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Adoption of Additive Manufacturing Technology in Small and Medium – Scale Enterprises: A Technology Management Framework

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ABSTRACT

This study aims to develop a technology management framework to support the adoption of additive manufacturing technology (AMT) in small and medium-scale enterprises (SMEs) in the Philippines. Data were collected through literature review, surveys, and interviews with AMT experts, and analyzed using descriptive statistics, t-tests, nonparametric analysis, the Delphi Technique, and Kendall's Coefficient of Concordance. Findings show that stakeholders are generally aware, ready, and willing to adopt AMT, recognizing its benefits in improving production efficiency and ease of operation. While technical and economic viability were rated high, operational viability was perceived as low due to high equipment costs and integration challenges. No significant differences were found in awareness, willingness, and readiness across stakeholder groups, though perceptions of technical viability varied by position, education, and business type. Key challenges include financial limitations, technical capacity, policy support, and infrastructure. The study concludes that AMT adoption is feasible for SMEs, provided that strategic management actions and government support are in place to address existing barriers and ensure sustainability.

RESUMO

Este estudo tem como objetivo desenvolver uma estrutura de gerenciamento de tecnologia para apoiar a adoção de tecnologia de fabricação aditiva (AMT) em pequenas e médias empresas (PMEs) nas Filipinas. Os dados foram coletados por meio de revisão da literatura, pesquisas e entrevistas com especialistas em AMT e analisados usando estatística descritiva, testes t, análise não paramétrica, a técnica Delphi e o coeficiente de concordância de Kendall. As descobertas mostram que as partes interessadas geralmente estão cientes, prontas e dispostas a adotar a AMT, reconhecendo seus benefícios em melhorar a eficiência da produção e a facilidade de operação. Embora a viabilidade técnica e econômica tenha sido classificada alta, a viabilidade operacional foi percebida como baixa devido aos altos custos de equipamentos e desafios de integração. Não foram encontradas diferenças significativas na conscientização, disposição e prontidão entre os grupos das partes interessadas, embora as percepções da viabilidade técnica variem por posição, educação e tipo de negócios. Os principais desafios incluem limitações financeiras, capacidade técnica, suporte de políticas e infraestrutura. O estudo conclui que a adoção da AMT é viável para as PME, desde que as ações de gestão estratégica e o apoio do governo estejam em vigor para abordar as barreiras existentes e garantir a sustentabilidade.

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Introduction

Traditional manufacturing around the world is undergoing a profound digital transformation, accelerated by rapidly advancing technologies and the emergence of Industry 4.0. This evolution, often likened to Moore's Law in terms of its exponential pace, is reshaping production landscapes and compelling industries to adopt smarter, more flexible, and more efficient systems. One such disruptive innovation is additive manufacturing technology (AMT), commonly known as 3D printing. Unlike conventional subtractive methods, AMT builds products layer by layer from digital models, allowing for greater design freedom, reduced material waste, faster prototyping, and the ability to produce complex geometries and customized parts. These advantages have made AMT a critical tool in enhancing competitiveness, reducing lead times, and improving product quality across various industries.

However, while large enterprises in developed economies have begun integrating AMT into their operations, small and medium-scale enterprises (SMEs)—especially those in developing countries like the Philippines—often lag behind. These businesses face significant barriers such as high initial investment costs, lack of technical expertise, limited infrastructure, and minimal policy support. Despite their critical role in driving economic growth and innovation, SMEs are frequently excluded from digital manufacturing advancements due to these constraints.

This study addresses that gap by developing a technology management framework specifically designed to support the adoption of additive manufacturing technology in SMEs within developing country contexts. The novelty of this research lies in its contextual and practical approach. Unlike existing AMT adoption strategies that focus predominantly on large-scale industries or generalized models, this framework is tailored to the unique challenges, resources, and readiness levels of SMEs in the Philippines. It integrates multiple dimensions—awareness, willingness, and readiness—across technical, financial, operational, organizational, and policy-related aspects.

Furthermore, the framework is grounded in empirical data gathered from industry experts and validated through rigorous statistical methods, including the Delphi Technique and Kendall's Coefficient of Concordance. This ensures that the model is both realistic and actionable. In addition to guiding initial adoption, the framework also proposes a sustainability roadmap, emphasizing long-term integration, capacity building, infrastructure improvement, and alignment with national innovation strategies. This comprehensive and adaptable approach makes the framework not only novel but also a valuable tool for SMEs seeking to remain competitive in the face of rapid technological change.

Background of the Study

Small and medium-sized enterprises (SMEs) contribute significantly to economic growth in developing nations such as the Philippines. According to Philippine Business Registry of Department of Trade and Industry (DTI), there are 1.5 million registered enterprises in the country and SMEs account for 25% of the country's total exports revenue. Due to the demand of globalization, SMSEs are now facing more challenging demand to upgrade than in past years (Sharma and Sharma, 2018; Singh, 2019). Previously, they just had to compete on price and quality, but now they must also compete on responsiveness and flexibility given the current industrial environment.

Statement of the Problem

The study aimed to formulate a technology management framework for the adoption of additive manufacturing technology in small and medium scale enterprises. Specifically, the research sought answers to the following questions: 1.What is the level of awareness and readiness of different stakeholders on the adoption of additive manufacturing technology considering such as skills, expertise, and knowhow? 2.What is the level of acceptability of additive manufacturing technology to stakeholders? 3.What is the level of readiness of small and medium-scale enterprises in terms of facilities and infrastructure in implementing additive manufacturing technology? 4.Is there a significant difference in the perception of the different stakeholders in terms of their level of awareness, willingness, and readiness to adopt additive manufacturing technology and their perception in different issues/problems in the adoption of additive manufacturing technology when grouped according to their demographic profile? 5.What challenges are faced/encountered by small and medium-scale enterprises in the adoption of additive manufacturing technology? 6.What is the viability of adopting additive manufacturing technology in small and medium-scale enterprises in terms of: a.Technical Factors; b. Operational Factors; c. Economics Factors.

Methodology

The research design, population sample, research tools, data collection techniques, and statistical analysis of the data that were systematically used in carrying out this study are presented in this area.

Research Design

This study employed a mixed method sequential explanatory design with two separate phases: quantitative and qualitative (Creswell, et al 2003). The quantitative results obtained in the first phase are explained or expanded upon by the qualitative data, which were collected and processed second in the sequence.

Population and Sample

This study employed a mixed-methods research design, combining qualitative interviews and quantitative surveys to gather comprehensive data on the adoption of additive manufacturing technology (AMT) in small and medium-scale enterprises (SMEs). The design aimed to explore both subjective expert insights and measurable patterns of awareness, readiness, and challenges among stakeholders.

Participant Selection Criteria

Participants were selected using purposive sampling, specifically targeting individuals with relevant knowledge and experience in AMT. The inclusion criteria for participants were as follows:

- ✓ Must be actively involved in AMT-related projects or decision-making processes in SMEs.
- ✓ Hold key positions such as CEOs, managers, supervisors, or top-level administrators in organizations implementing or considering AMT.
- ✓ Be a supplier of 3D printing technology or mechanical engineer with hands-on experience in the application of AMT in manufacturing processes.
- ✓ Government personnel or experts from relevant agencies (e.g., the Department of Trade and Industry) with knowledge of AMT policy, implementation, or technology dissemination.
- ✓ Academic faculty or researchers with recognized expertise in 3D printing or manufacturing technologies.

This multi-sectoral approach ensured a diverse but highly relevant range of perspectives for formulating a technology management framework tailored to SMEs.

Sample Size and Data Collection

A total of 20 experts were selected for the qualitative phase, which consisted of semi-structured interviews. These interviews were exploratory in nature, aimed at uncovering nuanced insights into the implications, benefits, and barriers related to AMT adoption that might not be readily available in existing literature.

Additionally, a broader survey was conducted to collect quantitative data from stakeholders representing various SMEs. The survey helped to statistically assess levels of awareness, willingness, and readiness to adopt AMT, as well as to identify common challenges and resource gaps.

Ethical Considerations

This study adhered strictly to ethical research standards throughout all phases of data collection and analysis. Ethical considerations included:

- ✓ Informed Consent: All participants were provided with a detailed explanation of the research objectives, procedures, potential risks, and benefits. Written or verbal consent was obtained prior to participation.
- ✓ Confidentiality and Anonymity: Participant identities were kept confidential, and data were anonymized to protect individual privacy. No identifying information was included in the final analysis or reporting.
- ✓ Voluntary Participation: Participants were informed that their involvement was entirely voluntary, and they had the right to withdraw at any point without consequence.
- ✓ Data Integrity: All collected data were securely stored and used solely for academic research purposes. The researcher committed to presenting findings truthfully and without distortion.

The study received clearance from the appropriate academic or institutional research ethics committee, ensuring compliance with local and international ethical guidelines for research involving human participants.

Statistical Treatment of Data

Statistical treatment of data depends upon the nature of the problem, specifically the specific problems and the nature of data gathered. The proponent used the following statistical treatment:

1. **Percentage.** The frequencies of the population of the study were computed in percentage. It was used to determine the profile of the respondents as regards to age, number of years in business, position, highest educational attainment and sales in the previous years.

2. **Weighted Mean.** The researcher computed the mean $\bar{X}$, which is defined as the sum of all values of a given parameter, divided by the number of data in the sample. It was used to compute the average data of the samples taken.

3. **t-test.** For the purpose of testing the null hypothesis and to determine whether or not there is a significant difference in the perceived problems by the respondents when they are grouped according to profile variables.

4. Analysis of Variance (ANOVA). For the purpose of testing the null hypothesis and to determine whether or not there is a significant difference of more than two groups to compare, ANOVA was used.

5. Delphi Method

The qualitative method was used to answer research questions regarding the problems and challenges faced/ encountered by small and medium scale enterprises in the adoption of additive manufacturing technology. Using Delphi method, the researcher gathered information from experts. Based on the expertise and experiences of the group of experts, the Delphi method was used as strategy in making decisions. Typically, a consensus is reached after rounds of inquiries.

The Delphi method allows experts to give their thoughts anonymously without interaction or interference. Opinions are formed depending on the judgment and merit of individual. After collecting replies, the researcher delivers anonymous comments to the participants on the responses that were not on agreement. The participants evaluate the input and may change their minds about the previous responses.

There were 20 experts invited to participate in the Delphi survey. Experts from shared-service facility recipients, from faculty who are familiar with the technology, experts from Department of Trade and Industry (DTI) and other government agencies and small and medium scale enterprises owners/engineers who has/knows 3D printing.

Kendall's Coefficient of Concordance

This statistic is non-parametric. It is a normalization of the Friedman test statistic and can be used to gauge rater agreement. The range of Kendall's W is 0 (no agreement) to 1. (complete agreement). These numbers can be used to determine Kendall's W. If the test statistic W is 1, then all survey participants have agreed and have ranked the list of concerns in the same order. If W is zero, the participants' responses can be taken to be essentially random because there is no overall tendency of agreement among them. Greater or less agreement among the various responses is indicated by intermediate values of W.

Table. 1

Level of Awareness and Readiness of Different Stakeholders on the Adoption of Additive Manufacturing Considering such as Skills, Expertise, and Knowhow

Awareness	Mean	SD	Verbal Interpretation	Rank
1. What is the general (company-wide) attitude towards the changes in your business processes?	4.38	0.87	Agree	2
2. Our company has allocated a budget for research and development on additive manufacturing technology	3.94	1.19	Agree	3
3. Our company has prepared for the adoption of 3D Printing by sending employees to train in 3D Printing.	4.54	0.50	Completely Agree	1
4. Our company has prepared the logistical support to develop and implement 3D Printing.	3.64	1.32	Agree	4
5. The company is aware of the government support for 3D Printing	2.41	1.20	Neutral	7
6. The company has identified the processes where 3D Printing can be applied.	3.00	1.38	Neutral	5
7. The company believes that 3D Printing can enhance the competitiveness of the company in the industry.	2.63	1.18	Neutral	6
Composite Mean	**3.79**	**0.51**	**Aware**	

Results and Discussion

a. Level of Acceptability in Adopting Additive Manufacturing Technology

Additive manufacturing technology's acceptability is the user's adequacy to employ technology for the tasks it is designed to support.

Table 2:

Level of Acceptability of Additive Manufacturing to Stakeholders

Acceptability	Mean	SD	Verbal Interpretation	Rank
1. Additive manufacturing technology is easier to operate compared to traditional manufacturing	3.68	0.34	Agree	3.5
2. Additive manufacturing will enable me to accomplish tasks more quickly	3.78	0.36	Agree	2
3. Additive manufacturing will allow our company to be highly competitive in the industry	4.95	0.37	Completely Agree	1
4. Using 3D printers allow me to accomplish task that would be otherwise impossible	3.10	1.45	Neutral	4
5. It's the company's view that additive manufacturing will improve production.	3.68	0.43	Agree	3.5
Composite Mean	**3.84**	**0.59**	**Accept**	

Stakeholders generally agree that AMT is useful and easy to operate. They believe it will help them complete tasks faster and make their companies more competitive. However, some are still neutral on whether AMT can help them do things they couldn't do before. This shows that while people like the idea of AMT, many may not have fully experienced its advanced benefits yet.

b. Level of Readiness to Adopting Additive Manufacturing Technology in terms of Facilities and Infrastructure

Additive manufacturing technology's readiness is the user's preparedness to employ technology for the tasks it is designed to support.

Table 3:

Level of Readiness in terms of Facilities and Infrastructure

Readiness	Mean	SD	Verbal Interpretation	Rank
1. The company has allotted storage/space for the 3D equipment and supply.	2.57	1.34	Neutral	9
2. The company has allotted a budget for facility and infrastructure improvement.	2.67	1.43	Neutral	8
3. Our company officers have complete control over the implementation, maintenance, and adoption of additive manufacturing	3.04	1.44	Neutral	7
4. Our company officers are fully aware of the benefits of additive manufacturing.	4.32	1.02	Agree	4
5. Our company officers have extensive background and experience in additive technology and are receptive to additive manufacturing	4.37	0.64	Agree	3
6. Our supervisors and rank and file are aware of the latest technology that can be adopted such as 3D Printing to improve production.	4.04	1.02	Agree	6
7. The inclusion of additive manufacturing in our processes will attain the objective of reducing variation in our manufacturing processes.	4.15	0.93	Agree	5
8. There are processes in the company where 3D Printing can be applied	4.45	1.04	Agree	2
9. 3D Printing is expensive.	4.60	0.67	Completely Agree	1
Composite Mean	**3.80**	**0.53**	**Ready**	

Companies feel somewhat ready to adopt AMT because they have knowledgeable staff and some processes ready for 3D printing. However, many see the cost of the equipment as high and feel they don't have enough space or budget for necessary facility improvements. This means that even if companies want to adopt AMT, they might face financial and logistical challenges that could slow down the process.

II. Viability Adopting Additive Manufacturing in Small and Medium-Scale Enterprises

Table 4:

Perceived Technical Viability in Adopting Additive Manufacturing

Technical	Mean	SD	Verbal Interpretation	Rank
1. Our company has prepared for the adoption of 3D Printing by hiring experts and sending employees to train in 3D Printing	4.88	0.38	Completely Agree	1
2. The company officers are fully aware of the benefits of 3D printing in the implementation of additive manufacturing.	4.38	0.87	Agree	4
3. Our company has allocated a budget for research and development on additive manufacturing technology	3.94	1.19	Agree	5
4. Our company is aware of the general design consideration and list of red flags for design specifications mentioned in AM standard.	4.54	0.50	Completely Agree	2
5. The company has seen that AM technology has been widely used in commercial production techniques and is widely accepted	3.64	1.32	Agree	6
6. Our company has prepared the logistical support to develop and implement 3D Printing.	4.41	0.90	Agree	3
Composite Mean	**4.30**	**0.37**	**Viable**	

Table 5:

Perceived Operational Viability in Adopting Additive Manufacturing

Operational	Mean	SD	Verbal Interpretation	Rank
1. The company has ample space for equipment and supplies.	3.00	1.38	Neutral	2
2. The company officers are aware of the AM technology that can be adopted to improve the design of the product.	4.63	0.36	Completely Agree	1
3. The integration of additive manufacturing in our processes will attain the objective of reducing variation in our manufacturing processes.	2.68	1.34	Neutral	5
4. The company has provisions for the maintenance of the adoption of additive manufacturing.	2.78	1.36	Neutral	4
5. To improve quality, the company is continuously making improvements and reducing the quality problems in the product and processes which can be achieved with the help of 3D Printing.	2.95	1.37	Neutral	3
Composite Mean	**2.81**	**0.98**	**Uncertain**	

Table 6:

Perceived Economic Viability in Adopting Additive Manufacturing

Economics	Mean	SD	Verbal Interpretation	Rank
1. Our company is aware of the financial benefits of adopting 3d printing technology	3.09	1.45	Neutral	5
2. The company is aware of the cost operation and integration upon adopting the new technology.	4.39	0.86	Agree	2
3. It is possible to eliminate non-value-added costs associated with all the operations upon the adoption of AM technology.	3.94	1.18	Agree	3

4. The company has allotted a budget for facility and infrastructure upon the adoption of additive manufacturing.	3.65	1.32	Agree	4
5. Our company cannot afford 3D Printing	4.41	0.90	Agree	1
6. The company has allotted a budget for the improvement of the facility and infrastructure upon the adoption of additive manufacturing.	3.00	1.38	Neutral	6
7. Our company has allocated a budget for research and development on additive manufacturing technology and for the training of personnel.	2.63	1.18	Neutral	7
Composite Mean	**3.71**	**0.53**	**Viable**	

III. Perception of the Respondents in terms of Level of Awareness, Acceptability, and Readiness to Adopt Additive Manufacturing in SMEs when Grouped According to their Demographic Profile

Table 7:

Analysis of Variance of the Level of Awareness to Adopt Additive Manufacturing in SMEs when Grouped According to their Demographic Profile

Age	**Mean**	**SD**	**p-value**	**Interpretation**
21-33	3.84	0.54	0.6899	Not Significant
34-46	3.75	0.42		
47-59	3.79	0.54		
60 and above	3.69	0.57		
Gender				
Female	3.82	0.48	0.5403	Not Significant
Male	3.8	0.53		
Marital Status				
Single	3.78	0.54	0.885	Not Significant
Married	3.79	0.51		
Profession				
Engineer	3.85	0.51	0.242	Not Significant
Business	3.81	0.47		
Accountant	3.64	0.45		
Others	3.69	0.6		
Position in the Company				
CEO/COO/Owners	3.67	0.46	0.0241*	Significant
Managers	3.67	0.53		
Supervisors	3.77	0.45		
AM Specialists/Experts	3.89	0.57		
Engineers	3.94	0.53		
Number of Years' Experience in tech department				
1 to 9	3.83	0.5	0.3208	Not Significant
10 to 18	3.81	0.51		
19 to 27	3.64	0.52		
37 and above	3.79	0.64		
Educational Attainment				
High School	3.7	0.61	0.2402	Not Significant
Tech-Voc	3.54	0.52		
Bachelor	3.85	0.5		
Masters	3.75	0.5		
Doctorate	3.7	0.46		
Number of years of Experience in Tech Management				

1 to 9	3.83	0.5	0.3208	Not Significant
10 to 18	3.81	0.51		
19 to 27	3.64	0.52		
37 and above	3.79	0.64		
Number of years of experience in 3D Printing				
1 to 5	3.76	0.5	0.1388	Not Significant
6 to 10	3.94	0.49		
11 and above	3.77	0.59		
Nature of Business				
Manufacturing	3.79	0.48	0.0123*	Significant
Processed Foods	3.76	0.55		
Fabrication	3.68	0.37		
Herbal	3.39	0.54		
Academe	3.99	0.54		
Government Agency	4.02	0.51		
Number of years of operation				
2 to 10	3.82	0.5	0.1911	Not Significant
11 to 19	3.82	0.53		
20 to 28	3.6	0.49		
38 and above	3.79	0.64		
Number of Employees				
7 to 25	3.79	0.5	0.3622	Not Significant
26 to 44	3.72	0.55		
45 to 63	4	0.51		
64 to 82	3.97	0.62		
83 and above	3.8	0.24		

Null hypothesis: There is no significant difference in the awareness of the respondents when grouped according to demographic profile. If p-value is < 0.05, reject the null.

The table above shows that the differences in the awareness of the respondents exist only when grouped according to position in their company and nature of business. The rest of the demographics have no significant result. This shows that the awareness of the respondents depends only on their position in the company and nature of business. The descriptive statistics show that engineers have the highest level of awareness as opposed to other positions while the CEO and Managers have the lowest level of awareness. In terms of nature of business, the government agencies have the highest level of awareness while those who are in herbal business have the lowest level of awareness.

Table 8:

Analysis of Variance of the Level of Acceptability to Adopt Additive Manufacturing in SMEs when Grouped According to their Demographic Profile

Age	**Mean**	**SD**	**p-value**	**Interpretation**
21-33	2.73	0.96	0.4768	Not Significant
34-46	2.81	0.98		
47-59	2.97	1.03		
60 and above	2.84	0.99		
Gender				
Female	2.70	1.02	0.1612	Not Significant
Male	2.90	0.97		

Marital Status				
Single	2.49	0.91	0.0603	Not Significant
Married	2.89	0.99		
Profession				
Engineer	2.96	0.99	0.2433	Not Significant
Business	2.68	0.96		
Accountant	3.01	1.21		
Others	2.88	0.96		
Position in the Company				
CEO/COO/Owners	2.83	0.94	0.7847	Not Significant
Managers	2.66	0.89		
Supervisors	2.81	1.02		
AM Specialists/Experts	2.91	1.05		
Engineers	2.93	1.03		
Educational Attainment				
High School	3.70	0.61	0.2402	Not Significant
Tech-Voc	3.54	0.52		
Bachelor	3.85	0.50		
Masters	3.75	0.50		
Doctorate	3.70	0.46		
Number of years of Experience in Tech Management				
1 to 9	2.95	1.00	0.0155*	Significant
10 to 18	2.85	1.02		
19 to 27	2.32	0.74		
37 and above	3.02	0.99		
Number of years of experience in 3D Printing				
1 to 5	2.86	0.98	0.049*	Significant
6 to 10	3.02	1.04		
11 and above	2.41	0.85		
Nature of Business				
Manufacturing	2.82	0.97	0.6035	Not Significant
Processed Foods	2.72	0.99		
Fabrication	2.88	1.06		
Herbal	2.73	0.89		
Academe	3.11	1.07		
Government Agency	2.70	0.84		
Number of years of operation				
2 to 10	2.97	1.00	0.0062*	Significant
11 to 19	2.83	0.99		
20 to 28	2.26	0.73		
38 and above	3.02	0.99		
Number of Employees				
7 to 25	2.77	0.93	0.0114*	Significant
26 to 44	2.87	1.02		
45 to 63	3.48	1.19		
64 to 82	3.34	1.19		
83 and above	1.96	0.41		

The table above indicates that the differences in the acceptability of the respondents exist only when grouped according to number of years' experience in technology management, number of years of operation, and number of employees. The rest of the demographics have no significant result. This shows that the acceptability of the respondents depends on the number of years' experience in technology management, number of years of operation, and number of employees.

The descriptive statistics show that those with 37 and above number of years of experience in technology management has the highest level of acceptability while the lowest are those with 19-27 years of experience. In terms of number of years of experience in 3D printing, those working for 6-10 years has the highest level of acceptability while those 11 and above has the lowest. The highest level of acceptability for the number of years of operation are those operating for 36 years and above while the lowest are those operating for 20-28 years. For the number of employees, the highest level of acceptability are those with 45 to 63 employees while the lowest are those with 83 and above employees.

Table 9.
Analysis of Variance of the Level of Readiness to Adopt Additive Manufacturing in SMEs when Grouped According to their Demographic Profile

Age	**Mean**	**SD**	**p-value**	**Interpretation**
21-33	3.82	0.45	0.5195	Not Significant
34-46	3.79	0.62		
47-59	3.76	0.52		
60 and above	4.01	0.52		
Gender				
Female	3.72	0.42	0.1013	Not Significant
Male	3.84	0.57		
Marital Status				
Single	3.69	0.41	0.2153	Not Significant
Married	3.82	0.54		
Profession				
Engineer	3.82	0.55	0.979	Not Significant
Business	3.79	0.51		
Accountant	3.81	0.42		
Others	3.77	0.57		
Position in the Company				
CEO/COO/Owners	3.84	0.52	0.8896	Not Significant
Managers	3.83	0.50		
Supervisors	3.81	0.60		
AM Specialists/Experts	3.73	0.49		
Engineers	3.77	0.51		
rccc				
1 to 9	3.81	0.55	0.7218	Not Significant
10 to 18	3.74	0.51		

19 to 27	3.85	0.49		
37 and above	3.88	0.47		
Educational Attainment				
High School	3.74	0.56	0.8114	Not Significant
Tech-Voc	3.90	0.66		
Bachelor	3.81	0.50		
Masters	3.73	0.60		
Doctorate	3.88	0.55		
Number of years of Experience in Tech Management				
1 to 9	3.81	0.55	0.7218	Not Significant
10 to 18	3.74	0.51		
19 to 27	3.85	0.49		
37 and above	3.88	0.47		
Number of years of experience in 3D Printing				
1 to 5	3.84	0.53	0.1774	Not Significant
6 to 10	3.66	0.54		
11 and above	3.78	0.45		
Nature of Business				
Manufacturing	3.79	0.49	0.0048*	Significant
Processed Foods	3.81	0.48		
Fabrication	3.82	0.75		
Herbal	4.37	0.54		
Academe	3.64	0.46		
Government Agency	3.69	0.61		
Number of years of operation				
2 to 10	3.82	0.56	0.6907	Not Significant
11 to 19	3.74	0.49		
20 to 28	3.83	0.52		
38 and above	3.88	0.47		
Number of Employees				
7 to 25	3.77	0.53	0.3439	Not Significant
26 to 44	3.83	0.56		
45 to 63	4.06	0.45		
64 to 82	3.89	0.48		
83 and above	3.64	0.32		

The table above shows that the differences in the readiness of the respondents exist only when grouped according to nature of business. The rest of the demographics have no significant result. This shows that the readiness of the respondents depends only on their nature of business. The descriptive statistics show that in terms of nature of business, the herbal business have the highest level of readiness while those who are in academe have the lowest level of readiness.

IV. Perception of the Respondents on the Viability of Adopting Additive Manufacturing in the Small and Medium-Scale Enterprises when Grouped According to Demographic Profile

Table 10.

Analysis of Variance on the Technical Viability in the Adoption of AM when Grouped According to Demographic Profile

Age	Mean	SD	p-value	Interpretation
21-33	4.37	0.37	0.2163	Not Significant
34-46	4.28	0.34		
47-59	4.27	0.37		
60 and above	4.20	0.42		
Gender				
Female	4.29	0.36	0.7214	Not Significant
Male	4.31	0.37		
Marital Status				
Single	4.27	0.42	0.6351	Not Significant
Married	4.30	0.36		
Profession				
Engineer	4.37	0.32	0.0526	Not Significant
Business	4.30	0.35		
Accountant	4.21	0.25		
Others	4.18	0.48		
Position in the Company				
CEO/COO/Owners	4.23	0.38	0.0463*	Significant
Managers	4.25	0.40		
Supervisors	4.27	0.34		
AM Specialists/Experts	4.28	0.36		
Engineers	4.42	0.34		
Number of years experience in tech department				
1 to 9	4.33	0.33	0.1073	Not Significant
10 to 18	4.31	0.40		
19 to 27	4.15	0.39		
37 and above	4.33	0.41		
Educational Attainment				
High School	4.22	0.46	0.0457*	Significant
Tech-Voc	4.02	0.51		
Bachelor	4.34	0.32		
Masters	4.27	0.40		
Doctorate	4.29	0.32		
Number of years of Experience in Tech Management				
1 to 9	4.33	0.33	0.1073	Not Significant
10 to 18	4.31	0.40		
19 to 27	4.15	0.39		
37 and above	4.33	0.41		
Number of years of experience in 3D Printing				
1 to 5	4.28	0.36	0.3633	Not Significant
6 to 10	4.38	0.33		
11 and above	4.29	0.42		
Nature of Business				
Manufacturing	4.35	0.34	0.0002*	Highly Significant

Processed Foods	4.27	0.39		
Fabrication	4.12	0.23		
Herbal	3.89	0.37		
Academe	4.39	0.36		
Government Agency	4.42	0.31		
Number of years of operation				
2 to 10	4.33	0.33	0.0783	Not Significant
11 to 19	4.31	0.40		
20 to 28	4.14	0.39		
38 and above	4.33	0.41		
Number of Employees				
7 to 25	4.29	0.38	0.2961	Not Significant
26 to 44	4.25	0.33		
45 to 63	4.46	0.31		
64 to 82	4.37	0.41		
83 and above	4.47	0.30		

The table above shows that the differences in the perception of the respondents regarding the technical viability of adopting AM only when grouped according to position in their company, educational attainment, and nature of business. The rest of the demographics have no significant result. This shows that the differences in the perception of the respondents regarding the technical viability of adopting AM depend on when grouped according to position in their company, educational attainment, and nature of business.

The descriptive statistics show that engineers have the highest level of perception regarding the technical viability of AM as opposed to other positions while the CEO /COO/ owners have the lowest level. Those graduates with bachelor degrees have the highest level while tech-voc graduates have the lowest. In terms of the nature of business, the government agencies have the highest level while those who are in the herbal business have the lowest level.

Table 11:

Analysis of Variance on the Operational Viability in the Adoption of AM when Grouped According to Demographic Profile

Age	**Mean**	**SD**	**p-value**	**Interpretation**
21-33	4.37	0.37	0.2163	Not Significant
34-46	4.28	0.34		
47-59	4.27	0.37		
60 and above	4.20	0.42		
Gender				
Female	4.29	0.36	0.7214	Not Significant
Male	4.31	0.37		
Marital Status				
Single	4.27	0.42	0.6351	Not Significant
Married	4.30	0.36		
Profession				

Engineer	4.37	0.32	0.0526	Not Significant
Business	4.30	0.35		
Accountant	4.21	0.25		
Others	4.18	0.48		
Position in the Company				
CEO/COO/Owners	4.19	0.37	0.0463*	Significant
Managers	4.25	0.40		
Supervisors	4.27	0.34		
AM Specialists/Experts	4.28	0.36		
Engineers	4.42	0.34		
Number of years experience in tech department				
1 to 9	4.33	0.33	0.1073	Not Significant
10 to 18	4.31	0.40		
19 to 27	4.15	0.39		
37 and above	4.33	0.41		
Educational Attainment				
High School	4.29	0.47	0.0457*	Significant
Tech-Voc	4.00	0.50		
Bachelor	4.34	0.32		
Masters	4.27	0.40		
Doctorate	4.29	0.32		
Number of years of Experience in Tech Management				
1 to 9	4.33	0.33	0.1073	Not Significant
10 to 18	4.31	0.40		
19 to 27	4.15	0.39		
37 and above	4.33	0.41		
Number of years of experience in 3D Printing				
1 to 5	4.28	0.36	0.3633	Not Significant
6 to 10	4.38	0.33		
11 and above	4.29	0.42		
Nature of Business				
Manufacturing	4.35	0.34	0.0002*	Highly Significant
Processed Foods	4.27	0.39		
Fabrication	4.42	0.31		
Herbal	3.89	0.37		
Academe	4.39	0.36		
Government Agency	4.22	0.23		
Number of years of operation				
2 to 10	4.33	0.33	0.0783	Not Significant
11 to 19	4.31	0.40		
20 to 28	4.14	0.39		
38 and above	4.33	0.41		
Number of Employees				
7 to 25	4.29	0.38	0.2961	Not Significant
26 to 44	4.25	0.33		
45 to 63	4.46	0.31		
64 to 82	4.37	0.41		
83 and above	4.47	0.30		

The differences in the perception of the respondents regarding the operational viability of adopting AM only when grouped according to position in their company, educational attainment, and nature of business. The rest of the demographics have no significant result. This shows that the differences in the perception of the respondents regarding the operational viability of adopting AM depends on when grouped according to position in their company, educational attainment, and nature of business.

The descriptive statistics show that engineers have the highest level of perception regarding operational viability of AM as opposed to other positions while the CEO /COO/ owners have the lowest level. Those graduates of bachelor's degree have the highest level while tech-voc graduates has the lowest. In terms of nature of business, the fabrication has the highest level while those who are in herbal business have the lowest level.

Table 12:
Analysis of Variance on the Economic Viability in the Adoption of AM when Grouped According to Demographic Profile

Age	Mean	SD	p-value	Interpretation
21-33	3.73	0.57	0.7284	Not Significant
34-46	3.66	0.45		
47-59	3.74	0.55		
60 and above	3.60	0.57		
Gender				
Female	3.71	0.51	0.9191	Not Significant
Male	3.70	0.54		
Marital Status				
Single	3.63	0.57	0.3749	Not Significant
Married	3.72	0.53		
Profession				
Engineer	3.78	0.56	0.3465	Not Significant
Business	3.69	0.46		
Accountant	3.58	0.49		
Others	3.62	0.62		
Position in the Company				
CEO/COO/Owners	3.60	0.44	0.0333*	Significant
Managers	3.57	0.54		
Supervisors	3.66	0.50		
AM Specialists/Experts	3.81	0.55		
Engineers	3.85	0.58		
Number of years experience in tech department				
1 to 9	3.75	0.53	0.0752	Not Significant
10 to 18	3.72	0.52		
19 to 27	3.48	0.48		
37 and above	3.73	0.62		
Educational Attainment				
High School	3.66	0.62	0.3019	Not Significant
Tech-Voc	3.40	0.51		

Bachelor	3.75	0.53		
Masters	3.67	0.47		
Doctorate	3.63	0.43		
Number of years of Experience in Tech Management				
1 to 9	3.75	0.53	0.0752	Not Significant
10 to 18	3.72	0.52		
19 to 27	3.48	0.48		
37 and above	3.73	0.62		
Number of years of experience in 3D Printing				
1 to 5	3.68	0.52	0.0955	Not Significant
6 to 10	3.86	0.55		
11 and above	3.60	0.57		
Nature of Business				
Manufacturing	3.70	0.49	0.0194*	Significant
Processed Foods	3.66	0.58		
Fabrication	3.60	0.45		
Herbal	3.35	0.50		
Academe	3.93	0.56		
Government Agency	3.94	0.53		
Number of years of operation				
2 to 10	3.75	0.53	0.0331*	Significant
11 to 19	3.73	0.53		
20 to 28	3.44	0.45		
38 and above	3.73	0.62		
Number of Employees				
7 to 25	3.69	0.49	0.1392	Not Significant
26 to 44	3.65	0.60		
45 to 63	3.98	0.56		
64 to 82	3.95	0.69		
83 and above	3.52	0.21		

The table above indicates that the differences in the perception of the respondents regarding the economic viability of adopting AM only when grouped according to position in their company, nature of business, and number of years of operation. The rest of the demographics have no significant result. This shows that the differences in the perception of the respondents regarding the economic viability of adopting AM depends on when grouped according to position in their company, nature of business, and number of years of operation. The descriptive statistics show that engineers have the highest level of perception regarding economic viability of AM as opposed to other positions while the managers have the lowest level. In terms of nature of business, the government agencies have the highest level while those who are in herbal business have the lowest level. Those who are operating for 2-10 years has the highest level while those operating for 20-28 years has the lowest.

V. Challenges Faced/ Encountered by Small and Medium Enterprises in Adopting Additive Manufacturing Technology

Identification of the Criteria for the Adoption of Additive Manufacturing by Expert Participants: The Delphi Consensus

The following are the identified criteria based on the feedback of the panel participants. The factors identified for the development of a technology framework include challenges, policy requirements, sustainability, technical, and socio-economic.

Delphi Round 1: Identification of the Criteria on the Challenges

CHALLENGES

1. The amount of cost needed to acquire, procure, implement, and maintain 3d printers.
2. The number of employees that will maintain the system
3. There is a stakeholders' resistance to change
4. Selecting the employees to be trained
5. Lack of AM personnel/experts within organization
6. Capacity to train staff
7. Cost of Integration
8. Cost of facility improvement and infrastructure
9. Capacity to select and install a software to be used
10. Integration in the system
11. Ensuring quality of output during integration
12. Identifying appropriate 3D printers to be used
13. Awareness of government support
14. Manual post processing
15. Ease of Use
16. Software challenges
17. Concern about loss of productivity during transition to the new system
18. Improper storing of materials/filaments
19. Limited budget for research and development

These are challenges/factors play a role in adoption of new technology in any organization based on the assessments of the experts. It is necessary to analyze and assess these factors based on the opinions of experts to formulate better programs to address the challenges faced.

Table 13:

Responses of Expert Participants in Round Two for Challenges

	Statements	Mean	Std. Deviation	Min	Max
1.	The amount of cost needed to acquire, procure, implement, and maintain 3d printers.	2.65	1.45521	1	5
2.	The number of employees that will maintain the technology	6.47	1.00733	1	4
3.	There is a stakeholders' resistance to change	2.94	1.59963	1	7
4.	Selecting the employees to be trained	2.71	1.26317	1	5
5.	Lack of AM personnel/experts within organization	2.47	0.71743	5	7
6.	Capacity to train staff	6.71	1.1048	1	5

7. Cost of Integration	2.59	1.22774	1	5
8. Cost of facility improvement and infrastructure	2.71	0.46967	6	7
9. Capacity to select and install a software to be used	6.18	0.88284	5	7
10. Integration in the system	2.82	1.07444	1	4
11. Ensuring quality of output during integration	1.82	0.88284	1	4
12. Identifying appropriate 3D printers to be used	2.12	1.45269	2	7
13. Awareness of government support	2.71	1.35585	1	5
14. Manual post processing	6.83	1.13111	1	5
15. Ease of Use	2.18	1.46779	2	7
16. Software challenges	6.47	0.62426	1	4
17. Concern about loss of productivity during transition to the new system	1.88	0.78121	1	4
18. Improper storing of materials/filaments	6.47	1.12459	1	4
19. Limited budget for research and development	2.76	1.39326	1	5
Kendall's W	**0.651**			

The table above shows the result of the consensus of the panel expert about the importance of the statements for the challenges in adopting additive manufacturing in small and medium scale enterprises.

Based on the results, the mean obtained for the number of employees that will maintain the technology (6.47), capacity to train staffs (6.71), capacity to install software to be used (6.18), manual post processing (6.83), software challenges (6.47), and improper storing of materials and filaments (6.47) were considered unimportant using the semantic scale of 7.

Round 2 obtained Kendall's Coefficient of concordance at 0.651 indicating lack of agreement between panel experts in rating the criteria since the researcher would like to obtain Kendall's coefficient of concordance at 0.7.

Table 14:

Components of Proposed Technology Management Framework to Address the Challenges Faced/ Encountered by Small and Medium Enterprises in Adopting Additive Manufacturing Technology (Round 3)

Statements	Mean	Std. Deviation	Min	Max
1. The amount of cost needed to acquire, procure, implement, and maintain 3d printers.	1.00	0.0000	1	1
2. There is a stakeholders' resistance to change	1.00	0.0000	1	1
3. Selecting the employees to be trained	2.00	0.0000	2	2
4. Lack of AM personnel/experts within organization	1.00	0.0000	1	1
5. Cost of Integration	2.00	0.0000	2	2
6. Cost of facility improvement and infrastructure	3.00	0.0000	3	3
7. Integration in the system	1.00	0.0000	1	1
8. Ensuring quality of output during integration	1.00	0.0000	1	1
9. Identifying appropriate 3D printers to be used	2.00	0.0000	2	2

10.	Awareness of government support	1.06	0.23550	1	2
11.	Ease of Use	2.18	1.46779	2	7
12.	Concern about loss of productivity during transition to the new system	1.00	0.0000	1	1
13.	Limited budget for research and development	1.00	0.0000	1	1
Kendall's W		**0.94**			

Round 3 obtained Kendall's Coefficient of concordance at 0.940 indicating the strong agreement between panel experts in rating the criteria which means that the 13 statements were acceptable to be included in the final survey questionnaire of the study.

Identified Criteria for Challenges by Expert Participants

The adoption of additive manufacturing (AM) in small and medium-scale enterprises (SMEs) presents several challenges that must be carefully addressed. **Economic factors** are among the most critical, as implementing new technologies requires substantial investment in software, facilities, and infrastructure. Policymakers must consider the high costs associated with acquiring, procuring, integrating, and maintaining 3D printing systems. These expenses also extend to upgrading existing facilities, improving infrastructure, and addressing the limited budget often available for research and development.

Organizational factors also pose significant challenges. Resistance to change among stakeholders is a common barrier, particularly when transitioning from traditional to digital manufacturing processes. Organizations may face difficulties in identifying suitable employees for training and may suffer from a lack of in-house additive manufacturing experts. These organizational concerns require proactive planning and support from decision-makers to ensure a smooth transition.

On the **technical and operational side**, SMEs must address several key issues related to the implementation of AM technology. These include integrating new systems into existing workflows, maintaining product quality during the transition, and selecting the most appropriate 3D printing technologies for their specific needs. There are also concerns related to the ease of use of the technology and the potential for reduced productivity during the integration period, all of which require careful consideration to minimize disruption.

Finally, **external factors**, such as the availability and accessibility of government support, also affect the adoption process. Even when support programs exist, many SMEs are either unaware of them or unable to access them effectively. Raising awareness and improving access to these external resources will be crucial in supporting the broader adoption of additive manufacturing across the sector.

Identified Criteria for the Policy Requirement by Expert Participants

Policymaking bodies must develop and implement comprehensive policies to support the adoption of additive manufacturing (AM) in small and medium-scale enterprises (SMEs). These policies are essential to provide clear direction, reduce uncertainty, and manage potential risks associated with technological integration. One key area is the **Training and Development Policy**, which should ensure that employees are equipped with the necessary skills and knowledge to operate and adapt to new AM technologies. This includes formal training programs designed to orient staff on new processes and tools.

Another crucial area is the **Policy on Quality Assurance**. As AM becomes integrated into the production system, quality must be consistently monitored and maintained. Policies should mandate regular review and validation of data, document authentication protocols, and procedures for evaluating the effectiveness of the technology's integration into existing operations. These measures help ensure product consistency, reliability, and compliance with industry standards.

The **Policy on Facility and Infrastructure Improvement** is also necessary. The transition to AM often requires upgrades to existing infrastructure and facilities to accommodate new equipment and workflows. Therefore, policies must guide strategic planning and budgeting for these upgrades to avoid operational bottlenecks.

Furthermore, a **Policy for Assessing the Acquisition of New Technology** should be established. Given the substantial investment typically required for AM adoption, thorough assessments are critical before proceeding. This includes conducting need assessments and feasibility studies to evaluate the financial, technical, and operational impact of the technology on the business.

Lastly, a strong **Policy on Safety and Security** must be implemented. The integration of costly and sophisticated equipment necessitates robust security protocols and workplace safety standards. This includes not only general safety and environmental policies but also specific considerations for employee health, as well as accessibility and accommodations for workers with disabilities. Collectively, these policy frameworks will help create an enabling environment for SMEs to adopt and benefit from additive manufacturing technology effectively and sustainably.

Identified Criteria on Sustainability Factors by Expert Participants

Sustainability factors must be carefully considered by top management to determine whether the company has sufficient resources to adopt additive manufacturing (AM). Policymaking bodies need to assess the company's financial capability, ensuring that the costs involved in acquisition, implementation, and maintenance are affordable and justified by the expected effectiveness. In addition, the readiness of facilities and infrastructure must be evaluated, including the availability of necessary devices, protocols, procedures, and information repositories to support 3D printing operations. Proper maintenance plans for the infrastructure are also essential to ensure smooth functioning over time. Equally important is the availability of comprehensive training programs for employees, with continuous assessments and updates to training materials to improve workforce quality and support the adoption process.

The ability of the company to integrate the new technology into existing operational processes is another critical factor. The system must allow necessary modifications without introducing defects or compromising quality, and the transition should avoid disrupting current management practices. Moreover, sustainability requires deciding whether to purchase systems from external vendors or develop them in-house, based on the skills of the IT team. Continuous research efforts should be maintained to monitor the integrity, reliability, and effectiveness of the technology, alongside policies that empower stakeholders and consider environmental protection.

Technical factors identified by experts highlight the importance of skilled manpower to manage and operate the new technology effectively. Personnel must be proficient in operating 3D printers and related design software like SolidWorks and AutoCAD, be willing to learn and adopt new technologies, and participate actively in relevant training. Technical support availability is equally necessary, with dedicated teams or individuals tasked with troubleshooting hardware and software issues, ensuring proper maintenance, and providing training on the technology's correct usage.

Stakeholders' capabilities in operating, installing, configuring, and diagnosing issues related to hardware and software also play a key role in the successful adoption of additive manufacturing. Additionally, willingness and enthusiasm among end-users to adopt the technology and apply their knowledge are essential for smooth implementation. Finally, awareness of additive manufacturing processes among stakeholders ensures effective utilization of the technology in daily work tasks, ultimately supporting a successful and sustainable transition to additive manufacturing.

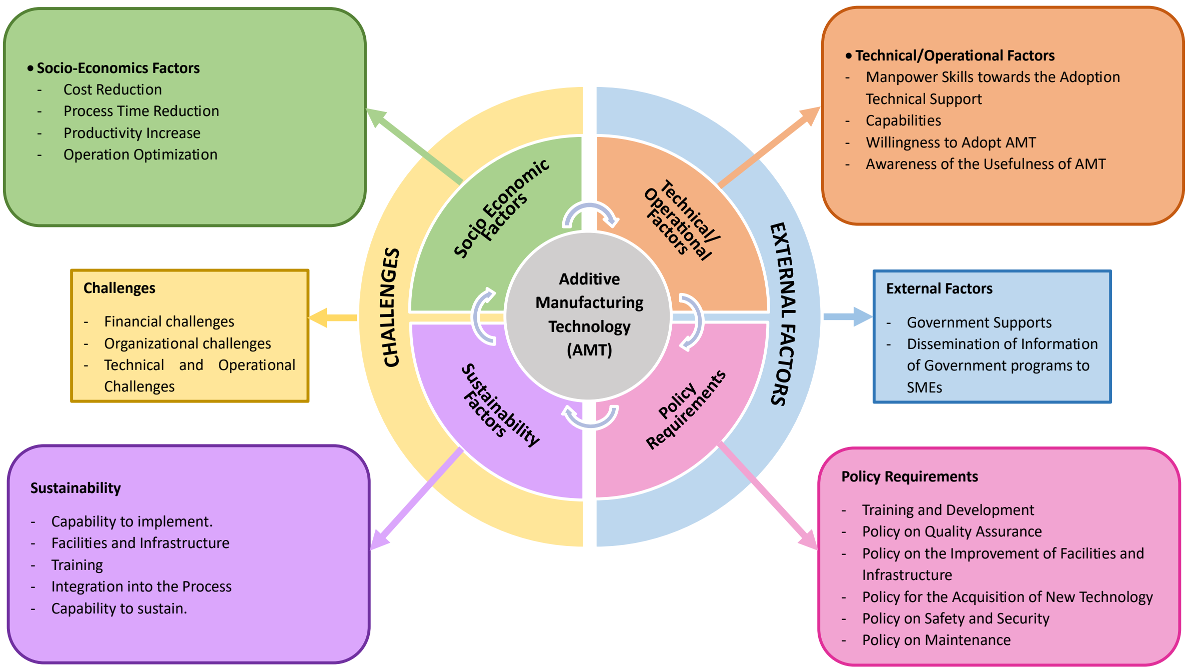
Identified Criteria for the Socioeconomic Factors by Expert Participants

The identified criteria for socioeconomic factors, based on expert consensus, highlight several key considerations for the successful adoption of additive manufacturing (AM) that can bring significant benefits to a company, especially when employees are properly trained and suited for their roles. One major factor is cost reduction; effective implementation of AM can lower operational costs in production, resulting in long-term advantages such as increased profitability and overall cost savings. This includes both short-term gains and sustained benefits as the technology becomes widely used within the organization and the broader community, supported by strong social networks and clear communication of change initiatives to stakeholders.

Another important factor is the reduction of process time, as AM minimizes material wastage, decreases the need for rework, and speeds up operations, thereby enhancing efficiency. Productivity improvements also play a crucial role, as the integration of AM allows employees to focus on more intellectual and value-added tasks while ensuring better quality output. This optimization of operations through AM leads to improved task accomplishment and greater efficiency, ultimately driving profitability and operational excellence. Overall, these socioeconomic criteria emphasize how additive manufacturing can transform company processes by enhancing cost-effectiveness, time management, productivity, and operational optimization.

Figure 23:

Technology Management Framework for the Ad



Conclusion

This study has established that there is a generally high level of awareness, readiness, and acceptability among stakeholders regarding the adoption of additive manufacturing (AM) in small and medium-scale enterprises (SMEs). Findings show that companies are making efforts to train employees, allocate resources, and assess the technical viability of 3D printing technologies. However, operational readiness—particularly in terms of space, maintenance planning, and integration—remains a challenge, as many respondents perceive the cost and complexity as significant barriers. Despite this, economic viability is seen as promising, with many companies recognizing the potential for cost-saving and process improvement in the long term.

Stakeholders expressed willingness to support the adoption of AM, provided there is sustained backing from both top management and government agencies. The proposed technology management framework and roadmap were also positively received, highlighting the perceived importance of strategic planning in technology integration.

In response to these findings, it is recommended that SMEs adopt a comprehensive management strategy that includes stakeholder engagement in planning and implementation. Training programs should be institutionalized to address knowledge gaps and resistance to change among the workforce. Simplifying AM technology usage and communicating its benefits can also improve acceptance and productivity.

Furthermore, national agencies such as the Department of Trade and Industry (DTI) and the Department of Science and Technology (DOST) are encouraged to play a more active role in information dissemination. Programs such as facility visits, hands-on workshops, and the use of digital platforms can help showcase the ease of adoption and practical benefits of AM. Policy support in terms of technology acquisition and workforce development should be clearly communicated and promoted at the grassroots level.

Lastly, this research was conducted with strict adherence to ethical guidelines. All participants were informed about the nature and purpose of the study, and their participation was entirely voluntary. Informed consent was obtained from each respondent prior to data collection. The data gathered were treated with full confidentiality and used solely for academic and research purposes, in accordance with ethical research standards.

In conclusion, while additive manufacturing is viewed as technically and economically viable, operational readiness and strategic alignment remain areas requiring continued focus. With collaborative efforts among SMEs, government agencies, and academic institutions, AM adoption can be a transformative step toward innovation-driven industrial growth in the country.

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