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Elements of additive manufacturing technology adoption in small- and medium-sized sized companies

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Abstract

Purpose – This study aims to examine factors that determine the adoption of additive manufacturing by small- and medium-sized industries. It provides insights with regard to benefits, challenges and business factors that influence small- and medium-sized industries when adopting this technology. The study also aims to expand the domain of additive manufacturing by including a broader range of challenges and benefits of additive manufacturing in literature.

Design/methodology/approach – Using data collected from 175 small- and medium-sized industries, the study has examined through Mann–Whitney test to understand the difference between owners and design engineers on additive manufacturing technology adoption in small- and medium-sized companies.

Findings – This study suggests contribution to academic discussion by providing associated factors that have significant impact on the adoption of additive manufacturing technology. Related advantages of additive manufacturing are reduction in inventory cost, lowering the wastage in production and customization of products. The study also indicates that factors such as cost of machinery, higher level of cost in integrating metal components have a negative impact on the adoption of this technology in small- and medium-sized industries.

Research limitations/implications – Because of the chosen research approach, the research results may lack generalizability. Therefore, researchers are encouraged to test the proposed propositions further in the field of challenges and growth in other areas of application of additive manufacturing, for instance, medical sciences, fabric and aerospace.

Practical implications – The study provides important implications that are of interest for both research and practitioners, related to technology management in small- and medium-sized industries, e.g. foundry and machining industries.

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Social implications – This work/study fulfills an identified need of the small- and medium-sized companies in adopting new technologies and contribute to their growth by understanding the need to accept and implement technology.

Originality/value – This paper fulfills an identified need to study how small- and medium-scale companies accept new technologies and factors associated with implementation in the manufacturing process of the organization.

Keywords Additive manufacturing, Manufacturing, quantitative research, Technology adoption

Paper type Research paper

1. Introduction

In the present era of digital manufacturing, three dimensional printing (3DP), also referred as additive manufacturing, rapid manufacturing or direct digital manufacturing, is considered to be a disruptive technology (Berman, 2012). Literature has identified many potential benefits of 3DP, which include the following:

- elimination of tooling, reducing the tool setup time and expenses;
- feasibility of production in small batch sizes;
- design flexibility (Ganesh et al., 2017);
- feasibility of product function optimization;
- high level of product customization (Montero, Roundy, Odell, Ahn, & Wright, 2001);
- reduction of production waste;
- shorter supply chains;
- reduced lead times; and
- low inventories (Shahrubudin, Lee, & Ramlan, 2019).

3DP allows for high level of customer involvement in the design and creation of the final products (Rayna & Striukova, 2014), within a manufacturing environment. Additive manufacturing is one of the significant technologies of Industry 4.0 platform and is expected to have a positive impact on the way that manufacturing organizations function (Kamble, Gunasekaran, & Sharma, 2018). When implemented to made-to-order supply chains, additive manufacturing may facilitate in addressing the issue of bullwhip effect by enabling the organizations to produce highly customized single or small batches of production (Huang, Liu, Mokasdar, & Hou, 2013). These developments will benefit the traditional supply chain by reducing the supplier base and bringing a customer focus in the organizations. Although the additive manufacturing is related with the aforesaid benefits, findings have shown a difference concerning implementation in developing economies, especially India, which has a large number of manufacturing units, but is still at an early stage with few companies having accepted and adopted the technology; at the same time, there is a large number of small- and medium-sized industries that are yet to accept and adopt the additive manufacturing printing technology (Ishengoma & Mtaho, 2014). Industry 4.0 is an integration between digital and physical world through the so-called cyber physical world, thus changing the work environment and creating new business models (Pereira & Romero, 2017). 3DP is an integrated part of Industry 4.0 as it includes intelligent automation (Ugur et al., 2017). Additive manufacturing has a vital role in the Industry 4.0, because of its reduced cycle time, economic process and highly decentralized production processes. The smart factories have their processes interconnected with greater flexibility (Horst, Duvoisin, & Vieira, 2018).

Nonetheless, there are no theoretical studies on the relevant factors that determine the adoption of the additive manufacturing to small- and medium-sized companies as an inclusive concept.

Hence, this paper aims to address this research gap by pursuing the following research question:

RQ1. Which factors determine the adoption of additive manufacturing in small- and medium-sized companies?

By evaluating this research question, this study provides the long-standing research on technology diffusion. Even though earlier studies have provided an insight into this area, it is still a research of high significance and interest. For instance, Marak, Tiwari, and Tiwari (2019) reveal factors that influence the adoption of additive manufacturing in large-scale companies in India. Niaki, Torabi, and Nonino (2019) examined which factors regulate the adoption of additive manufacturing for sustainability in manufacturing. Kolade, Obembe, and Salia (2019) observed the role of government support to small- and medium-sized industries in technology adoption.

To answer our research question, we made use of a quantitative research design based on a sample of 175 small- and medium-sized companies. By doing so, the study has identified three significant factors for the adoption of additive manufacturing for small- and medium-sized industries. To be more precise, the significant factors are benefits of additive manufacturing for small- and medium-sized industries, challenges of implementation of additive manufacturing and business factors that influence the adoption of additive manufacturing in small- and medium-sized industries.

The remainder of the paper is structured as follows: in Section 2, we propose the chosen research framework and study hypotheses. Section 3 describes the employed methodology before the results are presented in Section 4. The findings are discussed in Section 5 and, finally, Section 6 concludes the research and presents a few limitations, perspectives for the future and managerial implications.

2. Research framework

2.1 Additive manufacturing and small and medium scale industry

Additive manufacturing is one of the most promising technologies in the field of advanced manufacturing with a potential to change the manufacturing process and enhance the quality of products offering improved customer satisfaction (Yeh & Chen, 2018). Considering these promising aspects of additive manufacturing, the research framework applied for the study consists of factors, which are critical for the success of additive manufacturing in small- and medium-sized companies. The factors consist of benefits of additive manufacturing technology for SMEs, challenges of implementation of additive manufacturing in SMEs and business environment for acceptance of this technology in SMEs.

The above discussed factors are well researched in large manufacturing companies (Arnold & Voigt, 2019; Niaki, Torabi, & Nonino, 2019). However, with regard to small- and medium-sized industries, research requires directions. Hence, this study framework has considered these three factors, i.e. benefits of additive manufacturing, challenges of implementation of additive manufacturing and influence of business environment in the adoption of additive manufacturing in small- and medium-sized industries. In the following sections, the reasons for including these three factors are discussed.

2.2 Benefits of additive manufacturing for small- and medium-scale industries

India is the third largest casting manufacturer in the world (Metal world, 2016). Even then, in India, small- and medium-sized Indian companies face certain challenges, namely, the difficulty to lean implementation in manufacturing (Kumar et al., 2017), lack of skilled employees (Roy, Chakrabarti, & Das, 2015), high inventory costs and lack of inventory space, conventional design approach (Aruna, 2015), scarcity of raw materials (Garg, 2014) and lack of infrastructure (Subrahmanya, 2005). Most of these challenges can be overcome by implementing additive manufacturing printing in the industry.

Pattern controls most of the quality attributes in casting (Mehta, Gohil, & Doshi, 2018). Additive manufacturing is used to manufacture patterns, and any design changes needed can be made easily on computer aided design software and subsequently it is manufactured by an additive manufacturing process (Himanshu et al., 2015).

The design and development of the patterns is a challenging task and time consuming. Skilled persons are required for designing the pattern in the foundry. Metal, plastic and wood are the most used pattern materials. The computer aided design model can be stored in the computer and any changes required in the pattern dimension can be easily obtained. In conventional pattern design, more people are required for designing and manufacturing the pattern, whereas by using the additive manufacturing only one person can design and manufacture the pattern (Syed et al., 2018). Additive manufacturing is a cost-effective technology as the labor required and cycle time for designing and developing a pattern is minimum. The design changes can be done on the computer aided design model itself, and, with only one person, the entire component can be designed and manufactured. The printed plastic pattern is used to take trial castings and any modifications in design can be made in the computer aided design model (soft prototype).

This advantage of additive manufacturing is that it helps in reducing the product development time. Material wastage in the form of scrap can be reduced to a great extent (Jason et al., 2018). Additive manufacturing is economical even for mass customization (Rayna, Striukova, & Darlington, 2015).

Hence, the study considers the following benefit factors associated with additive manufacturing.

2.3 Challenges in implementing additive manufacturing

The additive manufacturing technology offers faster production rates compared to conventional investment casting and with better accuracy (Olkhovik, Butsanets, & Ageeva, 2016). However, challenges faced are first, notion of industries that additive manufacturing is useful for research purpose in laboratories rather than fabrication work on the industrial shop floor (Inigo et al., 2016). Second, surface finish and strength of the products obtained from additive manufacturing is poor as compared to conventional manufacturing processes (Hsien-Chieh et al., 2017). Third, all materials and colors cannot be printed (Lauralyn et al., 2017). Fourth, limitation with respect to dimensions of the component (Yunguang et al., 2017), and finally, investment is high (Weller, Kleer, & Piller, 2015). Therefore, this study considers the abovementioned factors associated with challenges of additive manufacturing implementation in the organization.

2.4 Business factors influence on the adoption of additive manufacturing

In today's dramatically challenging business environment, firms that are already using conventional manufacturing techniques fail to recognize the full potential of advanced technologies (Chiadamrong & O'Brien, 1999). This is mostly triggered by the fact that companies usually lack the tools that would allow them to make educated decisions regarding the complex problem of selecting the optimal vector of production strategies (Mohanty & Deshmukh, 1998). To that end, companies should evaluate the costs and benefits from the introduction of advanced manufacturing technology (AMT) alternatives in their production portfolio. Another constraint is the relatively low production when compared to conventional production methods (e.g. injection molding), which might lead to lack of faster reach to customer and loss of competitive advantage in the market (Gibson, Rosen, & Stucker, 2014).

2.5 Research methods

This study involved collection of data from small- and medium-sized industries from Belagavi, Karnataka. The survey was conducted through e-mail to examine the challenges faced by small- and medium-sized industries regarding the acceptance of additive manufacturing technology.

2.6 Participants

The study has undertaken 175 small- and medium-sized industries at Belagavi, Karnataka. A total number of 425 small- and medium-sized industries operate in Belagavi, Karnataka, specializing in foundry products and machining for automobile industry in India and abroad. The responses from the respondents were collected through e-mail survey. The participants in the study include SME owners and design engineers of the organizations. The two types of participants bring in the much needed variability and different perspectives; engineers' view is more on a functional level and owners view it from an economic and feasibility angle. Our study relies on 15 variables and structural equation modeling (SEM) was conducted to understand the challenges faced by small- and medium-sized industries in adopting additive manufacturing.

2.7 Instrument development and data collection

The construct for the study must include in the scale in a sufficient manner and address the research study (Moschis & Churchill, 1978). Each construct item must agree with one another. However, they must not match with other variables of the construct. The survey instrument was developed based on the literature review carried out herein. The study items were focused toward understanding AMT acceptance by small- and medium-sized industry and the response was collected based on five-point Likert scale ranging from "strongly disagree" to "strongly agree." The data was collected from 175 small- and medium-sized industries through e-mail. A pilot study on 25 SMEs was conducted and the results of reliability analysis were obtained. The details with regard to reliability analysis is presented in Table 4. The reliability score of more than 0.65 (Henseler, Ringle, & Sinkovics, 2009) are found to be acceptable for measurement. This study results have shown more than 0.65 on the construct in the instrument. The e-mails were sent to all the small-and medium-sized companies at Belagavi, Karnataka, India, and a total of eight weeks was spent on collecting

Table 1.
Benefits of additive manufacturing

Sr. No.	Benefits	Authors
1	Reduced inventory cost	Kumar et al., (2017)
2	Customized design	Himanshu et al., (2015); Mehta et al., (2018)
3	Reduced cost of labor	Syed et al., (2018)
4	Low wastage	Jason et al., (2018)
5	Mass customization of product	Thierry et al., (2015)

the response from the respondents. A total of 198 respondents received the e-mail and 175 respondents provided the responses for the study. About 88% of the respondents provided the information on challenges influencing accepting additive manufacturing. Responses were not obtained from the remainder of the respondents because of lack of awareness toward additive manufacturing and its application in the manufacturing process.

2.8 Data analysis

A three-stage data analysis was conducted; in the first stage, content validity was conducted to eliminate the subjectivity of the measurement. Content validity was conducted through

Sr. No.	Challenges	Authors
1	Poor surface finish compared to conventional production	Petrovic et al., (2011); Hsien-chieh et al., (2017)
2	Lack variety in color	Lauralyn et al., (2017); Cozmei et al., (2012)
3	Limited with dimensions of components	Yunguang et al., (2017)

Table 2. Challenges of additive manufacturing technology

Sr. No.	Business factors	Authors
1	Decision-making	Mohanty and Deshmukh (1998)
2	Cost benefit	Gibson et al. (2014)
3	Low production output	Gibson et al. (2014)
4	Supply chain	Gibson et al. (2014)
5	Customer satisfaction	Gibson et al. (2014)

Table 3. Business factors influencing additive manufacturing technology

Construct	Items	Acceptable score	Cronbach's alpha	Outcome
Reduced inventory cost	A1	$\geq$0.65	0.881	Supported
Customized design	A2	$\geq$0.65	0.884	Supported
Reduced cost of labor	A3	$\geq$0.65	0.878	Supported
Low wastage	A4	$\geq$0.65	0.881	Supported
Mass customization of product	A5	$\geq$0.65	0.880	Supported
Poor surface finish compared to conventional production	B1	$\geq$0.65	0.883	Supported
Lack variety in color	B2	$\geq$0.65	0.882	Supported
Limited with dimensions of components	B3	$\geq$0.65	0.884	Supported
High investment	B4	$\geq$0.65	0.884	Supported
Lack of skilled labor	B5	$\geq$0.65	0.879	Supported
Decision-making	C1	$\geq$0.65	0.883	Supported
Cost benefit	C2	$\geq$0.65	0.888	Supported
Low production output	C3	$\geq$0.65	0.886	Supported
Supply chain	C4	$\geq$0.65	0.886	Supported
Customer satisfaction	C5	$\geq$0.65	0.888	Supported

Table 4. Reliability analysis

Themes	Variables	N	Mean	SD
Benefits	Reduced inventory cost	175	5	1.25115
	Customized design	175	4	1.24839
	Reduced cost of labor	175	3	1.23171
	Low wastage	175	5	1.32365
	Mass customization of product	175	4	1.27855
Challenges	Poor surface finish compared to conventional production	175	2	1.2199
	Lack variety in color	175	3	1.28929
	Limited with dimensions of components	175	3	1.43466
	High investment	175	4	1.32489
	Lack of skilled labor	175	3	1.48273
Business factors	Decision-making	175	3	1.37923
	Cost benefit	175	3	1.1488
	Low production output	175	3	1.40998
	Supply chain	175	3	1.28078
	Customer satisfaction	175	4	1.15825

Table 5.
Descriptive statistics analysis

Model fit statistic	Recommended	Obtained
Chi square		1,182
Significance	$P \leq 0.05$	0.000
Chi-square degree of freedom	<5.0	1.469
GFI	>0.90	0.96
NFI	>0.90	0.91
RFI	>0.90	0.94
TLI	>0.90	0.91
CFI	>0.90	0.93
RMSEA	<0.05	0.042

Notes: GFI: goodness-of-fit statistic, NFI: normed-fit index, RFI: relative fit index, TLI: Tucker–Lewis Index, CFI: comparative fit index, RMSEA: root mean square error of approximation

Table 6.
Model fit statistics of the measurement model

the inclusion of four experts from academia and four experts from industry. Their selection was based on the number of years of experience in the field of 3DP and additive manufacturing. Academicians were involved in the area of technology management, manufacturing technology and additive manufacturing. The academicians had an experience of more than 10 years in the area of technology management and manufacturing technology, whereas two experts in the area of additive manufacturing had eight years of experience in the field of 3DP and additive manufacturing. All the four academicians were teaching in an engineering college of national repute. Although the experts from the industry include senior managers in the small- and medium-sized enterprise with more than 15 years of experience in the field of computer aided design, Cronbach's alpha (CA) and 3DP. One senior manager working at a reputed SME has designed and developed indigenous 3D printers and provided a few solutions to SMEs.

In the second stage, the pilot study was conducted with 30 managers from SMEs. In this stage, CA and composite reliability were applied in the study. Non-parametric analysis was applied for the study to understand the difference between respondents that own SMEs and design engineers in SME. Mann–Whitney test was applied to the study. This test was selected as the study had two different groups, namely, owners of SMEs and design

Table 7. Model analysis

	Estimate	SE	CR	P	Label
Lack variety in color ← Reduced inventory cost	0.713	0.056	12.627	0.000*	Supported
Supply chain ← Reduced inventory cost	0.2	0.076	2.628	0.000*	Supported
Limited with dimensions of components ← Customized design	0.093	0.087	1.071	0.000*	Supported
Customer satisfaction ← Customized design	−0.059	0.07	−0.845	0.398*	Not supported
Skilled labor ← Customized design	0.338	0.088	3.853	0.000*	Supported
Cost benefit ← Reduced cost of labor	−0.14	0.074	−1.882	0.006*	Not supported
Cost benefit ← Investment cost	0.043	0.073	0.585	0.558*	Not supported
Investment ← Low wastage	0.048	0.076	0.637	0.524*	Not supported
Low production ← Low wastage	−0.08	0.081	−0.994	0.032*	Not supported
Decision-making ← Customized design	−0.081	0.084	−0.974	0.033*	Not supported
Poor surface finish compared to conventional production ← Mass customization of product	0.437	0.064	6.789	0.000*	Supported

Notes: Level of significance: (*5% level of significance) SE: standard error, CR: critical ratio, *P*: probability value

	Participants	*N*	Mean rank	Sum of ranks
Reduced inventory cost	Owner	60	75.54	4,532.50
	Design Engineers	115	94.50	10,867.50
	Total	175		
Customized design	Owner	60	87.21	5,232.50
	Design Engineers	115	88.41	10,167.50
	Total	175		
Reduced cost of labor	Owner	60	88.44	5,306.50
	Design Engineers	115	87.77	10,093.50
	Total	175		
Low wastage	Owner	60	86.81	5,208.50
	Design Engineers	115	88.62	10,191.50
	Total	175		
Mass customization of product	Owner	60	80.32	4,819.00
	Design Engineers	115	92.01	10,581.00
	Total	175		
Poor surface finish compared to conventional production	Owner	60	112.81	6,768.50
	Design Engineers	115	75.06	8,631.50
	Total	175		
Lack variety in color	Owner	60	74.54	4,472.50
	Design Engineers	115	95.02	10,927.50
	Total	175		
Limited with dimensions of components	Owner	60	65.84	3,950.50
	Design Engineers	115	99.56	11,449.50
	Total	175		
High investment	Owner	60	68.40	4,104.00
	Design Engineers	115	98.23	11,296.00
	Total	175		
Lack of skilled labor	Owner	60	61.39	3,683.50
	Design Engineers	115	101.88	11,716.50
	Total	175		
Decision-making	Owner	60	59.18	3,550.50
	Design Engineers	115	103.04	11,849.50
	Total	175		
Cost benefit	Owner	60	71.70	4,302.00
	Design Engineers	115	96.50	11,098.00
	Total	175		
Low production output	Owner	60	45.63	2,737.50
	Design Engineers	115	110.11	12,662.50
	Total	175		
Supply chain	Owner	60	63.28	3,796.50
	Design Engineers	115	100.90	11,603.50
	Total	175		
Customer satisfaction	Owner	60	74.76	4,485.50
	Design Engineers	115	94.91	10,914.50
	Total	175		

Table 8.
Mean rank analysis

engineers (Field, & Hole, 2003). Further, SEM was applied for statistical intervention in the study. This method is a multivariate analysis applied to understand the relationships among variables. In this method, factor analysis and multiple regression techniques are applied to evaluate the relationship between measured and latent variables. This method is applied as it provides estimates of additive manufacturing benefits to SMEs and understands the challenges of implementation and business factors influencing the SMEs in evaluating the benefits of additive manufacturing in SMEs. The variables under

		Mann–Whitney *U*	Wilcoxon *W*	*Z*	Asymp. sig. (two tailed)
Benefits	Reduced inventory cost	1,961.5	8,631.5	−4.808	0.000*
	Customized design	2,642.5	4,472.5	−2.599	0.009*
	Reduced cost of labor	2,120.5	3,950.5	−4.294	0.000*
	Low wastage	2,274	4,104	−3.811	0.000*
	Mass customization of product	1,853.5	3,683.5	−5.127	0.000*
Challenges	Poor surface finish compared to conventional production	2,702.5	4,532.5	−2.417	0.016*
	Lack variety in color	3,402.5	5,232.5	−0.153	0.878*
	Limited with dimensions of components	3,423.5	10,093.5	−0.086	0.932*
	High investment	3,378.5	5,208.5	−0.23	0.818*
	Lack of skilled labor	2,989	4,819	−1.485	0.138*
Business Factors	Decision-making	1,720.5	3,550.5	−5.609	0.000*
	Cost benefit	2,472	4,302	−3.184	0.001*
	Low production output	907.5	2,737.5	−8.173	0.000*
	Supply chain	1,966.5	3,796.5	−4.792	0.000*
	Customer satisfaction	2,655.5	4,485.5	−2.591	0.010*

Note: a. Grouping variable: Participants (*5% level of significance)

Table 9. Mann–Whitney *U* test result analysis

consideration for SEM are based on the fit index, which is a single path coefficient that includes *p* value and standard error, modeling through the root mean square error of approximation (RMSEA) and chi square. The chi square provides results with regard to any discrepancy among variables in the model; any results with less than a *P* value of 0.05 are accepted, indicating that the variables in the study are consistent and any value higher than the *P* value of 0.05 is rejected. Thus, RMSEA with a value equal to 0 shows that the model fits, whereas values higher than 0 shows the lack of fitness of the model. The study applied Statistical Package for the Social Sciences (SPSS) 23 and AMOS 23 for data analysis of the study variables Figure 1.

2. Results and discussions

The analysis of the results obtained show that the inventory cost reduction through additive manufacturing and its relationship with variety in color shows supportive results ($p = 0.000 > 0.005$), which means that additive manufacturing reduces inventory costs and also provides variety in colors for production. However, there is a difference with regard to owners of SMEs who feel that additive manufacturing is limited to variety in color and also does not reduce inventory cost of SMEs.

Regarding supply chain management and inventory cost reduction, our investigation provides supportive results in the regression analysis ($p = 0.000 > 0.005$) and also in the

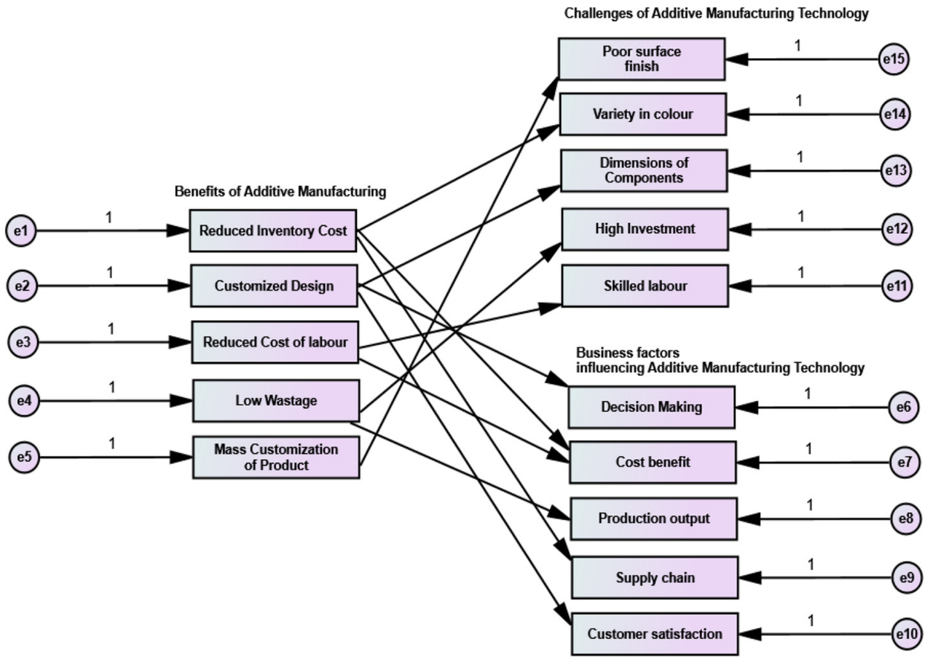

Figure 1.
Model of structural equation analysis

Mann–Whitney *U* test results for supply chain management (p = 0.000 > 0.005) and inventory cost reduction (p = 0.000 > 0.005).

Regression results with regard to additive manufacturing acceptance of component dimensions and customized design of components has shown supportive regression results (p = 0.000 > 0.005), the results from Mann–Whitney *U* test results have also indicated the same. Relationship with regard to customer satisfaction and customized designs of components has shown a negative relationship (p = 0.398 < 0.005); it occurred because the owners of SMEs feel that more components need to be added into this technology to enhance customer satisfaction.

Results with regard to skilled workforce and customized designs of components show positive regression results with (p = 0.000 > 0.005), results from Mann–Whitney *U* test have shown negative results as there is difference between owners' mean rank of 61.39 and design engineers' mean rank of 101.88. The owners of SMEs believe that there is an opportunity to enhance skill sets of employees to produce better designs for components through additive manufacturing.

Cost benefit advantage and reduction of labor cost shows positive regression results (p = 0.000 > 0.005). However, the result from Mann–Whitney *U* test have shown a few differences regarding the owners of SMEs and design engineers with mean rank value of (SME owners = 71.70 and design engineers = 96.50). The SME owners feel that labor cost can be reduced in the future with additional training of the workforce in this technology.

Investment cost in additive manufacturing and benefit of recovery of cost has shown negative regression results with (p = 0.006 < 0.005); the Mann–Whitney *U* test shows positive results, as design engineers feel that cost benefit can be achieved through the introduction of new products as this technology provides an opportunity to produce customized products, which can cater to new market and new customers. Therefore, the return on investment would be possible through additive manufacturing.

Wastage in production process through additive manufacturing has shown negative results with ($p = 0.524 < 0.005$) and same are the results with respect to Mann–Whitney *U* test, which shows differences with regard to investment (mean rank value of SME owner = 68.40 and design engineers mean rank value = 98.23). The SME owners feel that additive manufacturing has an opportunity to reduce wastage in production process.

Regression results through SEM shows ($p = 0.32 < 0.005$) lower production output through additive manufacturing, but the design engineers have differed with regard to lower production output, as additive manufacturing has the capacity to include large number of design components and can customize according to the requirement of the customer. Hence, the number of units would be lower in the overall manufacturing process of SMEs.

Decision to provide faster delivery of products with customized designs of products has shown negative regression results with ($p = 0.033 < 0.005$), however, results from Mann–Whitney *U* test has shown difference between the SME owner mean rank for decision-making with 59.18 and design engineers mean rank value of 103.04.

Surface finish of the product through additive manufacturing need further improvement as the regression results have shown ($p = 0.001 > 0.005$). This indicates that the final output of the product needs improvement with regard to final finishing.

Regarding technology-related elements, the study shows that a relative advantage of additive manufacturing in SMEs has a highly significant positive effect on the adoption decision of this technology. Additive manufacturing would benefit small- and medium-sized industries with reduced inventory cost, customized design, lower wastage in production and opportunity for mass customization of products (Himanshu et al., 2015; Kumar et al., 2017; Mehta et al., 2018). However, challenges that affect the acceptance of this technology are influenced by high investment in purchase and implementation of this technology in SMEs. Second, SMEs indicate that additive manufacturing cannot hold large dimensions of products in the production and indicate that metal-based product takes large investment in purchase of equipment of additive manufacturing. Third, regarding the challenges in recruiting skilled labor, SMEs must train the employees. Even though employees are aware of the situation, fully trained employees are still needed for implementation of additive manufacturing (Roy et al., 2015). Lack of skilled labor and high investment has influenced on production of finished surface product and acceptance of more variety of color combination, which might be needed for production of fiber components. With reference to the business factors influencing the adoption of additive manufacturing technology by SMEs, these firms perceived that customer satisfaction would be high; however, there are factors related to business such as decision-making to invest and implement this technology in the SMEs. As, these SMEs evaluate from the point of cost benefit to the firm. Thirdly, SMEs evaluate the application of this technology from production output and its influence on supply chain management. SMEs are quite apprehensive regarding these factors. Business factors have a significant influence on the adoption of additive manufacturing. In the first factor, i.e. decision to implement this technology, support is required to provide financial resources for the successful implementation of this new technology in a firm (Gibson et al., 2014). Production capacity expansion did not prove to have a significant influence on additive manufacturing. This contradicts our prior studies (Rayna et al., 2015). A reason for this finding might be the fact that SMEs already have fixed production capacity with present plant and machinery; hence, the companies in our sample cannot perceive additive manufacturing for mass customization and enhancing the production output. Additive manufacturing suggests digitization of all operations within the entire supply chain. Because of the digitization across the supply chain, a large amount of data acquisition is required with regard to design, process and supply of product to final customer. However, supply chain of SMEs is influenced by dynamic structures that change according to the needs of customers. The dynamic structures are a challenge to implement, considering the present business factors. For instance, procurement of components and design for individual customers with few units of order would entail higher cost of production and lacks application of mass production of units, which also might influence labor cost and inventory. Therefore, new algorithms are needed to manage supply chain with additive manufacturing technology in SMEs. Employee skill sets required for additive manufacturing is critical, as well as information technology-related aspects such as computer aided design, CAM and designing – these changes demand from employees an adaptation to new technological realities. The requirement for these changes in SMEs ensures a new model of adaptability among the employees of SMEs.

3. Conclusion and implications

In summary, the results indicate that factors from all three perspectives (benefits, challenges and business factors) have significant influence on the adoption of the additive manufacturing in small-and medium-sized industries. Relative advantage of reduction of inventory cost and reduction of wastage in production positively affect the adoption of additive manufacturing. Challenges with regard to high investment, skilled labor and acceptance of limited dimensions (size) of components have a negative effect on additive manufacturing. Business factors regarding supply chain management, production output and cost-benefit analysis need deeper understanding, as these firms perceived challenges associated with these factors in the business environment.

This study enhances existing research on technology adoption as well as on additive manufacturing in several ways. Various factors that already proved to be significant in previous examinations were assessed by applying the pervasive study framework. In this course, the study was able to extend the validity of earlier results. The three determinants associated in the study, i.e. benefits, challenges and business factors proved to have significant influence on the adoption of this technology. Moreover, business factors, which proved to also have a significant negative influence in prior studies, show a moderate positive impact on the adoption of additive manufacturing. Firm size, production capacity and other business factors, such as government regulations, customer expectations and location of the production seem not to affect the adoption of additive manufacturing. The participants approached in our research have mentioned a few challenges to the adoption of this technology, such as high investments and especially the acceptance of limited dimensions of components. Previous research dealt with potential challenges of additive manufacturing implementation but failed to examine the challenges from the perspective of small- and medium-sized industries in adopting this technology.

The findings also provide valuable insights for production managers. First, supply chain management shows significant importance in additive manufacturing in SMEs. Therefore, firms that plan to implement the additive manufacturing in their production should understand the present process of supply chain management and, with the evaluation based on the firm's business context, must implement this technology. Second, regarding high investments in technology by SMEs, these firms have an opportunity to expand the business horizons and cater to the needs of customers, they can enter in various market segments; like components for medical science; they do not need to be restrained to the engineering industry. This would provide an opportunity to recover investments in technology. Third, acceptance of limited dimensions of components and high investment in metal component additive manufacturing has a significant negative impact on the adoption of this technology in SMEs. Therefore, SMEs are well advised to consider the number of components that can be involved in manufacturing, which supports cost reduction and enhance production needs; SMEs are also advised to consider this technology based on their production process and manufacturing strategy. Finally, business factors need to consider, for instance, the acceptance of this technology by all the stakeholders of the firms and the decision to implement it in the firm, evaluating cost benefit analysis, which provides an insight on the long-term benefit from introducing this technology in SMEs.

In addition to our contributions, our research also presents a few limitations. The sample consists only of Indian small- and medium-sized companies. Since the additive manufacturing is also relevant for other companies, like in the fields of medical science, dental science, fabric manufacturers, among others, future studies should consider the adoption of this technology by SMEs in these other industries. Moreover, the study, which includes firm size as an independent variable, provides valuable insights on the influence of firm size and factors that influence the adoption of this technology by SMEs. Therefore, future studies should consider other factors that also proved to be significant in previous studies or factors that are newly identified in the adoption of additive manufacturing in small- and medium-sized industries.

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Appendix

Table A1.
Questionnaire for the study

	Items	Five-point Likert scale				
		Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
Benefits	Additive manufacturing reduced inventory cost for SMEs					
	Customized design of the products is possible through additive manufacturing					
	Cost of labor is reduced through additive manufacturing in SMEs					
	In the production process, there is low wastage through additive manufacturing					
	Mass customization of products is possible through additive manufacturing					
Challenges	There is a challenge with regard to surface finish of the product produced through additive manufacturing in comparison to conventional method of production					
	There is lack of color variety in additive manufacturing					
	Additive manufacturing is limited with dimensions of components					
	There is a high investment in additive manufacturing					
	There is lack of skilled labor to work on additive manufacturing					
Business factors	Decision-making is faster with additive manufacturing to supply components					
	Additive manufacturing provides cost-benefit advantage to SMEs					
	Additive manufacturing has low production output					
	Supply chain and additive manufacturing are supportive					
	There is higher level of customer satisfaction with additive manufacturing					