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ADDITIVE MANUFACTURING AND MASS CUSTOMIZATION: SOME KEY EXAMPLES TO REFLECT ON

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Abstract*: Additive manufacturing (AM) has been evolving rapidly in the last decade and captivated the imagination of the industry and academia. Currently AM is widely seen in scientific literature as enabler for mass customized manufacturing. However, the research on why this is the case is still lacking. This research explores this "why" by analyzing exemplary cases. Results show that there are MC applications in which AM competes with conventional manufacturing and presents some explanatory mechanisms. The research provides a fine-grained understanding on the impact of AM on MC capability that can be used by researchers and practitioners.*

Key words: Additive manufacturing, 3D printing, Digital manufacturing, Industry 4.0, Mass customization

1. INTRODUCTION

The ever-changing consumer desire [1] and the increasing competition among industries along with the emergence of more advanced and flexible manufacturing technologies [2] made mass customization (MC) one of highly important business competitive strategies [3;5]. MC represents an ability of the enterprise to fulfil the idiosyncratic needs of every customer without compromising cost, quality, and delivery speed [4]. MC has been around since late 1980s [5] and different companies used it to increase their market share, customer satisfaction and overall business profitability [6].

Following the emergence of Industry 4.0 paradigm, Additive manufacturing (AM), alternatively called 3D printing, has evolved rapidly in recent years, and captivated the imagination of both industry and academia. It is recognized as one of the industry 4.0 enabling technologies [7]. The capability of realizing individually customized product variety with complex geometries without increasing costs, resulted in fast development of AM and made it a preferable choice of MC manufacturers [8].

Currently AM is widely seen as an Industry 4.0 technology that enables MC and will have even bigger role in the near future [7–12]. On the contrary,[13] the practical barriers and limitations in using AM for MC are much less addressed.

Currently very few industries are using AM for MC [14] while many more practitioners are investigating AM to incorporate in their companies [15]. We acknowledge the AM technology potential in enabling MC manufacturing. However, most of the research in the field justify the applicability of AM for MC by considering only its capability related to the freedom of designing products in any shapes which lack the full investigation of AM technology capabilities and contributions in promoting and supporting MC strategy.

Hence, using an inductive literature review, the present research aims to explore and justify why AM enables MC by analyzing and illustrating some mechanisms through which AM supports MC with the help of case examples. The present research will provide an insight for academics and practitioners for a more fine-grained analysis and understanding of the impact of AM on MC capability.

The remaining part of this paper is organized in four sections. Section 2 gives some highlights on the methodology employed to do the research. Section 3, the theoretical background part provides information on the evolution of the manufacturing paradigm, AM, MC and available customization options for users in the AM era. AM capabilities that support MC are presented in the result section. Moreover, case examples are presented to illustrate the applicability of AM for MC. Finally, the paper concludes with the applicability of AM for MC.

2. METHODOLOGY

The present research work is intended to be an initial step of a longer path to unveil how, why and when AM support MC. We started considering academic and practitioner literature focused on both AM and MC to position our work on existing knowledge. We looked at various company web sites, which are focused on AM technology and products manufactured through AM to get further examples and information. Subsequently we selected some exemplary cases to dig deeper on why AM enables MC and to illustrate some of these whys. In this paper we report the analysis based on selected case-based examples from different AM technology application areas and justify the impact of the technology unique capabilities on production of mass customized products.

3. THEORETICAL BACKGROUND

3.1. Evolution of the manufacturing environment

Since 1880s, the manufacturing sector has passed through different revolutions. It had gradual improvements in terms of working principles and capabilities. The manufacturing went through four revolutions particularly considering energy source, production volume capability, and evolvement of flexible manufacturing technologies [16–18]. The 4th industrial revolution is enabled by different technologies and working systems of which AM play significant role in the realization of smart manufacturing [17]. During this period where Internet of Things (IoT) and advanced digital technologies are extremely enabled, MC has advanced to real-time customization [19].

Koren [20] identified four paradigms of manufacturing primary considering the enablers, principles and business models. Figure 1 depicts these manufacturing paradigm transitions as developed by Koren [20] and latter modified by Siemens [21]. It shows the relation between product variety and volume of production per product model with respect to the paradigm and technology used. Thus, according to [20] and [21] the craft production paradigm, which was focused on the production of one product at a time based on the individual customer needs using general purpose machines, is to be used for customization in a grand scale with the help of more flexible manufacturing technologies like AM without considerable trade-off between customization and operation performance. MC, which has been there since in 1980s, is evolving with more enabling technologies to achieve companies' competitiveness goal trough personalized product offer.

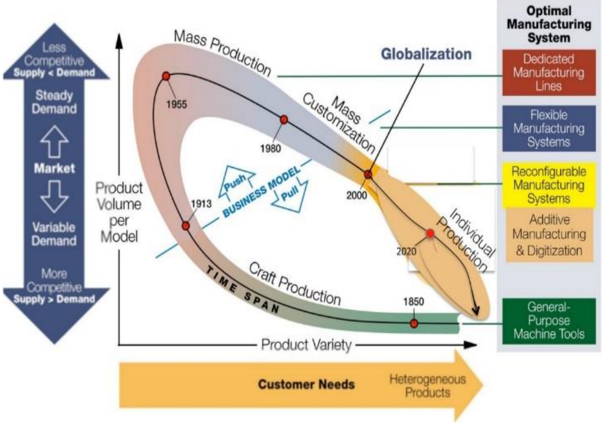


Fig.1. *Main paradigms of manufacturing* [20-21]

3.2. Mass Customization

Tough competition is one of the challenges that all manufacturing industries are facing. Therefore, companies have to do something unique to stand apart from the competition. One of the differentiation strategies is to give product customization options for their customers [22]. However, provision of a customized product based on individual customer idiosyncratic needs conflicts with economics of scale promoted in mass production. In other words, customization is not free [23]. MC is an enterprise capability that aims to provide a customized product or service with best value, speed and quality as compared with standardized product offerings [23]. To overcome the trade-off between customization and operation performance, in addition to flexible manufacturing technologies, literature has addressed different techniques and approaches as enablers for MC [24]. Among these, modularity [23] primarily for cost minimization, form postponement for facilitating early delivery and product configurator options to satisfy customer needs can be applied. Salvador et al. [25] formulated solution space development, robust process design and choice navigation are the three common capabilities that a company should have to successfully implement MC. The recent advancement of manufacturing technologies like AM, has changed the way products are designed and manufactured [11] which could provide more MC capability primarily by busting robust process design capability and by providing infinite solution space for the customers.

3.3. Additive Manufacturing

AM alternatively called 3D printing or free form fabrication technology is used to produce prototypes, components, and end-use items by addition of materials layer by layer from digital 3D model which simultaneously defines objects geometry and gives the potential to fabricate products almost with any geometric shape [8]. During the first years of existence the AM was primarily used in prototyping and was synonymous with rapid prototyping [14]. Following the expiration of the patents of some of fused deposition modelling (FDM) and selective laser sintering (SLS) technologies in 2009 and 2014 respectively, the accessibility and affordability of AM technologies significantly increased along with the increase in the number of application and parts fabricated [26-27].

There are different types of AM technologies being used in fabricating 3D objects. The AM technologies can be categorized based on the form of raw material being used and/or material bonding principle [27]. The AM can be liquid based, solid based or powder based. The currently available AM technology can use polymers, composites, metals, wood, wax, ceramic, gypsum, and sand as a raw material to fabricate parts with different mechanical properties and shapes. The technology may also use laser, adhesives, heat, electron beam and other binding agents to bond the materials together during printing/manufacturing. The selection of the technology can be based on cost, material used, surface finish requirements, dimensional accuracy, post processing requirements and dimensional accuracy and processing speed. An increasing research worldwide is expected to lead to a transition of the traditional manufacturing towards AM method in near future [8].

3.4. Customization options in AM environment

AM capability to produce a product with any geometry by giving almost unlimited freedom of design without cost penalty makes AM preferable by many MC companies [26]. In addition providing customers with more design freedom on their preference influence customers purchase intension [28]. During the era of conventional manufacturing, designers were forced to alter the design based on manufacturing capability rather than optimal design. The advancement of AM has lifted those constraints and supports enterprises capability to fabricate highly customized products with optimal design [29].

From the customer viewpoint, value is attained through customization due to the options available in the solution space where the product can be modified to a specific need [30]. A customer may customize a product by differentiating the fit (body measurements), the functionality, and the form (style and aesthetic design) of an offering. Better fit is identified as one of the strongest arguments in favor of MC. However, gathering the customers' measurements and transferring the data to a real product is a challenge, which is now solved with the coordinated application of 3D printers and 3D scanners.

Generally, AM gives customers the opportunity to have almost infinite number of aesthetic and functional feature customization options based on physical geometry, shape of an object, material type, AM process type, micro level product structure, product topology, color etc.

AM is being preferred in fabricating customized bespoke products (Fig. 2) which are unique for a specific customer with affordable price and considerable timing [27].

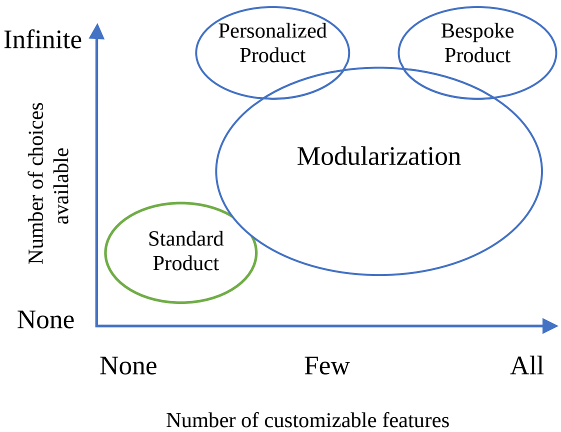


Fig. 2. *Degree of Customization* [31]

AM also gives manufacturers an ability to generate and fabricate parts with engineered materials with composition gradients, microstructures and properties that could not be made in the traditional material synthesis techniques [32]. Different materials may be mixed while printing to create a unique alloy.

AM plays significant role in realizing highly customized product designs across diverse fields based on ergonomics, which aims a safe, comfortable, and efficient products based on physical and human-machine interactions [27]. These ergonomic designs are being successfully implemented including medicine, developing assistive, and wearable technologies [33]. By enabling user involvement in the earlier stage of product design, AM can facilitate enhanced MC.

Fig. 3. *AM process flow*

A customer can bring his own product idea, available 2D drawing of product, or 3D object to be scanned and converted to a 3D CAD model appropriate of the printers. The general flow process of AM is depicted in the Fig.3.

4. RESULTS

Several articles present the relative freedom in designing products manufactured in AM as a key factor in justifying the AM enabling capability for MC. However, there are many other capabilities of AM, which support and facilitate MC. This part of the paper presents these capabilities of AM technology and mechanisms of impact on MC. Moreover, case examples are presented to illustrate AM capabilities and impact on MC.

4.1. AM capabilities and contributions to MC

AM has brought unique manufacturing capabilities that could not be possible with the conventional manufacturing. These capabilities create new opportunity for MC manufacturers through improved functionality and performance without increasing overall manufacturing costs [34]. AM helps companies to provide wider solution space without a need for extra cost while customers can fulfil their unique requirements. Moreover, the following major capabilities of AM technology are facilitating MC through cost reduction, part performance improvement and short delivery for a customized product.

- Capability to print multiple parts fused (part consolidation) [35]
- Capability to build a preassembled product where complex assembly is required with conventional manufacturing [15, 35]
- Capability to fabricate user specific objects based on individuals physical geometry [27] [32]
- Capability to produce complex geometries [36]

- Capability to optimize a product at macro and micro level [27, 34]
- Capability to avoid finished goods inventory [38]
- Capability to fabricate without tools and fixtures [35]

Integrated pars significantly improve performance where light weight parts are required. Moreover, it will help manufacturers to reduce the number of inventories, and material consumption which have direct impact on cost. In addition to reducing the wait of parts by avoiding fasteners, fabricating parts assembled could reduce assembly time and cost related to labor and material. Custom-fit and complex shape manufacturing capability of AM improves customer comfort and overall satisfaction. Optimizing a product topology and lattice structures significantly reduce material consumption and part weight. The different lattice structure designs provide different mechanicals properties as per the needs of customers. Replacing physical inventories by digital ones reduce inventory holding costs and risks related to part obsolescence. Moreover, AM facilitates rapid prototyping and cheaper molds[39] to speed up production for plastic injection molding, where mold making is an expensive and time taking process. Hence AM also indirectly supports MC through customized injection molding process.

4.2. Examples demonstrating applicability of AM in MC

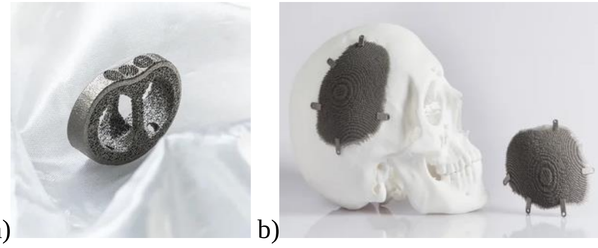
Aerospace and automotive, healthcare and medicine, fashion and jewelry, construction, and food industries are some of the sectors where AM has been successfully applied. The healthcare, jewelry, and other consumer goods like toys, gadgets, arts, and home decors are the early adopters and matured industries in using the technology for MC. This section presents examples demonstrating application of AM in MC identified from literature and websites in which, AM is used as a value adding technology with improved functionality, reduced time, and costs.

4.2.1. Healthcare

Implants

Patients with physical injuries require personalized treatments based on their anatomical data. Developing and manufacturing of a precise fit implant with proper stability, thermal conductivity and porosity was a challenge in the past. The conventional methods to produce patient specific implants are very complicated, costly, and time-consuming processes. It takes up to 6 weeks to make a customized implant ready for use [33]. Thus, any time saved during the process is critical for the patients' quality of life.

Figure 4 shows additively manufactured spinal and cranial implants used for spinal and skull injury from high quality medically compatible materials (e.g., titanium) directly from CAD data collected and prepared based on the wearers' anatomy using 3D scanners in a single production step. This process cuts waiting time from 6 weeks to 10 or less days [33]. At the same time, since the product is almost completely produced by the 3D printer, the cost of labor for manually crafting the product is significantly reduced. Furthermore, the production is performed up on request, which helps hospitals and health facilities to save costs related to storage and sterilization.



a) b)

Fig. 4. *a) Spinal implant b) Cranial implant*
(Source: EOS GmbH)

The customized and 3D printed cranial implant (Fig. 4b) made of a biocompatible titanium alloy results in a highly stable, porous and low degree of heat dissipation into the cranial cavity. The lattice structure customization also helps the implant to support the in-growth of bone tissue. AM enables greater variety of implants including shoulder joints, hip implants and implants for oral and maxillofacial surgery and help to avoid complications and speed up the healing process in cost effective manner.

Orthoses/ prostheses

Orthoses and prostheses are any artificial devices that are individually prescribed, fabricated, and fitted to reestablish the function of a damaged or missed part of a body according to the patient's anatomy and therapeutic needs. The devices are not readily available. The traditional manufacturing of the parts through casting, forming, modelling, and milling is time consuming and costly which has also limited capability due to material wall thickness [33]. Moreover, these process forces parts to be produced disintegrated which leads to time consuming assembly process and increased manufacturing cost.

AM processing of these parts starts with high resolution 3D scanning technology which is used to collect anatomical data of the patient which speeds up the design and fabrication process. Figure 5 shows foot prostheses made from carbon fiber material which is extremely strong, light weight, and thinner than the conventional methods of manufacturing. In addition to the strength and the light weight of these prostheses, the patient is also get easier to fit beneath clothing. Study also shows walking distance of those patients with additively manufactured foot prostheses with carbon fiber prostheses has doubled [33].

AM makes the manufacturing process short and cost effective especially for children as they grow quickly which needs the part to be changed frequently with the same functionality and structure. This can be achieved in an efficient way by scaling up the design to the appropriate size without spending time and cost for the redesign of the orthoses/protheses device.

Fig.5. *Foot prostheses*
(Source: EOS GmbH)

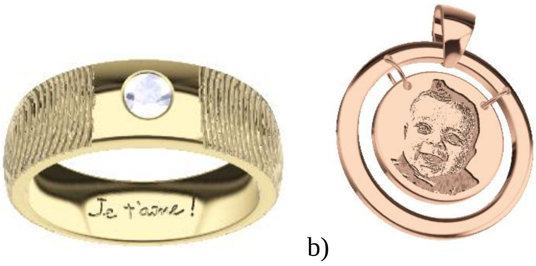
4.2.2. Other Consumer goods

Jewelry

Most jewelry is being bought to express emotion which could help companies to make more money. The lost wax casting, which is used for long time is the commonly used manufacturing technique in jewelry companies.

The jewelry industry is one of the sectors which is revolutionized by 3D printing by allowing customers to design a jewelry which they imagine. As lost wax casting is the best technique to produce a customized jewelry, Vowsmith leveraged 3D printing to produce high resolution customized wax patterns to produce highly customized jewelries which were unable to be realized with traditional manufacturing.

Vowsmith, an e-business company provides customers a wider available jewelry options including couples to customize and purchase their wedding rings (Fig. 6a) based on the type of material, colors, fingerprints, photograph, and name engravings of their beloved ones and help them to create something unique based on their interest and budget. The company uses the 2500 W printer supplied by 3D Systems, a machine that, provides the highest level of crisp details with and yield in real paraffin wax which can compete with mass production. During production there is no time waste either to remove support structures or repairing broken support surfaces. The high-resolution wax patterns can be burned out completely at low temperatures within short time. This helps the company to save energy and increase productivity. The company has no inventory produced, moved, and stored before consumption which leads considerable cost saving.



a) b)

Fig. 6. *a) Customized ring b) customized pendant*
(Source: Vowsmith)

The traditional lost wax manufacturing techniques leads to excessive labor cost and time consuming while engraving the wax pattern by hand. Moreover, the patterns are poor in precision and fit to the customer. In addition to providing customers with infinite options, the cost reduction, high yield makes 3D printing ideal for MC in jewelry industry. Vowsmith is capable of producing 35 to 40 rings per print run and expects to sell between 4,000 to 5,000 rings annually [40].

Lighting

I.materialise is a company which provides an online printing service, and also provides an online 3D printing service for several jewelries, arts, fashions, gadgets, games, home decors etc. It allows customers to select an item from the alternatives with customizable materials and sizes or to upload their own design to be printed. The customized causeway lampshade (Fig. 7a) is constructed by a random arrangement of overlapping hexagonal tubes, giving a pleasing range of textures when illuminated. Lamps like the one shown in Fig. 7b are directly printed based on customer designs and delivered in most 15 days to the customer's home.

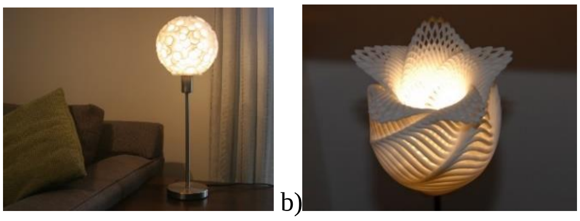
a)  b)

Fig. 7. *a) causeway lampshade b) equations lamp*
(Source: I.materialize N.V.)

Bicycle

Because of the crucial interaction between the cyclist and the saddle during the race, a custom-fit saddle (Fig. 8) is very important for the cyclist performance and comfort. In the previous times, finding perfectly customized seat was a big challenge. AM gives companies the ability to design paddings with seamlessly engineered zonal cushioning which can improve the rider comfort and performance without the constraints or limitations imposed by traditional production methods and materials.

Fig. 8. *Customized bicycle saddle*
(Source: Recreus Industries)

The process begins with a scan of the rider bone structure and biodynamic features to generate a pressure map, indicating the precise mass and pressure distribution applied to the saddle by the individual. Thus, based on the pressure map result the perfect-fit saddle design, which is then digitally created and optimized design including bespoke lattice design to absorb impact and improve stability is prepared for 3D printing. The result is a perfectly individualized saddle structure that optimally distributes bone and muscle pressure, maximizing rider comfort. The 3D printed lattice structure improves performance of the existing foam materials by making the seat more breathable. The mass production of bike seats may be cheaper but at the expense of high standardization.

4.2.3. Mechanical components and spare parts

AM allows companies engaged in providing 3D printing services by enabling customers to customize and deliver orders of any mechanical components and spare parts without significant trade-off in variety and operating performance. This is also quite important for original equipment manufacturers and maintenance, repair, and operation (MRO) service providers.

The aerospace and automotive industries at the moment benefit the most from AM, particularly through improving performance of components. Ability to customize micro cellular structures (Fig.10a), integrate parts (Fig. 11b) and topology optimization of the part (Fig. 10b) means AM plays significant role in aerospace and automotive industry.

Aerospace

3D printing technology by EOS helps Airbus to build a more cost- and resource-efficient aircraft. The part integration capability of AM helps the Airbus company on making locking shaft (Fig. 9) for its aircraft doors to reduce weight by 45%, costs savings by 25% and number of parts are reduced from 10 to one which results in significant cost and time reduction during the assembling process. An aircraft needs 4 of these components resulting a reduction of 4 kg in total. Weight reduction is critical in aerospace industry as it is directly related with fuel consumption. The process of storing spare parts, which currently ties up a lot of capital, is also becoming obsolete. Materials used for fasteners are avoided, cost and time for assembling the components is significantly reduced

a)  b) 

Fig.9. *Locking shaft for aircraft doors a) conventionally manufactured b) Additively manufactured*
(Source: EOS GmbH)

A 3D printed satellite antenna mount with optimized topology (Fig. 10b) exceeds stiffness requirement by 30% while weight is reduced by 40% which costs a satellite space mission over 20,000 Euro per kilogram. AM performance simultaneously helps to save costs of raw material and assembly cost. The toolless production also facilitates the part with short possible time compared with conventional manufacturing which requires expensive mold and setups.

a)  b) 

Fig. 10. a) *light weight break pedal b) satellite bracket*
(Source: EOS GmbH)

Automotive

Axile-pivot (Fig. 11) is an automobile part which connects the wheel axle with the wishbones and the track rod via a bearing. AM helps reducing the weight of the part by 660 grams (about 35 %). At the same time the engineers succeeded in increasing the rigidity by 20% which is significant for motorsports. This translates into faster lap times and reduced fuel consumption

Fig. 11. *3D printed Axile-pivot*
(Source: EOS GmbH)

5. CONCLUSION

The design freedom gained from AM at the macro and micro level for a customized part provides a variety of aesthetic, functional, economic, emotional, and ergonomic benefits. AM is being used to produce a wide variety of personalized and bespoke products. The minimization of manual activities in producing customized products along with the growing capabilities of 3D printers and 3D scanners cut the manufacturing time and cost. Specially for customized parts which require infinite variations based on individuals' physical geometry, AM play significant role in avoiding constraints and limitations of traditional manufacturing process.

Most of the time the cost of AM is viewed as one of the main barriers to be adopted in the industry. However, there are many demonstrations where the value added by AM outweighs the investment costs for the technology. Moreover, the speed and product size restrictions are also raised as a limitation of the technology to use it for MC. The current technology is successful in producing customized small size objects like hearing aids and jewelries in mass. The recently developed and commercialized 12 laser 3D printer by SLM Solutions brought a radical shift of the technology towards mass production of small to large size metallic products. However, still there are some limitations of AM for applying in every sector for MC. AM could not produce all parts in a cost-effective manner, which drives for a better understanding of when, why, and how to exploit the opportunities and consider the constraints associated with the technology.

6. REFERENCES

[1] J. Miguel Villas-Boas, 'A short survey on switching costs and dynamic competition', *International Journal of Research in Marketing*, vol. 32, no. 2, pp. 219–222, 2015.

[2] X. Yao and Y. Lin, 'Emerging manufacturing paradigm shifts for the incoming industrial revolution', *International Journal of Advanced Manufacturing Technology*, vol. 85, no. 5–8, pp. 1665–1676, 2016.

[3] S. Kotha, 'Mass customization: implementing the emerging paradigm for competitive advantage', *Long Range Planning*, vol. 28, no. 6, p. 124, 1995..

[4] A. Trentin, C. Forza, and E. Perin, 'Organisation

design strategies for mass customisation: An information-processing-view perspective', *International Journal of Production Research*, vol. 50, no. 14, pp. 3860–3877, 2012.

[5] G. Da Silveira, D. Borenstein, and F. S. Fogliatto, 'Mass customization: Literature review and research directions', *International Journal of Production Economics*, vol. 72, no. 1, pp. 1–13, 2001.

[6] R. S. Selladurai, 'Mass customization in operations management: Oxymoron or reality?', *Omega*, vol. 32, no. 4, pp. 295–300, 2004.

[7] S. Devi K, K. P. Paranitharan, and I. Agniveesh A, 'Interpretive framework by analysing the enablers for implementation of Industry 4.0: an ISM approach', *Total Quality Management and Business Excellence*, vol. 32, no. 13–14, pp. 1494–1514, 2021.

[8] T. D. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, and D. Hui, 'Additive manufacturing (3D printing): A review of materials, methods, applications and challenges', *Composites Part B: Engineering*, vol. 143, no. February, pp. 172–196, 2018.

[9] C. Schubert, M. C. Van Langeveld, and L. A. Donoso, 'Innovations in 3D printing: A 3D overview from optics to organs', *British Journal of Ophthalmology*, vol. 98, no. 2, pp. 159–161, 2014.

[10] T. Ellena, H. Mustafa, A. Subic, and T. Y. Pang, 'A design framework for the mass customisation of custom-fit bicycle helmet models', *International Journal of Industrial Ergonomics*, vol. 64, pp. 122–133, 2018.

[11] D. Deradjat and T. Minshall, 'Implementation of rapid manufacturing for mass customisation', *Journal of Manufacturing Technology Management*, vol. 28, no. 1, pp. 95–121, 2017.

[12] J. Woodburn, J. H. P. Pallari, K. W. Dalgarno, and J. Woodburn, 'Mass Customization of Foot Orthoses for Rheumatoid Arthritis Using Selective Laser Mass Customization of Foot Orthoses for Rheumatoid Arthritis Using Selective Laser Sintering', *IEEE Transactions on Biomedical Engineering*, vol. 57, no. September, pp. 1750–1756, 2016.

[13] M. Shukla, I. Todorov, and D. Kapletia, 'Application of additive manufacturing for mass customisation: understanding the interaction of critical barriers', *Production Planning and Control*, vol. 29, no. 10, pp. 814–825, 2018.

[14] D. Deradjat and T. Minshall, 'Decision trees for implementing rapid manufacturing for mass customisation', *CIRP Journal of Manufacturing Science and Technology*, vol. 23, pp. 156–171, 2018.

[15] J. W. Booth, J. Alperovich, P. Chawla, J. Ma, T. N. Reid, and K. Ramani, 'The design for additive manufacturing worksheet', *Journal of Mechanical Design, Transactions of the ASME*, vol. 139, no. 10, pp. 1–9, 2017.

[16] L. Da Xu, E. L. Xu, and L. Li, 'Industry 4.0: State of the art and future trends', *International Journal of Production Research*, vol. 56, no. 8, pp. 2941–2962, 2018.

[17] B. Bajic, A. Rikalovic, N. Suzic, and V. Piuri, 'Industry 4 . 0 Implementation Challenges and Opportunities : A Managerial Perspective', vol. 15, no. 1, pp. 546–559, 2021.

[18] Y. Lu, 'Journal of Industrial Information Integration Industry 4.0 : A survey on technologies , applications and open research issues', *Journal of Industrial Information Integration*, vol. 6, pp. 1–10, 2017.

[19] J. M. Tien, 'Toward the Fourth Industrial Revolution on Real-Time Customization', *Journal of Systems Science and Systems Engineering*, vol. 29, no. 2, pp. 127–142, 2020.

[20] Y. Koren, *The Global Manufacturing Revolution*. 2010.

[21] Individual mass production: The factory of the future. Retrieved from https://new.siemens.com/de/de/unternehmen/stories/industrie/the-factory-of-the-future.html. Accessed on May 1/2022

[22] J. I. Dirisu and O. S. Ibidunni, 'product differentiation : a tool of competitive advantage and optimal organizational performance (a study of Unilever Nigeria plc)', vol. 9, no. 34, pp. 258–281, 2013.

[23] B. Squire, S. Brown, J. Readman, and J. Bessant, 'The impact of mass customisation on manufacturing trade-offs', *Production and Operations Management*, vol. 15, no. 1, pp. 10–21, 2006.

[24] N. Suzić, E. Sandrin, S. Suzić, C. Forza, A. Trentin, and Z. Anišić, 'Implementation guidelines for mass customization: A researcher-oriented view', *International Journal of Industrial Engineering and Management*, vol. 9, no. 4, pp. 229–243, 2018.

[25] 'Cracking the Code of Mass Customization'. https://sloanreview.mit.edu/article/cracking-the-code-of-mass-customization/ (accessed Jun. 13, 2021).

[26] T. Sathish, M. D. Vijayakumar, and A. Krishnan Ayyangar, 'Design and Fabrication of Industrial Components Using 3D Printing', *Materials Today: Proceedings*, vol. 5, no. 6, pp. 14489–14498, 2018.

[27] T. Kermavnar, A. Shannon, and L. W. O'Sullivan, 'The application of additive manufacturing / 3D printing in ergonomic aspects of product design: A systematic review', *Applied Ergonomics*, vol. 97, no. May, 2021.

[28] H. Zhao, L. McLoughlin, V. Adzhiev, and A. Pasko, '"Why do we not buy mass customised products?" - An investigation of consumer purchase intention of mass customised products', *International Journal of Industrial Engineering and Management*, vol. 10, no. 2, pp. 181–190, 2019.

[29] C. Beyer and D. Figueroa, 'Design and Analysis of Lattice Structures for Additive Manufacturing', *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, vol. 138, no. 12, pp. 1–15, 2016.

[30] S. I. A. Kudus, R. I. Campbell, and R. Bibb,

‘Customer perceived value for self-designed personalised products made using additive manufacturing’, *International Journal of Industrial Engineering and Management*, vol. 7, no. 4, pp. 183–193, 2016.
[31] R. I. Campbell, H. Jee, and Y. S. Kim, ‘Adding product value through additive manufacturing’, *Proceedings of the International Conference on Engineering Design, ICED*, vol. 4 DS75-04, no. August, pp. 259–268, 2013.
[32] B. H. Jared *et al.*, ‘Additive manufacturing: Toward holistic design’, *Scripta Materialia*, vol. 135, pp. 141–147, 2017.
[33] 3D printing in Medical Technology. Retrieved from https://www.eos.info/en/all-3d-printing-applications/people-health/medical-3d-printing/implants-surgery. Accessed on May 1/2022
[34] H. Ko, S. K. Moon, and J. Hwang, ‘Design for additive manufacturing in customized products’, *International Journal of Precision Engineering and Manufacturing*, vol. 16, no. 11, pp. 2369–2375, 2015.
[35] S. Yang, Y. Tang, and Y. F. Zhao, ‘A new part consolidation method to embrace the design freedom of additive manufacturing’, *Journal of Manufacturing Processes*, vol. 20, pp. 444–449, 2015.
[36] B. Durakovic, ‘Design for additive manufacturing: Benefits, trends and challenges’, *Periodicals of Engineering and Natural Sciences*, vol. 6, no. 2, pp. 179–191, 2018.
[37] L. Jiang, H. Ye, C. Zhou, and S. Chen, ‘Parametric Topology Optimization Toward Rational Design and Efficient Prefabrication for Additive Manufacturing’, *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, vol. 141, no. 4, pp. 1–8, 2019.
[38] B. Berman, ‘3-D printing: The new industrial revolution’, *Business Horizons*, vol. 55, no. 2, pp. 155–162, 2012.
[39] N. Lei, X. Yao, S. K. Moon, and G. Bi, ‘An additive manufacturing process model for product family design’, *Journal of Engineering Design*, vol. 27, no. 11, pp. 751–767, 2016.
[40] 3D printing helps jewelry start-up ride the mass customization wave. Retrived from https://www.3dz.com.mt/3d-printing-helps-jewelry-start-up-ride-the-mass-customization-wave/. Accessed on May 1/2022

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