Additive Manufacturing: A Boost to Circular Economy

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Abstract:
Considering the present environmental issues related to manufacturing, there is a worldwide shift from linear to circular economy across the globe. A circular economy establishes a continuous, sustainable loop between new materials, product design, manufacturing, and end-of-life. Every phase calls for the use of 3D printing. The effective implementation of 3D printing can produce more functional products and consume less material than comparable conventional ones. It can lower manufacturing, waste, and material costs. This paper represents the current scenario of additive manufacturing processes in comprehensively accelerating the circular economy. In addition, the paper also discusses the role of the additive manufacturing process in strengthening the circular economy, mainly in terms of material considerations, design freedom, sustainable manufacturing, effective products, and simplified recapturing of resources. This technical paper has two main objectives: (i)to study and analyse the critical elements of the supply chain in supporting the circular economy and their potential benefits. (ii) Identify potential research gaps for the manufacturers, designers, inventors, and researchers working in a similar area.
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1. Introduction

The advancement of new, more effective manufacturing technologies paves the way for the potential of redefining the organizational structure of production processes. In connection with major developments in manufacturing processes, technological advancements may impact manufacturing distribution and the flow of resources and goods, potentially resulting in several positive outcomes for sustainability [**1**]. One example of such benefits is the possibility of shifting toward a Circular Economy (CE), the goal of which is to dramatically increase society's resource efficiency by doing away with the idea of waste and .3D printing, sometimes referred to as additive manufacturing in the industry, is one such cutting-edge technology that is "a process of combining materials to produce items using 3D model data, usually layer by layer" [**2**]. In other words, 3DP enables the "printing" of three-dimensional objects on demand by allowing items to be manufactured layer by layer continuously or incrementally.[**3**] Material extrusion, vat photopolymerization, and powder bed fusion are among the 3DP technologies that have been widely adopted. Other methods include sheet lamination, directed energy deposition, material jetting, and binder jetting. A diverse range of materials, including metals, polymers, composites, and ceramics, can be processed using these techniques (**4**).

According to various sources (5-8), 3DP offers substantial benefits regarding design flexibility, mass customization, co-creation, and novel business models. Using recycled and recovered materials as input for AM processes strengthens the circular manufacturing systems in the current industrial uses of 3DP. In the case of metal additive manufacturing, for example, more than 95% of the discarded powder can be locally filtered and utilized again without further processing. The remaining 5% can be transferred to a centralized recycling plant to create a new powder. As a result, the process uses less material because it is additive, and the system that supports the process is also built to allow for closed-loop material circulation. This paper investigates and assesses the essential factors that enable the circular economy.

2. Role of Additive Manufacturing in Strengthening the Circular Economy

The shift from a linear to a circular economy appears chaotic. However, the chaos necessary to adopt sustainable manufacturing is very similar to the chaos necessary for additive manufacturing, which promises the same kind of payback. Both additive manufacturing (AM) and sustainability require a disruption of the supply chain in the context of the material, the design, the production, the product, and the end of the product's life. They enable each other in these disruptions, as demonstrated in fig 1.

Figure 1. Role of AM in strengthening the circular economy

2.1 Novel Material Considerations

One of the initial difficulties manufacturers must overcome when implementing 3d printing for existing products has to do with materials. Although the range of materials available for additive manufacturing is expanding, there is no assurance that they will be equivalent to conventional injection molding resins, casting alloys, or machining stock[**9,10**]. At the same time, switching from a traditional technique to one that uses additive manufacturing presents a chance to reconsider the material. A previously milled component from steel may be more simply 3D printed in titanium using powder bed fusion since titanium is difficult to process but simple to print. Perhaps that machined item can be produced out of plastic using 3D printing, which would be lighter and more convenient than metal.

Therefore with additive manufacturing (AM), it is possible to use novel composites for manufacturing and apply challenging materials in novel ways[**11**]. However, switching to 3D printing for production frequently means that there isn't an exact alloy or polymer substitute for a conventional material. In addition, the design options made possible by 3D printing can let one material do several functions, lowering the number of parts overall and ultimately making material recapture easier.

2.2. Design Flexibility

The asymmetric and complicated shapes produced by topology optimization and generative design tools can be realized via 3D printing. However, its power is not simply in creating novel shapes but also in producing parts and components free from many constraints of conventional production. Designers are more liberated to create the exact size and design of the required product without the need for molds or another prevailing tooling. In contrast to subtractive machining, which increases processing time and costs with each piece of material removed, parts can be designed with less material, which minimizes or eliminates in-process waste and reduces processing time. Additionally, 3D printed designs can combine assembly, eventually reducing production costs and manpower requirements while making material recovery easier [**12**].

2.3. Sustainable manufacturing approach

Due to its digital nature, 3D printing is frequently a more efficient and environmentally friendly production process. A 3D printed part can be created using just a printer, material, and file, obviating the need for oversized stock materials, jigs and fixtures, mold tooling, and other traditional manufacturing expenses.[**13**] Production is more effective as a result and is available when needed. Manufacturing on demand makes it possible to keep less inventory on hand. Distributed manufacturing is possible because 3D printing can have a smaller overall footprint than traditional injection molding or machining operations. As needed, parts can be 3D printed nearby, minimizing their carbon footprint and accelerating their delivery to the user.[14]

2.4 Effectively fabricated products

Better products can be produced with 3D printing owing to the advantages associated with design freedom and environmentally friendly, on-demand production.[**15**] Individual parts can be quickly modified via 3D printing without needing heavy tooling. Many products can be customized to the customer's body type, price range, and preferences. These goods can now be made on order instead of having to be produced, stored, and possibly thrown away as inventory because of the ability to produce on demand. Custom-made goods that are useful to the client or fill a particular need may survive longer than similarly constructed goods, lowering consumer waste. Additionally, 3D printing incorporates sensors, and monitoring tools, that can be used to identify and track an object throughout its life. For example, a smart product of this kind could alert the owner when it needs maintenance or has run out of useful life and could reveal the precise composition of its materials to a recycling facility.

2.5. Simplified recapturing of resources

The aforementioned advantages of additive manufacturing may all simplify material recovery and reuse. The amount of fastening and specific materials that must be extracted to remanufacture, recycle or compost an object is reduced by using fewer materials and combined assemblies. Reuse can be made more accessible by new design possibilities provided by 3D printing, such as adding interchangeable components or simplifying a component's design. 3D printing in manufacturing allows production to match demand, reducing waste more closely. In contrast, superior items already on the market may reduce the required composting and recycling. The usage of recycled materials from other industries, like scrap metal, chips and trimmings from various operations, and more, is also demonstrated by 3D printing.

3. Conclusion:

The study indicated that the supply chain must be wiped out and rebuilt in all the same places that 3D printing requires to produce in a circular economy. The two disruptions work in conjunction, so pursuing one provides the chance to follow the other simultaneously and rapidly. The door must be open for new production techniques, design approaches, and ways of thinking if a firm is to disrupt existing processes in search of a more sustainable future. This is precisely the kind of atmosphere additive manufacturing requires to establish itself and flourish. Additionally, additive manufacturing provides a significant advantage when a business adopts a circular economy approach. No other manufacturing process can preserve materials and simplify assembly as effectively as additive manufacturing (AM). Different approaches match AM's product design, manufacturing, and marketing advantages. No other system so strongly promotes and facilitates the fundamental thinking that AM demands and that will be required to bring about a sustainable, circular economy.

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