Additive Manufacturing Awareness for Engineering Education in France

Rima A. Hleiss[1,*], Hiba B. Naccache[2], Hery C. Andriankaja[1], and Jean-Daniel Penot[1]

[1]LINEACT, CESI Graduate School of Engineering, Nanterre, France
[2]Department of Educational Science, Faculty of Education, Qatar University, Doha, Qatar
Email: rhleiss@cesi.fr (R.A.H.); hnaccache@qu.edu.qa (H.B.N.); handriankaja@cesi.fr (H.C.A.); jpenot@cesi.fr (J.D.P)
*Corresponding author

Manuscript received September 20, 2024; accepted December 14, 2024; published April 25, 2025.

***Abstract*—Additive Manufacturing (AM) is one of the pillars of the Industry 4.0. Compared to traditional manufacturing, AM is a layer-by-layer construction; it provides a prototype before producing in order to optimize the design and avoid the stock market and uses strictly necessary material, which can be recyclable, at the benefit of leaning towards local production, saving money, time and resources. Different processes of AM exist and it has a broad range of applications across several industries like aerospace, automotive, medicine, education and else. In the industry 4.0 and aligned with the numbers 9 (Industry, Innovation and Infrastructure) and 12 (Responsible Production and Consumption) of the Sustainable Development Goals of the UNESCO 2030 Agenda, AM's manufacturers committed to minimize the environmental impacts by being sustainable in every production. AM has several environmental advantages, like reduced waste production, lower energy consumption, and greater flexibility in creating components with lightweight and complex geometries. However, additive manufacturing also has environmental drawbacks, like energy consumption, gas consumption and emissions. It is critical to recognize the environmental impacts of AM in order to mitigate them. To increase awareness and promote sustainable practices regarding AM, the researchers use the Elaboration Likelihood Model theory where people process information in two ways: peripherally and centrally. The peripheral campaigns use superficial cues to get attention, and the central campaigns provide clear and concise information. The authors created a seminar including video showing experts' interviews on AM. The data is collected using questionnaire to test attitude about the public awareness before and after the seminar. The results reflected a great shift on the awareness toward AM and its impacts on the environment. With no presence of similar research, this study will add to the literature the human perception of the sustainability of additive manufacturing.**

***Keywords*—additive manufacturing, elaboration likelihood model theory, sustainable development goals, education, awareness, engineering students in France, energy consumption, environmental impact, lightweight components**

I. Introduction

Additive manufacturing is an industrial production process that creates layer-by-layer objects in three-dimension as shown in Fig. 1, thanks to precise geometric shapes.

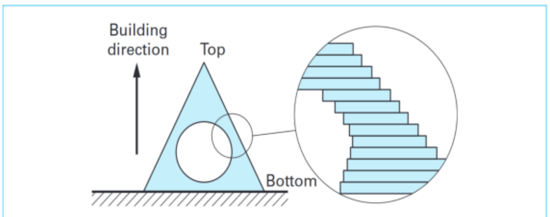

Fig. 1. Layer-by-layer material deposition, principle of additive manufacturing [1].

Additive manufacturing has experienced an enormous evolution in the recent years due to its speed, precision and saving, in material and time. This technology revolutionized the way objects are manufacturing, it is thus been a core sector in the fourth industrial revolution also known as Industry 4.0 [2]. Through the time, the industry had experienced four essential revolutions as depicted by Fig. 2.

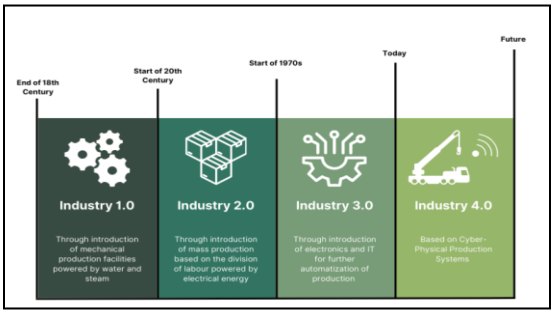

Fig. 2. The four industrial revolutions from the mechanization to the digitalization era.

The power of the fourth industrial revolution comes from adding advanced production and operations techniques to digital technologies to create connected enterprises that use data to drive intelligent actions in the physical world. With smart manufacturing, all industries seek to boost their productivity while trying, at the same time, to minimize the waste of production, respecting the concept of Lean Production and having the ability to deal with the quick change of customer demands.

Modern AM technologies enable to manufacture products from various materials, such as metals, polymers, ceramics and composites. Among them, the metal AM has shown the most significant impacts across the industries, especially in medical and transportation sectors. Further significant advances affect the building industry, as exemplified by the world's first printed metal bridge made of 308LSi (austenitic stainless steel), which spans 10.5 meters over the Oudezijds Achterburgwal canal in De Wallen, Amsterdam [3].

In terms of processing, additive manufacturing consists, as shown in the Fig. 3, of several sequential steps: Starting with a CAD computer-aided design, a conversion to an STL file readable by the Computer Aided manufacturing software follows. A digital slicing process is necessary to define the strategy for building layers. The preparation of the machine in terms of material loading and production parameterizing is done before the launching of the print process. After the layer-by-layer print, comes the removal of the piece from the platform, followed often by a post treatment as machining, or heat treatment. The inspection of the part ends the manufacturing process.

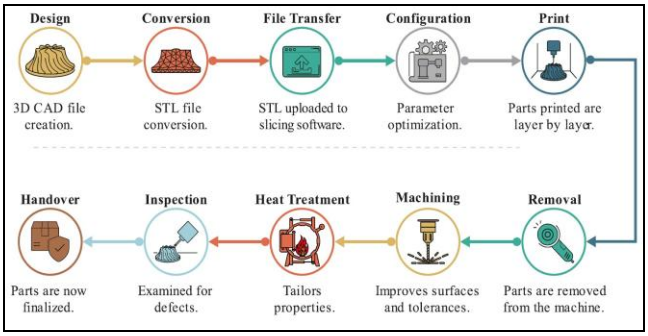

Fig. 3. Typical metal AM workflow [3].

Based on the above workflow, different additive manufacturing processes exist in the industries for prototyping, producing complex parts, customization and rapid manufacturing. Such processes are classified among seven standardized categories: sheet lamination, material extrusion, binder jetting, material jetting, powder bed fusion and direct energy deposition and VAT photo-polymerization.

Regarding the materials typology, polymers are widely used, plus other materials such as ceramics, due to their resistance to high temperatures. Composites (combinations of two or more materials), as resin mixed to another component are also used. For the metal AM, steel, nickel and titanium-based alloys are widely used. Occasionally, precious metals such as gold may be used to creating personalized and valuable objects.

Each subfield of the additive manufacturing industry, combining the manufacturing technique and the material of use, has its own range of applications. For example, the range of applications of the metal AM is from aerospace [4] to biomedical industries [5]. In aerospace, the AM technology can use grade titanium and nickel alloys to create complex structures while enabling light-weighting optimization. In addition to improving performance and reducing waste, the ability of testing complex or difficult to implement designs is a major advantage in aerospace using AM technologies. In the biomedical field, specifically through Powder Bed Fusion (PBF), AM offers the advantage of creating personalized implants and surgical tools [6], with ongoing research on printing human organs [2]. In the beauty and fashion design, Chanel has innovated with a first 3D printed mascara brush, “Le Volume Revolution de Chanel.” By 3D printing the mascara brush, Chanel took advantage of the low incremental costs of the easy customizable brush prototypes in additive manufacturing.

The AM process is emerging, while environment-friendly products are becoming a central requirement from the growth of both legislative constraints and customer environmental awareness. This situation has led the authors to be interested by how people percept the strength and the weakness of this technology and how it affects the environment. In this paper, they dedicate their study case to a sample of engineering students at France. The choice of engineering students is because they will be the potential AM users during their carrier. Then, the authors aim to aware them of its ecological impact and promote sustainable practices regarding it. The authors started the paper by reviewing previous researches comparing the traditional manufacturing to the AM based on environmental analyses.

II. Literature Review

As by the UNESCO 2030 Agenda, the AM’s manufacturers committed to minimize the environmental impact by being sustainable in every production, researchers are working hard to achieve this goal.

The authors in Ref. [7] aimed to compare Additive Manufacturing (AM) and Computer Numerical Control (CNC) machining through a Life Cycle Assessment (LCA) to determine the more environmentally sustainable manufacturing approach. Two AM processes, Fused Deposition Modeling (FDM) and Inkjet, were pitted against one Traditional Manufacturing (TM) process: CNC machining. The findings indicated that the ecological impact is more influenced by the utilization of the machines rather than the machines themselves. Three utilization scenarios were considered: Minimal utilization (one job/week) in idle mode, Minimal utilization (one job/week) in low-power mode, and Maximal utilization (running 24 hours/day, seven days/week). For each mode, the study assessed which manufacturing method had the lowest environmental impact. In the case of minimal utilization in idle mode, the LCA revealed that Inkjet had the lowest overall impact score. In minimal utilization low-power mode, the LCA indicated that FDM and CNC had a lower impact than Inkjet. Lastly, for maximal utilization, FDM demonstrated the lowest impact, while the comparison between Inkjet and CNC remained inconclusive.

The authors in Ref. [8] conduct an Environmental Assessment and comparison between Additive Manufacturing, specifically using Selective Laser Melting (SLM), and Traditional Manufacturing with Laser Cutting (LC) for flat washer production. The Life Cycle Assessment (LCA) employs the Dutch Eco-indicator 99 method to evaluate human health, ecosystem quality, and resource damage. The assessment indicates that laser cutting is approximately 2.5 times more environmentally and human-friendly than the selective laser melting process. The assessment conducted in this article concludes that laser cutting has a lower overall environmental impact than additive manufacturing selective laser melting, especially in electric consumption category.

In Ref. [9], the researchers explore the environmental performance of two manufacturing processes, comparing additive manufacturing Binder Jetting and Traditional Manufacturing Metal Injection Molding, in producing plates for microscale chemical reactors for dimethyl ether production. The study compares their cost and environmental impact across different production volumes. The life cycle assessment reveals that, at lower production volumes, Metal Injection Molding (MIM) has higher cumulative energy demand, global warming potential, and other impacts due to mold plates. At 1,000 reactors/year, MIM slightly outperforms Binder Jetting (BJ), but as production increases to 10,000 reactors, the ecological influence of MIM decreases by 32%, while BJ shows only a 10% reduction in global warming potential. At 100,000 reactors, BJ’s impacts remain stable, while MIM’s decrease by 7%. This indicates that, with increased production, metal injection molding becomes more environmentally favorable due to the amortization of mold and solvent impacts across a larger number of products. This effect is less apparent for Binder

Jetting, where the main environmental drivers are raw material and utilities.

The authors in the article [10] provide an overview of the integration of additive manufacturing into the production Supply Chain (SC), bringing significant changes to traditional manufacturing approaches. AM streamlines production by eliminating the need for equipment investments and reducing prototype development time. It enables the creation of intricate designs without increasing overall production costs, leading to a faster time to market. The technology simplifies the supply chain by eliminating semi-finished product stocks, enabling mass customization, and offering flexibility in integration models. Decentralized AM installations contribute to shorter supply networks, reduced transport needs, and quicker delivery times. AM also impacts logistics costs by eliminating the assembly phase and reducing warehouse stock needs, creating a positive "Made in" effect when adopted in the country of origin. The implementation of AM requires a shift in production flow and specialized knowledge among staff. Additionally, AM enhances environmental sustainability by producing lighter vehicle parts, reducing fuel consumption, and minimizing waste compared to subtractive processes. The article also reviews the adoption of AM in the COVID-19 supply chain to produce personal protective equipment, highlighting its crucial role in addressing urgent needs for personal protective equipment and medical devices through a collaborative supply chain using 3D printing technology.

The authors in Ref. [11] conduct an awareness study on the different methods of education delivery. They explored whether the forced implementation of remote learning techniques during the COVID-19 crisis had an impact on student's preferences. They developed a questionnaire that was answered by 100 students. At the conclusion of the study, the students consider more positively all methods of education delivery than they did before the pandemic experience. These results being consistent with the "Theory of Cognitive Dissonance" and the "Theory of Forced Compliance" show the importance of the awareness procedure.

From the above literature review, it has been observed that broader range of published researches have used Life Cycle Analysis approach in environmental assessment of AM components. Solely, almost all of them are restricted to either a partial LCA, or environmental metrics such as energy consumption or CO_2 emissions. Analyses have converged in interesting conclusions such as if energy demand is more significant for AM, compared to traditional manufacturing; however, this drawback is compensated by the gain in raw material and the lightweight production. Environmental impacts categories needed to be quantifiable within a more holistic vision to obtain the true environmental profile of additive manufactured products through their entire life cycle. Moreover, the majority of the studies have stressed on objects use cases comparison between additive and traditional manufacturing. The study is then focusing on how human percept this innovative technique. Through their process, authors have analyzed the knowledge and attitude of people (in particular engineering students) towards the additive manufacturing and its environmental challenges.

III. Materials and Methods

Raising awareness about the environmental effects of additive manufacturing can be advantageous in several ways. For instance, individuals who are informed about its environmental impacts may opt for a different manufacturing method that is less detrimental to the environment. Moreover, raising awareness can promote the use of recycled materials in AM or the development of new technologies that minimize its environmental impact. Recognizing the significance of additive manufacturing for the environment will foster the adoption of sustainable practices and safeguard the environment. This research aims to increase awareness of these impacts by implementing an awareness campaign on a sample of students in France. To achieve the objectives, an instructive video was addressed to the candidates and a survey was distributed to check their knowledge before and after watching the video.

Sample: The participants are 119 engineering students in an Engineering school in France; the sampling method was the convenient sampling since engineers, ensuring representation from the department, mostly use this technique.

Instruments: A survey questionnaire was developed to measure the awareness of engineering students regarding AM with a video of 30 minutes representing the history, applications, limits and challenges as well as environmental challenges of additive manufacturing. The video comprises short interviews with three experts in France (mentioned in the acknowledgment section) in the additive manufacturing technology. The questionnaire was based on established scales and items from previous research, assessing various dimensions of the topic, such as students' knowledge of AM, their awareness of its impact on the environment, and the future of its manufacturing. A reliability test was done and the Cronbach's alpha recorded 0.935 for the 45 items in the survey, which ensures its reliability.

The researchers used the software AMOS 28 and SPSS28, they used the Exploratory Factor Analysis (EFA) to explore the construct validity of the survey, and the method of Structural Equation Modeling (SEM) was also applied to check the relationship between variables.

Data Collection: The survey was administered electronically during fall semester to the selected participants through an online survey platform. Participants had a specific timeframe to complete the survey before and after watching the awareness video on additive manufacturing; clear instructions and confidentiality assurances were provided to encourage participation.

A paired sample t-test was applied after watching the instructive video to explore whether there was a change in the behavior of the students in terms of their knowledge about AM, its environmental impact, and its future in the industry.

Structural Equation: The model used in this study consists of the relationship between Attitude Towards Additive Manufacturing (ATAM), Acceptance of Additive Manufacturing (AAM) with its fundamentals (what is AM, advantages and limitations) and its application in (global market, industrial sector, industrial application and ecological impact). This model was tested using AMOS 28 to check its goodness of fit and its regression weights, the model as applied is shown in Fig. 1.

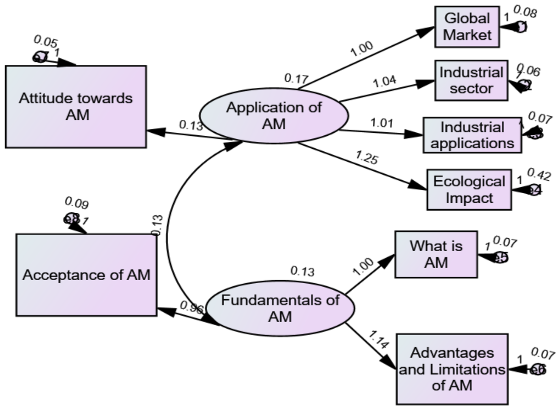

Fig. 4. SEM.

Fig. 4 showed a negative estimate between the applications of additive manufacturing and the attitude of students towards it while the rest of the estimates was positive, and this appears in the regression weights in Table 1.

Table 1. Regression weights

			Estimate	S.E.	C.R.	P-value
Global Market	<---	Applications	1.000	0.070	15.425	***
Industrial sector	<---	Applications	1.025	0.061	16.724	***
Industrial applications	<---	Applications	0.975	0.063	15.360	***
Ecological impact	<---	Applications	1.240	0.118	10.511	***
What is AM	<---	Fundamentals	1.000	0.127	11.611	***
Attitude	<-->	Acceptance	0.055	0.005	10.843	***
Fundamentals	<-->	Applications	0.200	0.018	10.910	***
Attitude	<-->	Applications	−0.255	0.035	−14.453	***
Fundamentals	<-->	Acceptance	0.240	0.049	12.730	***

According to Table 1, positive estimates appear in the relationship between acceptance of additive manufacturing on its fundamentals and negative estimate appears in the relationship between applications of additive manufacturing and the attitude of students towards it.

A. Goodness of Fit

These relationships were tested to check the goodness of fit of the model suggested by applying confirmatory factor analysis in AMOS software. The model appeared to have a good fit as seen in Table 2.

Table 2. Goodness-of-Fit Indicators Model2

Model	CMIN	DF	P	CMIN/DF	GFI	NFI	CFI	RMSEA
Default model	12.13	18.00	0.00	1.10	0.96	0.84	0.98	0.04
Saturated model	0.00	0.00			1.00	1.00	1.00	
Independence model	75.08	28.00	0.00	3.58	0.75	0.00	0.00	0.18

The goodness of fit with the demographic variables suggested that the model fit the data well. We have: $\chi 2$ (18) = 12.134, $p < 0.001$; CFI = 0.979; GFI = 0.958; RMSEA = 0.036, as seen in Table 2.

B. Paired Sample t-test

The study tested the improvement of the students' attitude towards additive manufacturing, its acceptance, and its fundamentals, its applications in the global market, industrial sector, and its ecological impact, before and after watching a 30 minutes instructive video covering all these subjects. As shown in Table 3, the instructive video improved the attitude of the students and their acceptance of additive manufacturing, they were also more aware of the fundamentals of AM and its applications.

Table 3. Paired samples test

		Paired Differences			
Pairs		Mean difference	Std. Deviation	t	significance
Attitude towards AM		0.04847	0.30343	1.735	0.045
Acceptance of AM		0.32347	0.5456	6.44	<0.01
Applications of AM		0.41373	0.53948	8.331	<0.01
	Global Market	0.3761	0.60658	6.735	<0.01
	Industrial sector	0.3627	0.5876	6.705	<0.01
	Industrial applications	0.36729	0.55964	7.129	<0.01
	Ecological impact	0.551	1.051	5.694	<0.01
Fundamentals of AM		0.35466	0.49245	7.823	<0.01
	What is AM	0.27085	0.52868	5.565	<0.01
	Advantages and Limitations of AM	0.43686	0.59983	7.912	<0.01

The differences between the mean values of the variables sketched after and before watching the video, reveal the improvement, as the significance in each variable where p-value is < 0.05 and students change their perceptions and approve the importance of using AM for the environment concerning its applications. These results also appear in the mean of each variable and categories of variables in Table 4.

Table 4. Means

Variables		**Mean Before**	**Mean After**
Attitude towards AM		1.908	1.957
Acceptance of AM		1.935	2.258
Applications of AM		2.125	2.539
	Global Market	2.180	2.556
	Industrial sector	2.171	2.534
	Industrial applications	2.146	2.514
	Ecological impact	2.000	2.550
Fundamentals of AM		2.074	2.429
	What is AM	2.018	2.288
	Advantages and Limitations of AM	2.131	2.568

Table 4 revealed a significant increase in the mean of the applications of AM in the ecological impact (mean before = 2.00, mean after = 2.55), industrial applications (mean before = 2.14, mean after = 2.51) and industrial sector (mean before = 2.17, mean after = 2.53), the applications of AM in industry was presented in the video as eco-friendly application. This will support the goal of this research where the emphasis was on the acceptance of AM and its application as improvement of this type of printing to protect environment. in addition to the significant increase in the mean of the acceptance of AM and its applications in the environment, a significant increase appear in the mean of the fundamentals of AM, its advantages and limitations, noting that it was presented in the video as eco-friendly to protect the environment. The mean of the attitude toward AM was also increased (mean before = 1.908, mean after = 1.957) which support the study aim.

IV. Result and Discussion

The results agreed with researchers' goals where the study proved that the awareness of the fundamentals and applications of additive manufacturing, improved students attitude, acceptance, towards applications and fundamentals of additive manufacturing. Authors demonstrated that their method, successfully addressed the UNESCO 2030 Agenda by bringing awareness on environmental challenges of additive manufacturing, which can promote sustainable practices in the future inside the industries.

This study was done for the first time in France to promote awareness among engineering students towards additive manufacturing. A next phase of research will follow by comparing these results with other universities after their acceptance of conducting the same study.

V. Conclusion

The additive manufacturing, being a crucial part of the Industry 4.0, is one of the critical skills that will be highly demanded in the future. It is attracting the attention of both academic and industrial world because of the high potential it is providing and most smart industries are now including it in their supply chains. The authors, through their study have successfully raised awareness on the environmental challenges of additive manufacturing, the students will now be more willing than before to consider the environmental impact of a manufacturing technique while using it. In parallel to this research study and as Qatar is also involved in the accomplishment of the UNESCO 2030 Agenda, the authors will conduct a similar research on a sample of engineering students in Qatar. The authors will start analyzing the Qatari data, and then they will conduct a comparison analysis with the French results, which aims to bring insights on the perception of the AM technology in both countries inside smart industries.

Therefore, authors believe that their method has a large variety of applications on innovative technologies. For example, consider the artificial intelligence, the science of making machines that can think like human; as well known, the debate on this technology being a threat or a benefit is going on and on, raising awareness on this revolution technique and promoting its useful practices remain very important.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Rima Hleiss and Jean-Daniel Penot conducted the research; Hiba Naccache analyzed the data; Rima Hleiss, Hiba Naccache, Hery Andriankaja wrote the paper; all authors had approved the final version.

Acknowledgment

The authors wish to thank the experts in additive manufacturing Tiphaine Baur AM expert CESI Graduate School of Engineering, Christophe Eschenbrenner President of the French association France Additive and Didier Boisselier application and development manager at IREPA LASER for kindly providing informative interviews on additive manufacturing.

The authors also wish to thank the engineering students at CESI Graduate School of Engineering, Priscilla Egue and Cyril Tilhou-Triep for their respective contributions on the final version of the paper and the editing of the instructive video on additive manufacturing as well as all the engineering students that conduct the survey.

References

[1] F. Laverne, F. Segonds, and P. Dubois, "Fabrication additive-Principes généraux," *Techniques de l'Ingénieur,* 2023.

[2] D. J. Horst, C. A. Duvoisin, and R. de A. Vieira, "Additive manufacturing at Industry 4.0: a review," *International Journal of Engineering and Technical Research (IJETR),* vol. 8, p. 6, 2018.

[3] M. Armstrong, H. Mehrabi, and N. Naveed, "An overview of modern metal additive manufacturing technology", *Journal of Manufacturing Processes*, vol. 84, pp. 1001–1029, Dec. 2022.

[4] B. Lyons, "Additive manufacturing in aerospace examples and research outlook," *The Bridge Linking Engineering and Society*, pp. 13–19, 2012.

[5] A. Giubilini, F. Bondioli, M. Messori, G. Nyström, and G. Siqueira, "Advantages of additive manufacturing for biomedical applications of polyhydroxyalkanoates," *Bioengineering*, vol. 8, no 2, Feb. 2021.

[6] G. Prashar, H. Vasudev, and D. Bhuddhi, "Additive manufacturing: expanding 3D printing horizon in industry 4.0," *International Journal on Interactive Design and Manufacturing (IJIDeM),* vol. 17, no. 5, pp. 2221–2235, June 2022.

[7] J. Faludi, C. Bayley, S. Bhogal, and M. Iribarne, "Comparing environmental impacts of additive manufacturing vs. traditional machining via life-cycle assessment," *Rapid Prototyping Journal*, vol. 21, pp. 14–33, Jan. 2015.

[8] S. Guarino, G. S. Ponticelli, and S. Venettacci, "Environmental assessment of selective laser melting compared with laser cutting of 316L stainless steel: A case study for flat washers' production," *CIRP Journal of Manufacturing Science and Technology,* vol. 31, pp. 525–538, Nov. 2020.

[9] K. Raoufi, S. Manoharan, T. Etheridge, B. K. Paul, and K. R. Haapala, "Cost and environmental impact assessment of stainless steel microreactor plates using binder jetting and metal injection molding processes," *Procedia Manufacturing,* vol. 48, pp. 311–319, Jan. 2020.

[10] F. Calignano and V. Mercurio, "An overview of the impact of additive manufacturing on supply chain, reshoring, and sustainability," *Cleaner Logistics and Supply Chain,* vol. 7, 2023.

[11] S. Joag, "Impact of COVID-19 pandemic on marketing of education," *Journal of Global Awareness*, vol. 4, no. 2, Article 6, Dec. 2023.