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UTILISING PLASTIC WASTE TO CREATE 3D-PRINTED PRODUCTS IN SUB-SAHARAN AFRICA

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1 Introduction

Plastics offer a wide range of benefits such as affordability, low weight, flexibility and versatility (Mwanza et al., 2018). This makes them extremely useful globally, especially in the Global South where it is commonplace to have infrastructure deficits. However, in recent times, there has been increased awareness of the significant environmental and health impacts associated with plastic pollution (Ryberg et al., 2019; Thompson et al., 2009; Wabnitz and Nichols, 2010). The problem of plastic pollution is particularly exacerbated in Africa due to poor infrastructure and waste management systems which are suboptimal. A promising approach for tackling this challenge is the adoption of the circular plastic economy (Oyinlola et al., 2022b). The circular plastic economy is a system which employs the principles of the circular economy to the plastic value chain, including design, manufacture, use and end-of-life phase.

The concept of the circular economy has been explored by several scholars including Araujo Galvão et al. (2018), Berg et al. (2018), Gall et al. (2020) and Murray et al. (2017), and many have shown that digital technologies such as mobile applications, geographical information system (GIS) and three-dimensional (3D) printing, can play a significant role in the circular economy (and by extension, the circular plastic economy) in Africa (Kolade et al., 2022b; Oyinlola et al., 2022). Adopting digital technologies for the circular plastic economy can be revolutionary in terms of bridging the circularity divide (Barrie et al., 2022) as well as positively disrupting the landscape (Kolade et al., 2022b).

Digital technologies have been applied to varying extents across multiple sectors in Africa such as finance (Kingiri and Fu, 2019), energy (Annunziata et al., 2015), education (Oke and Fernandes, 2020), water services (Amankwaa et al.,

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2021) and agriculture (Syngenta, 2019). The application of digital technology has resulted in leapfrogging in many areas, for example, up on till the 1990s, Africa's infrastructure for landline telephones was grossly inadequate and required huge investments to get a substantial number of the population connected. However, with the arrival of the global system for mobile communications (GSM), the communication sector has leapfrogged, cutting the need for heavy investment in landline infrastructure and improved access to mobile phones as it has been reported that "the world's poorest households are more likely to have a mobile phone than a toilet" (Devarajan, 2010).

This chapter makes a case for additive manufacturing, also known as 3D printing (a method of creating 3D solid items from a digital file) as one of the leading digital technologies for the circular plastic economy. Drawing on case studies in education, medicine, construction and local industries, this contribution illustrates how local plastic waste can be used to create new, innovative, locally made products which meet specific local needs.

2 3D printing as a promising intervention

A schematic of the process of converting plastic to 3D products is presented in Figure 6.1. First, the plastics are collected and sorted based on type to ensure each batch is homogeneous. The sorting is followed by cleaning, which involves removing labels and the label glue, washing and rinsing. This process ensures that

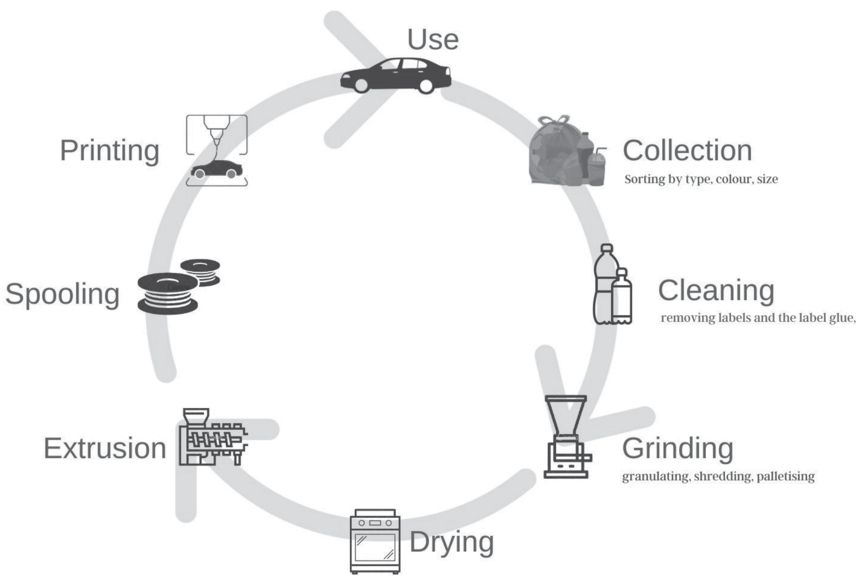

FIGURE 6.1 The basic steps of converting waste to 3D-printed products (Oyinlola et al., 2023)

the batch contains no contaminants. The cleaned homogeneous plastic batch will then be grinded into granules in readiness for extrusion to filaments. The granules must be dried as moisture content can affect the extrusion process. The granules can then be fed into the extruder through a hopper (Garmulewicz et al., 2016; Singh et al., 2017; Zander et al., 2018; Zhong and Pearce, 2018). The extruded filament is then cooled and spooled and can be used for 3D printing products. The production of a 3D-printed object is accomplished using additive processes. An object is built in an additive technique by laying down successive layers of material until the object is complete. Each of these levels is a thinly sliced cross-section of the object.

Additive manufacturing is widely recognised by international organisations such as the UK Foreign, Commonwealth and Development Office (FCDO), UNICEF and the United Nations as a leading frontier technology which would support international development (Ramalingam et al., 2016). Currently, the technology is at a "tipping point", where it is becoming a feasible manufacturing technique and is considered to be the cornerstone of the next industrial revolution (Rauch et al., 2016). This game-changing technology is expected to have substantial impact in low- and middle-income countries (LMICs) as the cost of an entry-level printer has declined from $30,000 to $200 in the last two decades (Berman, 2012; O'Connell and Haines, 2022). This is supported by the fact that in more recent times, 3D printers have been produced locally in Africa using e-waste such as servo motors from two-dimensional (2D) printers. For example, Kumar et al. (2021) repurposed e-waste to develop the essential components such as the stepper motors, power supply and iron supporting framework for a 3D printer–scanner hybrid from e-waste. Similarly, Simons et al. (2019) designed and developed a Delta 3D printer using salvaged e-waste materials. Three vertical axes spaced 120 degrees apart are used to move the printer. They used 17 stepper motors to operate the numerous carriages on the vertical axes to achieve accuracy and speed. Locally available square pipes, bearings and a 3D-printed rail were used in place of typical linear rails. A carriage support system was created, as well as a reasonably inexpensive but stable linear rail.

3D printing will allow communities to leapfrog traditional manufacturing (Kolade et al., 2022a; Swiss Business Hub and Swiss, 2018). Traditional manufacturing is characterised by manufacturing things in one place using highly capital-intensive methods such as injection moulding, in big factories. Products from these factories are then shipped through complex global supply chain networks which can be susceptible to delays when things go wrong such as the recent Suez canal blockage (Lawrence, 2021). Compared to traditional manufacturing methods, 3D printing provides a real opportunity to have a distributed supply chain where products or parts that people actually want or need in that local community can be made locally close to the point of demand. This means regardless of being in a rural village or a big city, products can be made locally, using local resources. Furthermore, this technology allows users to produce complex parts with essentially no waste, as it creates products layer by layer and can control the fill density of the product (Celik, 2020). Therefore, 3D printing offers the opportunity to reuse plastic materials in producing complex parts in remote areas while reducing the environmental footprint associated with traditional supply chain logistics. Converting the relative low-value plastic waste into a product that people can use makes the waste stream more of a resource than trash. This approach has become more popular as even the Dutch airline, KLM, started using polyethylene terephthalate (PET) bottles to make tools to repair and maintain its aircraft. According to the airline, empty bottles are collected at the end of every flight and transformed into filament, which is then used in a 3D printer to create new products (KLM, 2019).

With a promising growth forecast, 3D printing is likely to reduce the cost of manufacturing and result in shorter lead times while minimising the reliance on unsustainable and unreliable supply chains as well as create new businesses and support wealth generation (Shah et al., 2019). This is very significant for small and medium enterprises (SMEs) as it lowers the barriers to manufacturing since there are no tooling costs and one printer can produce specific parts for different applications at the same time. Chong et al. (2018) reviewed different initiatives in the area of 3D-assisted hybrid manufacturing and concluded that 3D manufacturing is promoted by major industrial countries as a technology starting point for the future of manufacturing.

Implementing 3D printing has the potential to increase recycling rate in Africa due to being a distributed recycling approach. Various scholars (Baechler et al., 2013; Cruz Sanchez et al., 2017; Kreiger et al., 2014; Woern et al., 2018) have shown that using waste materials for 3D printing allows consumers to recycle waste in their community which is a suitable intervention for improving recycling rates in LMICs. This decentralised approach differs from the usual centralised approach in the Global West which involves the transportation of the high-volume and low-weight polymers (Kreiger et al., 2014; Santander et al., 2020). Given the lack of adequate waste collection, transportation and recycling infrastructure, the concept of decentralised recycling is better suited for Africa. A centralised approach is not always economically viable due to the wide geographical spread in Africa (Kreiger et al., 2014; Santander et al., 2020) and can have a significant environmental footprint (Ragaert et al., 2017) due to the greenhouse gas emissions associated with the collection and transportation of the waste materials (Garmulewicz et al., 2016). Life cycle analysis of the distributed recycling method has shown that it has less embodied energy compared with the best-case scenario for centralised recycling. For example, Kreiger et al. (2014) note that more than 100 million MJ of energy was conserved annually, along with substantial reductions in greenhouse gas emissions. This is mainly because the process eliminates the environmental footprint associated with transporting waste to centralised collection points (Garmulewicz et al., 2016). In addition, 3D printing can increase the value of waste plastic by up to 20 times (Oyinlola et al., 2023). This can go a long way in incentivising sustainable plastic practices in communities (Adefila et al., 2020).

The rapid growth in the 3D printing sector and increased growth of open-source designs have fostered the use of 3D printers across Africa; however, the high cost of filaments, which are usually imported, remains a prohibiting factor. However, combining the prospects of repurposing electronic waste to develop 3D printers which will utilise filaments made from waste plastics implies that this technology aligns with several principles of the circular economy (Pavlo et al., 2018) such as supporting decentralised recycling, upcycling, reuse and distributed manufacturing (Sanchez et al., 2020). Furthermore, the application of 3D printing in Africa will lead to a quadruple bottom-line effect by increasing value (profit), reducing waste (planet), encouraging social well-being (people) and generating technical innovation (progress) (Oyinlola et al., 2023).

However, it is pertinent to note that the technology is still relatively in its infancy, therefore much more needs to be done to accelerate its adoption such as infrastructure (Oyinlola et al., 2023) and policy landscape (Schroeder et al., 2023). Furthermore, 3D printing is not capable of high-volume manufacturing, therefore much more suited to bespoke one-off production such as small-scale production, higher value items and replacement parts that are not readily available (Kolade et al., 2022a).

3 Case studies of products

There is a growing need for sustainably produced products by consumers (Cruz Sanchez et al., 2017; Feeley et al., 2014). Implementing 3D printing offers endless transformational possibilities including the creation of new, innovative, locally made products which meet specific local needs (Savonen, 2019). This section reviews how 3D printing has been utilised to aid development using various case studies. It specifically focuses on the application of 3D printing in four critical sectors: education, medicine, construction and local industries.

3.1 Education

Education underpins sustainable development; therefore, one way of tackling the developmental divide is by delivering quality education (Duran and Parker, 2021). Quality education will build the capacity and capability of local populations to tackle developmental challenges. 3D printing in education transcends numerous and separate clusters of works (Ford and Minshall, 2019), and it has been used to improve the quality of education across all levels ranging from primary to tertiary education. Schelly et al. (2015) investigated the use of open-source 3D printing technologies for education and concluded that science, technology, engineering and mathematics (STEM) education and career and technical education (CTE) can be improved via 3D printing because it provides a sense of empowerment resultant from active participation, as well as fosters cross-curriculum engagement. Obwoge et al. (2018) noted that 3D printing could be used for developing teaching

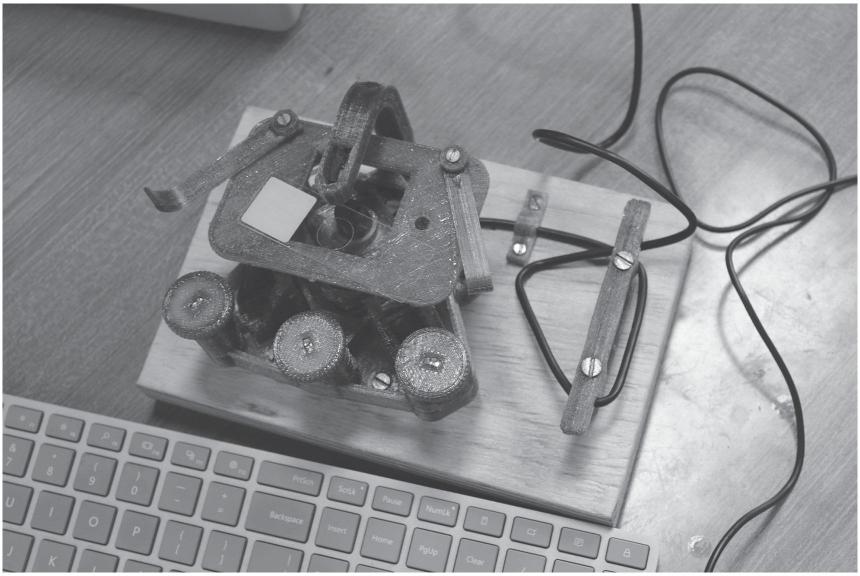

FIGURE 6.2 A 3D-printed microscope using waste plastics

and learning models to cater to different learning styles, teaching of 3D design in engineering education and for producing simple laboratory equipment.

Owen (2018) and Rogge et al. (2017) reported that the deployment of low-cost 3D-printed microscopes (see Figure 6.2) in Kenyan schools has been transformational in terms of improving access to teaching and learning equipment. Similarly, Garcia et al. (2018) reported that the fast development of 3D printing has created a novel learning and teaching approach required for medical education. Similarly, Del Rosario et al. (2022) noted that 3D printing has a unique impact on the medical education field by facilitating the manufacture of teaching equipment and aids such as the highly multifaceted robotic microscope, OpenFlexure. In architecture, 3D printing allows architects to produce complex parametric modelling geometries (Paio et al., 2012), while in engineering, Crowe et al. (2021) noted that 3D printing was effective in teaching about water interactions on both hydrophilic and hydrophobic surfaces. Pinger et al. (2019) reviewed the application of 3D printing in chemistry classrooms and concluded that the use of 3D-printed models for improved visualisation of chemical phenomena, as well as the educational use of 3D-printed laboratory devices, improves chemistry education. Santos et al. (2019) concluded that "3D printing with girls will be most successful when the context factor of role models, the child factor of engaging and relevant experiences, and the context factor of free play are taken into account".

Despite the numerous benefits of 3D printing in the education sector, Berman et al. (2018) who explored the 3D printing process for young children in curriculum-aligned making in the classroom noted that some students appeared more interested in printing designs for their visual aesthetics instead of their significance for their presentations, while others had difficulties in gauging the designs which begs the need for simplification of the process (Berman et al., 2018).

These examples illustrate that 3D printing can be utilised to transform teaching and learning in sub-Saharan Africa by giving teachers and students unprecedented access to aids. In practice, a financially challenged school in a remote location with a 3D printer and internet connectivity can receive the open-source designs for critical elements such as microscopes and print them locally.

3.2 Local industries

3D printing enables endless transformational possibilities, including the creation of new, innovative, locally made unique products which meet specific local needs (Savonen, 2019; Wu et al., 2022). Bespoke products used in cultural events such as local theatres and festivals could be produced from 3D printing since other manufacturing methods might be impractical and/or not economically attractive. 3D printing has been used to digitalise traditional arts and craft processes. For example, needle fleeting is a manual process for making intricate objects such as figurines or putting ornaments to textile objects (Becker, 2022). This process easily lends itself to 3D printing allowing for quicker turnaround time for prototyping of physical objects while also supporting a high level of customisation to be used with different types of materials (Hudson, 2014). 3D printing can be used to make the local practices in low-income communities more efficient. For example, a customised machete peeler was made for a community engaged in peeling tubers in Kenya. Using an ordinary machete to peel the skin of tubers results in removing a significant amount of the produce. The customised machete peeler was 3D printed according to the blade type and thickness typical to the community, with the angle at which the cutting edge is presented customised according to the product being peeled. Another example is the non-electric milk cooler, which is used to mitigate the food storage challenge in rural areas with poor access to electricity. The non-electric cooler maximises the complexities of structures that are possible with 3D printing to create a matrix for the rapid evaporation of water to generate natural cooling. These examples are illustrated in Figure 6.3.

3.3 Medicine

Sub-Saharan Africa is reported to have the worst health care in the world due to the fact that most countries are unable to spend required funds on medical facilities and medicines (IFC, 2022). For over three decades, improvements and innovations in medicine resulting from 3D printing have been documented (Heller et al., 2016). Ishengoma and Mtaho (2014) noted that with access to electricity and

FIGURE 6.3 Examples of 3D-printed products supporting local practices

internet, the adoption of 3D printing can transform the limited access to vital surgical services due to lack of facilities and basic equipment. Several scholars have highlighted the benefits that 3D printing can bring to health care in Africa. Abegaz (2018) noted that 3D technology can bring unprecedented comparative advantages to the health care in Africa. Liaw and Guvendiren (2017) reviewed the applications of 3D printing in medicine and highlighted that current application includes production of medical devices, anatomical models and drug formulation, dentistry and engineered tissue models. They noted that dentistry was one of the advanced fields with application in areas such as restorations, dental models and surgical guides. Another area of wide application of 3D printing is medical devices (both implantable and non-implantable products) such as bone tether plates, hip cups, spinal cages, knee implants, denture bases, craniofacial implants and surgical instruments (Liaw and Guvendiren, 2017).

Examples of functional medical products that have been created using 3D printing include advancement of clinical imaging and reproduction of the human anatomy through structural heart interventions (Vukicevic et al., 2020), production of locally fabricated and low-cost otoscopes to diagnose the prevalence of frequent ear problems (Capobussi and Moja, 2021), the development of a smartphone-based epifluorescence microscope (SeFM) for fresh tissue imaging (Zhu et al., 2020), face shields during pandemic (de Araujo Gomes et al., 2020), medical supplies for children in Haiti (Ishengoma and Mtaho, 2014) and vascularised and perusable cardiac patches production of prosthetic limbs (Abbady et al., 2022; Gretsch et al., 2016; Hofmann et al., 2016).

It should be noted that waste plastics are not suitable for all the applications listed above, especially, implantable devices, due to hygiene and standards; however, non-intrusive components and devices can be made from waste plastics with prosthesis being one of the leading medical applications of 3D printing in the Global South. Furthermore, an advancement in 3D technology will progressively lead to development of appropriate materials as Pugliese et al. (2021) observed that the deficiency of polymers, biomaterials, hydrogels and bioinks was the main drawback in biomedical manufacturing.

3.4 Construction

Construction in Africa is rapidly increasing to meet rising demand and historical deficits (ABP, 2022). There is a growing interest in the application of 3D printing in building and construction. 3D printing has the advantage of creating practical prototypes in rational build time with limited human intervention and the least material wastage (Tay et al., 2017). 3D printing has the potential to revolutionise the construction sector as it can be considered as environment-friendly derived from its limitless possibilities for geometric difficulty in achievability (Hager et al., 2016). El-Sayegh et al. (2020) reviewed 3D printing in construction and noted that the primary advantages of 3D printing in construction include constructability and sustainability benefits, while the drawbacks include material printability, buildability, scalability, structural integrity and lack of codes and regulations.

Hossain et al. (2020) noted that the construction industry is extremely labour-intensive and also a main employment provider and has been undergoing low productivity with minimum technological innovations for decades. 3D printing proffers a possible solution; however, it might not be so welcomed in countries where construction is one of the priority employers and labour is cheaper. However, Buchanan and Gardner (2019) in a review noted that instead of replacing the conventional practice, it can provide a hybrid option with benefits of closer structural efficiency, reduction in material consumption and wastage, streamlining and expedition of the design-build process, enhanced customisation, greater architectural freedom and improved accuracy and safety on-site but new challenges and requirements such as digitally savvy engineers, greater use of advanced computational analysis and a new way of thinking for the design and verification of structures would be required.

4 Conclusion

This chapter highlights the opportunities for waste plastic to be used as a feedstock for 3D printing in sub-Saharan Africa. Given the scale of the plastic challenge, it is fundamentally important to develop innovative solutions to the problem caused by plastic waste. This chapter illustrates that 3D printing coupled with the use of open-source designs can transform low-income societies characterised by underdeveloped infrastructure and inadequate manufacturing capabilities, while addressing the plastic challenge. However, given the infrastructural realities in Africa, it is important to plan around the lack of basic infrastructure such as access to electricity, water and transportation systems. For example, providing off-grid standalone alternate power supply from solar energy. Furthermore, the success of 3D printing at scale in sub-Saharan Africa requires developing capacity and capability of local skills to operate, maintain and develop 3D printing and extruder technology.

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