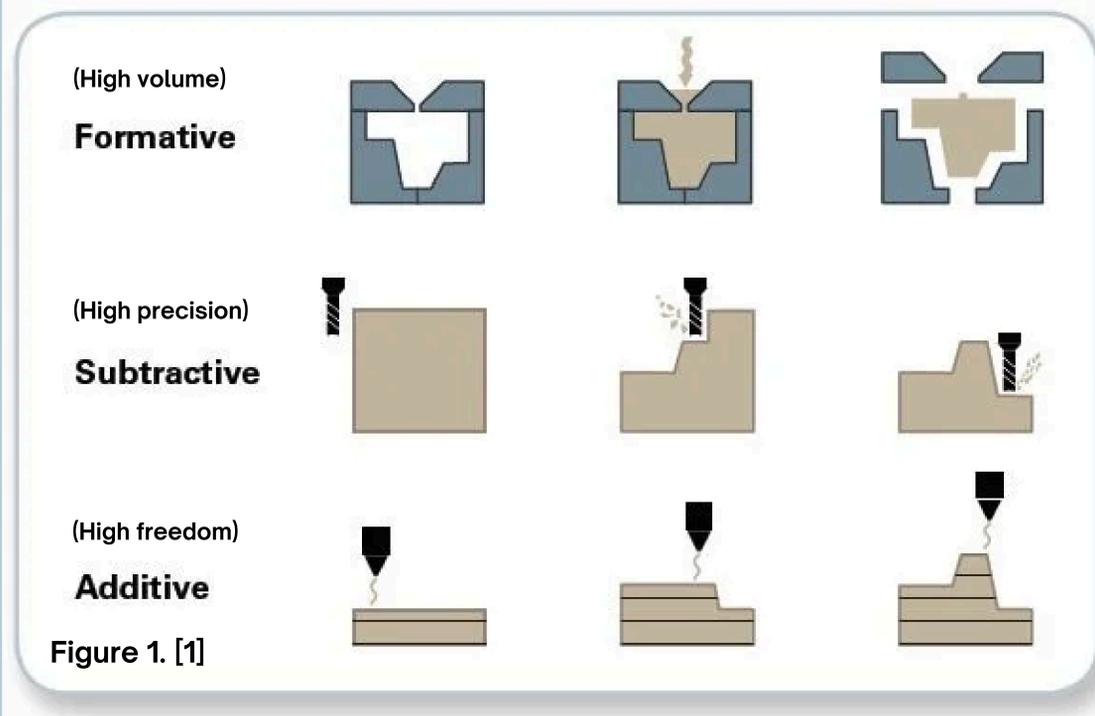


DESIGN FOR ADDITIVE MANUFACTURING

Material Efficiency and Customization in Additive Manufacturing: Challenges, Strategies, and Optimization

Manufacturing has evolved significantly over the years, with advancements in technology reshaping how products are designed, produced, and distributed. Traditionally, manufacturing processes have been categorized into subtractive, formative, and additive methods. Subtractive manufacturing is a traditional process of shaping components that involves material removal, starting with a single block of material larger than the size of the desired part and gradually removed using fabrication processes like milling, turning, drilling, sawing, laser cutting and other techniques until the desired shape is achieved. Formative manufacturing also shapes the component through compression/consolidation processes with the application of pressure.



A lot of material, time and energy is wasted through these traditional manufacturing processes. A major drawback of these traditional manufacturing processes is the high lead time involved in the introduction of new product from concept, prototype, to final introduction of the product to the market. With the increase in demand for customized products, these traditional manufacturing processes cannot deliver on the promise of mass customization. Hence, there is a need for an improved manufacturing process that can offset some, if not all of the drawbacks of the traditional manufacturing processes. [1]

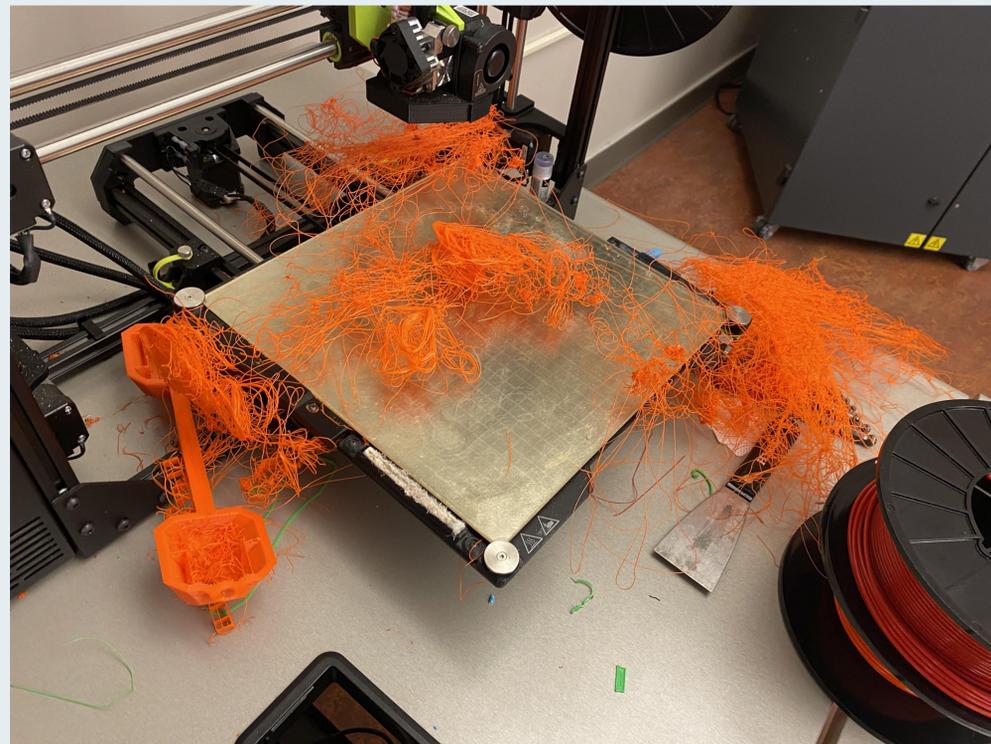


Figure 2

Additive Manufacturing (AM) has revolutionized product design by enabling mass customization – the ability to produce individualized products at scale without the constraints associated with traditional manufacturing. While AM is often perceived as a sustainable manufacturing method due to its ability to produce complex geometries with minimal material usage, mass customization can lead to inefficiencies in material consumption, print failures, and post-processing waste. How can designers increase material efficiency? What waste reduction strategies/design optimizations could be employed to reduce waste?

AM eliminates the need for expensive tooling (e.g., molds, jigs, fixtures) which are needed for each design as they are typically not transferable, hence reducing material waste associated with traditional manufacturing processes. Additive manufacturing allows for on-demand production, reducing the need for excess inventory and waste from unsold stock. [2]

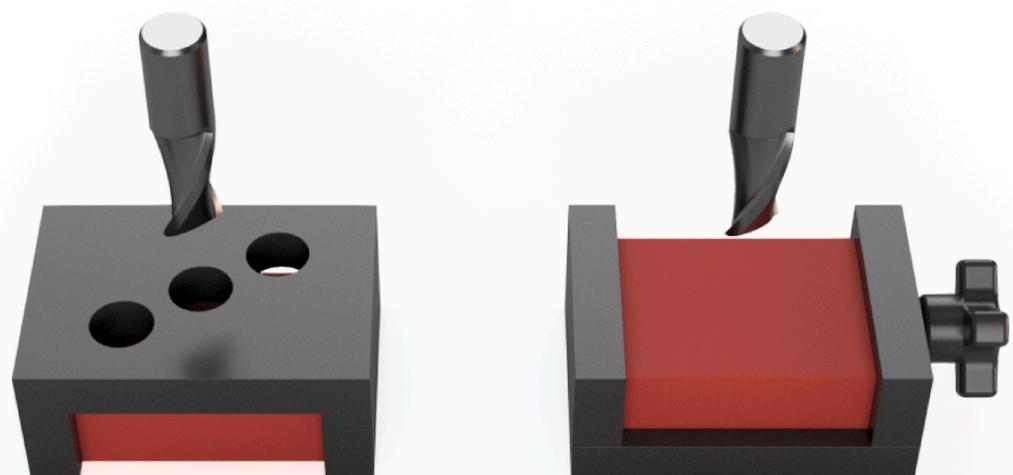


Figure 3 [2]

Jig

Fixture

DESIGN FOR ADDITIVE MANUFACTURING

Material Efficiency and Customization in Additive Manufacturing: Challenges, Strategies, and Optimization

Through precise material deposition, additive manufacturing ensures that only the necessary amount of material is used. These processes have been used in a lot of fields like architecture, especially through the concept of multi-performative components. Here, a single element can serve multiple roles. (e.g., structural support, insulation, airflow regulation). [3] These components improve efficiency and sustainability by reducing material usage and integrating functionalities into fewer parts.



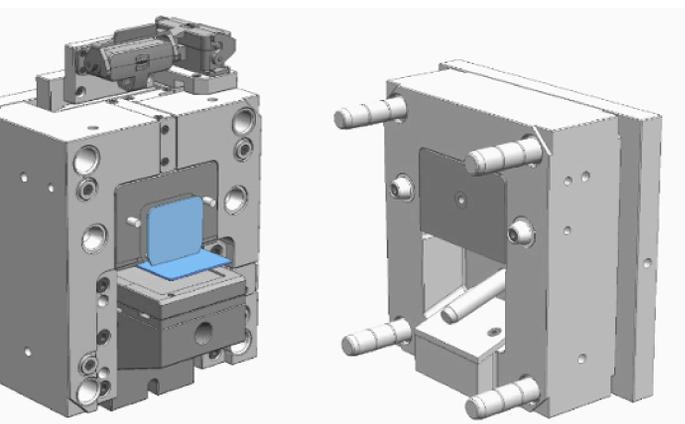
Figure 4. [4]

Arup studies on topological optimization of metal 3D printed joints.

By employing parametric designs it is possible to manufacture customized sustainable building components at scale. Parametric design in additive manufacturing (AM) refers to a computational approach where design parameters are defined as variables that drive the geometry of a part. This allows for the creation of complex, optimized structures that can be easily modified by adjusting input parameters.

Even though AM has several advantages, some challenges that have come up are high energy consumption, limited material options and recyclability concerns. However some of these concerns could be addressed with topology optimization and lightweight design strategies to improve material efficiency and product performance.[4]

Additive manufacturing in mass customization may not help much when mass production is needed. Some studies have investigated a hybrid approach by combining additive manufacturing and injection molding (IM) to leverage the benefits of both techniques.



(a)

(b)

a) Injection mold with the slider for overmolding; (b) Overmolded specimen containing a base plate

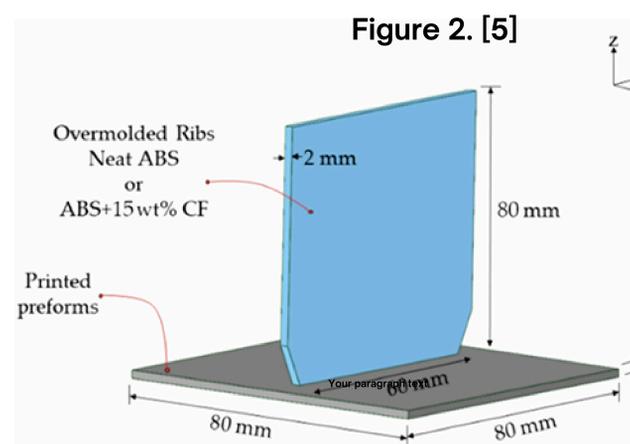


Figure 2. [5]

A method used is overmolding where a 3D-printed baseplate is combined with an injection-molded rib element. To improve the bonding strength between AM and IM parts, components could be to consider surface roughness of the 3D printed baseplate and to optimize print parameters like print speeds, layer heights and orientations.[5] some of the best bonding strategies were using local infill densities and microstructures, ridges and pits. This approach is ideal for medium-scale production (hundreds to thousands of units) with potential applications in medical devices, sports goods and aerospace components.

REFERENCES

- [1] R. M. Mahamood and E. T. Akinlabi, "Achieving mass customization through additive manufacturing," in *Advances in Intelligent Systems and Computing*, Springer Verlag, 2016, pp. 385–390. doi: 10.1007/978-3-319-41697-7_34.
- [2] "Springer Series in Advanced Manufacturing."
- [3] "Mass Customization with AM- New Perspectives for Multi Performative Building Components in Architecture".
- [4] H. Hegab, N. Khanna, N. Monib, and A. Salem, "Design for sustainable additive manufacturing: A review," Apr. 01, 2023, Elsevier B.V. doi: 10.1016/j.susmat.2023.e00576.
- [5] P. K. Rajamani, T. Ageyeva, and J. G. Kovács, "Personalized mass production by hybridization of additive manufacturing and injection molding," *Polymers (Basel)*, vol. 13, no. 2, pp. 1–19, Jan. 2021, doi: 10.3390/polym13020309.