and transition towards the Operator 5.0: a systematic literature review in light of Industry 5.0", *Journal of Manufacturing Systems*, Vol. 70, pp. 160-185, doi: 10.1016/j.jmsy.2023.07.008.

Hermann, M., Bücker, I. and Otto, B. (2019), "Industrie 4.0 process transformation: findings from a case study in automotive logistics", *Journal of Manufacturing Technology Management*, Vol. 31 No. 5, pp. 935-953, doi: 10.1108/jmtm-08-2018-0274.

Hines, P. (2021), "Human centred lean - an introduction to the people value stream", *International Journal of Lean Six Sigma*, Vol. 13 No. 5, pp. 961-988, doi: 10.1108/ijlss-03-2021-0061.

Hosseinian-Far, A., Varga, L., Daneshkhah, A. and Marinelli, M. (2023), "From industry 4.0 to construction 5.0: exploring the path towards human–robot collaboration in construction", *Systems*, Vol. 11 No. 3, p. 152, doi: 10.3390/systems11030152.

Hussain, D. and Figueiredo, M.C. (2023), "Improving the time-based performance of the preparatory stage in textile manufacturing process with value stream mapping", *Business Process Management Journal*, Vol. 29 No. 3, pp. 1463-7154, doi: 10.1108/bpmj-08-2022-0366.

Jick, T.D. (1979), "Mixing qualitative and quantitative methods: triangulation in action", *Administrative Science Quarterly*, Vol. 24 No. 4, pp. 602-611, doi: 10.2307/2392366.

Kassem, B., Callupe, M., Rossi, M., Rossini, M. and Portioli-Staudacher, A. (2024), "Lean 4.0: a systematic literature review on the interaction between lean production and industry 4.0 pillars", *Journal of Manufacturing Technology Management*, doi: 10.1108/jmtm-04-2022-0144.

Kose, Y., Muftuoglu, S., Cevikcan, E., Durmusoglu, M.B. (2022), "Axiomatic design for lean autonomous maintenance system: an application from textile industry", *Internation Journal of Lean Sig Sigma*, Vol. 14 No. 1/4.

Kossyva, D., Theriou, G., Aggelidis, V. and Sarigiannidis, L. (2023), "Definitions and antecedents of engagement: a systematic literature review", *Management Research Review*, Vol. 46 No. 5, pp. 719-738, doi: 10.1108/mrr-01-2021-0043.

Kumar, D.V., Mohan, G.M., Mohanasundaram, K.M., Kumar, D.V., Mohan, G.M. and Mohanasundaram, K.M. (2020), "Lean supply chain management in garment industry using value stream mapping", *International Journal of Services and Operations Management*, Vol. 37 No. 1, pp. 133-143, doi: 10.1504/ijsom.2020.109440.

Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D. and Wang, L. (2022), "Industry 5.0: prospect and retrospect", *Journal of Manufacturing Systems*, Vol. 65, pp. 279-295, doi: 10.1016/j.jmsy.2022.09.017.

Li, S., Zheng, P., Liu, S., Wang, Z., Wang, X., Zheng, L. and Wang, L. (2023), "Proactive human-robot collaboration: mutual-cognitive, predictable, and self-organising perspectives", *Robotics and Computer-Integrated Manufacturing*, Vol. 81, pp. 1-30, doi: 10.1016/j.rcim.2022.102510.

Lorenzon dos Santos, D., Giglio, R., Helleno, A.L. and Campos, L.M.S. (2019), "Environmental aspects in VSM: a study about barriers and drivers", *Production Planning and Control*, Vol. 30, pp. 1239-1249, doi: 10.1080/09537287.2019.1605627.

Lu, Y., Zheng, H., Chand, S., Xia, W., Liu, Z., Xu, X., Wang, L., Qin, Z. and Bao, J. (2022), "Outlook on human-centric manufacturing towards Industry 5.0", *Journal of Manufacturing Systems*, Vol. 62, pp. 612-627, doi: 10.1016/j.jmsy.2022.02.001.

Margherita, E.G. and Zabudkina, A. (2023), "Building human-centric organisations with Industry 4.0 technologies in the Industry 5.0 era: a micro and meso level perspective" in Bednar, P., Bednar, P., Zaghloul, F., Welch, C., Nolte, A., Nolte, A., Rajanen, M., Islind, A.S., Hult, V.H., Hult, H.V., Ravarini, A. and Braccini, A.M. (Eds), *CEUR Workshop Proceeding Presented at the CEUR Workshop Proceedings, CEUR-WS*, pp. 80-89.

Marta, I.A., Supartha, I.W.G., Dewi, I.G.A.M. and Wibawa, I.M.A. (2021), "Job enrichment, empowerment, and organizational commitment: the mediating role of work motivation and job satisfaction", *The Journal of Asian Finance, Economics and Business*, Vol. 8, pp. 1031-1040.

Mladineo, M., Ćubić, M., Gjeldum, N. and Crnjac Žižić, M. (2021), "Human-centric approach of the Lean management as an enabler of Industry 5.0 in SMEs", *10th International Conference on Mechanical Technologies and Structural Materials, MTSM 2021*, pp. 111-117.

Narula, S., Puppala, H., Kumar, A., Luthra, S., Dwivedy, M., Prakash, S. and Talwar, V. (2023), "Are Industry 4.0 technologies enablers of lean? Evidence from manufacturing industries", *International Journal of Lean Six Sigma*, Vol. 14 No. 1, pp. 115-138, doi: 10.1108/ijlss-04-2021-0085.

Netland, T. and Ferdows, K. (2015), "The S-curve effect of lean implementation", *Production and Operations Management*, Vol. 25 No. 6, pp. 1106-1120, doi: 10.1111/poms.12539.

Pagliosa, M., Tortorella, G. and Ferreira, J.C.E. (2021), "Industry 4.0 and Lean Manufacturing: a systematic literature review and future research directions", *Journal of Manufacturing Technology Management*, Vol. 32 No. 3, pp. 543-569, doi: 10.1108/jmtm-12-2018-0446.

Pizoń, J., Cioch, M., Kanski, L. and García, E.S. (2022), "Cobots implementation in the era of industry 5.0 using modern business and management solutions", *Advances in Science and Technology Research Journal*, Vol. 16 No. 6, pp. 166-178, doi: 10.12913/22998624/156222.

Prinz, C., Breitkopf, N. and Kuhlenkötter, B. (2018), "Lean meets Industrie 4.0 – a practical approach to interlink the method world and cyber-physical world", *Procedia Manufacturing*, Vol. 23, pp. 21-26, doi: 10.1016/j.promfg.2018.03.155.

Reda, H. and Dvivedi, A. (2022), "Application of value stream mapping (VSM) in low-level technology organizations: a case study", *International Journal of Productivity and Performance Management*, Vol. 71 No. 6, pp. 2393-2409, doi: 10.1108/ijppm-03-2021-0118.

Rojas, M.A.L. and Huamanchahua, D. (2022). "The confluence of lean manufacturing and industry 4.0: a literature review", *2022 IEEE ANDESCON*, pp. 1-6, doi: 10.1109/ANDESCON56260.2022.9989655.

Rossi, A.H.G., Marcondes, G.B., Pontes, J., Leitão, P., Treinta, F.T., De Resende, L.M.M., Mosconi, E., Yoshino, R.T., Rossi, A.H.G., Marcondes, G.B., Pontes, J., Leitão, P., Treinta, F.T., De Resende, L.M.M., Mosconi, E. and Yoshino, R.T. (2022), "Lean tools in the context of industry 4.0: literature review, implementation and trends", *Sustainability*, Vol. 14 No. 19, pp. 1-32, doi: 10.3390/su141912295.

Rossini, M., Costa, F., Tortorella, G.L. and Portioli-Staudacher, A. (2019), "The interrelation between Industry 4.0 and lean production: an empirical study on European manufacturers", *International Journal of Advanced Manufacturing Technology*, Vol. 102 Nos 9-12, pp. 3963-3976, doi: 10.1007/s00170-019-03441-7.

Rossini, M., Cifone, F.D., Kassem, B., Costa, F. and Portioli-Staudacher, A. (2021), "Being lean: how to shape digital transformation in the manufacturing sector", *Journal of Manufacturing Technology Management*, Vol. 32 No. 9, pp. 239-259, doi: 10.1108/jmtm-12-2020-0467.

Roth, E., Moencks, M., Beitinger, G., Freigang, A. and Bohne, T. (2022), "Microlearning in human-centric production systems", *IEEE International Conference on Industrial Engineering and Engineering Management 2022-December*, pp. 37-41.

Saad, S.M., Bahadori, R., Bhovar, C. and Zhang, H. (2023), "Industry 4.0 and Lean Manufacturing – a systematic review of the state-of-the-art literature and key recommendations for future research", *International Journal of Lean Six Sigma*, doi: 10.1108/ijlss-02-2022-0021.

Saks, A.M. (2006), "Antecedents and consequences of employee engagement", *Journal of Managerial Psychology*, Vol. 21 No. 7, pp. 600-619, doi: 10.1108/02683940610690169.

Salvadorinho, J., Bastos, T., Pintor, P. and Teixeira, L. (2024), "Lean manufacturing vs coaching alliance in engagement promotion: an employee suggestion system prototype", *Lecture Notes in Mechanical Engineering*, pp. 332-339, doi: 10.1007/978-3-031-38165-2_39.

Sanders, A., Subramanian, K., Redlich, T., Wulfsberg, J. (2017), " Industry 4.0 and lean management – synergy or contradiction?", *Advances in Production Management System. The Path to Intelligent, Collaborative and Suistainable Manufacturing*, pp. 341-349, doi: 10.1007/978-3-319-66926-7_39,

Shuck, B. and Rose, K. (2013), "Reframing employee engagement within the context of meaning and purpose: implications for HRD", *Advances in Developing Human Resources*, Vol. 15 No. 4, pp. 341-355, doi: 10.1177/1523422313503235.

Shuck, B., Reio, T.G. and Rocco, T.S. (2011), "Employee engagement: an examination of antecedent and outcome variables", *Human Resource Development International*, Vol. 14 No. 4, pp. 427-445, doi: 10.1080/13678868.2011.601587.

Siengthai, S. and Pila-Ngarm, P. (2016), "The interaction effect of job redesign and job satisfaction on employee performance", *Evidence-based HRM*, Vol. 4 No. 2, pp. 162-180, doi: 10.1108/ebhrm-01-2015-0001.

Singh, G. and Karmakar, S. (2021), "Scope of improvement in assembly-line of FMCG industries through ergonomic design", *Smart Innovation, Systems and Technologies*, pp. 201-214, doi: 10.1007/978-981-16-0084-5_16.

Souza, R., Ferenhof, H. and Forcellini, F. (2022), "Industry 4.0 and industry 5.0 from the lean perspective", *International Journal of Management, Knowledge and Learning*, Vol. 11, pp. 145-155, doi: 10.53615/2232-5697.11.145-155.

Stacchio, L., Armandi, V., Donatiello, L. and Marfia, G. (2023), "AnnHoloTator: a mixed reality collaborative platform for manufacturing work instruction interaction", *Proceeding - IEEE Conference on Virtual Real. 3D User Interfaces Abstr. Workshops, VRW. Presented at the Proceedings - 2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, VRW 2023*, Institute of Electrical and Electronics Engineers, pp. 418-424.

Subramanian, N. and Suresh, M. (2024), "Lean HRM practices in manufacturing SMEs: exploring the interplay among the influencing factors", *International Journal of Organizational Analysis*, doi: 10.1108/ijoa-08-2023-3916.

Taneja, S., Sewell, S.S. and Odom, R.Y. (2015), "A culture of employee engagement: a strategic perspective for global managers", *Journal of Business Strategy*, Vol. 36 No. 3, pp. 46-56, doi: 10.1108/jbs-06-2014-0062.

Tortorella, G., Sawhney, R., Jurburg, D., de Paula, I.C., Tlapa, D. and Thurer, M. (2021), "Towards the proposition of a lean automation framework: integrating industry 4.0 into lean production", *Journal of Manufacturing Technology Management*, Vol. 32 No. 3, pp. 593-620, doi: 10.1108/jmtm-01-2019-0032.

Tzeng, S.-F., Chen, W.-H. and Pai, F.-Y. (2008), "Evaluating the business value of RFID: evidence from five case studies", *International Journal of Production Economics*, Vol. 112 No. 2, pp. 601-613, doi: 10.1016/j.ijpe.2007.05.009.

Ünal, E., Urbinati, A. and Chiaroni, D. (2019), "Managerial practices for designing circular economy business models: the case of an Italian SME in the office supply industry", *Journal of Manufacturing Technology Management*, Vol. 30 No. 3, pp. 561-589, doi: 10.1108/jmtm-02-2018-0061.

Vilda, F.G., Fabra, J.A.Y. and Torrents, A.S. (2019), "Person-based design: a human-centered approach for lean factory design", *Procedia Manufacturing*, Vol. 41, pp. 445-452, doi: 10.1016/j.promfg.2019.09.031.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002), "Case research in operations management", *International Journal of Operations and Production Management*, Vol. 22 No. 2, pp. 195-219, doi: 10.1108/01443570210414329.

Wagner, T., Herrmann, C. and Thiede, S. (2017), "Industry 4.0 impacts on lean production systems", *Procedia CIRP*, Vol. 63, pp. 125-131, doi: 10.1016/j.procir.2017.02.041.

Wang, F.-K., Rahardjo, B. and Rovira, P.R. (2022), "Lean six Sigma with value stream mapping in industry 4.0 for human-centered workstation design", *Sustainability*, Vol. 14 No. 17, p. 11020, doi: 10.3390/su141711020.

Yin, R.K. (2014), *Case Study Research: Design and Methods (Applied Social Research Methods)*, Sage publications, Thousand Oaks, CA.

Zhang, C., Wang, Z., Zhou, G., Chang, F., Ma, D., Jing, Y., Cheng, W., Ding, K. and Zhao, D. (2023), "Towards new-generation human-centric smart manufacturing in Industry 5.0: a systematic review", *Advanced Engineering Informatics*, Vol. 57, 102121, doi: 10.1016/j.aei.2023.102121.

Appendix

Purpose	Preparatory statement	Question
Overview	Explanation of interview objectives	*Can you describe your company? (i.e. dimension, sector . . .)* *Can you describe your role in the company? (job position)*
Identify the lean HC practices	Explanation of the HC concept	*Among the lean practices you have implemented, which ones fall into the HC area?*
Focus on domain and categories	Explanation of *Empowerment* and *Engagement* concepts	*Can these lean HC practices be traced back to the areas of empowerment and engagement? How?*
	Explanation of *Training* and *Job Enrichment* concepts	*Can lean HC empowerment practices be traced back to these categories? How?*
	Explanation of *Organizational Engagement* and *Job Engagement concepts*	*Can lean HC engagement practices be traced back to these categories? How?*
Identify I4.0 technologies supporting lean HC practices	Explanation of I4.0 technologies	*Among the lean HC practices you have implemented, which are those supported by I4.0 technologies? How?*

Source(s): Authors' work

Table A1.
Interview protocol

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