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Additive manufacturing, 3D printing, and supply chain optimization in the commercial industry: an analysis of design for manufacturing and productive repatriation.

Additive manufacturing, 3D printing, and supply chain optimization in the commercial industry: an analysis of design for manufacturing and industrial reshoring

Additive manufacturing, 3D printing and optimization of the supply chain in the commercial industry: a design analysis for manufacturing and production repatriation

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Summary

This article analyzes the application of additive manufacturing and 3D printing technology as strategic tools for product optimization and supply chain resilience in the industrial and commercial sectors. Based on literature from industrial design, production engineering, and lean manufacturing , the study investigates how Design for Manufacturing and Assembly (DFMA) and rapid prototyping reduce product *lead time* and minimize dependence on external suppliers. The transition from centralized mass production to on-demand distributed manufacturing is discussed, evaluating the impacts of production repatriation *(reshoring)* on reducing logistics costs and strengthening industrial competitiveness.

Keywords: Additive manufacturing. 3D printing. Product design. Supply chain. Productive repatriation.

Abstract

This article analyzes the application of additive manufacturing and 3D printing technology as strategic tools for product optimization and supply chain resilience within the industrial and commercial sectors. Grounded in industrial design literature, production engineering, and lean manufacturing, the study investigates how Design for Manufacture and Assembly (DFMA) and rapid prototyping reduce product lead times and minimize reliance on external suppliers. It discusses the transition from centralized mass production to localized on-demand manufacturing, evaluating the impacts of industrial reshoring on logistics cost reduction and the enhancement of manufacturing competitiveness.
Keywords: Additive manufacturing. 3D printing. Product design. Supply chain. Industrial reshoring.

Introduction

The reconfiguration of global manufacturing in the Industry 4.0 era demands a transformation from the field of design.

industrial proposals for more flexible, decentralized, and efficient production solutions.

As Gibson, Rosen, and Stucker (2015) point out, additive manufacturing, popularly known as

Known as 3D printing, it has transcended its historical application limited to prototyping.

quickly establishing itself as a direct manufacturing technology for end components and

Industrial tooling. In the contemporary commercial context, the vulnerability of supply chains.

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Global supply disruptions and rising international freight costs necessitate...
Replace concentrated production models with local, on-demand manufacturing networks.
Developing products for commercial and hospitality ecosystems requires
Functional components, modular fixtures, and ergonomic enclosures capable of withstanding heavy-duty use.
Maintaining a high aesthetic standard. The use of traditional plastic injection molding methods.
Alternatively, subtractive machining imposes long mold manufacturing times and batch requirements.
Extremely high minimum production levels. The mismatch between product design and the
The production process results in capital being tied up in inventory and an inability to...
Respond quickly to changes in market demand.
This article aims to discuss the theoretical foundations of design for manufacturing.
additive, relying on consolidated theoretical frameworks from engineering and design of
product. Through the systematic analysis of the principles of complex geometry, consolidation
Regarding assembly and distributed manufacturing, the aim is to demonstrate that intelligent design combined
3D printing acts as the primary driver for shortening the development cycle.
of products and for the drastic reduction of logistical risks in modern industry.

Methodology

The methodological approach adopted in this study is based on a literature review.
systematic and descriptive analysis of industrial design models applied to manufacturing
additive, a structure recommended by Ashby (2011) for the selection of materials and processes
in the design of new products. Data collection is based on technical manuals of
polymer technology, manufacturing system specifications by modeling
Fused deposition (FDM) and selective laser sintering (SLS), in addition to academic literature.
in production engineering.
The analysis considers operational parameters of additive manufacturing, such as surface roughness.
surface, structural anisotropy, *infill* orientation , printing time and
cost of materials per unit produced. These variables were correlated with concepts
theoretical frameworks developed by authors such as Boothroyd, Dewhurst and Knight (2010), Womack and
Jones (2003) and Hopkinson, Hague and Dickens (2006), who investigate design for manufacturing,
Lean thinking and rapid additive manufacturing.
Additionally, the methodology assesses the economic and environmental impact of repatriation.
Production *(reshoring)* through local microfactories. The substitution of transport is examined.
Marine-grade finished parts manufactured through digital transfer of CAD files and printing under

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Demand close to the point of consumption, validating how manufacturing-focused design works.
Additives reduce the carbon footprint and eliminate waste in the supply chain.

Chapter 1: Fundamentals of Design for Additive Manufacturing and Consolidation Components

Product design geared towards additive manufacturing requires a fundamental shift in...
traditional engineering and design paradigms. According to Gibson, Rosen, and Stucker (2015), the
Design for Additive Manufacturing (DfAM) liberates the
designer of the constraints imposed by subtractive tools or rigid molds, allowing the
creation of complex geometries and lightweight cellular structures without corresponding increase in size.
in manufacturing costs. Freedom of form allows for optimizing the functionality of the part.
directly in the three-dimensional modeling phase.
The consolidation of assemblies is one of the greatest economic and technical advantages of DfAM.
According to the principles formulated by Boothroyd, Dewhurst and Knight (2010), the reduction
Reducing the number of parts in a set simplifies the assembly process and eliminates points of...
Failure due to mechanical fastening (such as screws and welds) reduces management costs.
Inventory. In additive manufacturing, complex assemblies containing joints, hinges, and...
Internal cooling channels can be printed as a single functional component.
pre-assembled *(print-in-place).*
Topological optimization represents the advanced mathematical application of DfAM for reduction.
of mass. Using computational algorithms to redistribute the material strictly to
Along the lines of mechanical stress, significantly lighter parts are obtained that maintain
or increase the necessary structural strength. This reduction in material volume translates to
directly resulting in shorter printing times, lower energy consumption, and reduced costs.
raw material.
In addition to geometric optimization, DfAM requires consideration of the physical variables of the process.
printing requirements, such as part orientation on the build table, and the need for structures.
support and direction of mechanical stresses in relation to the coupling between layers. The correct
Planning the slicing process *prevents* delamination and ensures accuracy.
dimensional requirements for utilitarian parts intended for intensive commercial use.
It can be concluded that the DfAM domain is the element that transforms 3D printing from a...
A prototyping tool in a viable industrial production system. The intelligence
When applied in design, it reduces material consumption and optimizes the mechanical performance of...

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products, laying the foundation for the creation of highly efficient commercial components and low cost.

Chapter 2: Supply Chain Resilience and the Transition to Manufacturing Distributed

The fragility of global supply networks, evidenced by geopolitical shocks and Increases in international freight costs have made it necessary to restructure the model. centralized production. As analyzed by Hopkinson, Hague and Dickens (2006), the transition from a centralized and distant manufacturing model to a distributed manufacturing network and localized technology redefines industrial logistics, allowing products to be manufactured under... Demand at the exact location and time of your business need.

Distributed manufacturing relies on the digital storage of three-dimensional models in Replacing physical inventories of spare parts. The concept of "digital inventory" allows companies to maintain product and component catalogs on servers. Secure cloud, sending machine code files directly to 3D printers. installed regionally. This approach eliminates the need for large parts warehouses. It replenishes stock and prevents losses due to inventory obsolescence. Eliminating international shipping *lead times* represents an advantage. A decisive competitive advantage for the retail and hospitality sectors. The ability to produce Locally source replacement fixtures, ergonomic supports, and functional accessories. Customized solutions reduce downtime for commercial facilities from weeks to just a few. hours. The agility in meeting specific operational demands protects the Business continuity and raises the standard of service to the end customer. Furthermore, local additive manufacturing enables sustainable production aligned with the principles. of lean thinking *(lean manufacturing).* As Womack and Jones (2003) teach, the Waste must be eliminated from all stages of the value stream. Manufacture only what you need. exact quantity of parts requested, using only the material necessary for the The formation of the object eliminates waste generated by overproduction and storage. prolonged.

Therefore, on-demand distributed manufacturing is a highly resilient strategic model for Modern industry. The union between industrial design focused on rapid manufacturing and Local 3D printing infrastructure strengthens regional productive sovereignty and protects the Corporations are fighting against disruptions and unpredictable costs of international logistics.

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Chapter 3: Rapid Prototyping, Functional Validation, and the Product Development Cycle Products

The speed at which a new product evolves from abstract concept to commercial validation.
In the market, it is a primary indicator of competitiveness in the industrial ecosystem. According to
Ulrich and Eppinger (2012) argue that the traditional product development cycle faces bottlenecks.
severe challenges arose during the physical prototyping phase, where the need to outsource models became apparent.
Conceptual issues generate delays and increase development costs. The integration of prototyping
Rapid 3D printing-based technology accelerates design iterations and reduces launch risks.
Performing rapid physical iterations allows designers and engineers to test and refine.
Ergonomics, usability, and the assembly of functional sets directly in the initial phase.
of the project. The ability to print multiple models in just a few hours makes it possible to
conducting grip tests, assembly with electronic components, and aesthetic validation before
freezing the final geometry of the product. Early identification of design flaws.
It avoids costly changes in advanced stages of production.
Functional prototyping extends to testing the mechanical and strength properties of...
materials in real-world conditions of use. The use of advanced technical polymers, such as
polycarbonate, nylon, and carbon fiber reinforced composites in 3D printers.
Industrial quality allows for the manufacture of prototypes with similar physical properties.
to those of mass-produced parts. These functional prototypes can be subjected to
Tensile, impact, and thermal fatigue tests in the customer's own commercial environment.
The bridge between prototyping and low-volume production is efficiently filled by...
additive manufacturing. For niche commercial products or limited editions, the cost of
Manufacturing an injection mold makes the operation unfeasible. The use of 3D printing
For the direct production of initial batches *(bridge manufacturing),* it enables acceptance testing of
market with minimal initial investment, allowing for immediate revenue generation while
The product's scale is evaluated.
It is concluded that rapid prototyping and continuous functional validation redefine the dynamics.
Innovation in the product industry. Reducing the cycle time between idea and product.
Physical technology gives companies the agility needed to lead their segments, launching
Innovative, high-quality solutions with controlled financial risks.

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Chapter 4: Enclosure Design for IoT and Technology Integration in Environments Commercials

The proliferation of Internet of Things (IoT) devices and intelligent automation systems.
In commercial buildings and hospitality establishments, the need for building envelopes has been imposed.
functional elements that protect the technology and integrate harmoniously into the environment.
architectural. As analyzed by Norman (2013), product design focused on interaction
Humans must balance functional clarity with perceptual aesthetics, ensuring that the object
It should be intuitive to use and visually pleasing in the space where it is placed.
The design of enclosures *for* smart devices requires careful consideration.
restrictions on heat dissipation, sealing against moisture and dust, and signal interference.
radio frequency (Wi-Fi, Bluetooth and Zigbee). The selection of polymeric materials with
suitable dielectric constants and the inclusion of ventilation grilles designed directly
The CAD model ensures that the enclosure protects the internal electronics without compromising the...
Wireless communication or causing overheating of the circuits.
The aesthetic and structural customization of packaging for commercial brands represents a
A key differentiating factor in the hospitality market: the manufacturing of boxes and supports.
For sensors, additive manufacturing allows for customization of the shape, color, and texture of the...
The product adapts to the visual identity of hotels, restaurants, and themed spaces. The absence of limitations.
Using standardized molds allows for the creation of unique solutions for each project.
Interiors without the prohibitive cost of traditional customization.
The durability and ease of maintenance of commercial enclosures require detailed planning.
of efficient locking and mounting systems. The use of *snap-fit closures,* threads
Direct to polymers or heat-knurled metal inserts in the printed casing.
ensures that technicians can access the internal electronic components to replace batteries or
Quick maintenance without damaging the product's external structure.
Therefore, the industrial design of IoT enclosures in additive manufacturing is the bridge that connects
Technology invisible to the user's physical experience. The ability to produce protections.
Customized, durable, and aesthetically refined solutions enhance the perceived value of the products.
Automation consolidates design as a fundamental element in the modernization of spaces.
commercial.

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Chapter 5: Production Cost Analysis, Economic Feasibility, and Break-Even Point in DfAM

Assessing the financial viability of transitioning from traditional manufacturing to plastic injection molding. For direct additive manufacturing, the basis is the precise determination of the equilibrium point. economic *(crossover point).* According to Christensen (1997), the replacement of technologies Consolidated by new manufacturing methods, a rigorous analysis of the Total Cost of Total Cost of Ownership (TCO), which includes not only the direct costs of raw materials, but also the Elimination of initial capital investments *(CAPEX)* in industrial tools and molds.

The additive manufacturing cost model presents a virtually unbalanced unit cost curve. constant in relation to production volume, unlike injection molding, which requires Amortization of high initial mold costs. The cost per unit produced in 3D printing. *Ctotal* can be formally modeled by the relation:

$$C_{total} = C_{material} + \left(\frac{C_{maquina} + C_{energia}}{t_{impressao}} \right) + C_{pos-processamento}$$

Where *Cmaterial* represents the cost of the polymer consumed, *and Cmaquina* the depreciation of the Equipment per hour, *printing time* total execution time and *post-processing* costs finishing. The absence of a fixed tool amortization term allows batches small and medium-sized (from 1 to 5,000 units) offer an unbeatable unit cost in compared to traditional methods.

Reducing indirect costs associated with logistics and warehousing consolidates the advantage. Financial implications of DfAM in commercial ecosystems. The opportunity cost of idle capital. Inventory issues and losses resulting from the disposal of obsolete parts are eliminated in this model. Production on demand. The flexibility to change the product design in the software without Incurring the costs of remaking molds drastically reduces financial risk in Launch of new commercial product lines.

However, the feasibility analysis must consider the limitations of production speed in large scale and the requirement for manual post-processing in certain technologies of Printing. For massive production volumes (above tens of thousands of units). (identical), injection molding continues to offer lower unit costs. The paper The industrial designer's task is to identify the volumetric transition zone in which additive manufacturing It offers maximum financial efficiency for the client.

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It is concluded that the economic decision to adopt additive manufacturing should be based on a
A comprehensive financial diagnosis that considers the entire product lifecycle. The intelligence of
Design applied to mass reduction and component consolidation shifts the point of
The balance favors 3D printing, transforming local on-demand manufacturing into a
A strategy focused on high profitability and asset efficiency.

Chapter 6: Technical Training and Knowledge Transfer in Design
Industrial

The consolidation of additive manufacturing as a pillar of modern industry depends strictly on...
from the training of qualified professionals and the dissemination of technical knowledge.
in industrial design. As theorized by Nonaka and Takeuchi (1995), sustainable innovation
In organizations, this requires converting the tacit knowledge of experts into knowledge.
Explicitly codified in manuals, training programs, and design methodologies.
reproducible by the technical team and partner institutions.
Organizing professional seminars, slicing workshops, and modeling workshops.
CAD focused on DfAM is the primary means of enabling the industrial workforce.
knowledge transfer regarding polymer selection, post-processing techniques and
Slicing optimization empowers designers, engineers, and operators to utilize the technology.
3D printing at its full productive potential, overcoming classic orientation errors and
parameterization.
The integration between academic knowledge and the real demands of the productive market strengthens the
Regional innovation capacity. The implementation of university extension activities, examination boards.
The evaluation of projects and technical lectures brings design and engineering students closer together.
of the problems of the manufacturing industry. This exchange of experiences revitalizes the university.
with real demands and provides companies with qualified professionals ready to operate
advanced manufacturing technologies.
The creation of educational booklets, guides for the practical application of materials, and databases.
The formal print parameterization process outlines the design studio's work methodology.
Standardization of technical language and product validation steps ensures that new
Teams replicate the company's quality standards, facilitating the expansion of operations and
The provision of consulting services on a large scale.
In short, investing in technical education and the transfer of design methodologies is...
A commitment to social responsibility and economic development. Democratization.

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Knowledge in additive manufacturing strengthens the local industrial fabric and stimulates... technological entrepreneurship and accelerates the adoption of efficient production practices and sustainable throughout society.

Final Considerations

The research presented throughout this article shows that additive manufacturing and... 3D printing technology has redefined the practice of industrial design and the organization of global supply chains. Research shows that the ability to integrate Design For Additive Manufacturing (DfAM), from the initial stages of product design, it is the element that transforms 3D printing from a simple prototyping tool into a system of Highly efficient, flexible, and cost-effective direct manufacturing for products commercial.

Overcoming supply chain bottlenecks through productive repatriation. *(reshoring)* and the adoption of the distributed manufacturing model reveals itself as a strategy Essential for corporate resilience. Replacing the transportation of physical parts with Cloud-based digital storage and on-demand local printing eliminate shipping costs. international shipping drastically reduces delivery times and protects companies against shutdowns and fluctuations in the external market.

The study reinforces the relevance of rapid prototyping and continuous functional validation in Shortening the new product development cycle. The ability to perform Rapid physical iterations and testing technical materials under real-world conditions minimize risks. launch financing and ensures the delivery of functional parts, IoT enclosures and High-quality and durable commercial fixtures.

Quantitative analysis of production costs and determination of the economic break-even point. This demonstrates that the elimination of industrial molds gives additive manufacturing an advantage. Unbeatable financial advantage for small and medium-sized plots. Topological optimization and mass reduction. Designed by the designer, these projects push the boundaries of economic viability, consolidating the 3D printing as a high ROI solution.

Furthermore, the design is geared towards integrating automation technologies and enclosures for IoT in commercial environments confirms the role of the product designer as the facilitator between Electronic functionality and architectural aesthetics. The flexibility of additive manufacturing. It allows the production of customized, high-value-added solutions without the prohibitive cost of traditional industrial molds.

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Furthermore, the dissemination of design methodologies and the transfer of technical knowledge.
through professional training and academic partnerships, they ensure the continuity of
Good practices and the empowerment of the local workforce. Educating designers and engineers in
Advanced DfAM techniques strengthen the productive ecosystem and accelerate the transition to...
Traditional industry towards digital and sustainable production models.

It can be concluded that technical rigor and a systemic vision in the application of product design are the
Tools capable of connecting technology to the real economy. Continued investment in
Project optimization, materials development, and personnel training ensures that
Operational efficiency in industry, reduces environmental impacts and drives development.
socioeconomic in a lasting way.

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