REVISTA TÓPICOS
ISSN 2965-6672 | Qualis A2

INDUSTRY 5.0 IN HANDBAG MANUFACTURING: TECHNICAL-ECONOMIC FEASIBILITY OF AUTOMATIC CUTTING MACHINES AT COMPANY ZETA

INDÚSTRIA 5.0 NA MANUFATURA DE BOLSAS: VIABILIDADE TÉCNICO-ECONÔMICA DE MÁQUINAS DE CORTE AUTOMÁTICO NA EMPRESA ZETA

Engenharias • 05/07/2026

REGISTRO DOI: 10.70773/revistatopicos/783006804

Júlio César Ramos[1]

Ermes Schmidt[2]

Marcelo Pereira Gomes[3]

Gabriel Maciel da Rosa[4]

Dusan Schreiber[5]

ABSTRACT

The object of investigation of this study is the implementation of automatic leather cutting machines in a handbag manufacturing company located in southern Brazil, referred to in this work as Company Zeta. The research objective is to analyze the technical and economic feasibility of adopting this technology in light of Industry 5.0 principles, which articulate sustainability, resilience and human-centricity with the technological advances inherited from Industry 4.0. The methodological procedures adopted characterize a single case study, of a qualitative and quantitative nature, with empirical data collection through documentary analysis of a technical-budgetary project developed by Company Zeta, complemented by simulation of productivity and savings scenarios, and by follow-up of the real results obtained after project implementation. The research results show that the project was approved by the company's board and that the machines began operating in 2023. Monitoring of leather consumption over the following quarter revealed an average reduction exceeding 7%, well above the 4% initially projected, in addition to elimination of outsourced cutting, a significant increase in production capacity through two-shift operation, and an estimated investment payback of eighteen months. It is concluded that Company Zeta's initiative represents a concrete, and successful, application of Industry 5.0 assumptions in the Brazilian leather-footwear sector, reconciling productive efficiency gains with reduced raw material waste and the reorganization of human labor in the cutting process.

Keywords: Industry 5.0; automatic cutting; sustainability; handbag manufacturing; economic feasibility.

RESUMO

O objeto de investigação deste estudo é a implantação de máquinas

de corte automático de couro em uma empresa de manufatura de bolsas localizada no Sul do Brasil, denominada neste trabalho de Empresa Zeta. O objetivo da pesquisa consiste em analisar a viabilidade técnica e econômica da adoção dessa tecnologia à luz dos princípios da Indústria 5.0, que articula sustentabilidade, resiliência e centralidade humana ao avanço tecnológico herdado da Indústria 4.0. Os procedimentos metodológicos adotados caracterizam-se como um estudo de caso único, de natureza qualitativa e quantitativa, com coleta de dados empíricos por meio de análise documental de um projeto técnico-orçamentário desenvolvido pela Empresa Zeta, complementada por simulação de cenários de produtividade e economia, e por acompanhamento dos resultados reais obtidos após a implementação do projeto. Os resultados da pesquisa evidenciam que o projeto foi aprovado pela diretoria da empresa e que as máquinas entraram em operação em 2023. O acompanhamento do consumo de couro ao longo do trimestre subsequente revelou redução média superior a 7%, valor bem acima dos 4% inicialmente projetados, além de eliminação do corte terceirizado, aumento expressivo da capacidade produtiva com operação em dois turnos e retorno do investimento estimado em dezoito meses. Conclui-se que a iniciativa da Empresa Zeta representa uma aplicação concreta, e bem-sucedida, dos pressupostos da Indústria 5.0 no setor coureiro-calçadista brasileiro, conciliando ganhos de eficiência produtiva com redução de desperdício de matéria-prima e reorganização do trabalho humano no processo de corte.
Palavras-chave: Indústria 5.0; corte automático; sustentabilidade; manufatura de bolsas; viabilidade econômica.

1. INTRODUCTION

Over the past decade, the fourth industrial revolution consolidated a production model driven by the integration of cyber-physical systems, the internet of things and intelligent automation, capable of substantially raising the operational efficiency of companies (Cannavacciuolo et al., 2023). However, the Industry 4.0 paradigm has been criticized for prioritizing technical efficiency to the detriment of social and environmental considerations, relegating the worker to a secondary role in the production process (León et al., 2025). In response to these limitations, the European Commission formalized, in 2021, the concept of Industry 5.0, grounded in three articulated pillars: human-centricity, organizational resilience and socio-environmental sustainability (Oeij et al., 2024; Fogaça; Grijalvo; Sacomano Neto, 2025).

The handbag and leather goods manufacturing industry operates in a context of growing pressure to reduce raw-material costs, decrease waste and eliminate outsourced production stages, while simultaneously facing competitiveness demands in global markets that are increasingly sensitive to sustainability criteria (Fani et al., 2024; Ratajczyk, 2025). In this scenario, automatic cutting technologies supported by nesting algorithms and computer vision emerge as an alternative capable of reconciling productivity, leather savings and the reorganization of human labor on the factory floor, without dispensing with the operator's role as a qualified agent of supervision and quality control (Górny, 2023; Vukelić; Cajner; Barić, 2024).

The present research focuses on a technical-budgetary project developed by a handbag manufacturing company located in southern Brazil, hereafter referred to as Company Zeta for purposes of preserving its commercial identity. The project evaluated comprises the acquisition of two automatic cutting machines, model CZ|XXL Plus, and a digital leather grading machine, model ESA|NEK, both from the Italian manufacturer Comelz, with the purpose of eliminating outsourced cutting, reducing leather consumption and expanding production capacity through two-shift operation.

The question guiding this investigation is: to what extent does the adoption of automatic cutting machines at Company Zeta present technical and economic feasibility, and how does this initiative relate to the principles of Industry 5.0? The general objective is to analyze the technical-economic feasibility of implementing these machines based on data from a real project, articulating the results obtained with the theoretical framework on the transition from Industry 4.0 to Industry 5.0. As specific objectives, the study seeks to: (i) characterize the theoretical foundations underpinning the transition between the two industrial paradigms; (ii) describe the methodological procedures of documentary analysis adopted; and (iii) discuss the results regarding productivity, leather savings and return on investment projected by Company Zeta in light of the literature reviewed.

Methodologically, the research is characterized as a single case study, with a qualitative and quantitative approach, with data collected through documentary analysis of a technical project developed internally by Company Zeta. The work is structured into five sections, in addition to this introduction: the theoretical framework, which discusses the pillars of Industry 5.0 and their relationship with industrial automation technologies; the methodology, which details the data collection and analysis procedures; the analysis and discussion of results, which confronts the project data with the literature reviewed; and the final remarks, which summarize the main conclusions and limitations of the study.

2. THEORETICAL REVIEW

2.1. From Industry 4.0 To Industry 5.0: Conceptual Foundations

Industry 4.0 originated in Germany in 2011, from a strategic initiative aimed at transforming production processes through the integration of advanced digital technologies (Roblek; Mesko; Krapez, 2016; Cannavacciuolo et al., 2023; Bravi et al., 2025). The model came to rest on cyber-physical systems and the internet of things, as shown by the systematic review of Piccarozzi et al. (2025), which began with an initial survey of 2,333 articles in the Scopus database and, after successive methodological filters, consolidated a final sample of 308 studies on the topic. The authors structured the analysis based on Porter's Value Chain, examining how Industry 4.0 enabling technologies affect both the company's primary activities, inbound logistics, operations, outbound logistics, marketing and services, and its support activities, such as infrastructure and human resource management. The results indicate that the internet of things and big data and analytics are the most frequently cited technologies across practically all internal activities analyzed, with the internet of things being particularly relevant for integrating sensors into machines and for more sustainable manufacturing initiatives, while big data and analytics underpins agile decision-making and the customization of products and services according to preferences identified among consumers.

This mapping showed, however, that the original purpose of the paradigm was centered on three priority objectives: efficiency gains, production flexibility and market competitiveness, with productivity occupying the role of an almost exclusive criterion for evaluating technological success (Schreiber et al., 2024; Bregar, 2024; El Jaouhari et al., 2025). This framing generated gaps that recent literature has critically revisited. Fogaça, Grijalvo and Sacomano Neto (2025) argue that environmental sustainability never occupied a strategic position in the predominant definition of Industry 4.0, remaining relegated to a secondary role and treated, at most, as a later adjustment variable. The same gap is reproduced with respect to human factors: issues related to working conditions, worker well-being and broader social dynamics received limited attention within the original model (León et al., 2025; Hansen; Christiansen; Lassen, 2025; Brodny; Tutak, 2026). This omission should not be interpreted as an isolated oversight, but as a consequence of a conceptual architecture built primarily on technical and economic gains.

This picture began to change when concrete events forced a reassessment of the prevailing paradigm. The Covid-19 pandemic exposed the fragility of global production chains excessively optimized for efficiency, to the detriment of safety margins and flexibility, while the intensification of the climate crisis accelerated regulatory and social pressures for a more responsible industrial model (Sarkar et al., 2024; Leitenbauer; Sorko; Lichem-Herzog, 2025; Goujon et al., 2024). It was in this context that the European Commission, in 2021, published the report that formally consolidated the concept of Industry 5.0, structured on three constitutive pillars: sustainability, human-centricity and resilience (Latino, 2025). It should be noted that, although the institutional formalization originated with the European Commission, the term had originally been proposed by futurist Michael Rada, gaining greater academic and political traction only after its adoption by the European body

(Madsen; Slåtten, 2023 apud Piccarozzi et al., 2025), a circumstance that helps explain the still incipient conceptual consolidation of the topic.

Jaime, Osorio-Sanabria and Bernal Torres (2026) propose a transition model grounded in a bibliometric review of the Scopus database, covering the period from 2019 to 2023, which identifies four axes of comparison between the two paradigms: human, technological, productive and environmental dimensions. According to the authors, the human dimension constitutes the central axis of Industry 5.0, insofar as collaboration between humans and machines expands industry's capacity to meet social objectives that go beyond employment and economic growth. In the technological dimension, the internet of things remains a common trait between the two paradigms, but its scope expands in Industry 5.0 to include deeper integration between human beings and cyber-physical systems, in addition to machine-to-machine communication. In the productive dimension, product life-cycle analysis and customization stand out, made possible by technologies capable of collecting detailed data on consumers' actual use of products, a finding also corroborated by an empirical study conducted with 1,436 Spanish industrial companies, according to which product customization generates greater added value relative to standardized products, although this does not necessarily translate into superior financial performance, since the additional transformation costs tend to absorb that value (Jiménez-Partearroyo; Medina-López; Juárez-Varón, 2024). In the environmental dimension, it is observed that Industry 4.0 already incorporated circular economy principles, but Industry 5.0 broadens this focus by incorporating a more comprehensive notion of sustainability, one that recognizes corporate responsibility toward society as a whole, and not merely toward its shareholders.

In the Brazilian context, case studies conducted in traditional industrial sectors illustrate the distance between the theoretical discourse of Industry 5.0 and current production practice. Research carried out in a furniture industry in the south of the country found that technologies such as the internet of things, big data and additive manufacturing had already been partially adopted, while resources such as collaborative robotics, digital twins and artificial intelligence remained technically viable but without effective implementation (Schreiber et al., 2024). This pattern of selective adoption, and its practical implications for Brazilian consumer-goods manufacturing, revisited in section 2.5, suggest that the transition to Industry 5.0 remains a distant horizon for a relevant portion of the national productive sector.

2.2. The Human-Centricity Pillar

Human-centricity does not appear in Industry 5.0 as a complementary element, but as one of its constitutive axes. Eriksson, Olsson and Carlsson (2024) argue that both lean manufacturing practices and Industry 4.0 technologies tend, in isolation, to lack a genuinely human-centered perspective, and it is precisely this gap that Industry 5.0 sets out to fill. The shift proposed by the new paradigm does not reject technology: it repositions its purpose, moving the focus from technical performance to quality of working life, and from automation as an end goal to human-machine collaboration as a means (Górny, 2023).

Oeij et al. (2024) detail this reorientation, proposing a conceptual model of workforce skills that articulates three dimensions: the pillars of Industry 5.0 itself, four levels of a production ecosystem (workplace, organization, industry and society) and four target groups for qualification (students, job seekers, workers and managers). According to the authors, human-centricity manifests in distinct ways at each level: at the workplace level, it relates to the concept of the resilient worker and to job quality; at the organizational level, it requires companies to incorporate into their business models indicators that go beyond traditional economic metrics, such as capitalization and market share, recognizing the socio-centric role the organization holds toward society, rather than treating the social environment merely as a resource for the company's isolated goals; at the sectoral level, it requires collective agreements among competitors to ensure equitable competitive conditions; and at the societal level, it demands the constitution of a "Society 5.0," supported by democratic institutions, broad education and access to social protection. According to the authors, this amounts to a reconfiguration of the very logic of who serves whom in the production process, and not merely a one-off concern with ergonomics or occasional well-being.

Robust empirical evidence supports this reorientation. Cimino et al. (2025) tested, with 217 non-specialized workers from the Italian manufacturing sector, a model grounded in socio-technical systems theory, investigating the impact of Industry 4.0 technologies on workplace well-being. The results, obtained through partial least squares structural equation modeling, indicate that system quality, experience with the technology and frequency of use positively influence well-being, with system quality being the variable with the greatest explanatory weight. Contrary to the fear that automation would increase worker alienation, the study suggests that more intuitive, reliable and responsive machines reduce stress and increase job satisfaction, especially among workers without specialized technical training.

This favorable picture, however, depends on organizational conditions that not all companies are able to guarantee, especially smaller ones. Eriksson, Olsson and Carlsson (2024) documented, through a longitudinal case study at a Swedish manufacturer of energy-sector components, with eighteen interviews and five focus groups totaling forty-four participants, that the coexistence of lean manufacturing practices and digital technologies is permeated by ambiguities: staff turnover, insufficient infrastructure and frequent organizational changes that prevent the consolidation of any digitalization initiative. One of the study participants reported that successive internal reorganizations resulted in the absence of a coherent digitalization strategy. Human-centricity, in this sense, does not happen automatically: it constitutes a permanent managerial challenge, rather than an end point.

2.3. The Sustainability Pillar

Industry 5.0 repositions sustainability as a structuring principle of industrial production, rather than as an externality to be eventually managed. This distinction matters because, while Industry 4.0 treated environmental issues peripherally, prioritizing economic efficiency gains, Industry 5.0 integrates socio-environmental objectives into the very logic of how factories and production chains operate. Ghobakhloo et al. (2025), in a systematic review conducted according to the PRISMA protocol, document that waste reduction constitutes the main micro-environmental benefit associated with the Industry 5.0 agenda. Through interconnected cyber-physical systems, advanced sensors and real-time data analysis, organizations are now able to identify inefficiencies and points of excess in their operations with a precision that was previously unfeasible. The authors also highlight that the integration of artificial intelligence and machine learning algorithms enables predictive maintenance, anticipating equipment failures and reducing both unplanned downtime and the resource waste resulting from sudden production interruptions.

The circular economy occupies a central position in this theoretical framework. Thompson-Bahm, Teixeira and Lobo (2025) and Carayannis and Morawska-Jancelewicz (2022) argue that Industry 5.0 breaks with the linear production model by incorporating remanufacturing, reuse and recycling practices directly into the design of industrial processes. Technologies such as the internet of things, artificial intelligence and digital twins make it possible to trace the flow of materials throughout the entire production chain, identifying reuse opportunities previously invisible to traditional management systems. According to Ratajczyk (2025), this shift from extractive chains to regenerative systems extends even to elements such as packaging, now conceived, from an Industry 5.0 perspective, as socio-technological systems integrated into the company's environmental responsibility.

Sarkar et al. (2024) add, based on research with manufacturing experts, that sustainability awareness ranks second among the critical success factors identified for the transition toward Industry 5.0. This finding reinforces that adopting advanced technologies is not enough if organizational culture fails to internalize environmental goals as an effective decision-making criterion, rather than merely as institutional discourse.

2.4. The Resilience Pillar

Resilience constitutes the third structuring pillar of Industry 5.0, understood not as a complementary attribute, but as a systemic capacity that determines the survival of organizations in the face of increasingly frequent and unpredictable disruptions. Oeij et al. (2024) define resilience as the capacity to anticipate external shocks, respond effectively after a disruption and return to stable operation, learning from the event and reformulating strategies for the future. The distinction between recovering and transforming is central to this definition: recovering a previous level of performance is not equivalent to developing lasting adaptive capacity.

Farivar, Klarin and Kanani-Moghadam (2026) advance a theoretical proposal that reformulates the very structure of the three pillars of Industry 5.0. Based on a systematic review of 732 studies, complemented by a bibliometric analysis that identified five dominant thematic clusters in the literature, technological foundations, human-centricity, and the three dimensions of sustainability, the authors propose a systemic model grounded in systems theory and institutional legitimacy theory. According to this proposal, human-centricity does not constitute a parallel and co-equivalent pillar to resilience and sustainability, as the traditional three-pillar framing suggests, but instead functions as a governing variable, the mechanism through which resilience and sustainability themselves are produced within the socio-technical system. The authors further argue that the transition from Industry 4.0 to Industry 5.0 is driven by deficits in institutional legitimacy, and not only by technological advances: organizations whose compliance with Industry 5.0 principles remains superficial face faster reputational and regulatory penalties than the rewards obtained from incremental improvements, which makes the transition a strategic necessity, rather than a discretionary option.

Historical background matters for understanding this pillar. Oeij et al. (2024) observe that, in contexts of stability, efficiency logic tends to predominate, leading companies toward outsourcing strategies and structural downsizing. The problem arises when these moves create latent vulnerabilities: rigid chains, with few redundancies, prove to be most fragile precisely at the moment when flexibility is most needed. Samuels and Pelser (2025) reinforce that the transition to Industry 5.0 requires integrating sustainability as a founding principle of supply chain management, proposing a strategic model organized into five axes, organizational learning, human capacity development, technological leapfrogging strategy, disruption mitigation and sustainable operations, capable of simultaneously sustaining the three pillars of what is called Supply Chain 5.0. Organizations that combine lean practices with the circular economy demonstrate greater capacity to reconfigure their processes with agility, such that resilience, in these cases, does not derive exclusively from available technology, but from organizational maturity to operate under conditions of uncertainty.

2.5. Barriers To The Adoption Of Industry 5.0 In Manufacturing

The transition to Industry 5.0 demands much more than institutional willingness. León, Puente, Fernandez and Luna (2025) mapped this set of challenges through a multi-criteria analysis that combined the Analytic Hierarchy Process (AHP) with fuzzy inference systems, consulting five experts to weigh four structuring dimensions of the transition: sustainability, human factor, resilience and organizational strategy. The results assigned sustainability the highest relative weight among the factors evaluated (0.38), followed by the human factor (0.25), resilience (0.21) and, lastly, organizational strategy (0.16), with implementation enablers outweighing the barriers themselves within this last factor. For the human factor, collaboration and worker well-being emerged as the most relevant criteria; for resilience, the flexibility of business processes; for sustainability, the financial and social dimensions.

Hansen, Christiansen and Lassen (2025) deepen this argument by examining thirty small and medium-sized Danish manufacturing companies at different stages of digital transformation, through a methodology inspired by cognitive apprenticeship, with in-person workshops and technical visits to the participating companies. The authors' diagnosis is direct: the most relevant barrier is not technological, but cognitive. Companies lack both content knowledge, that is, understanding of Industry 4.0 and 5.0 concepts, data management and systemic integration capability, and metacognitive knowledge, related to knowing how to strategically plan the transformation and develop competencies in a structured way. Without this prior foundation, digitalization initiatives stumble into what the authors call knowledge inertia: organizations repeat what they already know how to do, blocking innovation they have not yet mastered.

Latino (2025) corroborates this picture based on four case studies in small and medium-sized Italian manufacturing companies in the agri-food and fashion sectors, including a manufacturer of bags and accessories focused on highly customized production for the infant and maternity market. The dimension with the lowest maturity score across all four cases was that of technologies embedded in products and services, whereas organizational dimensions, such as leadership, a culture of continuous improvement and awareness of Industry 5.0 principles, achieved comparatively higher performance. The practical implication is direct: small and medium-sized companies recognize the value of the transformation proposed by the new paradigm, but face concrete difficulties in translating it into effective technological action on their own products.

The picture changes when one looks at the context of traditional, labor-intensive manufacturing. Grings, Schreiber and Schmidt (2025), investigating a large footwear company from Rio Grande do Sul, found that the production practices adopted are closer to Industry 2.0 and 3.0 models than to the requirements of Industry 5.0. Managerial conservatism, reduced profit margins and a shortage of skilled labor make up a set of constraints that delay technological investments. The authors themselves note, however, an important caveat: labor shortages can, paradoxically, become a driver of digitalization in these sectors, not through deliberate strategic vision, but through concrete operational necessity, a finding that connects directly with the automation trajectory observed at Company Zeta and discussed in the results section of this work.

2.6. Synthesis And Direction Toward The Case Study

The theoretical panorama assembled in the previous sections shows that the transition from Industry 4.0 to Industry 5.0 does not constitute an abrupt rupture, but a cumulative, multidimensional process, in which already-consolidated technologies are redirected toward objectives that go beyond isolated technical efficiency. A recent bibliometric analysis, conducted using Scopus data, confirms that Industry 4.0 remains the most prominent theme in academic discourse on advanced manufacturing, even though Industry 5.0 has shown a strong upward trend since its emergence, with greater relative emphasis on human interaction and sustainability than its predecessor paradigm (Ramos-Gutiérrez; García-Gutiérrez, 2025).

From the perspective of the digital economy, a study on the structuring of smart economies projects that investment in robotic manufacturing should reach 120.6 billion dollars by 2025, followed by autonomous operations and data-driven customer management, with the construction, securities services and banking sectors among those expected to show the fastest growth in digital transformation investment during the period (Suntsova, 2022).

The four factors mapped by León, Puente, Fernandez and Luna (2025), sustainability, human factor, resilience and organizational strategy, the four axes of comparison proposed by Jaime, Osorio-Sanabria and Bernal Torres (2026), human, technological, productive and environmental, and the proposal by Farivar, Klarin and Kanani-Moghadam (2026), which repositions human-centricity as the governing mechanism of the socio-technical system, function as complementary lenses for examining concrete industrial automation initiatives, especially in manufacturing sectors that are intensive in natural raw materials and labor, such as the Brazilian leather-footwear sector. This same type of pressure for technological modernization in traditional production chains had already been identified in a study on Turkish logistics, which used SWOT analysis to demonstrate that the transition toward Industry 5.0, driven by technologies such as collaborative robots and fleet management systems, constitutes a strategic necessity in the face of supply chain disruptions, and not merely an academic trend (Oran et al., 2022).

It is from this articulated framework that the present research analyzes the case of Company Zeta, seeking to understand to what extent its initiative to automate the leather cutting process engages with the theoretical pillars reviewed, and to what extent it confirms, or contradicts, the pattern of selective and gradual adoption identified in the literature on traditional Brazilian manufacturing.

3. METHODOLOGY

In terms of nature, the present research is classified as qualitative and quantitative, and in terms of objectives, as exploratory and descriptive, insofar as it seeks to understand a phenomenon still poorly consolidated in the national literature, the application of Industry 5.0 principles in concrete industrial automation decisions, while also describing and quantifying the projected results of a real technical project (Gil, 2010; Marconi; Lakatos, 2017). The research strategy adopted is characterized as a single case study, an approach justified by the possibility of conducting an in-depth investigation of a contemporary phenomenon within its real context, especially when the boundaries between the phenomenon and the context are not clearly defined (Yin, 2015).

Empirical data collection was based on documentary analysis of a technical-budgetary project developed internally by Company Zeta, called the Automatic Cutting Machine Acquisition Project, prepared by the organization's planning, cost, methods and processes team, with the evaluation carried out in November 2022. The document covers project overview data, technical objectives, specifications of the machines evaluated (models CZ|XXL Plus and ESA|NEK, from the Italian manufacturer Comelz), budget, delivery timelines, timed production rates, leather consumption savings simulations, cutting cost savings simulations and projected return on investment. Documentary analysis constitutes an appropriate methodological procedure when seeking to investigate organizations' internal records, complementing or substituting primary data collection when such data are already systematized in formal sources (Prodanov; Freitas, 2013; Marconi; Lakatos, 2017). As a complementary source for the technical characterization of the equipment evaluated, the official technical catalogs of the ESA|NEK and CZ|XXL Plus models published by the manufacturer Comelz were also consulted, allowing for the detailing of the specifications presented in the results section. Additionally, after the project's approval by Company Zeta's board of directors and the machines' effective entry into operation in 2023, internal leather-consumption monitoring records for the quarter following implementation were collected and analyzed, making it possible to compare the values projected in the feasibility study with the results actually observed on the production floor.

Data treatment followed the content analysis technique, understood as a set of systematic and objective procedures for describing message content, allowing for the inference of knowledge related to the conditions of production and reception of the information analyzed (Bardin, 2016). The quantitative data extracted from the document, related to production times, leather costs, outsourced cutting costs and savings projections, were organized into thematic categories corresponding to the theoretical pillars of Industry 5.0 (human-centricity, resilience and sustainability), enabling triangulation between the empirical findings and the theoretical framework reviewed in the previous section.

Because this is a single case study based on data from a real project, the decision was made to preserve the identity of the organization studied, which is why the company is identified in this work exclusively by the codename Company Zeta, in accordance with the ethical guidelines usually adopted in research involving sensitive data from private organizations. The complementary qualitative evaluative analysis was based on the assumptions of Demo (2022), who emphasizes the importance of articulating quantitative data with a critical interpretation of the organizational and sectoral context in which they are situated.

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1. Characterization Of Company Zeta's Technical Project

Before automation, the leather cutting process at Company Zeta was carried out manually, with the operator using a utility knife and ruler to mark and cut the pieces directly on the hide, as illustrated in Figure 1. This method, although dependent on the operator's individual skill, presented limitations related to cutting precision, processing speed and raw-material utilization, since the positioning of the pieces on the leather was defined visually, without the support of nesting optimization algorithms.

Figure 1 – Manual leather cutting with a utility knife and ruler, the method used by Company Zeta before automation.

Source: Prepared by the authors with the aid of AI, 2026.

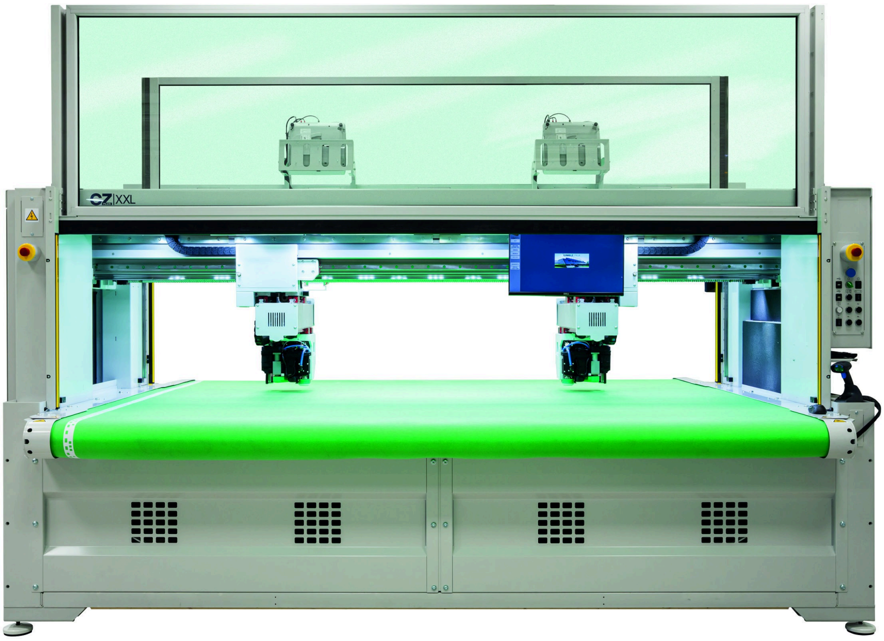
The technical project evaluated by Company Zeta included the acquisition of two automatic cutting machines, model CZ|XXL Plus, and a digital leather grading machine, model ESA|NEK, both manufactured by the Italian company Comelz, as illustrated in Figures 2 and 3.

Figure 2 – ESA|NEK digital leather grading machine

Source: Comelz (2024).

The ESA|NEK grading machine performs leather digitization and grading through a vision system with a working area of 3,000 x 1,400 mm and a resolution of 0.5 mm, with a maximum viewing angle of 22 degrees and maximum illuminance of 11,000 lux. The equipment features a matrix of 20 modular dual-color LED spots (2,700°K and 6,500°K, 48W each), with an anti-glare deflector, allowing independent control of the intensity and color temperature of the lighting for precise inspection of different types of leather, a feature particularly relevant given the natural heterogeneity of the raw material processed by Company Zeta. Defect and quality-area marking is performed using an integrated virtual pen, complemented by three lasers for precise projection onto the hide, while three independent sliding partitions shield the workbench from unwanted external light during inspection. The worktable is tiltable, a feature that improves the ergonomics of the operator responsible for grading. Technically, the machine operates on three-phase 400V power (50/60Hz), with maximum power draw of 3 kW and a net weight of 1,200 kg (Table 1).

Figure 3 – CZ|XXL Plus automatic cutting machine.



Source: Comelz (2024).

The CZ|XXL Plus, in turn, has a cutting area of 3,000 x 840 mm (in the XXL configuration acquired by Company Zeta, with the series also offered in an L configuration, with an area of 1,850 x 840 mm), a cutting speed of 60 meters per minute and a punch capacity of 600 perforations per minute per head, with the ability to cut between three and four handbag models simultaneously, and a maximum material height of 18 mm. Each cutting head is equipped with five independent punches and one pen, designed to operate in near-direct proximity to one another, which contributes to raising effective processing speed, as illustrated in Figure 4. The equipment incorporates the FAS (Front Active Screen) system, an option adopted by Company Zeta, which closes automatically during the cutting process, pressing the material for greater stability and significantly reducing operational noise, a feature that connects directly with the human-centricity pillar of Industry 5.0, insofar as it reduces the operator's exposure to unfavorable environmental conditions during extended shifts (Vukelić; Cajner; Barić, 2024). In addition, the RAS (Rear Active Screen) system provides additional stability to the material during cutting, allowing access to the worktable from both the front and rear of the machine, which facilitates the loading of large leather pieces. The machine operates on three-phase 400V power (or optionally 220V), with maximum power draw of 20 KVA and compressed-air consumption of 300 NL/min at 6 bar.

Figure 4 – Detail of the dual cutting heads of the CZ|XXL Plus, operating in close proximity to maximize processing speed.

Source: Comelz (2024).

The integration between the two machines, digital grading followed by automatic cutting, is what allows Company Zeta to operationalize automatic piece nesting taking into account the shade and quality of each region of the leather. This functionality, made possible by the ESA|NEK's virtual pen and by the optional vision system also available on the CZ Plus line, which allows the cutting of materials with pre-existing designs, logos and prints, as well as the cutting of pre-assembled or laminated pieces, optimizes raw-material utilization and corroborates the literature that highlights the role of computer vision technologies in reducing waste in sectors that work with heterogeneous materials (Górny, 2023; Ghobakhloo et al., 2025; Hines et al., 2026). Table 1 summarizes the compared technical specifications of the two pieces of equipment.

Table 1 – Compared technical specifications of the Comelz machines.

Specification	ESA|NEK (grading machine)	CZ|XXL Plus (cutting machine)
Main function	Leather digitization and grading	Multi-material automatic cutting
Work/cutting area	3.000 x 1.400 mm	3.000 x 840 mm (XXL) / 1.850 x 840 mm (L)
Resolution/precision	0.5 mm (vision resolution)	600 perforations/min per head
Speed	n/d	60 m/min
Vision technology	20 dual-color LED spots (2,700K-6,500K, 48W) + 3 lasers	Optional vision system (designs, pre-printed)
Marking interface	Virtual pen	5 independent punches + 1 pen per head
Power supply	400V three-phase + N, 50/60Hz	400V three-phase, 50/60Hz (220V optional)
Maximum power draw	3 kW	20 KVA
Air consumption	n/d	300 NL/min at 6 bar
Net weight	1,200 kg	n/d
Ergonomic features	Tiltable worktable	Active FAS/RAS screens (close during cutting, reduce noise)

Source: prepared by the authors based on Comelz technical catalogs (2024).

4.2. Productivity And The Reorganization Of Work

The times measured by the team at the supplier Comelz for the three best-selling handbag models at Company Zeta, identified by the number of pieces that make up each model (14, 18 and 37 pieces, respectively), indicate an average cutting time of 16.9 meters per minute and an average production of 637 units per shift at 100% efficiency, or 541 units at 85% efficiency. With the projected operation of two shifts and two machines, the estimated production capacity reaches 2,166 units per day, equivalent to 43,320 handbags per month, considering twenty business days of production (Table 2).

Table 2 – Projected productivity and production capacity.

Indicator	Value
Average cutting speed (3 models: 14, 18 and 37 pieces)	16.9 m/min
Production per shift (100% efficiency)	637 units
Production per shift (85% efficiency)	541 units
Projected configuration	2 shifts x 2 machines
Estimated daily production capacity	2,166 units
Estimated monthly production capacity (20 business days)	43,320 handbags

Source: prepared by the authors based on Company Zeta's technical project (2022).

This increase in production capacity is directly related to Company Zeta's strategic objective of eliminating outsourced cutting, a stage that, in the situation prior to the project, represented an average cost of R$ 3.54 per handbag, totaling a monthly expenditure of R$ 153,352.80. Internalizing the cutting process, made possible by automation, projects a monthly operating cost of R$ 57,130.61, including 14 operators distributed across two shifts, electricity, conveyor maintenance and replacement of cutting blades, resulting in a monthly saving of R$ 96,222.19 and a projected annual saving of R$ 1,154,666.28 (Table 3). This result connects with the literature on organizational resilience in Industry 5.0, which highlights the importance of reducing dependence on external suppliers as a strategy for mitigating disruptions in the production chain (Fares et al., 2025; León; Kanat, 2026; Kans; Campos, 2024). In addition, there is the benefit of keeping leather, the product's most expensive raw material, under the company's own internal management, rather than a third party's.

Table 3 – Cutting cost: outsourced versus internalized.

Item	Outsourced cutting (previous scenario)	Automated cutting (projected scenario)
Average cost per handbag	R$ 3,54	n/d
Total monthly operating cost	R$ 153.352,80	R$ 57.130,61
Cost composition	Outsourced service	14 operators (2 shifts), electricity, maintenance, blades
Monthly savings generated	n/d	R$ 96.222,19

Projected annual savings	n/d	R$ 1.154.666,28

Source: prepared by the authors based on Company Zeta's technical project (2022).

It is worth noting that internalizing the cutting process does not eliminate human labor from the production process, but rather repositions it: the fourteen operators planned for the two shifts take on supervision, machine-feeding and quality-control functions, in line with the human-centricity principle that guides Industry 5.0, according to which automation should expand, rather than eliminate, the worker's qualified role in the production process (Oeij et al., 2024; Cimino et al., 2025; Lachvajderová; Kádárová, 2022).

4.3. Raw-Material Savings And Sustainability

The sustainability dimension of the project manifests itself most clearly in the leather-consumption savings projected by Company Zeta. Based on studies by the manufacturer Comelz itself, an average reduction of 4% in leather consumption per unit produced was estimated, resulting from algorithm-based automatic nesting and the simultaneous cutting of similar handbag models, a feature that takes advantage of the similarity between models that share the same color and pattern from the same leather batch to optimize the positioning of pieces on the surface of the material. Considering the average leather cost of R$ 45.79 per unit, this percentage saving represents R$ 1.84 per handbag produced, totaling R$ 79,708.80 per month and R$ 956,505.60 per year, a projection consistent with a production volume of 43,320 handbags per month (Table 4).

Table 4 – Projected savings in leather consumption.

Indicator	Value
Average reduction in leather consumption per unit	4%
Average leather cost per unit (reference)	R$ 45,79
Savings per handbag produced	R$ 1,84
Monthly production volume considered	43,320 handbags
Projected monthly savings	R$ 79.708,80
Projected annual savings	R$ 956.505,60

Source: prepared by the authors based on Company Zeta's technical project (2022).

These results corroborate the literature that associates computer vision technologies and automatic nesting algorithms with the reduction of waste of heterogeneous raw materials, especially in sectors that work with natural leather, whose surface presents variations in shade, thickness and the presence of defects that make manual utilization less efficient than utilization mediated by digital grading systems (Górny, 2023; Ratajczyk, 2025; Maurya; Hazra; Kalita, 2025). The reduction in raw-material waste also connects with the environmental dimension of sustainability discussed by Ghobakhloo et al. (2025), who highlight the role of emerging technologies in minimizing the environmental impacts of production activity, although the authors note that the magnitude of these benefits still requires broader empirical validation, a contribution that the present case study offers by quantifying the impact of a real-world application of these technologies.

4.4. Return On Investment And Economic Feasibility

The total investment projected by Company Zeta for acquiring the two CZ|XXL Plus machines, the ESA|NEK grading machine and the integration software totaled €497,000, plus 21% for transportation, insurance, storage and customs clearance costs, in addition to €12,100 in services from Comelz Brazil, resulting in a total investment of €613,470, equivalent to R$ 3,128,697 at the exchange rate considered (Table 5).

Table 5 – Total investment projected for the project.

Item	Value
Acquisition (2x CZ|XXL Plus + 1x ESA|NEK + software)	€ 497.000
21% surcharge (transportation, insurance, storage, customs clearance)	€ 104.370
Comelz Brazil services	€ 12.100
Total investment (EUR)	€ 613.470
Total investment (BRL, exchange rate considered)	R$ 3.128.697,00

Source: prepared by the authors based on Company Zeta's technical project (2022).

Adding the projected annual savings in leather consumption (R$ 956,505.60) to the projected annual savings in cutting costs (R$ 1,154,666.28), a total annual saving of R$ 2,111,171.88 is obtained, which projects a return on investment in approximately eighteen months (Table 6).

Table 6 – Return on investment (ROI).

Annual savings component	Value
Annual savings (leather consumption)	R$ 956.505,60
Annual savings (elimination of outsourced cutting)	R$ 1.154.666,28
Total annual savings	R$ 2.111.171,88
Total investment	R$ 3.128.697,00
Investment payback period	≈ 18 months

Source: prepared by the authors based on Company Zeta's technical project (2022).

This payback horizon proves consistent with the literature on technological maturity in small and medium-sized companies, which highlights capital costs as one of the main barriers to the adoption of advanced manufacturing technologies, while also recognizing that projects well grounded in quantitative productivity and savings data tend to show more robust economic feasibility (Latino, 2025; Hansen; Christiansen; Lassen, 2025; Piccarozzi; Caboni; Bruni, 2026). The projected implementation timeline (Table 7), of 150 days for the equipment to leave Italy, installation within up to ten days after arrival, and ten days of training accompanied by a specialized technician from the manufacturer, also signals attention to the human-capacity-building component, a dimension recognized in the literature as a necessary condition, rather than merely a complementary one, for the effective appropriation of new production technologies (Erro-Garcés; Aramendia-Muneta, 2023; Samuels; Pelser, 2025; Piccarozzi et al., 2024).

Table 7 – Project implementation timeline.

Stage	Timeframe
Equipment departure from the factory (Italy)	150 days
Installation after arrival in Brazil	up to 10 days
Training accompanied by a Comelz technician	10 days

Source: prepared by the authors based on Company Zeta's technical project (2022).

Given the projected results regarding productivity, raw-material savings and return on investment, the technical project was submitted for review by Company Zeta's board of directors and formally approved for execution, with the actual acquisition of the CZ|XXL Plus and ESA|NEK machines. The equipment arrived at the company's production plant in 2023, beginning the installation and training phase according to the timeline set out in the original project.

4.5. Real Results Observed After Implementation

After the machines began operating, Company Zeta carried out systematic monitoring of leather consumption for a period of more than one quarter, comparing the consumption recorded in the technical sheets for manual cutting with a manual knife, the previously used method, with the consumption actually observed with the operation of the automatic cutting machines. This monitoring revealed that the actual reduction in leather consumption averaged more than 7%, a value significantly above the 4% initially projected in the feasibility study. Considering that leather is the highest-cost raw material in the final product, this result, higher than projected, represents a relevant additional financial gain relative to the original estimates presented in Table 3, further reinforcing the economic soundness of the investment decision.

This above-projection performance can be attributed to factors that tend to be underestimated in simulations carried out before the equipment's actual operation, such as the progressive refinement of automatic nesting parameters along the operators' learning curve, and the observation that the actual variability in shade and quality of the hides processed by Company Zeta favored the optimization algorithm more strongly than the average considered in the manufacturer's estimates. Taken together, the results observed in the first quarter of operation confirm, and to some extent exceed, the projected technical-economic feasibility, establishing the initiative as a success from Company Zeta's management perspective.

4.6. Synthesis Articulated With The Pillars Of Industry 5.0

The integrated analysis of the results of the Company Zeta project makes it possible to identify a concrete and measurable application of the three pillars of Industry 5.0. Human-centricity manifests itself in the reorganization, rather than elimination, of the cutting operators' functions, who now work in supervision and quality control supported by technology, as well as in the ergonomic improvements (the tiltable table of the ESA|NEK, the FAS/RAS systems of the CZ|XXL Plus) and noise reduction incorporated into the equipment. Resilience is expressed in the elimination of dependence on outsourced cutting suppliers, reducing the company's exposure to variations in price, lead time and quality among external suppliers. Sustainability, finally, materializes in the measurable reduction in leather consumption, a natural resource whose production involves significant environmental impacts throughout the entire production chain, a result that, as demonstrated in the previous section, significantly exceeded the feasibility study's initial projection.

These findings suggest that the transition from Industry 4.0 to Industry 5.0, described in the literature as a gradual and multidimensional process (Jaime; Osorio-Sanabria; Bernal Torres, 2026; Bravi et al., 2025), can be empirically observed in concrete technological investment decisions made by medium-sized manufacturing companies in the Brazilian context, even when these companies do not explicitly frame their projects under the academic terminology of Industry 5.0. The case of Company Zeta thus shows that the practical appropriation of the principles of this new industrial paradigm can precede its formal discursive incorporation by organizations, a pattern also observed, in the opposite direction, in the case study of the footwear company from the Paranhana region, in which still-incipient automation is driven less by deliberate alignment with Industry 5.0 and more by pragmatic pressures from labor shortages (Grings; Schreiber; Schmidt, 2025). The approval of the project by Company Zeta's board of directors, the actual implementation of the machines in 2023, and the finding, over the subsequent quarter, of an actual leather saving exceeding 7%, thus above the 4% initially projected, allow this initiative to be classified as a success case in the practical application of Industry 5.0 principles in Brazilian leather-goods manufacturing.

5. FINAL CONSIDERATIONS

The present research aimed to analyze the technical-economic feasibility of implementing automatic cutting machines at Company

Zeta, articulating the results obtained with the theoretical principles of the transition from Industry 4.0 to Industry 5.0. The results indicate that the research objectives were fully achieved: the documentary analysis made it possible to accurately characterize the productivity gains, the leather-consumption savings and the return on investment projected by the technical project evaluated, while also making it possible to articulate these empirical findings with the theoretical pillars of human-centricity, resilience and sustainability that characterize the new industrial paradigm.

The data analyzed show that the automation of the leather cutting process at Company Zeta, in the feasibility study phase, projected an average reduction of 4% in raw-material consumption, an annual saving of more than R$ 950 thousand resulting from this reduction, the elimination of outsourced cutting costs equivalent to an additional saving of more than R$ 1.1 million per year, an expansion of production capacity to more than 43 thousand handbags per month with two-shift operation, and an estimated return on investment of eighteen months. The project was approved by Company Zeta's board of directors based on these results, and the machines actually began operating in 2023. The monitoring carried out by the company over the quarter following implementation revealed that the actual reduction in leather consumption averaged more than 7%, a value significantly higher than the 4% initially projected, confirming, and to some extent exceeding, the estimated technical-economic feasibility. These results establish the Company Zeta project as a success case, showing how concrete industrial automation decisions can operationalize, in practice, the theoretical principles of Industry 5.0, even without explicit mention of this terminology in the organization's internal documents.

As the main limitation of the study, it should be noted that the research is based predominantly on data from a single technical-budgetary project and on a post-implementation monitoring period still restricted to one quarter, which limits the analysis of any seasonal or medium-term variations in equipment performance. Additionally, the methodological choice of a single case study restricts the possibility of generalizing the results obtained to other organizations in the leather-footwear sector, even though the findings offer relevant input for companies evaluating similar investment decisions in cutting automation.

For future research, it is suggested that the longitudinal monitoring of Company Zeta's results be continued over longer periods, making it possible to verify whether the leather saving exceeding 7% observed in the first quarter of operation is maintained, or eventually changes. It is also recommended that the scope of investigation be expanded to comparative studies involving multiple companies in the handbag and footwear manufacturing sector, in order to identify patterns and particularities in the appropriation of Industry 5.0 principles across different organizational contexts. Finally, it is suggested that further investigation be conducted into the perceptions of workers directly involved in the cutting process regarding the changes in their functions and working conditions resulting from automation, in order to deepen the empirical understanding of the human-centricity pillar of Industry 5.0 in the specific context of Brazilian leather-goods manufacturing.

REFERENCES

BARDIN, Laurence. Análise de conteúdo. São Paulo: Edições 70, 2016.

BRAVI, Laura; PIERLI, Giulia; MURMURA, Federica; MUSSO, Fabio. Integrating Industry 4.0 and Industry 5.0: a study of hybrid adoption in SMEs and its impact on sustainability, human-centricity, resilience. International Journal of Production Research, 2025. DOI: https://doi.org/10.1080/00207543.2025.2596960.

BREGAR, Andrej. Decision process for industry 5.0. Journal of Decision Systems, v. 33, supl. 1, p. 433-447, 2024. DOI: https://doi.org/10.1080/12460125.2024.2359158.

BRODNY, Jaroslaw; TUTAK, Magdalena. Towards Industry 5.0: an integrated readiness assessment of EU-27 Member States. Journal of Cleaner Production, v. 540, 2026. DOI: https://doi.org/10.1016/j.jclepro.2026.147486.

CANNAVACCIUOLO, Lorella; FERRARO, Giovanna; PONSIGLIONE, Cristina; PRIMARIO, Simonetta; QUINTO, Ivana. Technological innovation-enabling industry 4.0 paradigm: a systematic literature review. Technovation, v. 124, 2023. DOI: https://doi.org/10.1016/j.technovation.2023.102733.

CARAYANNIS, Elias G.; MORAWSKA-JANCELEWICZ, Joanna. The futures of Europe: Society 5.0 and Industry 5.0 as driving forces of future universities. Journal of the Knowledge Economy, v. 13, n. 4, p. 3445-3471, 2022. DOI: https://doi.org/10.1007/s13132-021-00854-2.

CIMINO, Antonio; ZANGARA, Gabriele; COSMA, Antonio Maria Igor; MAZZITELLI, Diego; FILICE, Luigino. On the verge of Industry 5.0: a socio-technical perspective on non-knowledge workers and workplace well-being. European Journal of Innovation Management, v. 28, n. 11, p. 301-320, 2025. DOI: https://doi.org/10.1108/EJIM-04-2025-0424.

COMELZ. CZ Plus: a máquina de corte definitiva. Catálogo técnico. Italia: Comelz, 2024.

COMELZ. NEK: instrumento perfeito para a digitalização de peles. Catálogo técnico. Italia: Comelz, 2024.

DEMO, Pedro. Avaliação qualitativa. Campinas: Autores Associados, 2022.

EL JAOUHARI, Aziz; ARIF, Jabir; SAMADHIYA, Ashutosh; DHAYAL, Krishan Sharma; LUTHRA, Sunil; SINGH, Sanjay. From automation to augmentation: exploring the role of Industry 5.0 advanced technologies for developing countries. EMJ – Engineering Management Journal, v. 37, n. 3, p. 306-323, 2025. DOI: https://doi.org/10.1080/10429247.2024.2407254.

ERIKSSON, Kristina M.; OLSSON, Anna Karin; CARLSSON, Linnea. Beyond lean production practices and Industry 4.0 technologies toward the human-centric Industry 5.0. Technological Sustainability, v. 3, n. 3, p. 286-308, 2024. DOI: https://doi.org/10.1108/TECHS-11-2023-0049.

ERRO-GARCÉS, Amaya; ARAMENDIA-MUNETA, M. Elena. The role of human resource management practices on the results of digitalisation. From Industry 4.0 to Industry 5.0. Journal of Organizational Change Management, v. 36, n. 4, p. 585-602, 2023. DOI: https://doi.org/10.1108/JOCM-11-2021-0354.

FANI, Virginia; BUCCI, Ilaria; ROSSI, Matteo; BANDINELLI, Romeo. Lean and industry 4.0 principles toward industry 5.0: a conceptual framework and empirical insights from fashion industry. Journal of

Manufacturing Technology Management, v. 35, n. 9, p. 122-141, 2024. DOI: https://doi.org/10.1108/JMTM-11-2023-0509.

FARES, Naila; ANASS, Cherrafi; SHARDEO, Vipulesh; GARZA-REYES, Jose Arturo. Supply chain management in the Industry 5.0 era: strategic implications. Benchmarking: An International Journal, 2025. DOI: https://doi.org/10.1108/BIJ-12-2024-1136.

FARIVAR, Farveh; KLARIN, Anton; KANANI-MOGHADAM, Venus. Industry 5.0: a socio-technical system perspective on human agency and institutional legitimacy. Journal of Management and Organization, 2026. DOI: https://doi.org/10.1017/jmo.2026.10095.

FOGAÇA, Diego Rorato; GRIJALVO, Mercedes; SACOMANO NETO, Mario. What are Industry 4.0 and Industry 5.0 all about? An integrative institutional model for the new industrial paradigms. Administrative Sciences, v. 15, n. 4, 2025. DOI: https://doi.org/10.3390/admsci15040118.

GHOBAKHLOO, Morteza; IRANMANESH, Mohammad; FATHI, Masood; REJEB, Abderahman; FOROUGHI, Behzad; NIKBIN, Davoud. Beyond Industry 4.0: a systematic review of Industry 5.0 technologies and implications for social, environmental and economic sustainability. Asia-Pacific Journal of Business Administration, v. 17, n. 4, p. 889-914, 2025. DOI: https://doi.org/10.1108/APJBA-08-2023-0384.

GIL, Antonio Carlos. Como elaborar projetos de pesquisa. 5. ed. São Paulo: Atlas, 2010.

GÓRNY, Adam. Developing Industry 5.0 to effectively harness production capacities. Management Systems in Production

Engineering, v. 31, n. 4, p. 456-463, 2023. DOI: https://doi.org/10.2478/mspe-2023-0052.

GOUJON, Alexandre; ROSIN, Florent; MAGNANI, Fabio; LAMOURI, Samir; PELLERIN, Robert; JOBLOT, Laurent. Industry 5.0 use cases development framework. International Journal of Production Research, v. 62, n. 17, p. 6064-6089, 2024. DOI: https://doi.org/10.1080/00207543.2024.2307505.

GRINGS, Jacques André; SCHREIBER, Dusan; SCHMIDT, Serje. Relevância da aprendizagem organizacional em empresas calçadistas para a adoção das práticas do modelo conceitual da Indústria 5.0. REUNA, v. 29, n. 2, p. 24-41, 2025.

HANSEN, Andreas Kornmaaler; CHRISTIANSEN, Lasse; LASSEN, Astrid Heidemann. Technology isn't enough for Industry 4.0: on SMEs and hindrances to digital transformation. International Journal of Production Research, v. 63, n. 18, p. 6585-6605, 2025. DOI: https://doi.org/10.1080/00207543.2024.2305800.

HINES, Peter; MAGNANI, Fabio; MULA, Josefa; SANCHIS, Raquel. Toward lean industry 5.0: a human-centered model for integrating lean and industry 4.0 in an automotive supplier. International Journal of Production Research, v. 64, n. 1, p. 250-273, 2026. DOI: https://doi.org/10.1080/00207543.2025.2551238.

JAIME, Astrid; OSORIO-SANABRIA, Mariutsi Alexandra; BERNAL TORRES, Deysi Yohana. Similarities and differences between Industry 4.0 and Industry 5.0: towards a transitioning model. Journal of Innovation and Knowledge, v. 13, 2026. DOI: https://doi.org/10.1016/j.jik.2025.100921.

JIMÉNEZ-PARTEARROYO, Montserrat; MEDINA-LÓPEZ, Ana; JUÁREZ-VARÓN, David. Towards industry 5.0: evolving the product-process matrix in the new paradigm. Journal of Technology Transfer, v. 49, n. 4, p. 1496-1531, 2024. DOI: https://doi.org/10.1007/s10961-023-10053-7.

KANS, Mirka; CAMPOS, Jesus. Digital capabilities driving industry 4.0 and 5.0 transformation: insights from an interview study in the maintenance domain. Journal of Open Innovation: Technology, Market, and Complexity, v. 10, n. 4, 2024. DOI: https://doi.org/10.1016/j.joitmc.2024.100384.

LACHVAJDEROVÁ, Lucia; KÁDÁROVÁ, Jaroslava. Industry 4.0 implementation and Industry 5.0 readiness in industrial enterprises. Management and Production Engineering Review, v. 13, n. 3, p. 102-109, 2022. DOI: https://doi.org/10.24425/mper.2022.142387.

LATINO, Maria Elena. A maturity model for assessing the implementation of Industry 5.0 in manufacturing SMEs: learning from theory and practice. Technological Forecasting and Social Change, v. 214, 2025. DOI: https://doi.org/10.1016/j.techfore.2025.124045.

LEITENBAUER, Lena Sophie; SORKO, Sabrina R.; LICHEM-HERZOG, Christof. Bridging the gap to Industry 5.0: comparative analysis of technologies in Industry 4.0 and 5.0 and the evolutionary path of the Smart Production Lab. Tehnicki Glasnik, v. 19, n. 4, p. 539-546, 2025. DOI: https://doi.org/10.31803/tg-20240519112501.

LEÓN, Omar; KANAT, Burak. The human bridge: how the human factor mediates the impact of Industry 4.0 technologies on supply chain resilience in the Industry 5.0 era. IEEE Transactions on

Engineering Management, 2026. DOI: https://doi.org/10.1109/TEM.2026.3670463.

LEÓN, Omar; PUENTE, Javier; FERNANDEZ, Isabel; LUNA, Manuel. Challenges in transitioning from Industry 4.0 to Industry 5.0: a multicriteria analysis. Journal of Industrial Integration and Management, v. 10, n. 1, p. 109-151, 2025. DOI: https://doi.org/10.1142/S2424862224500192.

MARCONI, Marina de Andrade; LAKATOS, Eva Maria. Fundamentos de metodologia científica. 8. ed. São Paulo: Atlas, 2017.

MAURYA, Pankaj; HAZRA, Anindya; KALITA, Anamika. Unleashing the potential of industrial IoT and Industry 5.0. IEEE Engineering Management Review, 2025. DOI: https://doi.org/10.1109/EMR.2025.3644409.

OEIJ, Peter R. A.; LENAERTS, Karolien; DHONDT, Steven; VAN DIJK, Wietse; SCHARTINGER, Doris; SORKO, Sabrina R.; WARHURST, Chris. A conceptual framework for workforce skills for Industry 5.0: implications for research, policy and practice. Journal of Innovation Management, v. 12, n. 1, p. 205-233, 2024. DOI: https://doi.org/10.24840/2183-0606_012.001_0010.

ORAN, İbrahim Bora; AYBOĞA, Mehmet Hanifi; EROL, Mikail; YILDIZ, Gülfer. The necessity of transition from industry 4.0 to industry 5.0: swot analysis of turkey's scm strategy. Journal of Organizational Behavior Research, v. 7, n. 2, p. 1-17, 2022. DOI: https://doi.org/10.51847/vrFR9HDvbh.

PICCAROZZI, Michela; CABONI, Filippo; BRUNI, Renato. Fostering well-being in Industry 5.0 through managerial behaviours and enabling technologies. Technological Forecasting and Social Change, v. 226, 2026. DOI: https://doi.org/10.1016/j.techfore.2026.124600.

PICCAROZZI, Michela; SILVESTRI, Cecilia; ROSSI, Fabrizio; SZOPIK-DEPCZYŃSKA, Katarzyna; IOPPOLO, Giuseppe. Ten years of Industry 4.0 adoption: external and internal perspective in a systemic model towards Industry 5.0. European Journal of Innovation Management, v. 28, n. 6, p. 2630-2660, 2025. DOI: https://doi.org/10.1108/EJIM-12-2023-1099.

PICCAROZZI, Michela; SILVESTRI, Luca; SILVESTRI, Cecilia; RUGGIERI, Alessandra. Roadmap to Industry 5.0: enabling technologies, challenges, and opportunities towards a holistic definition in management studies. Technological Forecasting and Social Change, v. 205, 2024. DOI: https://doi.org/10.1016/j.techfore.2024.123467.

PRODANOV, Cleber Cristiano; FREITAS, Ernani Cesar de. Metodologia do trabalho científico: métodos e técnicas da pesquisa e do trabalho acadêmico. 2. ed. Novo Hamburgo: Feevale, 2013.

RAMOS-GUTIÉRREZ, Sandra; GARCÍA-GUTIÉRREZ, Isabel. Comparison of Industry 4.0, Industry 5.0, and related political initiatives using bibliometric data. Journal of Industrial Engineering and Management, v. 18, n. 2, p. 328-341, 2025. DOI: https://doi.org/10.3926/jiem.8587.

RATAJCZYK, Monika. From traditional packaging to packaging 5.0: redefining the role of packaging in industry 4.0 and industry 5.0. Economics and Environment, v. 94, n. 3, 2025. DOI: https://doi.org/10.34659/eis.2025.94.3.948.

ROBLEK, Vasja; MEŠKO, Maja; KRAPEŽ, Alojz. A complex view of industry 4.0. Sage Open, v. 6, n. 2, p. 1-11, 2016. DOI: https://doi.org/10.1177/2158244016653987.

SAMUELS, Alexander B.; PELSER, Anna-Marie. Transitioning from Industry 4.0 to 5.0: sustainable supply chain management and talent management insights. SA Journal of Human Resource Management, v. 23, 2025. DOI: https://doi.org/10.4102/sajhrm.v23i0.2874.

SARKAR, Bishal Dey; SHARDEO, Vipulesh; DWIVEDI, Ashish; PAMUCAR, Dragan. Digital transition from industry 4.0 to industry 5.0 in smart manufacturing: a framework for sustainable future. Technology in Society, v. 78, 2024. DOI: https://doi.org/10.1016/j.techsoc.2024.102649.

SCHREIBER, Dusan; FROEHLICH, Cristiane; FEIL, Alexandre André; BECKER, Vilson José. Industry 4.0 technologies in a brazilian furniture industry. Revista de Administração da UFSM, v. 17, n. 2, e2, 2024. DOI: https://doi.org/10.5902/1983465974934.

SUNTSOVA, Olesia. The definition of smart economy and digital transformation of business in the concepts industry 4.0 and 5.0. Technology Audit and Production Reserves, v. 4, n. 4, p. 18-23, 2022. DOI: https://doi.org/10.15587/2706-5448.2022.265105.

THOMPSON-BAHM, Heather; TEIXEIRA, Josélia Elvira; LOBO, Rodrigo Cortopassi Goron. Enhancing sustainability and human centricity through emerging technologies from industry 4.0 to industry 5.0: an integrative literature review. Corporate Governance and Sustainability Review, v. 9, n. 3, p. 90-104, 2025. DOI: https://doi.org/10.22495/cgsrv9i3p7.

VUKELIĆ, Željko; CAJNER, Hrvoje; BARIĆ, Gordana. Research model of the degree of technological humanism in manufacturing companies in the transformation towards Industry 5.0. Tehnicki Glasnik, v. 18, n. 3, p. 410-417, 2024. DOI: https://doi.org/10.31803/tg-20240502091110.

YIN, Robert K. Estudo de caso: planejamento e métodos. 5. ed. Porto Alegre: Bookman, 2015.

---

[1] Bacharel em Engenharia de Produção pela Feevale, técnico em Calçado (SENAI) e Contabilidade (IFSUL), Mestrando em Qualidade Ambiental na Universidade Feevale (Bolsista CAPES) e cursando pós-graduação em Docência no IFSUL. ORCID: https://orcid.org/0009-0002-2821-0299 E-mail: acesse o artigo original para visualizar o e-mail

[2] Graduação em Administração pela Universidade Feevale e Técnico em Calçado (SENAI). E-mail: acesse o artigo original para visualizar o e-mail

[3] Curso Superior em Gestão Financeira pela Universidade Feevale. E-mail: acesse o artigo original para visualizar o e-mail

[4] Graduando em Engenharia de Produção pela Universidade Feevale. E-mail: acesse o artigo original para visualizar o e-mail

[5] Doutor em Administração (UFRGS), Mestre e Bacharel em Administração (Unisinos). Professor e pesquisador da Feevale nos programas de Pós-Graduação de Administração, Qualidade Ambiental e Indústria Criativa, e docente na IENH. E-mail: acesse o artigo original para visualizar o e-mail