Sustainable Manufacturing by Home Based 3D Printing

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Abstract. *3D printing or Additive Manufacturing (AM) is an emerging technology with great potential for the future. As an alternative to Conventional Manufacturing (CM) processes, the unique features of AM, such as enormous freedom of design, quick prototyping, easy entry, and higher materials yield, are paving the way toward sustainability. Nevertheless, AM can be challenging due to the weakness in manufacturing scaling and standards, and lower production speed.*

In sustainability, environment, societies and economies are the pillars, and AM assists sustainable manufacturing in reducing cost and lead time. Compared to CM, AM significantly enhances flexibility and shaping via the layer-by-layer method rather than subtracting processes.

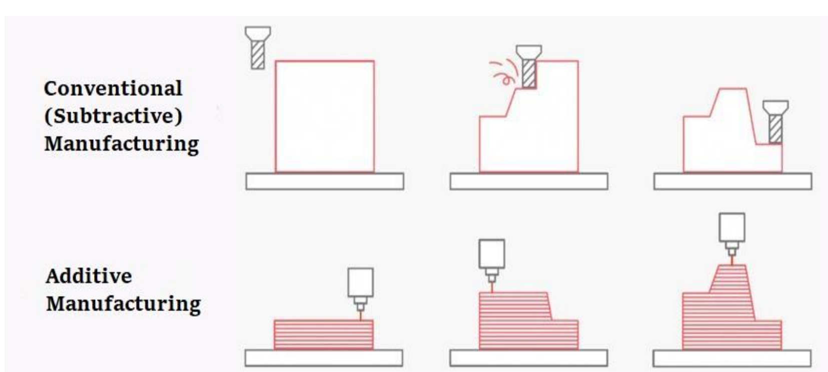
In this paper, the integration of plastic recycling and Home Based Manufacturing by 3D printing, through standardization and collaboration for a more sustainable future is discussed. This study indicates that strategy control of local recycling and 3D printing of plastics reduces energy consumption and CO2 emissions throughout the supply chain. More importantly, AM manufacturing may create jobs locally and reduces physical migration.

OVERVIEW OF ADDITIVE MANUFACTURING

Emerged in 1980s, AM business has grown exponentially, and is expected to keep an annual growth rate of 30.2%, reaching $21.50 billion in 2025 [1]. Another source estimates that global AM market could reach $34.8 billion by 2026 [2]. Technically, ASTM Standard categorizes 3D printing into seven types of technology: Binding jetting, Directed energy deposition, Material extrusion, Material jetting, Powder bed fusion, Sheet lamination and Vat photopolymerization [3]. Different types of AM technology carry out manufacturing in different manner, with either solid, liquid or powder, and have respective advantages according to materials used. Main components needed for 3D printing are: 3D printer frame, printer head and movement mechanics, build platform, stepper motors, electronics, firmware, software and filaments as support substances [4]. The software part is crucial, as it processes CAD files which the tool head moves according to.

COMPARISON BETWEEN CM AND AM

FIGURE 1. Comparison of the manufacturing process between CM and AM.



Attaran [5] identifies five key benefits that AM has over traditional manufacturing: Cost, speed, quality, innovation, and impact. Manufacturing processes between CM and AM are different in the nature and approach. As shown in Figure 1, CNC machining, one of the most common CM technology, typically subtracts a solid block of material to achieve the final shape, while AM proceeds in an additive manner, adding material one layer at a time.

Comparing the production time, cost and quantity, CM takes longer time in prototyping, but is much faster in manufacturing the final products compared to AM. CM requires high initial cost in tooling and moulding, but average cost per product reduces when production quantity increases, while AM requires low initial setup cost but average cost per item stays the same regardless of quantity, and filament material can be expensive [6]. As a result, CM is suitable for mass production of homogenous products, while AM is more suitable for unique, complex designs with low quantity. Moreover, AM is able to produce various components individually, and repair small components in a very short time, without having to remake the whole item from beginning. This allows lowering materials and energy consumption, reducing time and cost of manufacturing.

APPLICATIONS OF AM

3D printing has wide applications in various industries, from aerospace, automotive, machine tools, architecture, to healthcare, daily items, and food production. Typical examples and real cases are illustrated as follow:

- Aerospace: One of the key strengths of 3D printing is manufacturing and repair of spare parts. The ability to design and manufacture the components directly with CAD greatly assists the aerospace industry. Space items such as rovers, satellites and space craft demand highly customized, unbreakable and lightweight components, to be able to withstand extreme environments. According to NASA [7], the International Space Station requires more than 3200kg of spare parts annually, to facilitate the living space for astronauts. 3D printers developed by “Made in Space” is enabling the mission in an environment with microgravity, by feeding plastic material layer by layer to create three-dimensional objects. Moreover, it allows remote manufacturing, to send a design from the ground to the manufacturing system above. Being able to use recycled material as feedstock, it further solves the issue of material supply and waste.
- Automotive: Prototyping and printing spare parts are the common practice in the automotive sector. Short life cycle and flexibility are the unique AM characteristics in spare parts design and maintenance. 3D printing company Stratasys uses AM to improve efficiency for car manufacturer BMW. The jigs and fixtures department of the car manufacturer has decided to use AM as an alternative to traditional metal cutting processes such as milling, turning and drilling. Compared to CNC (CM) method, for one unit of manufacturing, AM cuts the cost by 58% and time by 92% [8]. Having extra time for maintenance and refining the parts, it further leads to higher quality and less errors. For some giant manufacturers, the shift from CM to AM is even more favorable, for the greater impact toward sustainability.
- Architecture: 3D printing can be promising for construction, with the following advantages: in-situ construction, low cost, environmental friendliness, reduced injury, and time saving [9] . AM enables users to design and adjust their own habitat in simple ways, which can be extremely helpful especially in developing societies and urgent conditions such as aftermath of disasters.
- Healthcare: With the ability of fulfilling high level of personalization and customization, AM has wide application in medical industry, from eyeglasses, hearing aids, orthodontics, to tissue repair and organ transplantation. The State University of New York has developed "FLOAT" method that is able to print human body parts in a few minutes [10]. This has huge potential to save millions of lives, by allowing rapid organ transplantation.
- Daily items: AM is able to produce almost anything imaginable, thus it allows anyone to produce and customize personal items, especially in times of emergency, when there is mass urgent need. During early stage of Covid-19 pandemic, there was severe shortage of facial masks. Two students in Japan collaborated to print self-designed mask “PITATT” and provided open-source code [11]. With the help of customer feedback, an improved version of the product was updated by fine-tuning initial shape to bring greater

comfort. With AM, since changing product shapes only requires changing the codes, improvements can be realized with minimum efforts, especially items with frequent usage and big number of users.

As AM applications are dramatically expanding through innovations, other significant applications can be expected in the coming future.

IMPACT OF AM TOWARDS SUSTAINABILITY

Environment, societies, and economies are the three pillars of sustainability. Environmentally, there are many qualities unique to AM, such as the ability of mass customization, de-centralization, manufacturing parts without penalty, and minimizing supply chain. These qualities reduce tremendous material waste, energy consumption and CO2 emissions, time and cost of manufacturing of products. If using recycled materials, it further materializes a zero waste or “cradle to cradle” virtuous loop of material flow. In terms of society, AM empowers individual start-ups, creates jobs, minimizes supply chain, and supports rural development. The low technical and economical hurdle allows anyone to become producers. Home based AM creates more jobs in local areas, reducing unemployment rate and physical migration. With regards to the economic aspect, since AM processes require no special tooling or fixtures, the initial setup costs are minimum. When recycled materials are used, it further reduces the cost for filaments.

AM TOWARDS RECYCLING AND REDUCING WASTE FROM SOURCE

The global recycling rate of plastics remain low, at 14~18%. Even the most developed states reach only 30% [12]. With the ability to use recycled plastic materials as feedstock, AM plays a huge role in recycling and promotion of circular economy, when all the design, materials, prototyping, manufacturing, products and EOL are linked in a sustainable loop [13].

However, although the concept of recycling is promising in minimizing landfill and making use of used products, environmental protection can in fact take place in all stages of a product. Besides recycling, it is also efficient to reduce waste and pollution from the beginning of product life cycle, to have a thorough investigation at how products are designed, what materials are used, and how they are manufactured. A promising feature of AM is the ability for anyone to become a “mini-producer”, manufacturing items for self-sustainment. Besides the role in recycling, AM also provides the chance of “reduce”, “refuse” and “reuse”, as consumers become designers of products, to be able to evaluate them from the source of production.

HOME-BASED MANUFACTURING AND RURAL DEVELOPMENT

3D printing assists development and job creation, especially in rural areas, by means of facilitating home-based manufacturing and recycling. 3D printing machines for entry levels usually cost around 300 to 1000 USD [14], and some websites such as “Repetier.com” provide free CAD software. Since AM requires minimum level of skills and capital for production, anyone can establish home business and become producers (prosumers). AM has the capability to create complex geometrical patterns, empowering designers to improvise with unique creations or folk art [15].

Public authorities can play a big role in strategy control of empowering both urban and rural areas with AM. In recent years, the over-crowdedness and over-dependency toward urban areas has created hazardous impacts, especially in terms of environment, health and living quality. By facilitating rural areas with AM equipment and recycling sites, it sustains households in suburban and rural areas, decreasing urban dependency.

With the help of small scale open-source hardware such as Recycle Bots that convert waste plastic into filament for 3D printers, it solves the issue of scattered recycling in rural areas. When AM production is implemented with recycled materials in these areas, it realizes the ideal "cradle to cradle" material flow.

IMPACT OF AM TOWARD SUPPLY CHAIN

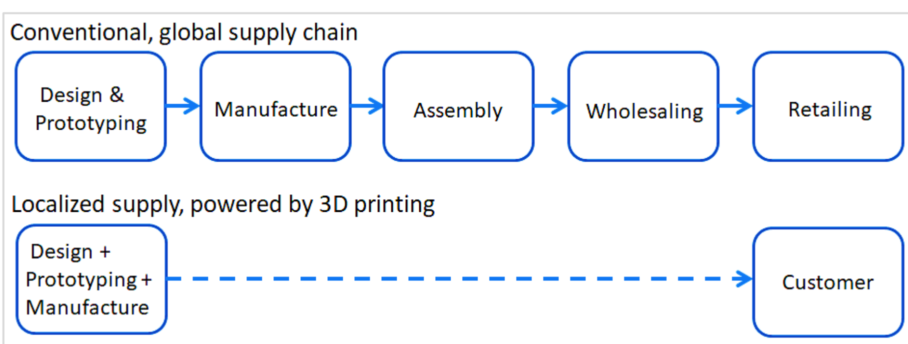
AM has huge potential in renovating supply chain. In conventional business models, the supply chain is literally a chain that pushes the supplies step by step, a player after another. From raw materials to finished products, it goes through processes of prototyping, manufacturing, assembly, wholesaling and retailing. The players in this chain include supplier, manufacturer, assembler, wholesaler, retailer, and multiple transporters. Each process is rigidly tied to another, with little flexibility. The major concerns in conventional supply chain, could be the value gap between original material and the price sold on the shelf.

After going through several stages, with each player contributing to the value of the product, the final price is often several times of the original value. Moreover, the transportation from one stage to another requires natural and economic resources, resulting in fuel usage, air pollution and higher cost. Freight transport is responsible for a large part of logistics-related carbon emissions. One way of improvement is to increase vehicle utilization, despite some statistics shows that in EU countries trucks are running empty 25% of their journeys [16]. Another way is by simplifying logistics.

IMPACT OF AM ON LIFE QUALITY

Due to the flexibility of design, AM can be a bridge between technology and the state of the art that touches human consciousness. Given that the linkage between technologies and consciousness is complex, although it can be an important area to which AM or 3D Printings can contribute, this research wishes to investigate the mechanisms in a long-running plan.

FIGURE 2. Comparison between conventional supply chain and the new supply system with 3D printing.



With support of local sourcing, AM has the power to reassemble the established global supply chain, into a new, local system. Enabling each user to become potential producers, the technology creates a close relationship between design, manufacturing and marketing. Goods can be directly reached to local customers, without sophisticated logistics and transportation.

AM bypasses constraints from traditional supply chain, by printing of low volume, customer specific items. Its flexibility and agile adaptation to demands engenders many benefits unwitnessed by traditional supply chain, such as customised production, localized manufacture and distribution, short lead time, low transport costs and low carbon footprint [17].

CHALLENGES

Health is a major concern for AM usage. There are cases that AM users develop respiratory issues from exposure to airborne emissions during the manufacturing process. A user with childhood history of asthma began to experience respiratory problems ten days after using 10 fused deposition modelling (FDM) 3D printers with acrylonitrile-butadiene-styrene filaments in a work area of approximately 85 m^3. After 3 months, his situation improved, by modifying the work environment, reducing the number of printers, changing to polylactic acid filaments, and using an air purifier [18]. From this case, ventilation, working space, number of printers and selection of filaments are crucial in improving health conditions.

The lack of standardization can be another major challenge for AM. The new industry is in crucial need of standards, for safety and quality of products, machinery as well as working environment. ISO and ASTM are currently the largest organizations for standardization. In 2013, the two organizations jointly agreed to develop global standards for AM. Besides, there are other Standard Development Organisations (SDOs) that are in the process of developing standards for specific domains of AM [19].

Evaluation of energy consumption is simpler in transportation, as the case study of a common scenario demonstrates that the transportation costs can be reduced 25-fold in AM processes and the associated CO_2 emissions can be reduced with a similar figure well. However, AM and CM processes vary significantly and require further study to investigate individual process energy consumption, efficiency, and CO_2 emissions.

On the other hand, AM requires a collaborative pattern to connect large enterprises, SMEs, and home-based businesses to fully utilize its advantages through localization and distributed manufacturing. Through this integration, the AM bottlenecks in scaling, speed and size issues can be eliminated, and mass production can be expected. Consequently, reduction of CO_2 emission, environment protection, job opportunities in rural areas, and cost saving in circular economies will become possible.

CONCLUSION

3D printing benefits human community in many aspects, most importantly in environment, society and economics. The additive nature of manufacturing and the ability to use recycled materials as feedstock greatly reduces material use, leading to less consumption and pollution.

With regards of societies, AM enriches life quality and empowers developing societies, as it creates new business models that allows each individual and household to support livelihood. In terms of economy, AM manufacturing is beneficial in minimizing supply chain and shrinking the income gap, by enabling consumers to become independent producers. However, since AM is a young technology, there are still many discoveries await, and requires standardization and technological improvements to overcome the current challenges.

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