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Chapter Thirteen

Building Capacity for Circular Economy Transitions: Exploring Knowledge of 3D Printing in Nigerian Universities

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Abstract

The circular plastic economy offers a promising pathway toward sustainable resource management, but its adoption in developing contexts, particularly in Nigeria, remains underexplored. This chapter examines the capacity of Nigerian universities to drive the transition to a circular plastic economy through the integration of 3D printing technologies. By investigating the relationship between students' knowledge of the plastic waste problem, their understanding of 3D printing and sub-technologies such as Filtech, and their engagement in plastic waste management actions, the chapter provides critical insights into this emerging field. Using Structural Equation Modelling (SEM) to analyse data collected from 151 university students, the findings highlight the statistically significant role of knowledge in influencing plastic waste management actions. However, the results reveal that 3D printing technologies and their sub-technologies have not yet significantly impacted plastic waste management, suggesting systemic gaps in infrastructure, policy, and institutional capacity. The chapter underscores the importance of universities as hubs of innovation, advocating for targeted investments in infrastructure, curricula, and policies to enhance capacity in 3D printing technologies. These measures are critical for fostering sustainable innovation and entrepreneurship, particularly in resource-constrained settings. The chapter concludes with recommendations for multi-sectoral partnerships and international support to bridge identified gaps and position Nigerian universities as leaders in sustainability and the circular plastic economy.

1. **Introduction**

As the global conversation on environmental sustainability gathers pace, the cricular economy emerged as an important operational frontier for scholars and practitioners interested in driving forward the sustainability agenda (Agyemang et al., 2019) . This increasing interest is noticeable in both the public sector and the business world, as the shortcomings of the traditional linear economy become increasingly evident (Skýpalová, 2024). It has been progressively applied in an effort to curb unsustainable utilisation of resources and production (Kirchherr et al., 2017). The circular economy is underpinned by three core principles, otherwise known as the 3Rs: reduce, reuse and recycle (Manickam and Duraisamy, 2019). In its expanded form, it incorporates the 9Rs: include refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover (Potting et al., 2017). The strategy is a paradigm shift from the linear economy model of manufacturing using virgin materials (Korhonen et al., 2018) using a "take, make, dispose" approach (Alamelu et al., 2024). Therefore, the concept of a circular economy is increasingly attracting global attention from a range of stakeholders, especially businesses and governments (Korhonen et al., 2018). It focuses on closing material loops and prolonging the life of resources, standing in stark opposition to the conventional 'take-make-dispose' approach (Antikainen et al., 2018). This transition necessitates collaboration among companies, consumers and policymakers to develop innovative business models, stimulate demand for sustainable products, and establish effective governance structures.

Alternatively, some scholars claim the circular economy concept is vague with varied definitions (Kirchherr et al., 2017), criticised as a "melting pot of concepts" lacking harmony among scholars and societal stakeholders (Reike, 2024). While it has gained international support from multilateral agencies like the EU and has gained traction with academia, industry and policymakers, some continue to view the concept as ambiguous and superficial with uncertain contributions to sustainability (Corvellec et al., 2022; Geissdoerfer et al., 2017; Korhonen et al., 2018).

Nonetheless, there have been calls from industry for guidance as the circular economy demonstrates the sustainable synthesis of economic actions and environmental wellbeing (Murray et al., 2017). This is a positive signal as organisations must consider the circular economy strategies and reassess wasteful manufacturing practices to tackle the emerging waste management crisis. As according to Geng et al, “*it takes a tonne of metal, silicon and plastic to produce a laptop computer weighing a few kilograms*” (Geng et al., 2019). However, the transition to a circular economy needs planning and policies (Morseletto, 2020).

Today, studies show that due to Big Data and the Internet of Things (Alcayaga and Hansen, 2024; Pagoropoulos et al., 2017), technologies are critical enablers for the establishment of servitised business models such as the circular economy in enterprises (Bressanelli et al., 2018). Therefore, digital technologies are seen as a viable solution for the adoption of the circular economy (Uçar et al., 2020). Nonetheless, some critics have mentioned that this approach is not always sustainable (Bressanelli et al., 2024) and it is difficult to establish a complete perspective on the implementation of digital technologies on the circular economy transition as further discussions on operationalisation are still required (Cagno et al., 2021).

Despite the criticisms, considerable empirical evidence and scholarly observations (Berg et al., 2018; Gall et al., 2020; Galvão et al., 2018; Murray et al., 2017) have indicated that digital technologies including mobile applications, geographical information system (GIS) and 3D printing, can play a key role in driving the circular economy. Creative applications of digital innovations can play a keyrole in disrupting societal lock-in to linear habits of production and production (Hariyani et al., 2024). It has the potential to bridge the circularity divide (Barrie et al., 2022; Berg et al., 2018; Gall et al., 2020; Galvão et al., 2018; Murray et al., 2017) and positively impact the landscape (Kolade et al., 2022a), as exemplified by recent empirical evidence on the potentials and promise of digitally-enabled circular plastic economy in Africa (Kolade et al., 2022b; Oyinlola et al., 2022).

3D printing, also known as additive manufacturing, has been identified as a disruptive technology that would transform the manufacturing sector and have a significant impact on other fields such as aerospace, defence, art and design. Over the years, its popularity and adoption has grown due to its features (Pîrjan and Petroşanu, 2013). Its speed, cost effectiveness and ability to build prototypes from three-dimensional computer-aided designs (CAD) (Noorani, 2017) has also enhanced its growing popularity. The technology has allowed businesses to adopt the circular economy principles through re-design and re-manufacturing of new products that promote a shared economy (Nikolaou and Tsagarakis, 2021), especially in developing economies (Kolade et al., 2022a; Oyinlola et al., 2022).

The 3D printing technology has varied functionalities in the manufacturing sector such as mass customisation of products, on demand component production and ability to produce physical component which can be utilized to make alterations (Madhav et al., 2016). Its rapid growth is spreading to various disciplines such as mechanical, medical, civil, electrical, amongst others (Mahapatra et al., 2024). In the medical field, it directly impacts tissue engineering, dental (Dawood et al., 2015), drug delivery, crisis delivery (Manero et al., 2020), nutrition (Severini and Derossi, 2016), prosthetics, and implants as it has the ability to create precision and difficult components (Barua et al., 2021).

The 3D printing technology operates by transforming waste material, specifically plastics, to feedstock (filaments) for production (Garmulewicz et al., 2016; Pavlo et al., 2018; Sanchez et al., 2017). It aims to utilise available resources at maximum capacity to derive the best value during their useful life (Grdic et al., 2020), thereby achieving circular value chains (Oyinlola et al., 2022). This strategy is promoted by various multilateral organisations as an important frontier to drive sustainable development (Ramalingam et al., 2016). It is viewed as an approach that would empower developing countries to leapfrog from traditional manufacturing to sustainable alternatives (Kolade et al., 2022a; Swiss, 2018), as they would be able to reuse materials, such as plastics, in remote areas and gain economic value by up to 20 times (Oyinlola et al., 2023) . This approach also has the potential of incentivizing sustainable plastic protocols in communities (Adefila et al., 2020).

While it offers promising opportunities, it is important to consider that the 3D printing technology is still at an early stage of development. Therefore, capacity needs to be built to accelerate its adoption and optimise it benefits. This would need to be supported by adequate infrastructure (Oyinlola et al., 2022) and appropriate policy landscape (Schröder et al., 2023). In addition, the technology is suited to customisation at a small-scale such as replacement parts and high value items and not large-scale production (Kolade et al., 2022a). It replaces the economy of scale, associated with traditional manufacturing, with the economy of one. It also works on much simplified logistics, with no requirements for centralised high-volume production and large inventory stocking.

3D printing technology application has the capacity to improve day-to-day life while evolving our economic and social standing (Chatzoglou and Michailidou, 2019). Nonetheless, there has to be the readiness to use the technology regardless of experience to make a real impact. A study found that there is an absence of correlation between experience and behavioural intention to use 3D printers which indicates that people can introduce 3D printer technology notwithstanding the experience of the possible user (Chatzoglou and Michailidou, 2019).

Another study on the manufacturing industry suggested some success factors small and medium enterprises (SME's) could consider for the adoption of 3D printing technology, which includes:

- "*Identification of the main factors for its implementation provides valuable contributions to manufacturers and their decision-making process.*
- *Cost and environment should be taken into consideration for evaluating the feasibility of its adoption.*
- *Different parties have different concerns which should all be considered.*"

(Yeh and Chen, 2018)

Scholars have also highlighted the need to build capacity and develop technical skills that will accelerate uptake of digital technologies among SMEs for local manufacturing of products using 3D printing (Balogun et al., 2018; Rogge et al., 2017; Sæterbø and Solvang, 2023). It is also important that in a local context such as sub-Saharan Africa, 3D printers and extruders are sustainably manufactured as it requires being robust, reliable and durable to avert the need for frequent repairs (Minetola and Galati, 2018). This is vital as the population consists of mainly low-income communities with a dearth of highly skilled labour.

The main goals of universities have been widely accepted as the production, dissemination and- more recently application- of knowledge which are viewed as the linchpin of the new knowledge economy. 3D printing technology is knowledge intensive, and offers a potentially transformative promise in the economy of knowledge (Birtchnell et al., 2017; Olatunji et al., 2023). The responsibility is now for the schools to react swifty by building capacity through the design of plans (labs, teachers and curricula) that would prepare students for the modern reality (Huleihil, 2017). This is critical as the evolution of 3D printing technology creates an opportunity for contemporary teaching practices in different educational environments and subjects (Ford and Minshall, 2019).

Accordingly, the required actions of universities are clear as it includes building knowledge by conducting fundamental and applied research, generating essential innovations, training, and harnessing human capital development of researchers, scientists and engineers. Universities are therefore critical actors in the societal ecosystem with the primary function of bridging the divide between industry and innovative systems such as 3D printing technology (Oyelaran-Oyeyinka and Adebowale, 2017). This can also be achieved through the application of the triple helix model of university-industry-government in promoting a sustainable manufacturing future for SMEs (Kolade et al., 2022a). The universities can achieve this by driving environmental policy formulation that support decentralized recycling, upcycling, reuse and distributed manufacturing (Sanchez et al., 2020).

Although available literature has established that 3D printing technology is positively disruptive and critical for the facilitation of the circular economy, there are still limited studies on the roles required by universities to drive positive actions. In particular, its impact on waste management, especially the menace of plastic waste. This paper looked at variables such as knowledge and building capacity in Nigerian universities and their relationship to foster positive circular plastic economy actions in the society.

2. Africa: the new frontier of 3D printing for circular economy?

Africa holds immense potential to lead in sustainable 3D printing applications, but its adoption of the technology remains uneven, with South Africa standing as a notable outlier. While 3D printing has seen significant growth in regions such as Asia, Middle East and North Africa, Africa still lags behind (Alzhrani et al., 2024). However, the continent offers immense opportunities for technological leapfrogging, where strategic investments in additive manufacturing could address pressing challenges in manufacturing, waste management, and sustainability. For instance, Pilogallo (2018) estimated a 23% growth in 3D printing purchases through 2017, highlighting the sector's latent potential.

South Africa has the most advanced 3D printing ecosystem on the continent, with significant investments and dynamic partnerships between government, academia, and industry. Initiatives such as Aeroswift, a homegrown additive manufacturing platform supported by the South African Council for Scientific and Industrial Research and private aerospace firms like Aerosud, underscore the country’s success, (Desiderio, 2018). Between 2012 and 2015, the number of 3D printers grew by over 400%, with investments exceeding $30 million (de Beer et al., 2016). The Rapid Product Development Association of South Africa (RAPDASA) has also been instrumental in promoting technology diffusion, fostering a robust innovation ecosystem (Cruywagen, 2017). South Africa’s coordinated efforts among government, academia, and private enterprises illustrate the transformative potential of additive manufacturing when supported by strategic collaboration.

In other parts of Africa, the 3D printing landscape is less developed but demonstrates significant ingenuity. For instance, Elephab, a Nigerian start-up supported by GE Lagos Garage, aims to address Nigeria’s chronic energy challenges by producing replacement parts with lower power requirements than traditional manufacturing (Desiderio, 2018; Scott, 2017). In Togo, Woelabs exemplifies innovative approaches by using electronic waste to produce Africa's first homegrown 3D printers. This initiative addresses the continent's e-waste problem while fostering sustainable local manufacturing. Woelabs has further expanded to develop 3D printing materials from recycled plastics, promoting circular economy principles (Besliu, 2018; Matthews, 2016).

Rwanda's Great Lakes Energy leverages 3D printing to create packaging for solar products, showcasing the synergy between renewable energy and additive manufacturing (Davis College Akilah, 2016). In Uganda, the Comprehensive Rehabilitation Services Hospital has partnered with Canadian organisations to produce prosthetic limbs for amputees using 3D printing, meeting critical healthcare needs in a resource-constrained environment (Baike, 2016; Simon, 2020). These initiatives underline the potential of 3D printing to address diverse societal challenges, from healthcare to renewable energy, while promoting sustainable practices.

Despite these promising cases, significant barriers hinder the widespread adoption of 3D printing across Africa such as limited infrastructure, high costs and the need for specialised training (Olatunji et al., 2023). Unlike South Africa, where the government plays an active role, the growth of additive manufacturing in most African countries relies predominantly on private sector initiatives. This lack of coordinated support from universities, governments, and research institutions limits the scalability and integration of 3D printing technologies into national development strategies. For example, while South Africa benefits from government-funded R&D grants and policy direction, countries like Nigeria and Rwanda lack such institutional frameworks to drive the sector forward.

Universities, in particular, are underutilised in fostering 3D printing innovations. In most African countries, higher education institutions have not fully integrated additive manufacturing into their curricula or research agendas, thereby missing an opportunity to develop skilled professionals and advance localised solutions. The absence of university-led initiatives contrasts sharply with South Africa's model, where academic institutions have been central to the development and diffusion of additive manufacturing technologies.

To address these challenges, African policymakers must prioritise the establishment of supportive ecosystems that promote 3D printing (Fahfouhi et al., 2024). Governments should provide funding for R&D, create incentives for businesses adopting sustainable practices, and establish recycling hubs to convert waste into 3D printing feedstock. Universities must integrate additive manufacturing into their teaching and research activities, fostering partnerships with industry to bridge the gap between academic knowledge and practical application. Triple Helix partnerships, which bring together government, academia, and industry, could provide a framework for scaling 3D printing technologies across the continent.

The role of 3D printing in promoting the circular economy is particularly significant. By enabling the reuse of materials and reducing reliance on virgin resources, 3D printing supports closed-loop manufacturing systems that align with sustainability principles. For instance, initiatives such as Woelabs' use of e-waste and recycled plastics demonstrate how additive manufacturing can address environmental challenges while creating economic opportunities (Besliu, 2018). However, scaling such efforts requires targeted interventions to address systemic barriers, such as fragmented supply chains, inadequate infrastructure, and limited awareness of 3D printing technologies.

Africa's ability to harness 3D printing for sustainable development hinges on building inclusive, innovative ecosystems. Drawing on successful examples like Aeroswift in South Africa, Woelabs in Togo, and Elephab in Nigeria, the continent has the potential to lead in sustainable additive manufacturing. By addressing gaps in infrastructure, policy, and education, African countries can position themselves as global leaders in leveraging 3D printing to meet critical societal and environmental challenges. This would not only accelerate the transition to a circular economy but also promote economic empowerment and resilience across the continent.

3. Methodology

The study collected quantitative data which was then analysed and modelled. The data was analyses based on the following hypothesis:

H_1 Knowledge of plastic waste problem has a positive relationship with plastic waste management action.

H_2 Understanding of 3D printing technology has a positive relationship with plastic waste management action.

H_3 Understanding of 3D printing sub-technology has a positive relationship with plastic waste management action.

3.1 Data Collection

With the use of a Likert scale, the questionnaire was created to capture respondents' perceptions on the circular plastic economy (Bell and Waters, 2018). The quantitative data was gathered through an electronic questionnaire for students. Participants were randomly selected via invitation from professors, university departments, social media profiles and several WhatsApp university groups. To ensure a balanced pool of respondents, in terms of gender, study level and course of study, interested participants were asked for basic demographic information, contact information and their area of study or specialisation. The questionnaire obtained responses from 151 respondents (Okoya et al., 2024; Oyinlola et al., 2024). Table 1 below summarises the respondents' profiles:

Table 1: Profile of Questionnaire Respondents

Variable	-	**Frequency**	**Percent**
Gender	Male	103	31.8
-	Female	48	68.2
-	**Total**	**151**	**100**
Age	18-24	71	47
-	25-34	56	37.1
-	35-44	17	11.3
-	45-54	7	4.6
	Total	**151**	**100**
University	Ahmadu Bello University	56	37.1
-	University of Nigeria	23	15.2
-	University of Lagos	40	26.5
	Obafemi Awolowo University	29	19.2
	Other	3	2.0
	Total	**151**	**100**
Current Level of Study	Post PhD	5	3.3
	PhD	17	11.3
-	Masters	44	29.1
-	Undergraduate	82	54.3

-	Others	3	2.0
-	**Total**	**151**	**100**

3.2 Model Specification

A model was built to investigate the relationship between student’s 3D printing technology capabilities and their plastic waste management action. With emphasis on micro capability around 3D printing, an assessment was conducted to establish the relationship between understanding of 3D printing and understanding of another sub technology of 3D printing (FILTECH) with plastic management action. To avoid the error of over-simplification of the relationship, a control for student’s knowledge of the plastic waste problem was incorporated in the model. To assess the sensitivity of the result, the model was extended to create control for other very common capacities i.e., mobile application awareness and web application awareness.

In both models, the outcome was evaluated using a binary variable that indicated whether a student had taken any action to manage plastic waste in their environment. Each model included four endogenous variables, with the outcome variable (ACTN) being one of them. The other three endogenous variables, KNOW1, KNOW2, and KNOW3, were used to measure the latent variable "Knowledge." Respondents' answers to questions about their knowledge of the circular plastic economy, their awareness of the connection between plastic pollution and climate change and their concerns regarding the environmental effects of plastic waste were analysed. The distinction between Model 1 and Model 2 was based on the number of exogenous variables included. Model 1 accounted for students' understanding of 3D printing technology and their familiarity with Filtech, a technology that converts plastic waste into filaments for 3D printing. In contrast, Model 2 introduced additional exogenous variables related to common resources in the country, specifically by assessing respondents' awareness of mobile and web applications designed to address these issues.

Table 2 presents the summary statistics of variables used in the study. Variables with maximum values of 2 are binary while others were measured in 5 Linkert scales, except for KNOW3 which was collapsed to 4 because of an insignificant number of respondents in one of the categories.

Table 2: Summary Statistics of Variables

Variables	Mean	Std. dev.	Min	Max
KNOW1	2.9073	0.9754	1	5
KNOW2	3.0596	1.0213	1	5
KNOW3	2.6887	1.3913	1	4
ACTN	1.5563	0.4985	1	2
UND3D	3.3576	1.2347	1	5
UNDS3	1.2450	0.4315	1	2
MOAPP	1.9536	0.2110	1	2
WEAPP	1.9205	0.2714	1	2

Table 3 maps the link between the variables and their corresponding survey questions. It presents all variables for model 1 and model 2.

Table 3: Model Variables and their Corresponding Measures

Variable	**Names**	**Survey Question**
Dependent Variable	ACTN	Taken action to manage plastic waste
Knowledge	KNOW1	Knowledge of circular plastic economy
	KNOW2	Awareness of climate change
	KNOW3	Plastic challenge concern
3D Printing Technology	UND3D	Understanding of 3D printing
3D Printing sub-Technology	UNDS3	Understanding of FIltech
Mobile Application	MOAPP	Awareness of mobile application
Web Application	WEAPP	Awareness of web application

4. Data Analysis and Results

To analyse the data, the study employed Structural Equation Modelling (SEM). The model choice was determined by the view that SEM is a powerful and robust statistical method used in many fields and its suitability for understanding relationships between variables such as the model developed (Hair et al., 2012). As the study was interested in investigating the relationship between knowledge, capacity and plastic waste management action, it opted for the covariance-based SEM (CB-SEM) instead of the partial least squares SEM (PLS-SEM). This choice hinged on the fact that the study was interested in exploring likely factors that influence actions of students to manage plastic waste rather than attempting to predict the factors.

Measurement and Structural Models: Prior to discussing the estimation results, the study undertook analysis of goodness of fit of the models. Due to high similarity in results, it discussed the measurement model and the structural model evaluation in the same segment. Table 4 presents the table of relevant indices for judging the models. It evaluated their reliability by comparing the fit indices with some established benchmarks (Kolade et al., 2022a; Weston and Jr, 2006). The chi^2 likelihood ratio divided by the degree of freedom (CMIN/DF) for both models were approximately 1 in which they were less than the theoretical cut-off (expected to be less than 3). Likewise, the Comparative Fit Index (CFI) was close to 1 in both models and the Root Mean Square Error of Approximation (RMSEA) was close to 0 for both models. The results holds for both measurement and structural parts of the developed models. Therefore, the study concluded that the model’s goodness of fit was good.

Table 4: Check of Estimation Goodness of Fit

Fit Indices	**Measurement Model**	**Structural Model**	**Model Criteria**
Model 1			
CMIN/DF	<1	<1	< 3
CFI	~ 1	~ 1	>0.90
RMSEA	~ 0	~ 0	< 0.08
Model 2			
CMIN/DF	<1	1.15	< 3
CFI	~ 1	~1	>0.90
RMSEA	~ 0	0.03	< 0.08

4.1 Results

The results of the models were presented in the figures and tables respectively. The figures 1 and 2 highlighted the path estimation results which reflect same results as shown in the tables 5 and 6. Model 2 was used as a sensitivity test and conclusions from the 2 models regarding the parameters of interest were the same, the interpretation of results and hypotheses discussion used model 1. Knowledge was found to be positively associated with plastic waste management action and it is statistically significant at 5%. While the results for the two components of 3D printing that were investigated (understanding of 3D printing and understanding of a sub-technology that can power 3D printing – Filtech), showed a positive relationship with plastic waste management action, they were both statistically insignificant in affecting plastic waste management action of respondents in the Nigerian universities surveyed.

The extension of the model to consider other common capabilities such as mobile application and web application (model 2) to further test the robustness of the conclusion returned same conclusion for knowledge and the two components of 3D printing. Interestingly, the study found web application statistically significant in the second model (discussion of which was outside the scope of the study).

Figure 1: Model 1 Path Diagram Results

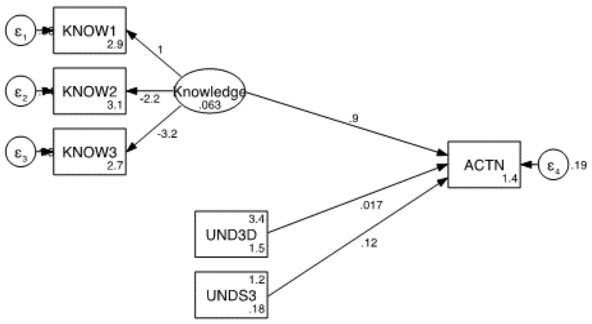

Figure 2: Model 2 Path Diagram Results

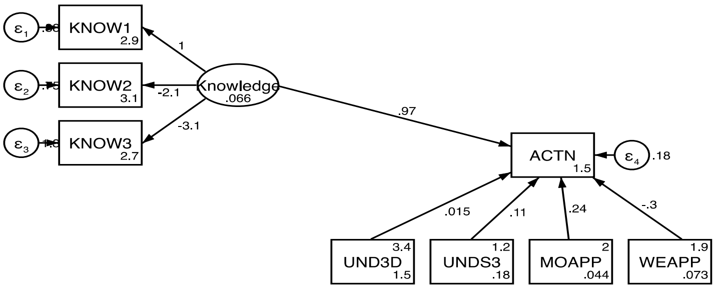

Table 5: Model 1 Results

Variables	ACTN	KNOW1	KNOW2	KNOW3	/
var(e.KNOW1)					0.882***
					(0.108)
var(e.KNOW2)					0.736***
					(0.135)
var(e.KNOW3)					1.293***
					(0.262)
var(e.ACTN)					0.191***
					(0.0290)
var(Knowledge)					0.0633
					(0.0548)
UND3D	0.0168				
	(0.0332)				
UNDS3	0.120				
	(0.0958)				
Knowledge	0.900**	1	-2.178**	-3.156*	
	(0.436)	(0)	(1.024)	(1.627)	
Constant	1.350***	2.907***	3.060***	2.689***	
	(0.194)	(0.0791)	(0.0828)	(0.113)	
Observations	151	151	151	151	151

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 6: Model 2 Results

Variables	ACTN	KNOW1	KNOW2	KNOW3	/
UND3D	0.0150				
	(0.0327)				
UNDS3	0.106				
	(0.0946)				
MOAPP	0.239				
	(0.191)				
WEAPP	-0.298**				
	(0.146)				
Knowledge	0.970**	1	-2.096**	-3.129**	
	(0.445)	(0)	(0.961)	(1.552)	
var(e.KNOW1)					0.879***
					(0.108)
var(e.KNOW2)					0.747***
					(0.128)
var(e.KNOW3)					1.279***
					(0.252)
var(e.ACTN)					0.179***
					(0.0295)
var(Knowledge)					0.0657
					(0.0551)
Constant	1.480***	2.907***	3.060***	2.689***	
	(0.442)	(0.0791)	(0.0828)	(0.113)	
Observations	151	151	151	151	151

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7 presents the mapping of the results to the hypotheses. It rejected the implicit null hypothesis for the hypothesis 1 and concluded that knowledge of plastic waste problem has a positive and significant relationship with plastic waste management action of respondents in Nigerian universities. For hypotheses 2 and 3, it failed to reject their implicit null hypotheses and concluded that the understanding of 3D printing and understanding of 3D printing sub technology has a positive relationship with plastic waste management action, but they do not have significant impacts on the plastic waste management actions of respondents in Nigerian universities.

Table 7: Hypotheses Testing, Results and Conclusion

Hypothesis	Coefficient	P-value	Conclusion
H_1	0.9355	0.0370	Positive and significant at 5%
H_2	0.1272	0.8910	Positive but statistically insignificant
H_3	0. 0034	0.9190	Positive but statistically insignificant

5. Discussion

The findings highlight that knowledge plays a statistically significant role in advancing plastic waste management actions within a circular economy framework. This aligns with the university’s mission to transfer and disseminate knowledge, positioning it as a key driver of innovation in sustainability. For example, Kolade et al. (2022) discuss the potential of university-industry-government collaborations in leveraging 3D printing technologies to address pressing sustainability issues. By equipping students with contemporary tools like 3D printing, universities can foster entrepreneurial thinking and sustainable innovation, thereby contributing positively to Nigeria's environmental challenges (Kolade et al., 2022a).

However, this role necessitates significant investment in infrastructure, resources, and policy support, which remain underdeveloped in many Nigerian universities. Without targeted governmental and international backing, these institutions may struggle to meet the technological and pedagogical demands required to catalyze a sustainable circular economy.

Despite its promising potential, the study found that 3D printing technologies and sub-technologies like Filtech were statistically insignificant in influencing plastic waste management actions among Nigerian universities. This finding contrasts with global success stories in additive manufacturing, where 3D printing has been pivotal in achieving sustainable manufacturing practices. Kolade et al. (2022) argue that such technologies are uniquely suited to disrupting traditional supply chains, enabling localised production with minimal waste (Kolade et al., 2022a). The lack of impact in Nigeria suggests a technology gap, which universities must urgently address through targeted capacity-building initiatives.

The low adoption rates of 3D printing in Nigerian universities also reveal systemic barriers, including inadequate infrastructure, limited access to funding, and insufficient awareness among stakeholders. As Oyinlola et al. (2022) note, transitioning to a circular plastic economy requires an ecosystem that supports technological integration and policy innovation. For Nigeria, this underscores the need for multi-sectoral partnerships to address structural deficiencies in higher education and foster a culture of innovation (Oyinlola et al., 2022).

In contrast to the limited impact of 3D printing technologies, the study found a positive relationship between web applications and plastic waste management actions. This finding highlights the practical utility of digital innovations, which are more accessible and scalable in resource-constrained environments. Oyinlola et al. (2022) discuss similar innovations in Africa, where web-based platforms have been employed to incentivise waste collection and recycling. These solutions demonstrate that even in the absence of advanced technologies like 3D printing, digital tools can drive meaningful progress toward sustainability (Oyinlola et al., 2022).

For Nigerian universities, web applications represent a low-cost, high-impact opportunity to engage students and staff in sustainability initiatives. By integrating these tools into curricula and campus operations, universities can build a foundation for broader technological adoption and environmental stewardship.

The findings expose critical gaps in the capacity of Nigerian universities to act as hubs of innovation for the circular economy. While their role as knowledge institutions is well-established, their ability to translate this knowledge into practical action remains limited. The low traction of 3D printing technologies highlights the disconnect between global advancements and local realities, suggesting a need for tailored strategies that account for Nigeria's unique challenges.

Moreover, the study underscores the importance of aligning academic curricula with industry needs. Kolade et al. (2022) advocate for a Triple Helix model, where universities, industry, and government collaborate to drive technological leapfrogging (Kolade et al., 2022a). For Nigerian universities, adopting such a model could facilitate the integration of disruptive technologies like 3D printing into teaching and research, fostering a new generation of sustainability-oriented entrepreneurs.

6. Conclusion and Recommendations

The study offers valuable insights into the challenges and opportunities facing Nigerian universities in their quest to contribute to the circular plastic economy. By highlighting the critical role of knowledge, the potential of digital innovations, and the limitations of current technological capacities, it provides a roadmap for actionable change. With targeted investments and collaborative efforts, Nigerian universities can not only overcome these challenges but also position themselves as leaders in sustainability and innovation on the global stage.

To bridge the identified gaps, the study recommends targeted investments in infrastructure, capacity-building, and policy reforms. Universities should prioritise partnerships with industry and government to secure funding and technical expertise. In addition, international bodies promoting the circular plastic economy should extend their support to Nigerian universities, enabling them to access cutting-edge technologies and best practices.

Future research should explore the scalability of digital innovations like web applications in promoting sustainability actions. Given their proven impact in this study, these tools could serve as a stepping stone toward broader technological adoption. Research should also investigate the socio-cultural factors influencing the uptake of 3D printing technologies, providing insights into how universities can better engage students and staff in sustainability efforts.

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