

36th CIRP Design Conference (CIRP Design 2026)

Organizational Perspectives on Additive Manufacturing Adoption: Challenges, Effects, and Success Factors

Gregory-Jamie Tüzün^{a*}, Florian Joseph Günther^b, Haoyang Zhuang^a, Daniel Roth^a, Matthias Kreimeyer^a, Alexander Koch^b

^aUniversity of Stuttgart, Pfaffenwaldring 9, 70569 Stuttgart, Germany

^bUniversity of the Bundeswehr Munich, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany

* Corresponding author. Tel.: +49-711-685-68059; fax: +49-711-685-66219. E-mail address: gregory-jamie.tuezen@iktd.uni-stuttgart.de

Abstract

Additive Manufacturing (AM) is widely regarded as a key technology for industrial transformation, with growing influence on product development. While technological potentials such as design freedom and shortened development cycles are well studied, less is known about the organizational challenges that persist in practice and how they translate into barriers and effects. Prior research has often remained fragmented, case-specific, and difficult to generalize. This study addresses this gap through a quantitative international survey of 32 industrial organizations and exploratory analysis. First, existing literature was analyzed to outline key organizational challenges, barriers, and effects. In addition, 32 industrial organizations from Europe, North America, and Asia participated in an online survey comprising 6-point Likert scales covering organizational challenges, barriers, and observed effects along the product development process. The sample includes prototype and series manufacturers, system providers, service providers, and development-oriented consultants. Most respondents work in R&D, production, or related technical functions. Descriptive results show that managing expectations and process integration into product development are perceived as the most critical challenges, while guiding the mindset towards AM and balancing all requirements are challenging but less pressing. Correlation analysis indicates that barriers function as mediators between organizational challenges and observable effects. Hierarchical clustering suggests that barriers and effects occur in coherent bundles rather than isolation. K-means clustering distinguishes organizations that are highly aware of AM challenges from those that are not, which we classify as high- and low-perception organizations. From these findings, preventive success factors are derived for low-perception organizations, including awareness-building, business case development, and capability training, while corrective strategies are proposed for high-perception organizations, such as cross-departmental collaboration, infrastructure investment, validation procedures, and systematic knowledge management. While exploratory due to the limited sample size, the study provides structured, indicative insights into AM adoption and introduces a preventive-corrective logic of success factors as a basis for future validation and refinement.

© 2026 The Authors. Published by Elsevier B.V.

This is an open access article under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0>)

Peer review under the responsibility of the scientific committee of 36th CIRP Design Conference (CIRP Design 2026)

Keywords: additive manufacturing; product development; empirical study; organizational integration; barriers; challenges; industrial success factors

1. Introduction

Additive manufacturing (AM) is widely considered a key technology for advanced manufacturing. AM shortens development cycles, expands design possibilities, and enables cost-efficient customization making it essential in aerospace, medical, and engineering sectors [1,2]. Beyond technical

benefits, AM supports new business models, decentralized production, and greater adaptability to market demands [3,4].

Despite its benefits, the industrial adoption of AM is still associated with substantial challenges, particularly in product development. While technological challenges such as process reliability, material properties, and quality assurance are well documented [5,6], organizational challenges such as limited workforce skills [7], high investment costs [8], and difficult

integration into existing processes [9] are also critical. Practitioner insights highlight the inefficient use of human resources, the lack of an additive mindset within organizations, uninformed or ill-timed decision-making, and unrealistic expectations towards AM [10]. These findings underline that challenges extend beyond technology into organizational aspects of industrial product development.

Existing research on organizational aspects provides valuable insights but remains fragmented and context-specific, which restricts generalizability and limits the development of actionable managerial guidance. To address this gap, this study builds on a review of existing literature and focuses on a quantitative international survey to analyze interdependencies among organizational challenges, barriers, and effects, and to identify context-specific success factors for effective AM adoption.

Accordingly, this study addresses the following research questions (RQ):

- RQ1: What are the key challenges that organizations encounter when adopting AM across the product development (PD) process?
- RQ2: What are the systematic interrelationships between organizational challenges, barriers, and effects?
- RQ3: Based on these insights, what success factors can be identified in different contexts?

2. Background

This study examines the organizational perspective of AM adoption in product development, focusing on the concepts of challenges, barriers, effects, and success factors. The emphasis is on organizational dynamics and their interrelations, rather than on technical aspects.

2.1. Challenges derived from literature

Based on literature, four main organizational challenges that hinder the adoption or use of AM in product development can be distinguished:

The first challenge concerns the development of an AM-oriented mindset and the related skills within organizations. This includes a lack of AM-specific knowledge, skills, and qualified personnel, as well as insufficient training programs, human resources, and difficulties in fostering an AM-oriented mindset [11,12].

The second challenge relates to establishing and managing realistic expectations for AM. This includes the high cost of AM equipment and technologies, the absence of convincing business cases, and unclear implementation strategies [10,13].

A third challenge arises when integrating AM into existing business processes from development to production. This includes the absence of standardized procedures and technical norms for AM, limited internal collaboration, communication difficulties, and the late involvement of AM specialists [11,14].

Finally, organizations encounter challenges in maintaining an internal balance in environmental and product-related requirements during AM adoption. This includes the lack of

adequate infrastructure, material supply, and supporting tools to meet the specific requirements of AM [11,15].

These challenges vary across contexts. SMEs often face limited human resources and rely on external collaborations, while large organizations struggle with strategic alignment, managerial support, and coordination across divisions [7,16].

Despite these insights, most studies remain descriptive and fragmented, offering limited evidence on how challenges manifest in practice or how barriers emerge. Furthermore, the empirical base is narrow, often restricted to specific industries or regions [13,17], which limits the generalizability of findings.

2.2. Research framework

This study adopts a quantitative survey approach structured around a three-dimensional framework of challenges, barriers, and effects. The framework first examines how these dimensions interrelate across the full sample. Second, it combines these interrelationships with contextual factors such as size, industry, and region, enabling the derivation of context-specific success factors for the effective integration of AM in product development. Considering contextual factors is essential, as organizational conditions strongly influence the perception and impact of challenges and barriers.

By distinguishing challenges, barriers, and effects, the framework allows not only the identification of obstacles but also the tracing of their consequences and the derivation of actionable success factors.

To ensure clarity, the three dimensions are defined as follows: *Challenges* are understood as structural or strategic problems within an organization that hinder the adoption and use of AM [18]. *Barriers* refer to specific organizational, technical, or cultural impediments that block or delay the practical implementation of AM [17]. While challenges capture higher-level structural and strategic obstacles, barriers denote more specific difficulties encountered during operationalization and practice. *Effects* refer to the observable consequences that arise when challenges and barriers remain unresolved, such as delayed projects, restricted application, or underutilized innovation potential [15]. Although literature sometimes uses these terms interchangeably, this study applies them in a consistent, operational manner to ensure clarity.

This three-dimensional framework structures the analysis of the three research questions. RQ1 is addressed by identifying and prioritizing the challenges most critical to organizations adopting and using AM. RQ2 investigates the empirical interrelationships among challenges, barriers, and effects. RQ3 builds on these insights to derive context-specific success factors.

3. Research methodology

This study applies a quantitative survey design targeting experts and managers in organizations using AM. To ensure international relevance, the survey focused on countries listed in the *Wohlers Report 2024* as leading adopters of AM [19].

The questionnaire was structured into four parts: contextual and demographic information (e.g., size, industry sector, country), standardized items on challenges (first 4 items, Q3.1-

Q3.4), standardized items on barriers (17 items, Q4.1-Q4.17), and standardized items on effects (17 items, Q5.1-Q5.17). Items were measured on six-point Likert scales, chosen to avoid a neutral midpoint and to elicit clear directional responses. To maximize accessibility, the survey was provided in three languages (English, German, and Chinese) and remained open from May to August 2025. For clarity and reproducibility, the complete set of questionnaire items is provided in Appendix A Table 1.

Starting off the analysis, descriptive statistics were used to summarize organizational characteristics and response distributions (RQ1). This was followed by correlation analysis (Spearman's ρ) to examine associations between challenges, barriers, and effects. Next, hierarchical clustering was applied to group related items into broader categories (RQ2). Finally, k-means clustering was applied to derive organizational typologies, enabling the contextualization of findings and the identification of success factors (RQ3). As illustrated in Figure 1, the analytical design follows a stepwise structure in which each method addresses a specific research question while building on the previous results, ensuring a coherent link between RQ1, RQ2, and RQ3.

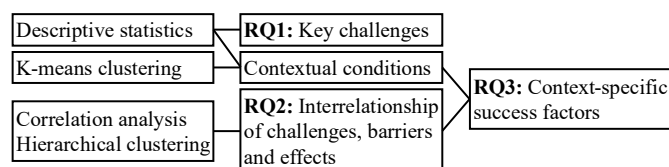


Fig. 1. Multi-stage analytical design.

4. Results

The results are reported in an exploratory manner, beginning with descriptive statistics before moving to interrelationships and success factors.

4.1. Descriptive statistics

The survey yielded 32 valid responses, of which 26 came from small and medium-sized enterprises (≤ 500 employees) and 6 from large organizations. Most respondents were based in Europe ($n = 19$), with additional cases from North America ($n = 8$), Asia ($n = 2$), and some indicating cross-regional operations (e.g., Europe and North America) ($n = 3$).

Respondents represented a range of organizational functions. Most frequently, participants worked in executive management ($n = 11$) or research and development or design ($n = 8$). Further responses included customer-facing roles such as marketing and sales ($n = 5$), as well as production and manufacturing ($n = 4$). Other functions, including process engineering ($n = 1$) and quality management ($n = 1$), were less frequently represented. In addition, two respondents participated as external consultants. This distribution highlights the strong presence of strategic and technical roles in the sample.

Respondents indicated their industrial sectors in open-ended form. For analysis, these were clustered into broader categories: Medical/Healthcare, Military/Security,

Consulting/Services, Systems/OEM, Materials/Processing, Automotive/Aerospace/Transport, Academic, Software, and General Manufacturing. This categorization illustrates the wide cross-sectoral relevance of AM across different domains.

In addition to demographic and contextual data, respondents indicated the AM-related activities of their organizations. As this question allowed multiple selections, the reported numbers do not sum to the total sample size. The most frequently reported business activity was AM prototyping ($n = 19$). Further responses included AM series production ($n = 17$), AM manufacturing services ($n = 17$), AM consulting ($n = 16$), AM product developer ($n = 16$), AM product development services ($n = 14$), AM training ($n = 12$), and AM system provider ($n = 6$). This distribution illustrates the diversity of roles represented in the dataset and shows that many organizations are active in multiple areas of the AM value chain.

With respect to the four challenge items (Q3), managing expectations (Q3.2) received the strongest agreement, with nearly 90% of respondents rating it critical, followed by process integration (Q3.3, ~78%). These two dimensions clearly represent the most pressing challenges in the sample. At the same time, mindset formation (Q3.1, ~72%) and balancing environmental requirements with product requirements (Q3.4, ~67%) also attracted substantial agreement, though with somewhat lower intensity. Taken together, this suggests that while expectation management and process integration are viewed as the dominant challenges, mindset and resource balance remain relevant organizational issues that cannot be neglected.

4.2. Correlation analysis

To analyze interrelationships among challenges, barriers, and effects, Spearman's rank correlations (ρ) were calculated on the ordinal Likert-type items [20]. This provided the empirical basis for RQ2.

The analysis revealed only a few strong direct associations between challenges and barriers or between challenges and effects, whereas numerous strong links emerged between barriers and effects. This pattern suggests that barriers mediate the relationship between high-level challenges and observable outcomes.

Among the strongest correlations ($|\rho| \geq .50$), process integration (Q3.3) was positively associated with missing AM success stories (Q4.1), which in turn was linked to postponed organizational changes, project termination, and non-approval of projects (Q5.4, Q5.8, Q5.11). Similarly, unclear objectives (Q4.2) and time pressure in day-to-day business (Q4.4) were associated with early project failures (Q5.8). In addition, a negative correlation between internal balance (Q3.4) and reliance on conventional methods (Q4.9) indicated that organizations struggling with internal alignment were more likely to persist with conventional manufacturing technologies rather than adopt AM.

Collectively, these exploratory findings suggest that challenges themselves show only limited direct associations with outcomes, while barriers may act as transmission mechanisms through which structural challenges manifest as observable organizational effects.

4.3. Hierarchical clustering

Hierarchical clustering was used to group barrier (Q4) and effect (Q5) items into broader and indicative clusters, applying Ward's method with squared Euclidean distance [21]. The silhouette coefficient supported a four-cluster solution for both barrier clusters and effect clusters (see Figure 2).

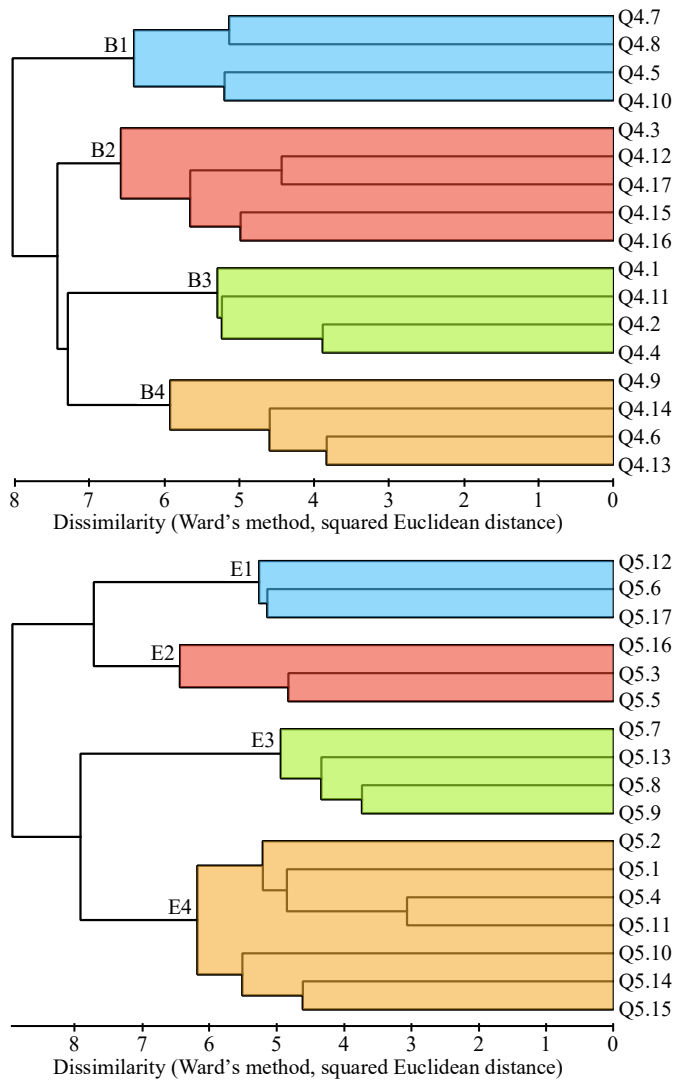


Fig. 2. Results of hierarchical clustering for barrier items (Q4, labeled as B1-B4) and effect items (Q5, labeled as E1-E4) using Ward's method (four-cluster solutions).

For *barriers*, four clusters emerged: (B1) capability-building barriers (insufficient training resources, high-effort learning, limited decision transparency), (B2) process and institutional barriers (unclear decision rules, misaligned infrastructure, missing validation standards), (B3) strategic and visibility barriers (lack of success stories, weak business cases, unclear communication), and (B4) organizational inertia barriers (persistence of conventional methods, limited collaboration, late expert involvement).

For *effects*, four clusters were revealed: (E1) design and innovation underutilization (products not leveraging AM, additional iteration cycles, untapped time-to-market potential), (E2) restricted application scope (reliance on prototyping,

limited use of metal AM, exclusion from regulated contexts), (E3) expertise and execution deficits (shortage of experts, late involvement, early project failures), and (E4) organizational and managerial effects (disagreement on AM goals, postponed change, non-approval, costly rework, knowledge loss, external dependency).

The barrier clusters (B1-B4) and effect clusters (E1-E4) reveal typical bundles of co-occurring issues, which directly inform the preventive and corrective success factors. For instance, capability and process barriers (B1, B2) align with preventive measures, while managerial and execution-related effects (E3, E4) highlight the need for corrective interventions.

Overall, the exploratory results indicate that barriers and effects tend to co-occur in bundled constellations. While not conclusive, these indicative patterns highlight the potential value of addressing them in an integrated manner. Given the limited sample size ($n = 32$), these clusters should be viewed as exploratory aspects that provide a basis for future validation with larger datasets.

4.4. K-means clustering

K-means clustering was applied to identify organizational typologies in the evaluation of challenges (Q3) and barriers (Q4). The optimal number of clusters was determined using silhouette scores, which consistently suggested a two-cluster solution ($k = 2$). For visualization, cluster membership was projected into two dimensions using principal component analysis (PCA), with the first and second principal components (PC1 and PC2) plotted as the x- and y-axes (see Figure 3) [22]. This procedure enabled the derivation of organization types. The 32 samples are represented by U1-U32 in Figure 3.

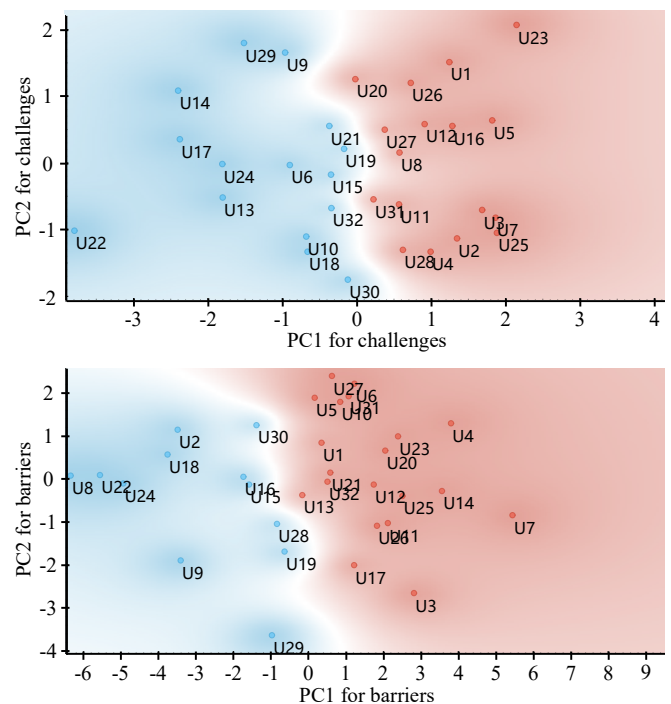


Fig. 3. K-means clustering of challenge items (Q3) on the top and barrier items (Q4) on the bottom, visualized in PCA space; Axes represent the first two principal components (PC1 and PC2) derived from the barrier dataset; $k = 2$; blue = Cluster 1, red = Cluster 2.

For challenges, two groups emerged: Cluster 1 (blue, 15 cases) comprised organizations that rated challenges lower overall, indicating comparatively few perceived restrictions; Cluster 2 (red, 17 cases) included those that rated challenges higher, reflecting greater sensitivity to adoption difficulties.

4.5. Context-specific success factors

Combining the clustering results with demographic variables revealed several indicative patterns that can be linked to two types of organizations. High-perception organizations recognize AM challenges clearly (Fig. 3, Cluster 2), whereas low-perception organizations do not (Fig. 3, Cluster 1):

- SMEs were more often in the high-perception cluster than large firms, indicating greater awareness of AM challenges. High-perception organizations report more obstacles due to maturity or prior difficulties, while low-perception ones, often at an early stage, perceive fewer constraints and may underestimate latent issues.
- Industry differences showed that AM service and consulting firms were almost exclusively high-perception. This may reflect their exposure to clients struggling with AM integration, which provides them with a broader view of recurring obstacles and barriers compared to firms focused solely on internal adoption. Manufacturing and engineering firms were evenly split between the two clusters, which may reflect sectoral heterogeneity and differing maturity levels: some firms appear to underestimate adoption obstacles, while others encounter them more directly depending on size, resources, and application context.
- Regional variation revealed a particularly noteworthy pattern: European organizations predominantly appeared in the high-perception cluster across both Q3- and Q4-based solutions, whereas North American organizations clustered in the low-perception group when challenges (Q3) were considered, but shifted to the high-perception group when barriers (Q4) were analyzed. This indicates that North American organizations may underestimate broad strategic challenges while being more sensitive to specific organizational and technical barriers.

Other demographic factors could not be meaningfully interpreted due to limited subsample sizes.

Building on the findings from hierarchical clustering, success factors can be derived for two distinct contextual patterns of organizations:

Organizations with a low perception of challenges and barriers tend to be at an early stage of AM adoption. Their ratings suggest that many obstacles are not yet recognized, which creates the risk of underestimating latent problems. For such organizations, success factors are primarily preventive.

- On the organizational-strategic side, it is important to raise awareness by clarifying AM goals, developing convincing business cases, and communicating internal success stories. These measures reduce the likelihood of strategic underutilization effects such as project non-approval or postponed organizational change.

- On the technical-infrastructure side, capability building is essential. Targeted training programs, early pilot projects, and timely involvement of AM experts can prepare the organization for advanced applications, thereby preventing operational inefficiencies such as aborted projects or costly rework.

Organizations with a high perception of challenges and barriers are already confronted with multiple co-occurring obstacles and report substantial negative effects. For these organizations, success factors should be corrective, focusing on overcoming entrenched barriers and mitigating observed outcomes.

- On the organizational-strategic side, success may depend on fostering cross-departmental collaboration, defining clear decision points for AM, and ensuring early expert involvement. These steps directly counteract strategic underutilization effects such as project rejection and unexploited innovation potential.
- On the technical-infrastructure side, investments in infrastructure, the establishment of validation and certification procedures, and systematic knowledge management are critical. Such measures help address capability and infrastructure deficits while reducing operational inefficiencies like rework and premature project termination.

Overall, these findings suggest that effective success factors are context dependent. Organizations with low perceptions benefit most from preventive awareness- and capability-building, while those with high perceptions require corrective integration across organizational and technical domains. Importantly, barriers and effects tend to occur in bundled constellations rather than isolation, suggesting that success factors must target systemic sets of co-occurring obstacles rather than single issues. These findings should be interpreted as exploratory, context-specific patterns derived from this dataset rather than universal prescriptions.

5. Conclusion

This study analyzed the challenges, barriers, and effects of AM adoption in product development and derived context-specific success factors. Descriptive results show that managing expectations and process integration are perceived as the most critical challenges. Correlation and clustering analyses indicate that barriers and effects occur in bundled constellations. Moreover, the distinction between low- and high-perception organizations demonstrates that success factors are context-dependent.

Although the individual responses are not novel due to the predefined survey items, the study contributes by revealing new patterns in how challenges, barriers, and effects interrelate, offering an exploratory lens on AM organizations. It further introduces a preventive-corrective logic of success factors, providing hypothesis-generating insights for research and indicative guidance for practice. These findings are exploratory and context-specific, and future studies with larger and more

diverse samples are needed to validate and refine the identified patterns. Despite limitations in sample size and regional scope, the approach offers a structured foundation for subsequent longitudinal and large-scale investigations.

Appendix A. Questionnaire items

Table 1. Overview of survey items (Q3-Q5, shortened wording). Items are presented in shortened wording. The questionnaire is available upon request.

Q	Type	Content	Mdn.
3.1	Challenge	Establishing AM mindset	4
3.2	Challenge	Managing realistic expectations	4
3.3	Challenge	Integration into processes	4
3.4	Challenge	Balancing environmental requirements vs. product requirements	3
4.1	Barrier	Missing AM success stories	3
4.2	Barrier	Unclear AM objectives	4
4.3	Barrier	Benefits prototyping vs. series unclear	3
4.4	Barrier	Lack of time in daily business	4
4.5	Barrier	Reluctance toward metal AM	4
4.6	Barrier	AM potentials and limits not recognized	5
4.7	Barrier	Lack of AM training resources	4
4.8	Barrier	Iterative learning process required	3
4.9	Barrier	Existing methods focus on conventional manufacturing	5
4.10	Barrier	AM decisions not comprehensible	4
4.11	Barrier	Missing business case	4
4.12	Barrier	Unclear decision timing for AM	4
4.13	Barrier	Late involvement of AM experts	5
4.14	Barrier	Lack of cross-department collaboration	4
4.15	Barrier	Infrastructure not aligned with AM	3
4.16	Barrier	Missing validation/certification procedures	4
4.17	Barrier	Rare use for minimum viable or market-ready products	3
5.1	Effect	Added value of AM questioned	3
5.2	Effect	Departments disagree on AM goals	3
5.3	Effect	AM primarily used for prototyping	3
5.4	Effect	Transition to AM postponed	3
5.5	Effect	Metal AM is rarely used in series production	4
5.6	Effect	Designs not leveraging AM possibilities	5
5.7	Effect	Lack of qualified AM experts	3
5.8	Effect	AM projects abandoned after failures	3
5.9	Effect	AM not considered in early development	5
5.10	Effect	Late design changes require rework	3
5.11	Effect	AM projects not approved	3
5.12	Effect	Extra iterations between dev & production	4
5.13	Effect	Experts involved too late	4
5.14	Effect	Knowledge from AM projects lost	3
5.15	Effect	Dependence on external partners	4
5.16	Effect	AM not used in regulated applications	5
5.17	Effect	Innovation potential and time-to-market unused	4

References

- [1] Gibson I, Rosen D, Stucker B, Khorasani M. Additive Manufacturing Technologies. 3rd ed. Cham: Springer; 2021.
- [2] Kellens K, Baumanns M, Gutowski TG, Flanagan W, Lifset R, Duflou JR. Environmental Dimensions of Additive Manufacturing: Mapping Application Domains and Their Environmental Implications. *Journal of Industrial Ecology* 2001;21:S49-S68.
- [3] Rayna T, Striukova L. From rapid prototyping to home fabrication: How 3D printing is changing business model innovation. *Technological Forecasting and Social Change* 2016;102:214-224.
- [4] Gao W, Zhang Y, Ramanujan D, Ramani K, Chen Y, Williams CB, Wang CCL, Shin YC, Zhang S, Zavattieri PD. The status, challenges, and future of additive manufacturing in engineering. *Computer-Aided Design* 2015;69:65-89.
- [5] Colosimo BM, Huang Q, Dasgupta T, Tsung F. Opportunities and challenges of quality engineering for additive manufacturing 2018;50:3.
- [6] Scott J, Gupta N, Weber C, Newsome S, Wohlers T, Caffrey T. Additive Manufacturing: Status and Opportunities. Washington: Science and Technology Policy Institute; 2012.
- [7] Omidvarkarjan D, Rosenbauer R, Klahn C, Meboldt M. Implementation of Additive Manufacturing in Industry. In: Pei E, Bernard A, Gu D, Klahn C, Monzón M, Petersen M, Sun T, editors. *Springer Handbook of Additive Manufacturing*. Cham: Springer International Publishing; 2023. p. 55-71.
- [8] Chekurov S, Metsä-Kortelainen S, Salmi M, Roda I, Jussila A. The perceived value of additively manufactured digital spare parts in industry: An empirical investigation. *International Journal of Production Economics* 2018;205:87-97.
- [9] Ford S, Despeisse M. Additive manufacturing and sustainability: an exploratory study of the advantages and challenges. *Journal of Cleaner Production* 2016;137:1573-1587.
- [10] Günther FJ, Tüzün G, Kreimeyer M, Koch A. Current challenges in the development of products for additive manufacturing - an interview study. *Proceedings of the Design Society* 5; 2025. p. 1061-1070.
- [11] Brahma A, Hajali T, Mallalieu A, Isaksson O. A risk analysis method for implementation of additive manufacturing. *Journal of Engineering Design*.
- [12] Gustafsson C, Sannö A, Bruch J, Chirumalla K. Exploring Challenges in the Integration of Additive Manufacturing. In: Kim DY, von Cieminski G; Romero D, editors. *Proceedings of APMS: Turning Ideas into Action*. Cham:Springer; 2022. p. 370-379.
- [13] Martinsuo M, Luomaranta T. Adopting additive manufacturing in SMEs: exploring the challenges and solutions. *Journal of Manufacturing Technology Management* 2018;29-6:937-957.
- [14] Gustafsson C, Sannö A, Chirumalla K, Bruch J. Integration of Additive Manufacturing in an Industrial Setting: The Impact on Operational Capabilities. In: Alfnes E, Romsdal A, Strandhagen JO, von Cieminski G, Romero D, editors. *Proceedings of APMS*. Cham: Springer; 2023. p. 590-604.
- [15] Rylands B, Böhme T, Gorkin R, Fan J, Birtchnell T. The adoption process and impact of additive manufacturing on manufacturing systems. *Journal of Manufacturing Technology Management* 2016;27-7:969-989.
- [16] Conner BP, Manogharan GP, Meyers KL. An assessment of implementation of entry-level 3D printers from the perspective of small businesses. *Mechanical Engineering* 2015;21-5:582-597.
- [17] Thomas-Seale L, Kirkman-Brown JC, Attallah MM, Espino DM, Shepherd D. The barriers to the progression of additive manufacture: Perspectives from UK industry. *International Journal of Production Economics* 2018;198.
- [18] Tidd J, Bessant J. Managing Innovation Integrating Technological, Market and Organizational Change. In: Giannattasio G, Kongar E, Dabić M, Desmond C, Condry M, Koushik S, Saracco R, editors. *TEMSBOK*. New Jersey: Wiley; 2023. p. 97-108.
- [19] Wohlers T, Diegel O, Kowen J. Wohlers Report 2024: 3D Printing and Additive Manufacturing: Global State of the Industry. Fort Collins: Wohlers Associates; 2024.
- [20] Boone Jr HN, Boone DA. Analyzing Likert Data. *Journal of Extension* 2012;50-2.
- [21] Murtagh F, Contreras P. Algorithms for hierarchical clustering: an overview. *WIREs Data Mining Knowledge Discovery* 2012; 2:86-97.
- [22] Wu J. *Advances in K-means Clustering*. Berlin: Springer; 2012.