EVALUATING THE CHALLENGES OF ADDITIVE MANUFACTURING ADOPTION USING THE AVERAGE ANALYTIC HIERARCHY PROCESS (A(AHP)) METHOD: EMPIRICAL RESEARCH IN VIETNAM

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Digital transformation, modern technologies to enable autonomous production capabilities, and smart logistical systems are prerequisite strategies to gain competitive advantages in developing countries. Additive manufacturing (AM) or three-dimensional printing offering more significant advantages, can manufacture complex geometries of products with various materials. AM plays a main role in reducing the number of parts, helping reduce and eliminate assembly time and cost. However, the application is still limited, especially in developing countries like Vietnam. This research paper aims to identify and assess the challenges associated with applying additive manufacturing in Southeast Vietnam. This study is conducted in three phases. Step one identifies challenges by reviewing previous studies. Step two applies semi-structured interviews with experts to consolidate these challenges to build a multi-level hierarchical structure of challenges. The third stage is to use a multi-hierarchical process method to rank these issues in order to organize the necessary resources for a successful response. The results show that there are five main challenges and 25 sub-challenges in implementing additive printing technology. Using the Average AHP method, financial and strategic challenges are ranked first and second significant, respectively. This paper contributes by identification of Additive Manufacturing implementation challenges based on the literature review and semi-structured interview with the experts. It provides an assessment of the challenges to help the practitioners robust the addictive manufacturing implementation in the manufacturing industry in Vietnam with limited resources.

KEYWORDS

Additive manufacturing (AM), Critical Challenges, Adoption, Manufacturing Industry, multi-hierarchical process (A(AHP)).

1 INTRODUCTION

Additive manufacturing (AM), known as 3D printing technology, was first introduced in the 1940s [Attaran 2017]. However, since the Fused Deposition Modeling (FDM) printing process patents expired in 2009, it has become popular now. More and more Additive manufacturing (AM) has been introduced to the residential market. The price of 3D printer's price is reducing day by day, especially low-price FDM printers becoming popular and normally born from the Raprep community, maker spaces, FabLab, and other manufacturing communities. Other terminologies can be used to describe AM such as rapid prototyping (RP), direct digital manufacturing (DDM), rapid manufacturing (RM), and solid freeform fabrication (SFF). Currently, there are many types of AM technology being used in manufacturing for industrial production, including Selective laser sintering (SLS), FDM or Fused Filament Fabrication (FFF), Stereolithographic (SLA), Jet Fusion, Digital Light Processing (DLP), Polyjet, Direct Metal Laser Sintering (DMLS) or Selective Laser Melting (SLM), Binder Jetting, Digital Light Synthesis (DLS) [Abdulhameed, Al-Ahmari, Ameen & Mian 2019; Redwood, Schöffer & Garret 2018a; Jansa et al., 2023]. The advantages of additive manufacturing include the ability to produce items with high levels of customization in size and shape without further machining add-ons, which lowers costs. AM may use various materials to build extremely complicated parts; Topology optimization and AM work together to lighten parts and conserve material; AM can speed up the process of getting a product to market [Tofail, Koumoulos, Bandyopadhyay, Bose, O'Donoghue & Charitidis 2018; B.A & Buradi 2022a ; Mesicek et al., 2019]. With these features, AM could be a revolution in industrial production.

In recent years, additive manufacturing (AM) has been extensively used in a variety of industries, including the aerospace, automobile, chemical, construction, dental, drone, apparel, footwear, health care, and toy industries [Richard Sheng 2022; Ben Redwood et al 2018b; Shivakoti et al., 2021]. According to a Sculpsteo survey report from 2022, 66% of users have used 3D printing for education and R&D activities, 40% for after-sales services, spare parts, and replacement, 69% for making mechanical parts, 49% for making tools, 23% for making products based on personal preferences, 37% for making finished products, and 1% for other applications. Only 25% of respondents believed that AM could speed up the launch of a product, and 33% claimed that the most significant barrier preventing organisations from implementing AM is funding. However, 41% acknowledge that AM raises their company's efforts to achieve sustainability goals, 89% of respondents consider AM as a critical factor that creates a competitive advantage in the company's development strategy, and 84% are extremely optimistic about AM's future prospects [Gaget 2022]. Therefore, the majority has positive views of the benefits AM can bring great impact on the transformation of technology and the ability to give organisations a competitive edge.

Vietnam is a developing country that is attracting a lot of FDI, but the majority of it is in outsourcing, and the value added is still low. Therefore, to gain competitiveness, Vietnam must lift up rapidly in technology, digital transformation, and skilled labour. Integrating AM in the production, research, and creation of high-value products is being recognized as a strategic technological movement in the provinces of the southern key economic region, where the industrial proportion is the highest in Vietnam.

However, the investors have not fully recognized the benefits and challenges when deciding to invest in AM application in production. This study, intends to provide an overview of AM to professionals, investors, and enterprises. It also identifies and evaluates the challenges of adopting AM to manufacturing in economic and technological conditions like Vietnam.

2 LITERATURE REVIEW

Companies based on economies of scale will still support commodity and high-volume production, but AM will become a viable and competitive option in cases where end-user customization is highly desirable, a production is a single unit or very small volume, or the end product requires features that cannot be manufactured by traditional means [Petrick & Simpson 2013].

The competitive nature of 21st-century markets requires the continuing enhancement of existing products, and AM is crucial to the fourth industrial revolution [Kantaros, Piromalis, Tsaramirsis, Papageorgas & Tamimi 2021]. Therefore, AM can be implemented in various industries to leverage its significant advantages for [Petrick & Simpson 2013], maximizing profitability, including aerospace [Joshi & Sheikh 2015], automotive industry [B.A & Buradi 2022b], food manufacturing, which is commonly referred to as "3D food printing" [Liu, Meng, Dai, Chen & Zhu 2018], healthcare [Dodziuk 2016], construction [Tay, Panda, Paul, Noor Mohamed, Tan, & Leong 2017], fashion industry [Vanderploeg, Lee & Mamp 2016], education [Ford & Minshall 2019], etc,. According to previous research, AM offers a variety of positive aspects for comparison with the traditional methods, especially in manufacturing sectors. For instance, ability to create customised products in small batches [Ford & Despeisse 2016a], the designs are able to be shared and produced digitally and through outsourcing [Ford & Despeisse 2016b; Berman 2012a], It enables quick, simple, and flexible product design and modification [Peng 2016a; Frazier 2014a; Berman 2012b], It promotes material reuse and waste reduction, which results in material savings [Ford & Despeisse 2016b; Weller, Kleer, & Piller 2015], It may result in less reliance on manufacturing processes that require a lot of energy, such as casting and forging [Peng 2016b], and It might result in a value chain that is better and shorter [Niaki & Nonino 2017; Peng 2016c; Gebler, Schoot Uiterkamp & Visser 2014].

In addition to research on the benefits of 3D printing technology, studying the challenges of adopting 3D printing technology has also received significant attention from scholars [Lin, Lee, Lau & Yang 2018]. Several challenges that have been identified in previous studies include: AM is costly [Dwivedi, Srivastava & Srivastava 2017a], the speed of production is still too slow [Berman 2012c], limited number of available materials [Frazier 2014b], having trouble changing the designers' attitudes and thinking [Dwivedi et al. 2017b], organisational knowledge and awareness are lacking [Martinsuo & Luomaranta 2018], inadequate management and leadership support [Dwivedi et al. 2017c], and a shortage of sufficient infrastructure [Marak, Tiwari & Tiwari 2019].

To assess and identify these challenges, A(AHP) approach is used to figure out the important elements impacting on AM technology adoption among the industries. There are some previously considerable studies used the A(AHP) approach for seeking some beneficial aspects and limitations of this technology. A study claimed that the framework for implementing AM that includes strategy, technology, operating systems, organizational transformation, and supply chain. Existing and possible future AM project managers will need the A(AHP) framework to guide their efforts in embracing this new and possibly disruptive technology class in order to deliver high-value products and create new business prospects, but this study just used the single case research [Mellor, Hao & Zhang 2014]. The group of researchers carried out A(AHP) to evaluate implementation factors of AM in India situation. In this research, the criteria or issues that have arisen since implementing AM have been examined by the authors. These include AM technology, top management commitment, information sharing, supply chain coordination, organizational capability and human resource, process improvement practices, customer and service management, market support, financial capability, technological awareness, and education & training [Khanzode & Akarte 2021]. The study revealed that the commitment of the top management ranks first in the hierarchy; thus, the top management is vital for the effective implementation of AM. In case of Taiwan, a study has integrated A(AHP) and TOE framework combining with cost criteria to analyse and offer producers with a useful resource for planning the adoption of AM. The authors conducted empirical research on Taiwanese manufacturing firms and it has yielded a wealth of information that may assist producers in gaining a deeper understanding of these critical factors. Moreover, the study resulted that different firms have diverse worries with the use of AM due to distinct dimensions and assessment standards and confirmed that there are some factors that might not have been considered [Yeh & Chen 2018a].

However, a comprehensive assessment of these challenges has not been conducted, and there are particularly few studies on this issue in developing countries such as Vietnam. Therefore, based on the holistic framework of Kabra, Ramesh, Jain & Akhtar, this research seeks to identify and assess the challenges of the adoption of 3D printing comprise of five perspectives: Strategic challenges (SCs), Organisational challenges (OCs), Financial challenges (FCs), Human challenges (HCs), and Technological challenges (TCs) [Kabra, Ramesh, Jain & Akhtar 2023]. This research will employ MCDM (Multi-Criteria Decision Making) approaches, such as A(AHP), which are well suited to determine and evaluate the challenges.

3 MATERIALS AND METHODS

3.1 The average analytic hierarchy process A(AHP) method

The AHP approach is a Multi-criteria decision-making (MCDM) technique that was first suggested by Wind and Saaty [Wind and Saaty 1980a] based on the pairwise comparisons of several criteria to determine their relative importance.

There are four steps in A(AHP):

- The hierarchical model's structure
- Pairwise comparisons and measurements are used to acquire data.
- Calculating the normalised weights for each factor, analysing the weights,
- Formulating answers to the issue.

According to the A(AHP) approach, the decision-making problem is first clearly described, followed by determing the objective, primary criteria, sub-criteria, and alternatives. The connections between criteria and options are then determined, and a hierarchical structure is developed. A numerical scale is employed in the A(AHP) approach to compare the criterion or attribute the importance of one component to another. For example, the fundamental Saaty scale shows nine degrees of relative importance through pair-wise comparisons indicated by numbers between one to nine [Wind and Saaty 1980b]. In this research, we suggested the percentage scale (from 1 to 9) for the pair-wise comparison shown in Figure 1.

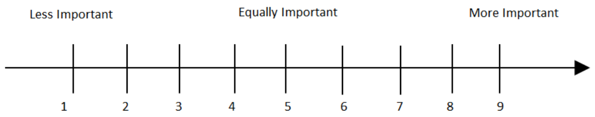

Figure 1. The suggested numerical scale.

It is necessary to calculate each generated matrix's consistency ratio to determine the consistency of subjective judgment. The result will answer the question of what it means for the opinion of experts to be consistent. According to Wind and Saaty in 1980, the consistency ratio must be one (1) or less. If it is larger than one (1), the comparison matrix and consistency ratio must be recalculated.

3.2 The Average AHP method

AHP comparison tables for criteria are produced for each expert to compute relative weights of criterion (risk factors), which are also considered AHP values. If there is more than one expert (for instance, n experts), an evaluation is performed based on each expert (AHPEi), and the average AHP value of experts (A(AHP)) is calculated using the arithmetic mean of the (A(AHP)) values of the experts, as indicated in Equation 1.

$$A(AHP) = \frac{\sum_{i=1}^{n} AHPE_i}{n} \qquad (1)$$

4 RESULTS

The results were divided into two parts: Part I identified the challenges in the 3D printing technology adoption, whereas Part II employed the average AHP approach to prioritize challenge factors found in the previous part.

4.1 Identifying challenges of Additive Manufacturing Adoption

Using the technology adoption challenges from the research of Kabra [Kabra 2023a] the multi-hierarchical structure of challenges will be constructed in this study. This structure will then be supported by the most recent literature review of the relevant literature on addictive manufacturing adoption and experts' opinion. The challenges of Additive Manufacturing Adoption have been classified into two levels, as can be shown in Table 1.

Criteria	Sub challenges	Relevant studies
Main challenges	Strategic Challenges	[Campbell et al. 2011a]
	Organizational Challenges	[De Roy & Saratchand 2021]
	Human Challenges	[Despeisse et al. 2017a]
	Financial Challenges	[Despeisse et al. 2017b]
	Technological Challenges	[palo et al. 2017]
Strategy (S)	Lack of policies to adopt technology	[Aghimien et al. 2020]
	Inadequate policy awareness and support from government	[Doherty 2012]
	Lack of management vision	[Olsson et al. 2021]
	Lack of cross-organization development program	[Cohen 2014]
	Lack of supply chain understanding	[Beltagui et al. 2020]
Organisation (O)	Conflicting short-term focus goal-oriented culture	[Lewis 2018]
	Not inviting end-user input	[Huber et al. 2017]
	Lack of 3D Printing personnel	[Shahrubudin et al. 2020a]
	Lack of pressure from other organizations	[Olsson et al. 2021]
	Lack of transparency in the utilization of funds	[Rodríguez-Espíndola et al. 2020]
Human (H)	Lack of skills to use 3D Printing	[Shahrubudin et al. 2020b]
	Lack of education and training to the employees	[Shahrubudin et al. 2020c]
	Lack of benchmarking about the knowledge of 3D Printing	[Cooray & Coomasaru 2022a]
	Workforce resistance to change	[Cooray & Coomasaru 2022b]
	Lack of motivation to use 3D Printing	[Medina Herrera et al. 2019]
Finance (F)	Donors support	[Munoz-Abraham et al. 2016]
	Lack of funds for investment in technology	[Rayna & Striukova 2021a]
	High Cost	[Buchanan & Gardner 2019]
	Competition for funding	[Rayna & Striukova 2021b]
	Fundraising expenses	[Buehler et al. 2016]
Technology (T)	Lack of awareness about exact technological solutions	[Tofail et al. 2018]
	Lack of 3D Printing enabling infrastructure	[Soo et al 2021]
	Lack of customization	[Barsky et al. 2018]
	Frequent updates of technology	[Campbell et al. 2011b]
	Incompatibility in 3D Printing facilities linked with different organizations	[Dankar et al. 2018]

Table 1. Identification of challenge factors from the previous literature.

4.2 *Prioritisation of the 3D printing adoption with A(AHP)*

The purpose of the A(AHP) questionnaire was to assess and prioritise the five primary challenge factors and their corresponding sub-factors. Figure 2 illustrates the AHP framework, which encompasses both the main and sub-factors. As previously noted, data was collected through the AHP questionnaire. The study enlisted the involvement of five professionals who specialise in 3D printing technology. To determine the priority of adopting 3D printing technology, the experts were directed to utilise numerical scales ranging from 1 to 9 while making their decisions. Each participant spent between forty to fifty minutes completing the questionnaire, which involved a decision-making process and pairwise comparisons. Table 2 illustrates an instance of pairwise comparisons of decision criteria for a specific goal identified by expert No.1. The importance was measured on a scale of 1 to 9, as described in Figure 2. The reciprocal values of these importance scores were used as transverse values (aij = 1/aji). Expert No. 1 concluded that Strategy was three times more important than Organization, resulting in a transversal value of 1/3. Similarly, Organization was deemed three times less significant than Strategy, resulting in a reciprocal value of aij = 1/aji.

	S	O	H	F	T
S	1.00	3.00	0.20	0.11	0.33
O	0.33	1.00	0.14	0.11	0.33
H	5.00	7.00	1.00	0.33	3.00
F	9.00	9.00	3.00	1.00	5.00
T	3.00	3.00	0.33	0.20	1.00

Table 2. Pairwise comparison matrix of expert No. 1's decision criteria (challenge factors) with respect to the goals.

We generated a pairwise comparison matrix of challenge factors, as presented in Table 3, by dividing each element of the matrix by the total of its corresponding column. For example, to calculate the value 0.055 in the matrix, we divided 1 (from Table 2) by the total of column values (1.00 + 0.33 + 5.00 + 9.00 + 3.00 = 18.33) (from Table 2). We computed the Eigenvector or relative weights of the criteria (challenge factors) that align with the goal of Table 3 by calculating the row averages. To illustrate, the relative weight of a strategic challenge was obtained by dividing the sum of the rows (0.05 + 0.130 + 0.043 + 0.063 + 0.034) by the number of challenge factors/criteria (6), which yielded a value of 0.065.

	S	O	H	F	T
S	0.055	0.130	0.043	0.063	0.034
O	0.018	0.043	0.031	0.063	0.034
H	0.273	0.304	0.214	0.190	0.310
F	0.491	0.391	0.642	0.570	0.517
T	0.164	0.130	0.071	0.114	0.103
	Weight	Rank			
S	0.065	4			
O	0.038	5			
H	0.258	2			
F	0.522	1			
T	0.117	3			

Table 3. Priorities of main adoption challenge factors.

Following Saaty's guidelines [2004a], we calculated consistency indexes (C.I.) and consistency ratios (C.R.) to assess the consistency of the comparison matrix. The C.I. is computed using the formula C.I. = $(\lambda max - n) / (n - 1)$, where λmax refers to the largest eigenvalue of the pairwise comparison matrix. The C.R. is obtained by dividing the C.I. by the random consistency index (R.I.), which is presented in Table 4. For a five-by-five matrix, the appropriate R.I. value is 1.12. If the C.R. is less than or equal to 0.1, the assessment is deemed acceptable. Otherwise, a new pairwise comparison matrix needs to be formulated until the C.R. is less than or equal to 0.1 [Saaty 2004b]. We determined the C.R. using the above formula and discovered that it was 0.071040846, which did not surpass the 0.10 (10%) threshold. Thus, the experts' opinions were reasonably consistent and could result in a suitable decision for these criteria.

n	1	2	3	4	5	6	7
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32
n	8	9	10	11	12	13	14
R.I.	1.41	1.45	1.49	1.51	1.48	1.56	1.57
n	15						
R.I.	1.58						

Table 4. Average random consistency index (R.I.).

Five experts employed the A(AHP) method to compare each adoption challenge in Figure 2 with itself. The prioritisation of each adoption challenge level was conducted by calculating the average score, as displayed in Table 5. The average AHP value of experts A(AHP) was determined by computing the arithmetic mean of the A(AHP) values of the experts. To illustrate, the average AHP of the strategic challenge in the table was obtained by adding up the rows (0.065 + 0.232 + 0.069 + 0.228 + 0.260), which yielded a value of 0.171 and was ranked second. Table 6 summarises the results of priorities for all challenge factors, including the major and sub-challenges.

	Criteria weights				
	RES 1	RES 2	RES 3	RES 4	RES 5
SC	0.065	0.232	0.069	0.228	0.26
OC	0.038	0.039	0.037	0.069	0.035
HC	0.258	0.085	0.111	0.074	0.134
FC	0.522	0.496	0.528	0.38	0.503
TC	0.117	0.148	0.255	0.25	0.068
	Average	Ranking			
SC	0.1709	2			
OC	0.0435	5			
HC	0.1323	4			
FC	0.4857	1			
TC	0.1675	3			

Table 5. Average of the AHP values of the experts for major challenges.

Criteria	**Weights**	**Ranks**
Main Factors		
Strategic Challenges	0.1709	2
Organisational Challenges	0.0435	5
Human Challenges	0.1323	4
Financial Challenges	0.4857	1
Technological Challenges	0.1675	3

Sub-Challenge Factors (S)		
Lack of policies to adopt technology	0.1828	3
Inadequate policy awareness and support from government	0.2552	2
Lack of management vision	0.3048	1
Lack of cross-organization development program	0.0773	5
Lack of supply chain understanding	0.1799	4
Sub-Challenge Factors (O)		
Conflicting short-term focus goal-oriented culture	0.0893	5
Not inviting end-user input	0.2446	2
Lack of 3D Printing personnel	0.435	1
Lack of pressure from other organisations	0.1043	4
Lack of transparency in the utilisation of funds	0.1267	3
Sub-Challenge Factors (H)		
Lack of skills to use 3D Printing	0.2313	2
Lack of education and training to the employees	0.0844	5
Lack of benchmarking about the knowledge of 3D Printing	0.1846	4
Workforce resistance to change	0.2931	1
Lack of motivation to use 3D Printing	0.2066	3
Sub-Challenge Factors (F)		
Donors support	0.1498	4
Lack of funds for investment in technology	0.2759	2
High Cost	0.3163	1
Competition for funding	0.1068	5
Fundraising expenses	0.1511	3
Sub-Challenge Factors (T)		
Lack of awareness about exact technological solutions	0.2774	2
Lack of 3D Printing enabling infrastructure	0.105	4
Lack of customization	0.2147	3
Frequent updates of technology	0.1033	5
Incompatibility in 3D Printing facilities linked with different organisations	0.2996	1

Table 6. Summary of Priorities of criteria (Challenge factors).

5 CONCLUSIONS

Several challenges were identified in a recent study on the factors that influence additive manufacturing challenges, including technology, organization, environment, and cost [Yeh & Chen 2018b]. However, there is a dearth of research examining the comprehensive set of barriers affecting the adoption of additive manufacturing. Therefore, this study presented five main challenges and 25 sub-challenges by using adopting digital technology framework of [Kabra 2023b].

The results of the survey of five experts on main and sub-challenges were reasonably similar, and the criteria's C.R. index was acceptable, with a C.R. of less than ten percent [Saaty 2004c]. Table 7 presents the main findings of the research, which include the ranking of the primary challenge factors and the top sub-challenges.

Main challenge factors		Top sub-challenges	
Financial challenges	49%	High cost	32%
Strategic challenges	17.09%	Lack of management vision	38%
Technological challenges	16.75%	Incompatibility in 3D Printing facilities linked with different organisations	30%
Human challenges	13%	Workforce resistance to change	29%
Organisational challenges	4%	Lack of 3D Printing personnel	44%

Table 7. Summary of main results

This study is consistent with the findings of a previous study by [Yeh & Chen 2018c] in Taiwan, which identified financial challenges as the biggest obstacle to the implementation of additive manufacturing technology in production. Despite the relatively advanced levels of manufacturing and finance in Taiwan, cost is still seen as the biggest issue, suggesting that in Vietnam, financial solutions should be considered as a top priority. Future studies could explore financial challenges in greater detail, examining why additive manufacturing is often more expensive than traditional manufacturing methods and finding ways to reduce costs.

In Vietnam, the majority of businesses are small and medium-sized enterprises (SMEs) that often rely on subcontracting for multinational companies with a cost-focused strategy. Despite this, Vietnam has been making significant progress in developing its manufacturing and technology sectors, including advancements in 3D printing. However, specific information on organizations in Vietnam that can address the financial aspects of 3D printing investments has not been widely disclosed yet. Given that financial challenges have been identified as the main obstacle to implementing additive manufacturing technology, managers should prioritize finding solutions to reduce costs. This requires exploring why additive manufacturing is more expensive than traditional methods and seeking ways to mitigate these cost differences. The application of 3D printing technology in Vietnam has revealed a reluctance toward continued development and future investments in the next ten years [Akbari & Ha 2020]. This could pose challenges in addressing the issue of high cost and harnessing the advantages of 3D printing technology. Therefore, it can be concluded that while there may be organizations capable of tackling the high-cost issue in the implementation of 3D printing technology in Vietnam, the avoidance and lack of future investment in this technology could diminish interest and efforts in seeking solutions. Hence, further research and understanding of the reasons and orientation behind this concern are necessary to fully leverage the potential of 3D printing technology and effectively resolve the high-cost problem in Vietnam.

Further research is also necessary to identify organizations in Vietnam that can provide financial assistance, such as local venture capital firms, government initiatives, industry associations, or technology-focused incubators/accelerators. The limited vision of many manufacturing businesses in adopting new technologies for breakthroughs highlights the need for further research to understand and overcome strategic challenges. Additionally, the study emphasizes the importance of addressing human and organizational challenges in adopting additive manufacturing, which may involve investing in training and education programs or developing supportive organizational structures for the technology's use.

In conclusion, this study comprehensively identified the challenges of adopting additive manufacturing. The AHP method was employed to evaluate the ranking of risks. Significantly, the study applied the scales for pair-wise comparisons from 1 to 9 [Saaty 2002]. this study provides a valuable starting point for further research into the challenges of adopting additive manufacturing, and emphasizes the need for ongoing efforts to address these barriers.

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