3D PRINTING FOR SUSTAINABLE LOW-INCOME HOUSING IN SOUTH AFRICA: A CASE FOR THE URBAN POOR

Douglas Aghimien,[1] Clinton Aigbavboa,[2*] Lerato Aghimien,[3] Wellington Thwala,[4] and Lebu Ndlovu[5]

ABSTRACT

This paper presents the findings of an assessment of the possible measures needed for the adoption of three-dimensional (3D) printing for sustainable low-income houses that can be beneficial to the urban poor. The study adopted a quantitative approach and answers were sought from construction professionals actively involved in a construction project in the country. The study revealed through factor analysis that 3D printing for sustainable low-income housing delivery in South Africa could be encouraged through effective promotion and training, government support, improvement of 3D printing technology, and affordability of the technology. The study contributes significantly to the body of knowledge as it reveals the possible measures for improving the adoption of 3D printing in housing delivery in South Africa—an aspect that has not gained significant attention in the fourth industrial revolution and housing delivery discourse in the country.

KEYWORDS

3D printing, additive manufacturing, low-income housing, contour crafting, South Africa

1. INTRODUCTION

In 2015, the United Nations (UN) came up with seventeen life-changing sustainable development goals (SDGs) as against the eight-millennium development goals that were earlier in existence. This was done with the aim of eradicating poverty while protecting the planet by the year 2030. Providing a sustainable and livable city through innovative infrastructure delivery is part of the goals of this sustainable development agenda (UN, 2015). Since this declaration, countries around the world have pledged their support to improve the planet by focusing on different aspects of these SDGs. South Africa, for example, came up with the National Development Plan (NDP) 2030 with the sole aim of reducing poverty and inequality by the year 2030. To achieve this, several milestones were established, one of which is producing infrastructures such

1 & 2. cidb Centre of Excellence, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, South Africa

3, 4 & 5. SARChi in Sustainable Construction Management and Leadership in the Built Environment, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, South Africa

* Email: caigbavboa@uj.ac.za

as housing, water, sanitation, roads, parks and so on, that supports sustainable human settlement (National Planning Commission, 2012). Unfortunately, despite such initiatives, the number of the urban poor continue to rise in most developing countries (South Africa inclusive) and this is mostly as a result of the rapid urbanisation that has characterised most cities in recent times (Bradlow *et al.*, 2011; UN, 2020). These set of urban dwellers live in houses that are below standard with complete lack of necessities required for decent human living.

The housing shortage has become a major issue for the South African government, as several housing strategies have been initiated in recent times. Ajayi (2012) noted that the government sought to tackle this issue through scale delivery of subsidised housing for low-income households. However, this approach has not achieved the desired output as the housing shortage continues to grow (Bradlow *et al.*, 2011). The housing backlog in the country is around 2.3 million houses, and this figure continues to increase each year (Hartmann, 2018). The Reconstruction and Development Program (RDP) initiative introduced by the government has also not yielded the expected result, as problems such as low quality of buildings and slow pace of housing delivery have been reported (Bradlow *et al.*, 2011; Aigbavboa and Thwala, 2013; Manoano and Tanga, 2018; Moolla *et al.*, 2011).

To deliver more sustainable low-income houses that the urban poor can benefit from, the government and other housing developers can find solace in the adoption of digital technologies that can help provide quality houses that are affordable and delivered within the expected timeframe. One of such technology is Additive Manufacturing, also known as three-dimensional (3D) printing which is the process of creating a physical object from a 3D digital model in a layer by layer process (Lim *et al.*, 2012). 3D printing has been described as an automated process that requires the use of software, hardware and materials, to produce a solid final product. Variety of 3D software programs are available for the creation of a 3D digital model which after creation is scanned using a 3D scanner. This 3D scanner converts the model into a readable file format that the 3D printer can understand. The 3D printer then extrudes printable material on-site in accordance with the layers and processes of the digital model (Sakin and Kiroglu, 2017). The most common 3D printing technology that has been adopted for housing delivery is the Contour crafting, and immense benefits have been recorded with the use of this technology (Hager *et al.*, 2016; Sakin and Kiroglu, 2017; Wu *et al.*, 2016).

Despite these benefits, the adoption of this digital technology in most developed and developing countries has been slow (Bos *et al.*, 2016; Nematollahi and Sanjayan, 2017). This problem has been linked with several factors acting as barriers to its full adoption. Barring these barriers, this current paper examines the possible ways by which the adoption of 3D printing can be improved in South Africa with a view to providing sustainable low-income houses that can be beneficial to the urban poor.

2. 3D PRINTING AND SUSTAINABLE HOUSING

As a result of its ability to give significant environmental, social as well as economic benefits (Hager *et al.*, 2016; Lim *et al.*, 2012; Pîrjan and Petroşanu, 2013; Sakin and Kiroglu, 2017), the use of 3D printing for construction project delivery is believed to be the way forward in the quest for sustainable construction projects—housing inclusive (Sakin and Kiroglu, 2017). With its project cost reduction benefits in terms of labour and materials (Lim *et al.*, 2012; Mohd-Tobi *et al.*, 2018), along with its ability to reduce the cost of transporting materials to site (Sakin and Kiroglu, 2017), economically sustainable housing projects that are affordable for low-income earners can be delivered. Furthermore, social sustainability can be achieved through 3D printing as the technology offers the creation of new jobs and the reduction of site accidents and fatalities (Fonseca, 2018; Pîrjan and Petroşanu, 2013). Aside from its economic and social attributes, the use of 3D printing promises the reduction in construction material wastage (Ellis 2018) which over time has been a source of environmental concern for most construction experts (Ametepey and Aigbavboa, 2014).

To improve the use of 3D printing for sustainable low-income housing delivery, several factors can be considered. Pîrjan and Petroşanu (2013) found that the most important criteria customers consider when choosing a 3D printer is the size, affordability, friendly use of technology without the need for advanced training, quality of products printed and time frames in which products are printed. Customers require 3D printers to fit within customers space ranging from wide to limited spaces. The price of 3D printer, additional devices and supplies needed by the 3D printer should be affordable for everyday use. The improvements in cementitious printing material methods have also been noted as there have been references of the weak bonding created by backfill of compound material within a one-hour interval from when the walls are printed (Lim *et al.*, 2012; Paul *et al.*, 2018). There is a need for alternative 3D printing methods that can be compactable with the building codes in most countries (Poullain *et al.*, 2018). Similarly, the integration of 3D printing with multiple building services and developments of a variety of printable materials will go a long way in improving its usage (Wu *et al.*, 2016). Furthermore, more safety precautions within 3D printers are still needed as studies done on construction workers safety found the main source of injuries are collisions with machines, machines running over people and workers being trapped between objects (Abderrahim *et al.*, 2003). The advantage of 3D printing possibly eliminates the need for humans to perform hazardous operations hence the reduction of site injuries and fatalities is double fold. There is a great threat of mass injuries that can result in the malfunction of enormous 3D printing equipment on-site or collapse of printed buildings (Sakin and Kiroglu, 2017). Developments of safety precautions need to be built in the 3D printing model for large scale construction operations. Abderrahim *et al.* (2003) proposed an active security feature for new technological construction methods.

Oke *et al.* (2018) noted that stakeholders in the construction industry need to prioritise education and training in digital technologies for construction industry participants. The training will facilitate easier adoption of digital technologies. In the same vein, Becerik (2004) recommends that software and technology vendors train and develop skills for prospective users. Although the adoption of 3D printing is slowly increasing in the global industry, there is a lack of adoption of 3D printing educational activities in school curriculums (Dickens *et al.*, 2012). Only a few elementary, middle schools and universities globally have adopted 3D printing in their courses (Kayfi *et al.*, 2015). Other possible measures include national building regulations adopting 3D printing methods (Poullain *et al.*, 2018), government support for 3D printing through sponsoring of 3D programs, creation of legislation and regulation (Breann, 2012; Dickinson, 2018) as well as better public enlightenment on 3D printing's inherent benefits by digital technology vendors, institutes of higher learnings, and professional bodies (Dickens *et al.*, 2012; Ford and Minshall, 2017; Wang and Tain, 2015). Based on the above issues, Table 1 reproduced the measures that can be put in place to encourage the use of 3D printing for construction delivery (housing inclusive).

TABLE 1. Measures for improving 3D printing for sustainable low-income housing.

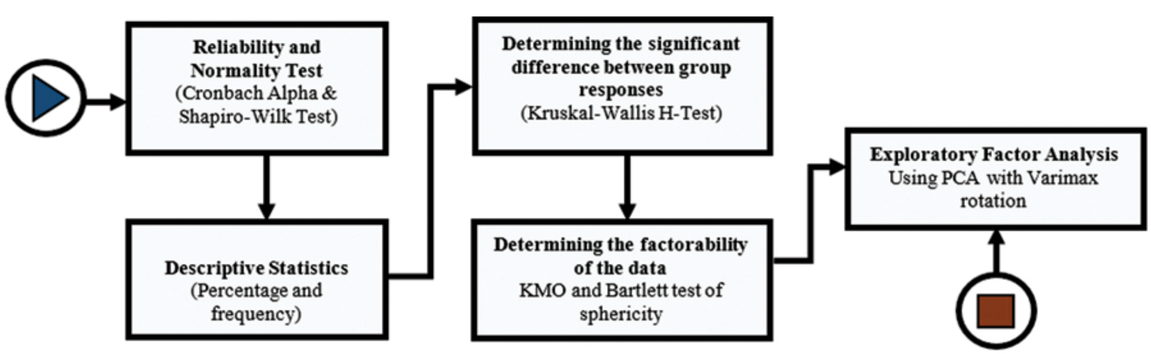
Measures	Authors
Improved printer size	Pîrjan and Petroşanu (2013)
Affordable 3D printing technologies	Pîrjan and Petroşanu (2013)
Improvements in current 3D printing methods	Lim *et al.* (2012); Paul *et al.* (2018)
Development of alternative 3D printing methods compatible with building codes	Poullain *et al.* (2018)
Developments of a variety of printable materials	Paul *et al.* (2018); Wu *et al.* (2016)
Integration of 3D printing with multiple building services	Wu *et al.* (2016)
Developments of safety precautions measurements within the 3D printer system	Abderrahim *et al.* (2003); Sakin and Kiroglu (2017)
3D printing method certified to build Green Building designs	Pîrjan and Petroşanu (2013); Yossef and Chen (2015)
Life cycle cost analysis feature in 3D printing	Tay *et al.* (2017)
Increased research and development in 3D printing	Berman (2012); Ng *et al.* (2015)
Government support for pilot programs in 3D printing	Breann (2012); Mazzucato (2015)
Training of construction participants in 3D printing	Oke *et al.* (2018)
Adoption of 3D printing educational curriculums in elementary and higher institutions	Dickens *et al.* (2012); Ford and Minshall (2017); Kayfi *et al.* (2015)
More Seminars and workshops on 3D printing by professional bodies	Oke *et al.* (2018)
3D printing software and technology vendors to increase visibility and connect with potential industry users	Wang and Tain (2015)
3D printing software and technology vendors to actively provide long term training and assistance for participants	Becerik (2004)
Development of government policies that incentivise the procurement of 3D printing technologies	Paul *et al.* (2018); Poullain *et al.* (2018)
Adoption of 3D printing by building regulatory bodies	Poullain *et al.* (2018)

3. RESEARCH METHODOLOGY

A post-positivism philosophical stance was adopted for this study using a quantitative approach. Responses were sought from construction professionals with at least five years working experience and working within government, consultancy and contracting organisations in the Gauteng province of South Africa. This was based on the premise that since housing projects in South Africa are mostly contractor-driven (Bradlow *et al.*, 2011), getting information from those that work with these contractors and those involved in supervising the delivery of these contractor's projects would prove beneficial to the study. The instrument for data collection was a structured close-ended questionnaire designed from the findings of existing literature. The questionnaire was designed in two sections with the first section seeking answers on some defined background information on the respondents. This includes the type of profession of the respondents, the type of organisations they work for, their highest academic qualification as well as their years of experience within the industry. The information gathered from this first section served as a quality check for the answers given in the other section. The second section sought answers to questions on the possible measures for improving the use of 3D printing in housing delivery. The respondents were presented with18 measures that were identified from the review of literature and were asked to rate the extent to which these measures can help promote the use of 3D printing in the country using a 5-point Likert scale with 5 being a very large extent, 4 being a large extent, 3 being moderately extent, 2 being low extent, and 1 being no extent at all. Due to the difficulty in getting the exact number of professionals with the set years of experience and practising within the province, a snowball sampling approach was adopted to get respondents for the study. This is because the sampling approach has the potential to significantly increase the sample size of a study since it is based on referral. Based on the approach adopted, a total of 73 professionals with at least five years of working experience and currently practising within the construction domain in the study area participated in the survey.

Figure 1 shows the framework for data analyses. First, percentage and frequency were used to analyse the data on the background information of the respondents. Then, the reliability and the normality of the data gathered from the second section were tested using the Cronbach alpha test and Shapiro-Wilk normality test, respectively. The Cronbach alpha test gives an alpha value of between zero to one, and the closer the alpha value generated is to one, the more reliable the data gathered (Moser and Kalton, 1999). An alpha value of 0.916 was derived, thus, confirming the reliability of the instrument used. On the other hand, using the Shapiro-Wilk test, which is most suitable for a sample size of less than 2000 (Ghasemi and Zahediasl, 2012), a significant *p*-value of 0.000 was derived for all assessed variables. This implies that the data gathered are non-parametric in nature. Since the data is non-parametric, the Kruskal-Wallis H-test (*K-W*) which is a non-parametric test used in determining the significant difference in the opinion of participants was adopted. This test was conducted on the premise that since professional views differ, there might be the possibility of the construction professionals having diverse views of the variables under assessment. *K-W* helped determined the specific variables with a statistically significant difference in the rating by the different professionals. Finally, exploratory factor analysis (EFA) was adopted in grouping the identified measures into more manageable sub-scale that can give the key measures needed for the adoption of 3D printing.

FIGURE 1. Framework for Data Analyses.



In doing this, the factorability of the data gathered was determined using Kaiser–Meyer–Olkin (KMO) and Bartlett test analyses. On meeting the required threshold, EFA was conducted using the principal component analysis (PCA) with varimax rotation. Although significant literature has emerged on the use of EFA and the ideal sample size, there has been no agreement on the best fit sample size for this analysis (Pallant, 2005). While some advocates express the need for a large sample size (Tabachnick and Fidell, 2007), others believe that as long as the communalities derived are reasonably high, and the expected number of extractions is low, then significant emphasis should not be placed on the sample size of the study (Field, 2000; Preacher and MacCallum, 2002). The communalities of between 0.428 to 0.807 were generated. This result confirmed that the use of EFA was appropriate for the study.

4. FINDINGS AND DISCUSSION

4.1 Background information of respondents

The results in Table 2 show the background information of the respondents for the study. The result revealed that more engineers (civil, mechanical and electrical) participated in the study (47.9%). This is followed by quantity surveyors (26%), construction managers (16.4%) and

TABLE 2. Background information of the respondents.

Category	Classification	Frequency	Percentage
Profession	Architect	7	10.0
	Construction Managers	12	16.4
	Engineer (Civil, Mechanical, Electrical)	35	47.9
	Quantity Surveyors	19	26.0
	Total	73	100.0
Type of organisation	Consulting	19	26.0
	Contracting	33	45.2
	Government	21	28.8
	Total	73	100.0
Highest Academic Qualification	National Diploma	31	42.5
	Bachelor's Degree	28	38.4
	Master's Degree	8	11.0
	Doctorate	6	8.2
	Total	73	100.0
Years of experience	5 years	33	45.2
	6–10 years	5	20.5
	11–15 years	11	15.1
	16–20 years	11	15.1
	Above 20 years	3	4.1
	Total	73	100.0
	Average	9.4 years	

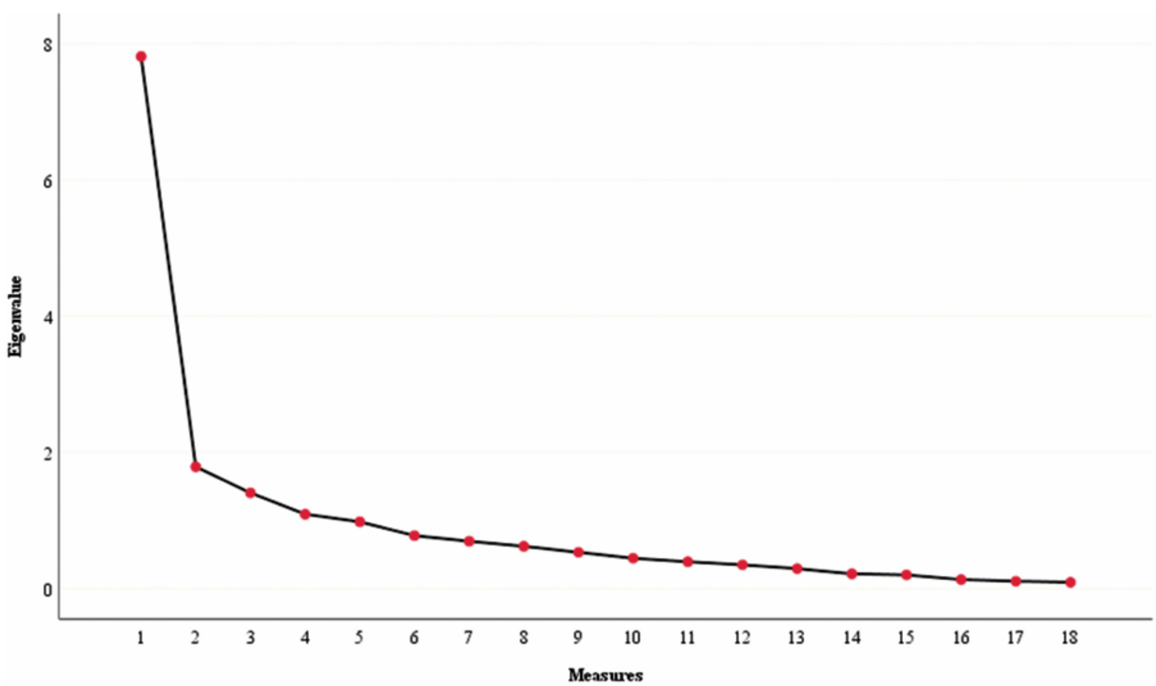
architects (10%). Out of these respondents, 45.2% currently work within contracting organisations, 28.8% work for the government, and 26% work for consultancy firms. In terms of highest academic qualifications, 43% possess a national diploma, 38% possess a bachelor's degree, 11% have a master's degree, and 8% have a doctorate degree. For their years of experience within the construction industry, 45.2% have at least 5 years experience, 20.5% have up to 10 years experience while 34.3% have up to 20 years working experience. The average years of working experience for all the respondents was calculated as 9.4 years which shows a considerably high number of years in the industry. This result implies that the target respondents for the study were adequately represented, and they have a reasonable level of academic background to understand the questions of the research and these questions were answered based on the vast wealth of experience they have accumulated during their years of working within the industry.

4.2 Improving 3D printing in Housing Delivery

In determining the measures for improving 3D adoption in housing delivery, the respondents rated the 18 measures identified from the review of literature. The significant difference between the different professionals was tested using *K-W*. It was discovered that there is no significant difference in the rating of the respondents as a *p*-value of above 0.05 was derived for all the measures assessed (see Table 3). This implies that the result can be taken as a true reflection of happenings in the industry as there is a convergent view among the respondents sampled.

The factorability test conducted revealed a Kaiser-Meyer-Olkin (KMO) value of 0.825, which is higher than the 0.6 thresholds required (Pallant, 2005). A Bartlett test also gave a chi-square value of 799.52 and significant p-value of 0.000, which meets the significant threshold (Tabachnick and Fidell, 2007). EFA was conducted using PCA with varimax rotation. The result from the PCA conducted revealed 4 extractions with an eigenvalue of one and above.

FIGURE 2. Scree plot.



The Scree plot in Figure 2 also confirms the retaining of these 4 factors as a significant elbow is revealed from the fourth component. The first components account for 43.4%, while the second account for 10.0%. The third component accounts for 7.8% while the last component accounts for 6.1%. The final statistics of the PCA and the components extracted accounted for 67.3% of the total cumulative variance, which is well above the 50% limit (Stern, 2010). These four extracted components and their variables are shown in Table 3.

A. Promoting 3D printing and training

The first extracted component has six variables loading heavily on it, and it accounts for 43.4% of the total variance explained. This implies that this component requires considerable attention as it weighs more than the three other extracted components put together. The variables loading here are 3D printing software and technology vendors to actively provide long term training and assistance for construction participants, increased research and development in 3D printing, more seminars and workshops on 3D printing by professional bodies, adoption of 3D printing educational curriculums in elementary and higher institutions, training of construction participants in 3D printing, and 3D printing software and technology vendors to increase visibility and connect with potential industry users. Based on the nature of these variables, this component was subsequently named 'promoting 3D printing and training'.

B. Government support

The second extracted factor accounted for 10.0% of the variance explained and has six variables loading into it. These variables are government support for pilot programs in 3D printing, development of government policies that incentivise the procurement of 3D printing technologies, development of alternative 3D printing methods compatible with building codes, 3D printing methods certified to build Green Building designs, The Council of the South African Bureau of Standards for the application of the national building regulations to adopt 3D printing method and developments of a variety of printable material. This component was subsequently named 'government support' based on the latent similarity of these variables.

C. Improvement of 3D printing technology

Component three accounts for 7.8% of the total variance explained and has three variables loading heavily on it. These variables are developments of safety precautions measurements within the 3D printer system, integration of 3D printing with multiple building services, and improved printer size. This component was subsequently named 'improvement of 3D printing technology'.

D. Affordability of 3D printers

The fourth component accounts for 6.1% of the variance explained and has variables such as affordable 3D printing technologies, life cycle cost analysis feature in 3D printing, and improvements in current 3D printing methods. The component is seen as 'affordability of 3D printer'.

4.3 Discussion

The barrier to and consequently slow adoption of innovations has been noted to be lack of awareness. It is highly unlikely that innovation will be fully adopted when there is a paucity of information regarding its existence and the benefits thereof. The same is the case of 3D printing which, according to Jin and Yu (2016), has suffered slow adoption in most countries as a

TABLE 3. Exploratory factor analysis result and Kruskal-Wallis H-Test.

Measures	Component				*K-W*	
	1	2	3	4	X^2	Sig.
3D printing vendors to actively provide long term training and assistance for participants	0.794				1.124	0.890
Increased research and development in 3D printing	0.794				7.458	0.114
More Seminars and workshops on 3D printing by professional bodies	0.749				2.184	0.702
Adoption of 3D printing educational curriculums in elementary and higher institutions	0.667				1.690	0.793
Training of construction participants in 3D printing	0.666				1.469	0.832
3D printing vendors to increase visibility and connect with potential industry users	0.632				1.252	0.869
Government support for pilot programs in 3D printing		0.807			1.991	0.737
Development of government policies that incentivise the procurement of 3D printing technologies		0.785			1.226	0.874
Development of alternative 3D printing methods compatible with building codes		0.676			0.952	0.917
3D printing certified to build Green Building designs		0.629			0.635	0.959
Adoption of 3D printing by building regulatory bodies		0.626			2.488	0.647
Developments of a variety of printable material		0.607			2.633	0.621
Developments of safety precautions measurements within the 3D printer system			0.731		2.557	0.634
Integration of 3D printing with building services			0.715		2.373	0.667
Improved printer size			0.705		1.122	0.891
Affordable 3D printing technologies				0.765	0.820	0.936
Life cycle cost analysis feature in 3D printing				0.630	1.030	0.905
Improvements in current 3D printing methods				0.497	3.872	0.424
KMO		0.825				
Bartlett's Test of Sphericity	X^2	799.521				
	df	153				
	Sig.	0.000				

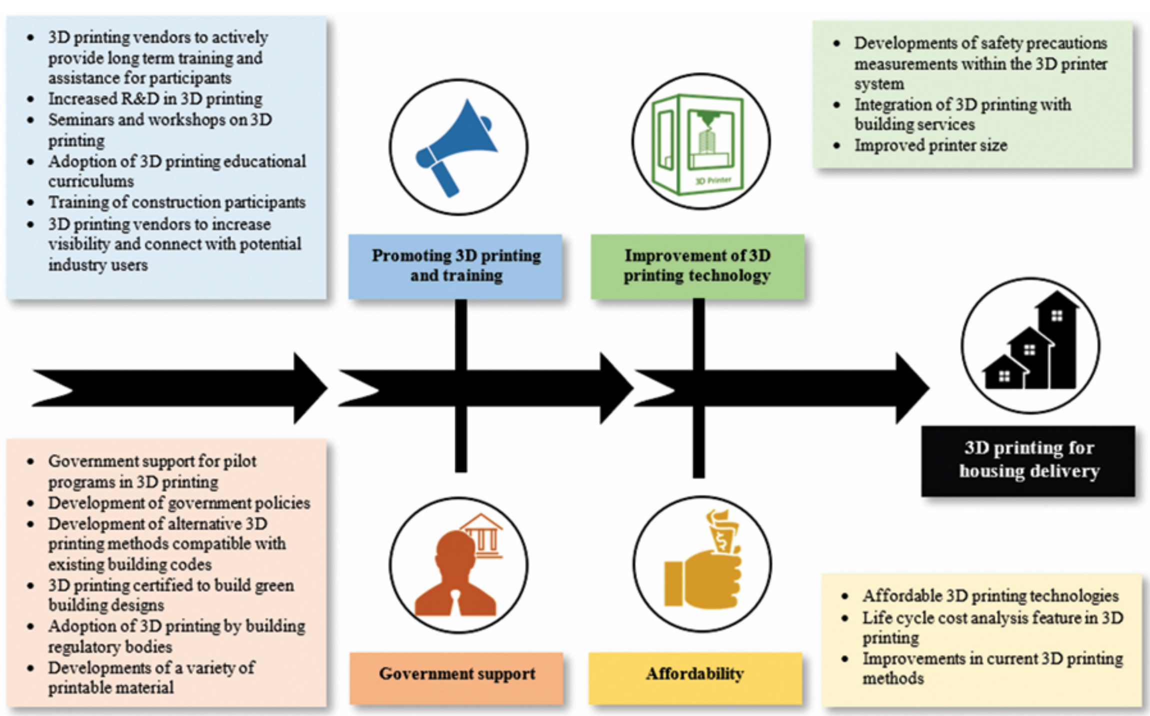
Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

result of lack of awareness and understanding of its concepts. Similarly, this lack of awareness significantly leads to a lack of available trained personnel to handle its operations (Ng *et al.*, 2015). Consistent with past studies, the findings of this study revealed that if 3D printing is to be adopted for sustainable low-income housing delivery, then there is a need to promote the use of this technology and to train personnel that will be able to handle it. The findings are in line with the submissions of Oke *et al.* (2018) that stakeholders in the construction industry need to prioritise education and training in digital technologies for construction industry participants.

The role of government in the promotion of innovations particularly relating to the sustainable development of citizens has also been emphasised in past studies (Aghimien *et al.*, 2018; Oke *et al.*, 2019). Therefore, if the use of 3D printing is to be successful in the delivery of housing in South Africa, the government must be willing to champion its course through the sponsoring of pilot programs and creating policies that ensure the use of this technology on government procured projects. Also, the government can help support the use of this technology through the provision of some form of financial incentives for building contractors willing to adopt the technology. In the same vein, building regulatory bodies should strive to understand the potential benefits inherent in the use of this technology and promote its adoption for building delivery. This finding is consistent with past submissions that have advocated the need for government support in the quest for the adoption of 3D printing for project delivery (Breann, 2012; Dickinson, 2018).

Past studies have noted that the technicality involved in the operation of 3D printers which in most cases are too big can serve as a problem to the adoption of the technology (Lanko, 2018). Thus, the findings of this study further affirm past submissions that noted the need for a more reasonable size of 3D printers that can meet the available space of the customer (Pîrjan

FIGURE 3. Measures for improving the adoption of 3D printing for sustainable housing delivery.



and Petroşanu, 2013) and at the same time be safe for use (Abderrahim *et al.*, 2003; Sakin and Kiroglu, 2017).

The cost of acquiring digital technologies can sometimes be a major problem to their adoption, as in most cases, these technologies are expensive to acquire and maintain. It has been noted that the affordability of 3D printers is one of the factors most investors will consider when deciding whether to invest in the technology or not (Pîrjan and Petroşanu, 2013). Thus, if inventors can make these technologies and their accessories more affordable, this will aid its adoption particularly in South Africa where the construction industry is filled with small and medium contractors that are constrained financially to make huge investments on technologies. Figure 3 gives an overview of the measures needed to improve the adoption of 3D printing in the quest for sustainable low-income housing in South Africa.

5. CONCLUSION

This study assessed the possible ways by which the adoption of 3D printing can be improved in South Africa with a view to providing sustainable low-income houses for the urban poor. Using the view of construction professionals, the study has been able to identify the major areas through which the adoption of 3D printing for housing delivery can be improved. Based on the findings, the study concludes that to adopt 3D printing for sustainable low-income housing in the country, there is the need to promote the technology among relevant stakeholders and create some form of training for construction practitioners. This can be done through seminars, workshops, and conferences organised by both the vendors of these technologies and respective professional bodies responsible for building delivery in the country. Similarly, there is the need for government support through legislation and the creation of policies to support 3D printing and enforcing of the same, as well as the creation of some form of incentives for the use of 3D printing in government procured projects. Furthermore, there is a need for improvement in the 3D printing technology itself, especially in the areas of safety and printer size. Lastly, making these printers more affordable will go a long way in promoting their usage, particularly in South Africa, where small and medium contractors dominate the construction industry.

It is believed that the findings of this study can encourage the South African government and construction organisations with the capability to fund 3D printing projects to adopt the technology based on the measures identified. Since the provision of standard and affordable housing is one of the critical elements of the country's National Development Plan 2030, the findings of this study could serve as a basis for achieving this plan using this technology. The study, therefore, contributes significantly to the body of existing knowledge as it reveals the measures needed for the adoption of 3D printing for low-income housing delivery in South Africa—an aspect that has not gained significant attention in the fourth industrial revolution and housing delivery discussions in South Africa. However, while the study contributes significantly to the body of knowledge, care must be taken in generalising its findings as the study was limited to professionals in the Gauteng province alone. Further studies can be conducted in other provinces within South Africa to get a much wider view of the topic. Furthermore, the cost implication of adopting this technology can be explored through future empirical cost analysis.

ACKNOWLEDGEMENTS

The authors acknowledge support from the Construction Industry Development Board (cidb) of South Africa.

REFERENCES

Abderrahim, M., Garcia, E., Diez, R., and Balaguer, (2003). A mechatronic security system for construction site. *Journal of Automation in Construction*, 14(4), 460–466

Aghimien, D. O., Adegbemo, T. F., Aghimien, I. E., and Awodele, A. O. (2018). Challenges of Sustainable Construction: A Study of Educational Buildings in Nigeria. *International Journal of Built Environment and Sustainability*, 5(1), 33–46

Aigbavboa, C.O., and Thwala, W.D. (2013). Residents' Perception of Subsidised Low-income Housing in South Africa: A Case Study of Kliptown, Johannesburg. *J Hum Ecol*, 42(1), 17–23

Ajayi, RJ (2012). *Strategies for sustainable housing co-operatives in South Africa*. Unpublished PhD thesis submitted to the department of Construction management, Nelson Mandela University, Port Elizabeth.

Ametepey, O. and Aigbavboa, C. (2014). Practitioners perspectives for the implementation of sustainable construction in Ghana. *Proceedings of the DII-2014 Conference on Infrastructure Investments in Africa*, Livingstone, Zambia, 25–26 September, 114–124.

Becerik, B. (2004). A review on past, present and future of web-based project management and collaboration tools and their adoption by the US AEC industry, *Int. J. IT Architect, Engineering and Construction*, 2(3), 233–248

Berman, B. (2012), 3-D printing: The new industrial revolution. *Business horizons*, 55(2), 155–162.

Bos, F., Wolfs, R., Ahmed, Z., and Salet T. (2016). Additive manufacturing of concrete in construction: potentials and challenges of 3D concrete printing, *Virtual and Physical Prototyping*, 11(3), 209–225

Bradlow, B., Bolnick, J., and Shearing, C. (2011). Housing, Institutions, Money: The Failures and Promise of Human Settlements Policy and Practice in South Africa. *International Institute for Environment and Development*, 23, 267–275

Breann, D. H. (2012). Asserting Patents to Combat Infringement via 3DPrinting: It's No "Use. *Fordham Intellectual Property, Media & Entertainment, Law Journal*, 23(3), 771–814

Dickens, P., Reeves, P., and Hague, R. (2012). Additive Manufacturing Education in the UK, in: *23rd Annu. Int. Solid Free. Fabr. Symp., Laboratory for Freeform Fabrication*, University of Texas at Austin, Austin, USA, 1–13

Dickinson, H. (2018). The Next Industrial Revolution? The Role of Public Administration in Supporting Government to Oversee 3D Printing Technologies. *Public Administration Review*, 78(6), 922–925

Ellis, G. (2018). The Truth About 3D Printing in Construction. Construction productivity blog. Available online: https://blog.plangrid.com/2018/11/the-truth-about-3d-printing-inconstruction/

Field, A. (2000). *Discovering Statistics using SPSS for Windows*, London–Thousand Oaks–New Delhi: Sage publications

Fonseca, L.M. (2018). Industry 4.0 and the digital society: concepts, dimensions and envisioned benefit. *Proceedings of the 12th International Conference on Business Excellence*, 34, 386–397

Ford, S., and Minshall, T. (2017). 3D printing in teaching and education: A review of where and how it is used. *Additive Manufacturing*, 25, 131–150

Ghasemi, A. and Zahediasl, S. (2012). Normality test for statistical analysis: a guide for nonstatisticians. *International Journal of Endocrinology and Metabolism*, 10(2), 486–489.

Hager, I., Golonka, A., and Putanowicz, R. (2016). 3D printing of buildings and building components as the future of sustainable construction? *Procedia Engineering*, 151, 292–299

Hartmann, M. (2018). *A solution to SA's housing crisis is right under our noses*. Available on: https://www.fin24.com/Opinion/a-solution-to-sas-housing-crisis-is-right-under-our-noses-20181224-2

Jin, Y., and Yu, J. (2016). Research on 3D Printing in China: A Review. *International Journal of Research Studies in Science, Engineering and Technology*, 3(7), 54–60

Kayfi, R., Ragab, D., and Tutunji,T.A. (2015). Mechatronic System Design Project: A 3D Printer Case Study, *IEEE Jordan Conf. Appl. Electr. Eng. Comput. Technol.*, IEEE, Amman, Jordan, 1–6

Lanko, A. (2018). Additive technologies in construction of temporary housing for victims of natural disasters and other emergencies. *Springer International Publishing*, 692, 1102–1108

Lim, S., Buswell, R.A., Le, T.T., Austin, S.A, Gibb, A.G.F., and Thorpe, T. (2012). Developments in construction-scale additive manufacturing processes, *Automation in Construction*, 21, 262–268

Manomano, T., and Tanga, PT (2018). Housing needs: the quality and quantity of housing provided by the government for the poor in the Eastern Cape Province in South Africa. *Social Work/Maatskaplike Werk*, 54(1), 19–36

Mazzucato, M. (2015), *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. New York: Public Affairs.

Mohd-Tobi, A.L, Omar, S.A, Yehia, Z, Al-Ojail, S, Hashimi, A, and Orhan, O. (2018). Cost viability of 3D printed house in UK. *IOP Conference Series: Materials Science and Engineering*, 319, 1, 1–7

Moolla, R., Kotze, N., and Block, L. (2011). Housing satisfaction and quality of life in RDP houses in Braamfischerville, Soweto: A South African case study. *Urbani izziv*, 22(1), 138–143

Moser, C.A. and Kalton, G. (1999). *Survey Methods in Social Investigation*, 2nd ed., Gower Publishing, Company, Aldershot.

National Planning Commission (2012). *National Development Plan 2030: Our Future—Make it work, Executive summary*. Available on: https://www.gov.za/sites/default/files/Executive%20Summary-NDP%202030%20-%20Our%20future%20-%20make%20it%20work.pdf

Nematollahi, B., Xia, M., and Sanjayan, J. (2017). Current Progress of 3D Concrete Printing Technologies. *34th International Symposium on Automation and Robotics in Construction*, held in National Taiwan University of Science and Technology, Taipei, Taiwan

Ng, W., Tan, J., and Wang G. (2015). Opportunities and challenges in China's 3D printing market. Ipsos Business Consulting, China. Available on: https://www.ipsos.com/sites/default/files/ct/publication/documents/2018-09/opportunities_and_challenges_in_chinas_3d_printing_market-may2015.pdf

Oke, A. E, Aghimien, D. O, Aigbavboa, C. O, and Musenga, C. (2019). Drivers of Sustainable Construction Practices in the Zambian Construction Industry. *Energy Procedia*, 158, 3246–3252

Oke, A. E., Aghimien, D. O., Aigbavboa, C. O., and Koloko N. (2018). Challenges of Digital Collaboration in the South African Construction Industry. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Bandung, Indonesia, March 6–8, 2472–2482

Pallant, J. (2005). *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using SPSS for Windows (Version 12)*. 2nd ed, Allen and Unwin, Crows Nest NSW2065 Australia (2005)

Paul, S.C., van Zijl, GPAG, Tan, M. J., and Gibson, I. (2018). A review of 3D concrete printing systems and materials properties: current status and future research prospects. *Rapid Prototyping Journal*, 24(4), 784–798

Pîrjan, A., and Petroşanu, D.M. (2013). The impact of 3D printing technology on the society and economy. *Journal of Information Systems and Operations Management*, 7(2), 163–173

Poullain, P., Paquet, E., Garnier, S., and Furet, B. (2018) On site deployment of 3D printing for the building construction—The case of Yhnova TM, *MATEC Web of Conferences*, 163, 1–10

Preacher, K. J., and MacCallum, R. C. (2002). Exploratory Factor Analysis in Behaviour Genetics Research: Factor Recovery with Small Sample Sizes, *Behaviour Genetics*, 32, 153–161

Sakin, M., and Kiroglu, Y.C. (2017). 3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM. *Energy Procedia*, 134, 702–711

Stern, L. (2010). *A visual approach to SPSS for Windows: a guide to SPSS 17.0*. 2nd ed., Boston: Allyn and Bacon

Tabachnick, B.G., Fidell, LS: Using Multivariate Statistics," 5th edition, Pearson Education, Boston (2007).

Tay, Y.W.D., Panda, B, Paul, S.C, Mohamed, N. A. N., Tan, M.J and Leong, K.F. (2017). 3D printing trends in building and construction industry: a review. *Virtual and Physical Prototyping*, 12(3), 261–276

United Nations (2015). Transforming our world: The 2030 agenda for sustainable development. Available on: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

United Nations (2020). Urban Poor. Available on: https://unfccc.int/climate-action/momentum-for-change/urban-poor

Wang, G., and Tain, A. (2015) Ipsos Business Consulting, Opportunities and challenges in China's 3D printing market, May 2015, Shanghai

Wu, P., Wang, J., and Wang, X. (2016). A critical review of the use of 3-D printing in the construction industry. *Automation in Construction*, 68, 21–31

Yossef, M., and Chen, A., (2015). Applicability and Limitations of 3D Printing for Civil Structures. *Civil, Construction and Environmental Engineering Conference Presentations and Proceedings*, 35, 287–246