A Review of Frugal Approaches for Sustainable Productivity Improvement in Manufacturing

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Abstract:

In today's competitive environment under high resource constraints, the manufacturing field has to look into increased productivity and cost minimization as well as minimizing the resource consumption and its impact on the environment. Improvements in productivity through conventional means seem to include the well-respected applications of lean manufacturing philosophies, offering quite modest improvements at rather high investment prices. This global environment gives occasion for some new experiences. Frugality brings an important dimension to productivity, focusing the concept again on doing more with less through efficient use of resources, simplicity, affordability, and contextual innovativeness. This paper, therefore, provides a systematic analysis of frugal methods of improving the manufacturing industry's productivity. A base of a very comprehensive literature review, industrial case studies, a study on benchmark practices engages key principles, applicability fields, and productivity outcomes related to frugal manufacturing. The approach underscores the importance of frugal practices that they dilute the hardness caused by conventional lean tools due to capital, material, energy, and skill constraints, especially in emerging and developing economies. Some significant themes reflected this; they contain cost-efficient process redesign; recycled resources; low-cost automation; localized problem-solving; and workforce-driven innovation. This paper shows that frugal practices are of value to enhancing productivity metrics such as throughput, cycle time, resource utilization, and overall operational efficiency while driving a sustainability and social impact thrust. The review also creates awareness about the gaps in some structured implementation frameworks, measurable performance evaluation criteria, and scaling requirements among different manufacturing sectors for frugal solutions. All in all, this paper would be giving useful insights to researchers and practitioners by consolidating current ideas regarding frugal-driven productivity enhancement, together with the outlines of the future areas of inquiry required for the structured and sustainable frugal manufacturing perspective.

Keywords: *Frugal manufacturing, Productivity improvement, Resource-constrained environment, Lean manufacturing, Cost-effective innovation, Sustainable manufacturing, Industrial efficiency*.

I. INTRODUCTION

Production is very crucial for economic growth, employment and technology spread in both advanced and developing economies. In recent decades this has put an immense amount of pressure on the manufacturing sector to enhance competitiveness while innovating production and reduction of costs and avoidance of resource wastage and pollution at the same time by harmonizing these seemingly divergent goals [1]. Thus, in the last two to three decades, enhancement of productivity has turned out to be the premier and the most important means of competitiveness, profitability and sustenance for any manufacturing outfit [2]. Traditionally, productivity enhancement in manufacturing has been pursued using lean manufacturing tools and techniques: 5S, Kaizen, Total Productive Maintenance (TPM), Value Stream Mapping (VSM), Single Minute Exchange of Die (SMED), Just-in-Time (JIT) and Overall Equipment Effectiveness (OEE)[4]. These tools have been widely accepted and have helped to eliminate much of the waste and improve operating efficiency, but generally, they also call for a major investment in terms of technology enhancement, infrastructure development, training, and overall organizational change. Again, productivity gains achieved via the traditional lean practices are mostly incremental in nature and may not be enough to support the thin-bottomed industries operating in environments with scarce resources [5].

The capacities of manufacturing sectors have been concomitantly facing the constraint of the limited availability of raw materials, escalating energy costs, shrinking skilled manpower, and the environmental regulations and sustainability imperatives [6]. The growing importance of sustainable manufacturing has made it necessary to construct a foundation where economic performance is balanced with environmental responsibility and social impacts. A sustainable solution identifies the adaptive, scalable, and cost-effective routes to improve productivity [7]. The concept of frugal approaches has lately won broad attention from the depth of researchers, practitioners, and policymakers. Frugal approaches promote the principle of "doing more with less" by providing affordable, simple, and productive solutions under many constraints. Instead of capital-intensive technologies or complex systems, a frugal approach means intelligent utilization of resources, simplified processes, regenerative or repurposed use of existing assets, locally rooted problem-solving, employee-driven innovation [8]. The above characteristics make the frugal approach highly relevant to the manufacturing industry in emerging markets, small and medium enterprises (SMEs), and organizations that face severe cost and resource constraints.

Cost-effective manufacturing implies all perspectives of transforming, starting with product designs, processes assist, and administration, even the taking of decisions within the organization [9]. In industrial settings, factory-fresh examples have come to reveal that inexpensive engineering solutions, such as low-cost tool modification, fixture simplification, machinery repurposing, reduced component count, and imaginative process layouts, offer manifold benefits in terms of productivity, quality, throughput time, resources, and efficiency, making these benefits a reality while never stepping-back aesthetics or pleasing the consumer [10]. Frugal approaches, indeed, regularly find reinforcement in sustainability practices due to controlled consumption of material-use efficiencies, energy consumption, waste generation, and carbon footprint [11].

Despite the growing emphasis on frugal manners, the current literature on enterprise wastage elimination arising in the manufacturing sector still remains fragmented; instead, developers have been absorbed by either lean manufacturing or frugal innovation for products, whereas systematic productivity improvement with frugal principles barely gets any interest within professional literature [12]. There have been very few articles painting case application of frugal successfully: however, no comprehensive review integrating all findings is available towards any one point. This could equate to the consolidation of all available literature, thus stressing the presence of common binding principles, outcome performance, and any highlighted research issues toward long-term productivity enhancement through frugal approaches [13].Figure 1 represents Productivity Improvement

Figure 1: Productivity Improvement

According to existing literature, another huge issue that has been largely emphasized is the lack of structured methodologies serving as a tool to implement frugal approaches in manufacturing processes. Many frugal practices and outcomes appear improvised or knowledge-based rather than being framed in some clear, systematic, replicable mode this fact further allows these practices to be scalable, transferable, and well positioned to impact [14]. However, understanding the quantitative improvements in productivity; for example, throughput, cycle-time, cost, quality, and resource utilization made possible through frugal habits, is still grossly underresearched in those studies.

These unused areas develop the need for a comprehensive review of frugal approaches to sustainable productivity improvement in manufacturing [15]. Such a review will assist in the unfolding of frugal existence, applicability or domain, and potential for mopping up the productivity and sustainability concerns. From real-life industrial applications to rigorous empirical studies, these reviews will provide a synthesis of views supported by a variety of studies. Per contra, this will build up comprehensive understanding of how frugal approaches extend and complement more traditional productivity improvement ways [16]. The primary goal for reviewing the document is to critically analyze the given resources regarding frugal approach in manufacturing with a special emphasis upon the usefulness of the same in sustainable productivity improvement [17]. It therefore aims at unveiling the basic principles and themes underpinning frugal manufacturing with their integration into lean and sustainable manufacturing paradigms, towards an investigation on their demonstrated effects on manufacturing performance. Also, the review enunciates the challenges and limitations involved in frugality adoption and sketches out future path-leading to structured, data-supported, and scalable frugal productivity-enhancing frameworks [18].

In this review, by systematizing and identifying gaps in current knowledge, the authors contributed to both academic discourse and industrial practice. This, in turn, provides a solid background for researchers for further exploration into frugal manufacturing methodologies while suggesting practical inputs to the practitioners for enhancing efficiency in those manufacturing setups governed by resource constraints and sustainability mandates. This paper sheds light on the juncture where the frugal ideal stands as an established strategic enabler for sustainable product improvement in the culture of modern manufacturing systems.

II. CONCEPT OF FRUGAL APPROACHES IN MANUFACTURING

The concept of frugal approaches in manufacturing has emerged as a response to increasing resource constraints, cost pressures, and sustainability challenges faced by modern industries. Frugal approaches emphasize the development and implementation of solutions that deliver essential functionality, acceptable quality, and high value at minimal cost by

optimally utilizing available resources[19]. The core philosophy of frugality is based on the principle of "doing more with less," where innovation and productivity improvements are achieved not through heavy capital investment, but through simplicity, creativity, and intelligent use of existing assets [20].

In manufacturing, frugal approaches are rooted in the need to operate efficiently under constrained conditions such as limited capital, restricted access to advanced technologies, scarcity of skilled manpower, energy limitations, and volatile market demand. Unlike traditional manufacturing strategies that often rely on sophisticated automation and expensive infrastructure, frugal manufacturing focuses on affordability, robustness, and practicality [21]. It encourages manufacturers to question conventional design and process assumptions and to eliminate non-essential features, components, and activities that do not contribute directly to customer value or operational performance [22].Figure 2represents frugal approaches in manufacturing

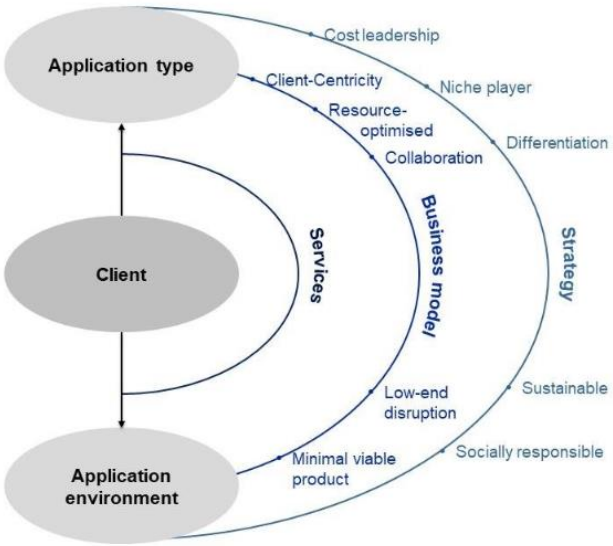

Figure 2: FRUGAL APPROACHES IN MANUFACTURING

Frugal approaches in manufacturing extend beyond product innovation and encompass process design, operations management, maintenance practices, and organizational decision-making. From a process perspective, frugal manufacturing involves simplifying workflows, reducing process complexity, minimizing material usage, and improving resource utilization through low-cost modifications [23]. Examples include redesigning fixtures and tools using locally available materials, modifying existing machines to enhance performance, repurposing old equipment, and reducing setup times through simple mechanical or procedural changes. Such interventions often result in significant productivity gains with minimal financial investment [24].

A defining characteristic of frugal approaches is their strong alignment with sustainability principles. By emphasizing reduced consumption of materials, energy, water, and other resources, frugal manufacturing naturally supports environmental sustainability. Practices such as reuse, recycling, refurbishment, and life extension of machinery help reduce waste and lower the environmental footprint of manufacturing operations [25]. At the same time, frugal approaches contribute to social sustainability by promoting inclusive innovation, skill development, and workforce participation, particularly in small and medium enterprises and emerging economies.

Another important aspect of frugal manufacturing is its customer-centric orientation. Frugal approaches prioritize understanding the actual needs and constraints of end users and designing solutions that are "good enough" to meet functional requirements without unnecessary sophistication [14]. This mindset enables manufacturers to deliver cost-effective products and services that remain competitive in price-sensitive markets while maintaining reliability and performance. In manufacturing operations, this translates into focusing on critical quality attributes, eliminating over-processing, and aligning production capabilities closely with demand.

Frugal approaches also complement and enhance conventional productivity improvement methodologies such as lean manufacturing. While lean focuses primarily on waste elimination and process efficiency, frugal manufacturing adds a resource-conscious and constraint-driven perspective [15]. Frugal approaches encourage innovative problem-solving when lean tools alone are insufficient due to limited resources or financial constraints. In practice, many frugal solutions evolve

as extensions of lean initiatives, where simple, low-cost ideas proposed by shop-floor employees lead to substantial improvements in productivity, quality, delivery, safety, and morale.

The organizational culture plays a crucial role in enabling frugal approaches in manufacturing. A frugal mindset promotes experimentation, learning from failures, and continuous improvement driven by frontline workers. Decision-making is decentralized, allowing teams to develop context-specific solutions rather than relying solely on standardized, top-down interventions [16]. This participative approach not only accelerates problem resolution but also enhances employee engagement and ownership of productivity improvement initiatives. Despite their advantages, frugal approaches are often perceived as informal or ad hoc practices rather than as systematic manufacturing strategies. However, growing evidence from industrial case studies demonstrates that when guided by structured frameworks and performance evaluation metrics, frugal approaches can deliver sustainable productivity improvements comparable to, or even exceeding, those achieved through conventional methods [17]-[18]. As manufacturing industries increasingly operate under constrained and uncertain conditions, frugal approaches are gaining recognition as a viable and strategic pathway toward resilient, efficient, and sustainable manufacturing systems.

III. PRODUCTIVITY IMPROVEMENT AND SUSTAINABILITY IN MANUFACTURING SYSTEMS

Manufacturing systems have tried to enhance their productivity throughout; convenient situations for these processes are the results of higher production costs, competitiveness, and increased profitability. In a more canonical version, productivity denotes the ratio of output to input, conventionally enhanced through higher discharge, reduced input consumption, or both simultaneously; this entirely compresses any hope of profitability out of the normal manufacturing course. Manufacturing entities have long signaled one another in the pursuit of process-based enhancement of productivity linked to resources and work [11]. Until recently, however, the issue of rising productivity underscored purely economic considerations. Only of late, businesses have come to work towards making sustainability also a goal in efforts aimed at maximum output, considering increasing attention towards environment consciousness and corporate social responsibility [12].

When it comes to evaluating sustainability in manufacturing systems, it is resolved around three timeliness: economic sustainability, environmental sustainability, and social sustainability. Economic sustainability is a fundamental depiction of long-term profitability through a focus on a cost reduction, capital utilization, and efficient resources. Hence, the thrust of the discussion of employment in relation to the economy is in the thought of economic sustainability [13]. This would emphasize growth an increase in any sale value through an asset under an economic force. On the other hand, environmental sustainability focuses on minimizing waste generation, reducing energy consumption, reducing emissions, and saving exclusiveness [14]. The other sustainability is social in scope. It is dependent upon people and thus encompasses things like safety, skill development, job satisfaction, and community well-being. Incorporating sustainability with a productivity viewpoint is mandated as a strategic mandate by modern manufacturing systems rather than an antagonistic goal [15].

Some conventional strategies to improve productivity in the factories are lean manufacturing, total quality management, six sigma, automation, and digitalization, with the objective of reducing waste, minimizing variation, presenting better process competence, and increasing efficiency in operation [16]. However, they often require sophisticated infrastructure and skilled manpower, sometimes forcing the user to divert much resource-intensive development. In a party-solving system, the above-mentioned system efficiencies might require investment in the redesigning of dull shapes. Eventually, if not addressed, the application of the labor-cum-profit systems should be targeted for a limited initiative in the resource-scarce or markets dominated by small-medium enterprises in manufacturing. Delivering higher productivity via capital-oriented approaches may sometimes unconsciously give high energy consumption, overuse of materials, tossing of environmental impacts, provided sustainability was not considered [17].

Sustainable manufacturing is creating a renewed focus by using resourcefulness and an ecologically sound ethos for productivity improvement. The implementation of good practices whereby resources can be made efficient or conserved is one base value of sustainable manufacturing. The implementation includes the design of energy-efficient processes, the minimization of materials with its re-use and recycling, eco-designing, and life-cycle assessment [18]. Most importantly, it is worth noting that productivity enhancement and sustainability are not on parallel tracks but, influenced as compost. Why? It is the case that materials' waste and energy loss go as far as exerting pressure on the productivity output; for example, feeding into the per-unit cost of the input.

Manufacturing systems are increasingly recognizing that sustainable productivity improvement needs systemic learning, rather than piecemeal intervention. Interactions among machines, processes, materials, energy, and human resources need to be optimized, taking into account the entire product lifecycle. One important aspect of sustainable productivity improvement is indeed linked to continuous improvement, adaptability, and resilience when faced with market uncertainty, regulatory pressures, and resource scarcity [19]. Another element of sustainable productivity improvement is the measurement of performance. Currently, traditional metrics of productivity (such as throughput, lead time, and labor productivity) are now being complemented with sustainability indicators, including energy intensity, material efficiency,

carbon emissions, and waste reduction. When combined with sustainable indicators, the measurement proliferation exposes manufacturing firms to choosing from clefts in one direction or another [20] economic performance or social/environmental responsibility. Viewing metrics of productivity in continuum, it is apparent that there is so much left to be tackled in the formal categorisation of standards to be developed for these practices of productive sustainability.

The modernization of manufacturing paradigms such as the circular economy, green manufacturing, and smart manufacturing further underscores the merging of productivity and sustainability objectives. Essentially, these paradigms aim to promote closed-loop material flows, bettered resource use, and data-driven decision-making for enhancing operational performance while reducing impacts on the environment [21]-[22]. However, the integration of these paradigms is constrained by prevailing barriers to cost, high-tech Illumination toutomation, and readiness for operational acceptance.

IV. FRUGAL APPROACHES FOR PRODUCTIVITY IMPROVEMENT

The importance of frugal innovation is broadly appreciated in debates involving organizations, institutions, and societies that strive to spawn value in the context of economic, environmental, and technological limitations. If high-tech frugal innovation undermines the principle of some costly, highly technical amelioration, the former must enhance the relationship between simplicity, affordability, and artistic reconfiguration of existing resources for efficient performance. Higher education considers frugal ideas an instrument not only for fostering institutional rejuvenation but also for fostering adaptive strategies that might help ensure that universities scale up quality education, even amid funding or resources shortages [1]. The rapidly growing relationship between digitalization and frugality underscores that technology not only reduces overhead expenses but also helps drive creativity, providing a foundation for inclusive and scalable solutions for both developed and developing countries [2]. In the African context, frugal innovation is posited perhaps more as a set of strategies for economic purposes rather than as a means of inclusive and sustainable development, serving marginalized populations, and engendering wider societal change [3].

There is a sizeable body of literature that supports the idea of technological frugality and that highlights the extent to which organizations and establishments make use of minimally equipped platforms to stay competitive and improve operational efficiencies in the process [4]. The balance between exploration and exploitation appears crucial in such a context, as companies that balance out flexibility and discipline have been seen to deliver amazing ESG benefits from frugal ways. Leadership is with this core. Research papers hold that inclusive leadership practice of bricolage, experimentation, and plant themselves with knowledge diversity can co-create such grounds where frugal innovation meets, collaborates or marries action equality. At the operational level, managerial action chains empirical; entrepreneurially oriented organizations are predis-posed to providing a solid groundwork for generating new, frugal solutions that influence organizational performance.

These findings strongly stress the fact that frugal innovation is not mere cost-cutting exercise but a culture-and strategy-driven mindset indeed supported by leadership and learning abilities.

Frugal innovation extends to other sectors, from environmental monitoring to agriculture and robotics, thus exemplifying its cross-disciplinary relevance. Frugal designs in the act of monitoring grazing pressure in mountain ecosystems offer useful environmental information, even within the reach of individuals facing resource scarcity [9]. In the context of budgeting, researchers give more precedence to the ability of organizational control systems in urging for a balancing act between budget constraints, creativity, and clear goal setting. Hence, due to such effects of budgeting as diagnostic and constructive rather than only restrictive, it nurtures creativity and innovation while putting a positive light on them [10]. Thus, knowledge-sharing emerges as a great driver: inclusive leadership and competitive pressures for teams to share their knowledge in favor of practical yet inexpensive innovations within firms [11]. Building on this, it is inferred from technological research that efficient computer models, here the lightweight diffusion architectures and resource-optimized large language models, offer expected high performance-in-effect with less computing power; in other words, they exemplify in the most advanced digital contexts the genius of frugal innovation [12,13,14].

Hierarchical modeling deals with other variables onstage such as environment types, behaviors prevalent in new project-based organizations, decision-making policies, and systems as well as theories to explain their prospect on the business environment. Briefly, fast and frugal heuristics offer validation to reduce the uncertainty and risk inherent in varying environments that may not respect the exigencies of thorough analysis within stable uncertainty or dynamic project environment. This insight surfaces easily, in places the disciplines of engineering and agriculture offer faint support for evidence that simple strategies are having superior functions in other instances while complex designs. Indeed, frugal products are not only functional but also sophisticated-from the known range of lean management-a powerful angle to advocate against waste from scrap and promptability. This is more so since quit simply the elementary day-to day operation is directly under the duress for lowering waste, recycling materials, and integrating environmental perspective into production processes. This likelihood for action through competing models while frugal is more like the reconsideration of going green by a proactive response to avoid resource wastage. Yet, applications of frugality parallel the efficiency for economical gain.

V. INTEGRATION OF FRUGAL PRACTICES WITH LEAN AND SUSTAINABLE MANUFACTURING

Consumer-focused research further delineates frugal innovation as an outcome of the rising global consciousness around responsible consumption and sustainability preferences [20]. Lean environment and innovation culture influence the environmental practices of manufacturing companies like food processing. A new aspect of the sustainable production paradigm can only emerge when there is complete openness toward trying new ideas and running a series of experiments [21]. Ergonomics and human factors contribute to frugal pathways in efficient, safe, and worker-oriented manufacturing processes that are sustainable over the long term [22]. Meanwhile, companies have barriers in applying smart sustainable manufacturing, while dealing with decision-making processes that are in place to aid in prioritizing strategies through the right fusion of frugal beliefs matching soft and hard digital transformation objectives [23]. The impetus from green industrial manufacturing experimentation further adds a guiding light towards an appropriate action path, showing how companies design operational processes that reduce their environmental footprints while yet staying apace of this competitive trade [24].

Frugal innovation has a social dimension in the context of rural and inclusive development research. Frugal strategies benefit rural transformation by providing access to affordable technologies, entrepreneurial potentials, and valuable social services, which otherwise would have been difficult to access. Industry 4.0 literature confers new meaning to the use of green information systems and knowledge-driven decision architecture for optimized sustainability of the manufacturing system. In the digital innovation cycle, it advocates a new environmental discipline. Green practices in manufacturing have shown to improve sustainable performance of SMEs - provided the company is looking for additional innovation capabilities [27]. Hence the linkage between frugal innovation and knowledge-intensive business, which could signal a more human perspective of development in the emerging regions by showing that frugal solutions could empower human beings and foster economic growth [28]. The performance in doing business has gained new life once again with modern, frugal, and digital tools being positioned in such business structures. Not only do the tools favor well, but they strengthen existing advantage through ongoing improvement systems [29]. All together, thoroughly deliberating on Lean, Six Sigma, and all throughout the range of continuous improvement models, the growing tendency mirrors to show that principles of efficiency do meet up magnificently ESG performance expectations, thus bonding frugality, efficiency, and forward-thinking businesses into one and the same strategic agenda [30].

Table 1: Overview of Key Studies Linking Frugal Innovation, Digitalization, and Sustainable Development

Ref	Domain	Methodology	Focus	Key Variables	Major Findings
[1]	Higher Education	Conceptual / Case Insights	Institutional renewal through frugality	Resource efficiency, transformation	Frugal innovation supports adaptive academic systems.
[2]	Innovation & Digitalization	Conceptual Analysis	Digitalisation–frugality relationship	Digital tools, cost efficiency	Digitalisation creates scalable frugal innovation pathways.
[3]	African Development	Policy/Conceptual	Inclusive & sustainable development	Social inclusion, innovation access	Frugal innovation supports community transformation.
[4]	Organizational Performance	Case/Conceptual	Frugal disruptive technologies	Digital tools, competitiveness	Enhances sustainable competitive advantage.
[5]	Entrepreneurial Firms	Empirical	Ambidexterity & ESG	Exploration, exploitation, ESG	Ambidexterity improves ESG via frugal innovation.
[6]	Leadership & Sustainability	Empirical	Frugal innovation drivers	Leadership, bricolage, knowledge diversity	Leadership shapes sustainable frugal practices.
[7]	Firm Performance	Empirical	Managerial proactiveness	Innovation, proactiveness	Proactiveness strengthens frugal innovation outcomes.
[8]	Organizational Learning	Empirical	Learning capability & entrepreneurship	Innovation capability	Learning orientation enhances operational performance.

[9]	Ecosystem Monitoring	Field Application	Frugal tracking technology	Grazing indicators, monitoring	Low-cost tools support environment management.
[10]	Management Control	Empirical	Budget use & creativity tension	Diagnostic budgets	Proper budget controls encourage creativity.
[11]	Knowledge Management	Empirical	Knowledge sharing for innovation	Inclusiveness, competition	Leadership builds knowledge-sharing culture.
[12]	AI / Diffusion Models	Technical	Algorithm design	Efficiency, speed, accuracy	Achieves strong performance with lower cost.
[13]	Large Language Models	System Development	Serving framework optimization	Latency, computational cost	Enables resource-frugal AI deployment.
[14]	Computer Vision	Model Development	Cheap high-resolution scaling	Self-cascade diffusion	Demonstrates cost-efficient high-resolution outputs.
[15]	Project Uncertainty	Conceptual/Framework	Fast-and-frugal heuristics	Risk, uncertainty	Simple heuristics improve decision quality.
[16]	Production Planning	Conceptual	Rework assessment heuristics	Uncertainty, rework	Supports adaptive decision toolkits.
[17]	Agricultural Robotics	Experimental	LQR optimization	Robot performance	Efficient control improves agricultural operations.
[18]	Sustainable Manufacturing	Conceptual Review	Lean + circular economy	Waste reduction, reuse	Integration advances sustainability performance.
[19]	Industrial Operations	Review	Lean + sustainability	Eco-efficiency	Improves both cost and environmental outcomes.
[20]	Consumer Behavior	Conceptual	Conscious consumption links	Sustainability, frugality	Aligns frugality with modern consumer expectations.

VI. IMPACT OF FRUGAL APPROACHES ON MANUFACTURING PERFORMANCE

Frugal manufacturing involves getting more by using less resources through simplified processes, and aesthetically affordable products and system design without a compromise in functionality. With the higher manufacturing cost, environmental regulations, and global competition facing the industry, such practices are showing significant benefits to the performance of manufacturing [21]. Frugal strategies add value to an organization by developing into enhanced production flows, less material wastage, new, leaner process designs, shorter cycle times, lesser defect rates, and enhanced operational efficiency; focusing on product value rather than consuming resources in technical advancements for drawing up items fulfilling basic needs within a low cost and broad-market penetration, especially in resource-constrained settings. Additionally, frugality also promotes resilience through support for modular design, local sourcing, and simplified maintenance, reducing a business's reliance on the extensive and cumbersome supply-chain structure and costly technologies [22].

Regarding sustainability aspects, frugality, unlike green manufacturing principles, may embody energy efficiency, recyclability, and circular economy creations. The use of frugal approach may even trigger environmental performance improvements in terms of fuel gas emissions, rejections, and overproduction. Organizational decisions towards that thinking favor the culture of continuous improvement, which improves problem-solving. Employees are then encouraged to innovate through internally available resources, rather than hang all hope on the halo of expensive technology upgrades [23]. This approach, assuming high potential for learning, engagement, and cross-functional experimentation, nurtures the ecosystem of innovation itself. A benefit that should be considered in the list is the advantage of improving financial performance through a minimum expenditure of money on capital, effective asset utilization, and the promotion of competitive-cost pricing mechanisms.

Nevertheless, such benefits are not confined to the economic realm. Frugal manufacturing methods can create social value by providing low-cost products, and have been able to ensure the broadest public access to technological and essential goods. Often, even under resourced conditions, there can be a source of local entrepreneurship and employment creation, with the building of capacities for sustainable industrial growth. Yet, the implementation of the frugal approach is fraught with the necessity for the subtlest of balancing acts because excessive cost cutting with no strategic alignment may affect quality or the potential for long-term innovation [24]. The viable implementation of such approaches will highly rely on the commitment of leadership, disciplined processes, and integration with the organization's broader goals. Therefore, evidence highlights that the application of frugal pathways concerning build-up of the manufacturing competence span to both the front and back ends of performance, environment, finance, and social sectors for a competitive edge toward achieving sustainable development objectives [25].

VII. CONCLUSION AND FUTURE WORK

This review highlights that frugal approaches have evolved from cost-reduction tactics into a comprehensive strategic philosophy that integrates efficiency, innovation, and sustainability. Frugal innovation focuses on innovating products, processes, and systems to create substantial value with fewer resources while still being functional and reliable. Proofs show that when frugal strategies apply to an organization, such a practice brings operational efficiencies along with decreased production costs and a better environmental footprint for enhanced market access, especially in lean contexts or emerging market settings. Leadership, organizational learning, and knowledge sharing have underscored themselves as the key foundation stones, followed by digitalization and lean thinking providing a necessary platform to amplify the effect of frugal practices.For starters, frugality does not equate to wholesale cutting short of cost, lest misaligned initiatives jeopardize the quality, depth of innovation, and long-term competitiveness. Here again, successful execution marks a fine balance between affordability, performance, and sustainability, made possible only through a strong foresight strategy, genuinely engaged employees and data-laced decisions. Therein lies the challenge for derailing the possibility of win-win indicators for frugality. Further, the growing link between frugal innovation, ESG outcomes, and the principles of the circular economy shows that frugal approaches can generate value outside of the firm-environmental care and inclusive development. Further researches could try to harden these empirical proofs in different industries; sample the synergies between digital and frugal systems, and analyze the long-term consequences on competitiveness and societal well-being. The embedding of this thus as some of its new design solutions into practice. Operations, established practices, and opportunities will assist firms in the acquisition of a sustainable level of performance in reaction to greater goals of development.

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