Exploring the Prospects of Using 3D Printing Technology in the South African Human Settlements as Part of the Innovation for Inclusive Development (IID) Seminar Series

PROCEEDINGS REPORT

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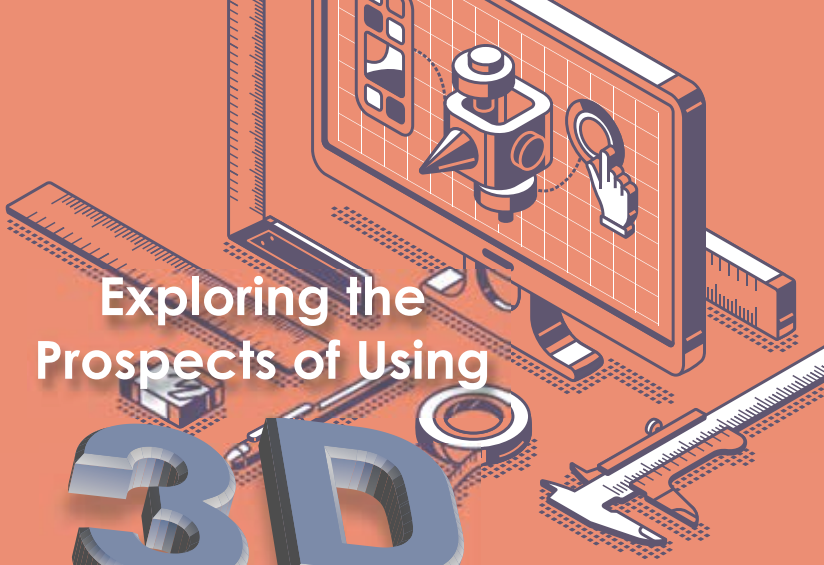
The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science and scholarship for the benefit of society, with a mandate encompassing all scholarly disciplines that use an open-minded and evidence-based approach to build knowledge. ASSAf thus, adopted in its name the term 'science' in the singular as reflecting a common way of enquiring rather than an aggregation of different disciplines. Its Members are elected based on a combination of two principal criteria, academic excellence and significant contributions to society. The Parliament of South Africa passed the Academy of Science of South Africa Act *(No 67 of 2001)*, which came into force on 15 May 2002. This made ASSAf the only academy of science in South Africa officially recognised by government and representing the country in the international community of science academies and elsewhere.

This report reflects the proceedings report of Exploring the Prospects of using 3D Printing Technology in the South African Human Settlements webinar as part of the Innovation for Inclusive Development (IID) Seminar Series held on Zoom Webinar.

Views expressed are those of the individuals and not necessarily those of the Academy nor a consensus view of the Academy based on an in-depth evidence-based study.



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Acknowledgements

This proceedings report is a product of the Academy of Science of South Africa (ASSAf) in partnership with the Department of Science and Innovation (DSI) on the Innovation for Inclusive Development (IID) seminars. The IID learning interventions align with one of DSI's strategic objectives, namely, to use "knowledge, evidence and learning to inform and influence how science and technology may be used to achieve inclusive development". The purpose is to demonstrate how innovative technology solutions may be used to improve the capacity of the State to deliver and improve access to basic services, and thereby advance local economic development.

The webinar titled: **Exploring the Prospects of Using 3D Printing Technology in the South African Human Settlements**, was co-hosted by The Academy of Science of South Africa (ASSAf), the Department of Science and Innovation (DSI) and the University of Johannesburg (UJ). South Africa is a country with significant socio-economic development challenges, with the majority of South Africans having limited or non-existent access to basic infrastructure, services, housing and socio-economic opportunities etc. The urban housing backlog currently exceeds 2.4 million houses, with many families living in informal settlements. The Breaking New Grounds Policy, 2014 for the creation of sustainable human settlements, acknowledges the challenges facing human settlements, such as, decreasing human settlements grants allocation, increasing housing backlog, mushrooming of informal settlements and urbanisation.

The Science and Technology Roadmap's intention is to unlock the potential of South Africa's human settlements for a decent standard of living through the smart uptake of science, technology and innovation. One such novel technology is the Three-Dimensional (3D) printing technology, which has produced numerous incredible structures around the world. The effects of such a technology have a potential to change the world we live in and could subsequently pave the roadmap to improve on housing delivery and reduce the negative effects of conventional construction methods on the environment.

The webinar presented preliminary findings from a study conducted by the UJ to explore the potential use of 3D printing technology in human settlements. The following were addressed: 1. **The viability of 3D printing technology**; 2. **Cost comparison of 3D printed house to conventional construction**; and 3. **Preliminary perceptions on 3D printing of houses**. There was a unanimous consensus that collaborative efforts from all stakeholders are key to take advantage of this niche technology. Speakers included: Dr Jennifer Mirembe, National Department of Human Settlements (NDoHS), Dr Jeffrey Mahachi, Mr Refilwe Lediga, Mr Khululekani Ntakana and Dr Luxien Ariyan, all from UJ.

ASSAf greatly acknowledges all the partners, speakers and participants in attendance. The contributions by Dr Stanley Maphosa and Dr Tebogo Mabotha from the ASSAf Liaison Programme to this project are hereby acknowledged and appreciated.

Prof Himla Soodyall
ASSAf Executive Officer

FACILITATOR:

Dr Tebogo Mabotha, Academy of Science of South Africa, ASSAf

WELCOME REMARKS

Prof Himla Soodyall, Executive Officer, Academy of Science of South Africa, ASSAf

Prof Soodyall welcomed everyone to the webinar. In line with its mission to use evidence-based science in the service of society, the Academy collaborates with the Department of Science and Innovation (DSI) and other academic institutions to host the Innovation for Inclusive Development (IID) seminar series on topics of current relevance, such as 3D printing technology and its application in South Africa's human settlements.

PURPOSE OF THE WEBINAR

Mr Imraan Patel, Deputy Director-General and Mr Tshepang Mosiea, Director, Department of Science and Innovation, DSI

The core purpose of webinar is to encourage an evidence-based approach to the way in which things are done in South Africa, both in the formulation of policy and in terms of the implementation of that policy, using monitoring more effectively to drive the development of an evidence base. This webinar is evidence of the trend adopted by the DSI to adopt a more systems way of approaching issues and thinking about things in socio-technical terms. Technology has a wide-range impact and the more the art of a socio-technical systems approach is mastered, the more inter-disciplinary linkages will be able to be made to the broader benefit of the country.

Another purpose of the webinar is the increasing focus on partnering with the DSI's partner departments. We welcome colleagues from the Department of Human Settlements at the national and provincial levels involved in work relating to 3D printing technology to the webinar. Using the socio-technical approach as well as resources in a strategic way requires a strong partnership. The DSI is looking forward to seeing how the initial work with respect to using 3D printing technology to benefit the country's human settlements would be used to build a strong collaborative

partnership, where respective strengths are used to give directionality to the innovation agenda.

Discussions to date around this new opportunity for 3D printing clarified that it was not only about the technology push but also about understanding that it makes sense to use this technology in a sound and evidence-based way. The cost comparison, availability and other aspects relating to the use of the technology that will be presented by the University of Johannesburg (UJ) team is expected to add to this evidence base.

Thank you to ASSAf for your contribution towards maturing the DSI's IID Seminar Series around a wide range of areas, building up a loyal following, and creating a platform for intense and robust discussion to do evidence-based policy and practice.

Mr Mosiea provided context to the topic of the webinar, which has to do with urbanisation and societal challenges. Cities and infrastructure are under pressure and the challenge concerning access to housing is growing. Policymakers need to be able to respond to these issues. The DSI believes that it is necessary to look at innovation capacity across government, but also to adopt policy that is more transformative as a means of implementation and look at innovation policy as a way to respond to urbanisation and the challenges facing cities, particularly in terms of informal settlements. The 2019 White Paper on Science, Technology and Innovation (STI) is a critical policy for the country because it takes a whole-of-society approach to deal with informal settlements, housing and other basic service delivery challenges, highlighting cross-sector collaboration. The White Paper provides guidance for using innovation to achieve sustainability and inclusive development and addressing societal challenges. In terms of 3D printing technology, it is important to ensure that there are spin-off opportunities for small, medium and micro enterprises (SMMEs) as well as artisanal opportunities that emanate from localised technology use.

It is anticipated that the UJ project will provide the DSI with knowledge, evidence and learnings on 3D printing technology as a potential for widespread adoption in human settlements. The webinar will also provide information about the full lifecycle costs (cost benefits) of using the 3D printing technology in human settlements as well as social acceptance and beneficiary attitudes towards the technology.

3D PRINTING AND THE 3D WORLD FOR INNOVATION IN THE HUMAN SETTLEMENT SECTOR

Dr Jennifer Mirembe, Director, National Department of Human Settlements, NDoHS

Technology in itself is very unpredictable and complex. The human settlements sector is faced with a number of challenges where technology change is rapid and developing fast, but at the same time different technologies, such as 3D technologies, are emerging. These have a number of positive and negative effects on human settlements development that bring uncertainty about how technology can shape the future of human settlements especially with regard to 3D printing and the opportunities it presents for different settlements. Human settlements are on a transformation journey that connects shelter, space, design and planning, and the challenges with funding. Proposals received from private sector professional bodies have led to an emergence of fresh research areas and the integration of different systems with sector departments is becoming evident. It is possible to demonstrate that poor households can benefit from human settlements innovations such as 3D printing. A systematic, transparent and accountable approach, and an understanding of the situation in the country's human settlement will help improve quality of life for all.

The National Department of Human Settlements (NDoHS) has therefore established an Innovation Task Team and begun to debate the future for human settlements in three dimensions. A framework has been developed that forms part of the roadmap for innovation together with the DSI. What is ultimately important is the transformation and consolidation of human settlements in a way that ensures sustainability and improves quality of life for households. The framework presents six main layers in innovation that present different opportunities for spatial layouts and the economy, the participation of citizens and resources within human settlements, demonstrating how human settlements can become inclusive and integrated. New layers emerge through 3D printing, such as new building materials, methods and processes, and being to the fore the need to analyse what is meant by affordability and resilience in human settlements. Software, planning, design and communication and the speed of construction can be explored in order to present better choices for integrating human settlements.

Artificial Intelligence (AI) is implemented alongside 3D printing and has the potential to be used to monitor human settlements. Automation is layered with 3D printing in order to provide better monitoring systems for the management of human settlements to make them functional and affordable. The introduction of so much new information into the human settlement sector and the profiling of human settlements lead to a new understanding of human capital to make the human settlements better, more accessible and equitable. Fresh opportunities for research are becoming available, such as around communication of the different options available to citizens and urbanisation in terms of how cities are formed and how to interpret this with 3D printing in order to leverage better funding for new approaches. In terms of innovation building technologies, it is possible to move from upgrading informal settlements to transforming human settlements.

3D printing allows for the different legislation and policies to be aligned, and the recognition of the overlaps between different sector departments in innovation. Through co-investment, stronger funding will open doors to work with the banks, businesses, international donors and professional institutions to make the 3D printing technology project happen. This will encourage more digital interactive spatial development frameworks for the human settlements sector.

NDoHS' plans for 2021 include:

- 3D printing projects in partnership with UJ and the KwaZulu-Natal (KZN) and Western Cape Provinces.
- Projects with the Department of Energy on current and future off-grid solutions for poor households throughout the country.
- Projects with the Department of Water and Sanitation (DWS) to find water and sanitation solutions through 3D printing, linking structures and simulate various options.
- Projects with the Department of Environment, Forestry and Fisheries, tapping into Green Building certified expertise as well as expertise in environmental design and 3D technologies.
- Working with the National Home Builders Registration Council (NHBRC) to incorporate the 3D aspect into policies and ministerial directives to make the incorporation of 3D printing technology in some of the housing projects compulsory in provinces that can afford it.

- Exploring partnerships with the Architecture Institute and working with architectural firms that are using 3D technology to upgrade informal settlements.

Through 3D printing in the human settlements sector, the NDoHS is encouraged by the overlaps between this technology and other modern technologies. The department will definitely have a very systematic, more transparent, implementable and accountable approach to the construction and implementation of many of its human settlements projects. The Housing Development Agency has been designated to manage the projects that are innovation driven. Therefore, provinces and municipalities will be clearer on the specifications, procurement processes and contracting of innovations. This will be facilitated by the fact that 3D printing technology allows for simulation of innovations for human settlements. It is anticipated that there will be improved uptake of innovation and transformation technologies in the human settlements sector.

PROJECT OVERVIEW OF 3D PRINTING OF HOUSES

Dr Jeffrey Mahachi, Head of School, School of Civil Engineering and Built Environment, University of Johannesburg, UJ

The project involves a partnership between the DSI and UJ to research the potential of 3D printing of houses and the implementation of a pilot 3D housing project in a selected province. The project aims to:

- Promote, facilitate, research and finance the transfer of environmentally sound 3D concrete printing technologies in human settlements.
- Transfer knowledge and skills and support the development and enhancement of local SMME capacities and youth development.
- Assist other government departments in the formulation and implementation of policies that will contribute to the delivery of sustainable human settlements.

The strategy incorporated in government's vision for sustainable human settlements addresses:

- Acceleration of delivery (Current backlog in excess of 2.3 million),
- Using housing provision as a job creation strategy,

- Ensuring access to property and home loans by all,
- Leveraging economic growth, combat crime, reduce duality within the housing market,
- Developing integrated and sustainable human settlements.

Current challenges in housing delivery include:

- Limited physical production capacity.
- Availability of funds, land etc.
- The most popular method of construction ('Brick and Mortar') has a slow delivery rate that impacts on cost.

There is a need to promote innovative building technologies to take advantage of shorter per unit construction periods, without compromising on the quality and integrity of the product.

Challenges with current house construction include:

- Heat gain and loss is difficult to manage with current methods of construction.
- In-door environmental quality is often less than ideal.
- Logistics in rural areas are a major problem.
- The distance from waste connection makes it difficult to provide sanitation.
- The quality of final products and input materials are not of acceptable levels due to issues pertaining to the lack of competencies and skills in construction.
- Compliance with standards cannot always be met by the current construction methods without additional funds.

These challenges led to the exploration of innovative building technologies, but there were challenges in the adoption of these technologies including the perception that there is a high initial capital outlay and a misunderstanding about cost (cost of construction vis-à-vis Life Cycle Costing (LCC)), benefits, long-term cost savings, reduction of energy poverty, job creation and climate change mitigation, and uncertainty concerning the social acceptability of the product.

The future of house construction has to do with manufacturing, designs that address the physical environment and architectural typologies to fast-track the delivery of quality social infrastructure in building houses. These factors require a design that responds to a range of parameters and contexts and allows buildings to evolve as needs change.

The project objectives are to:

- Explore the potential of using 3D printing technology to build houses in South Africa.
- Research and develop materials suitable for 3D printing of houses using local materials and waste materials.
- Pilot 3D printing on a real project comprising 50 houses.
- Study the level of acceptability (socially and technically) of houses produced using 3D printing methodology.
- Analyse the cost-benefit of using 3D printing technology for house production.
- Investigate the spin-offs of 3D printing through enterprise development of designated groups.

The project is being implemented in three phases. Phase one focusses on the identification and procurement of a 3D printer, developing a mixed design using different types of materials and printing structural elements of a house, and performing relevant tests to establish whether performance requirements are met. Phase two focusses on building a prototype housing system and developing a detailed LCC model and failure prediction models. Once all the system performance requirements have been met, the project will move to Phase three involving the formulation of a printing strategy and the appropriate certification process so the products can be implemented. A number of social acceptability studies and SMME beneficiary studies will be conducted before and during construction in order to ascertain whether construction using 3D printing can be scaled-up.

THE VIABILITY OF 3D CONCRETE PRINTING (3DCP) TECHNOLOGY

Mr Refilwe Lediga, PhD Candidate, University of Johannesburg, UJ

An international perspective shows exponential growth in the uptake of 3D concrete printing (3DCP) technology and the global industry is worth more than USD 300 million.

The research questions addressed in the research were:

- Is 3DCP technology mature enough to be embraced by the industry?
- Has 3D printing of buildings, specifically houses, been implemented on a large scale elsewhere in the world and what technologies have been used?
- Is the South African housing construction industry ready for 3D printing of houses and what could be the potential inhibitors thereof?
- What are the materials used for 3D printing of buildings? Is there the potential to use re-cycled and/or waste materials? What are the contributions of these materials to passive green homes and combating the negative effects on climatic change?
- Is it cost effective to use 3DCP?

There were limitations to the research in that 3D printing was currently limited to printing of walling elements and a lack of future research that extends to printing of other building elements. However, pilot project implementation in KZN will focus on innovation of all construction elements (3D printed walls and other building elements using other forms of innovation).

In terms of technologies used for 3DCP, a detailed desktop study was done on local and international suppliers of the printers. Referrals by contacts were obtained and enquiries were made with other academic institutions. Although the intent was to visit the suppliers of 3DCP, studies were limited to virtual meetings and internet searches due to the outbreak of the COVID-19 pandemic. The project was based on the principles of cost effectiveness, speed, customisable materials (Open Source), industrial scale and sustainability.

Findings of the study were:

- 3DCP as an emerging technology is still in its infancy stages.
- Very few companies have managed to successfully establish a manufacturing plant and run 'real-life' projects.
- Printers are manufactured on request and take about 3 months to assemble.
- They generally use commonly available building materials (cement and sand) with special proprietary material (additive).
- As an emerging technology, suppliers are reluctant to provide information.
- There is an opportunity to develop customised materials using local and waste materials.

The most common 3DCP machines available are the Robotic Arm System and the Gantry Girder System. 3DCP technology is able to build structures with curved walls, which are expensive and difficult to construct when using the traditional method. Some of the advantages of the Gantry Girder System are that it is relatively inexpensive compared to the Robotic Arm system and it has high material flexibility. Disadvantages include the difficulty in moving the large structure from one position to the other and length of time taken to setup and calibrate the machine before printing can commence. The Robotic Arm System is smaller in size and easier to move from one position to another, but is relatively more expensive than the Gantry Girder System. It has high material flexibility and limited restrictions in terms of materials, but constructs large buildings in parts as it cannot reach all areas.

Materials used for 3DCP need to have specific characteristics and a limited number of materials have been used to date. Researchers at UJ are investigating the use of multiple materials and locally produced waste materials to produce complex mix designs.

It is suggested that 3DCP has a future in South Africa, as it could be a transformative technology that revolutionises and fast-tracks the delivery of houses. An exercise to compare LCC with costs of conventional construction has been undertaken. The use of 3DCP could potentially reduce on-site health and safety risks, as well as waste materials, transportation and other costs. Materials for 3DCP are available locally.

Most printers can print 40-100m^2 and will be capable of printing a standard-size house. The pilot project will produce 50 houses in order to demonstrate and validate some of the preliminary findings of the research.

If the machines are very large, they will be difficult to assemble and disassemble on-site and therefore be more costly. The LCC validates the initial high capital cost. Certification through Agreement SA (an agency that evaluates the fitness-for-purpose of non-standardised construction products) will facilitate compliance with the South African National Building Regulations. 3DCP is expected to have a disruptive impact in terms of on-site skills as it requires more high-tech skills than unskilled labour. The complete value chain of housing delivery from material acquisition to disposal needs to be reviewed and research on this topic is already in progress. There is huge potential to create more efficient and interesting designs for 3DCP as it is capable of constructing shapes that conventional building techniques are unable to do.

COST COMPARISON OF 3D PRINTED HOUSING TO CONVENTIONAL CONSTRUCTION

Mr Khululekani Ntakana, Lecturer, University of Johannesburg, UJ

The purpose of the study is to provide a quantitative analysis and evaluation of the cost and time benefit, the labour contribution and the local economic contribution of 3DCP compared to the conventional building method. This will be based on the final account of the pilot project involving 3DCP construction of 50 houses. The sub-objectives of this report are to:

- Develop benchmark for comparing building methods.
- Assess investment opportunities in 3DCP.
- Measure social benefits of 3DCP.
- Develop reasonable conclusions around the feasibility and/or advisability of building methods.

The methodological approach followed for this study involves:

- A preliminary quantitative desktop study to determine the potential cost systems, the materials used, and their local availability.
- An analysis of the building components that the two systems can print and the manner or systemic approach to be adopted in

printing the houses (only the walling system of the houses can be printed).

- Using the conventional structure to compile a Bill of Quantities (BoQ).
- Using the published human settlement housing subsidy quantum to analyse any potential cost savings.

It was also necessary to understand the functionality of the two 3DCP systems (Robotic Arm and Gantry Girder), the materials used and their local availability, as well as the printable building components of both systems, and the systemic approach adopted by both systems in printing the houses. The cost analysis looked at construction costs and the local economic contribution in order to understand the LCC. The norms and standards for Breaking New Ground (BNG) housing were applied in the comparison of construction costs, allowing for variations in terms of painting and plastering of walls. The BoQ was structured in accordance with BNG houses.

The preliminary LCC approach involved conducting an adequate Whole Life Costing (WLC) employing a standard LCC plan structure, which allows for easy comparison and benchmarking of similar projects. A conceptual plan structure that centres around WLC (total cost of ownership) incorporating non-construction costs (associated with land acquisition, fees, relevant liabilities and so forth), LCC (costs associated with construction, environment, renewal, operation, maintenance and end of life/ disposal), and externalities (costs associated with an asset but not reflected in the transaction costs of the acquisition) was employed for this LCC. The costing exercise also had to consider specific functionalities of the Robotic Arm System and the Gantry Girder System such as the minimum printable area, layout speed and extrusion capacity. The LCC uses a Housing Subsidy Quantum (with no variations) for 50 units.

A comparison of the cost of construction in relation to conventional brick and mortar as opposed to the two 3DCP systems showed that the Robotic Arm System presents a 1.22% saving and the Gantry Girder System presents a 2.13% saving. In both cases there was also a saving in terms of time. In addition, the following aspects of the local economic contribution were relevant in order to ensure economic sustainability:

- **Material purchasing:** Due to the nature of materials used, employment of labour and the purchasing of materials will be

split between the geographic position of the factory and the construction site. In remote areas, materials may not be readily available.

- **Labour:** Conventional construction requires employment of low skilled local labour for the duration of the project, while 3DCP requires two machine operators, but does not necessarily reduce the number of low skilled labour as 3DCP only produces the walling and other components of the house have to be built conventionally. In addition, 3DCP creates factory-based employment for manufacturing materials.
- **Time:** 3DCP reduces the construction time compared to the conventional building methods. Depending on the system used and the thickness of the walling, it would take a maximum of 15 hours to print the whole house.

The LCC of the 3DCP houses was analysed using the following key variables:

- The period of analysis: 30 years
- The interest rate for future costs: 11.5%
- The discount rate: between 1% and 5%
- The cycles or intervals between maintenance activities
- The unit rates for work to be done

Sensitivity was analysed to manage risk in the WLC of 3DCP houses. In this context, the analysis was primarily through changing the variables to answer the 'what if' questions. Findings of the options appraisal were that in terms of cost, the Gantry Girder System is more viable than the Robotic Arm System.

In conclusion:

- There is preliminary evidence to substantiate that 3D printing additive technologies are a cheaper building method than their conventional counterpart.
- The exact quantum of the savings is dependent on the type of system used and the location at which it is used.

- Allocating the savings in a direct comparative way can be a challenge due to the pricing structure of the 3DCP.
- Because the systems can only print walls, construction cost savings seem to occur only at two cost centres (walls and Preliminary and General (P&Gs)).
- A preliminary conclusion could be made that the biggest contributor to the overall savings is a reduction in construction time and the cost of keeping the asset (asset life cycle).

Data will be collected during the pilot project of 50 houses in order to:

- Develop an LCC plan structure for 3DCP and analyse all costs involved.
- Audit the final account for time and cost benefits.
- Identify the areas in which time and cost benefits are located in the project.
- Analyse any potential further time and cost benefits in the project.
- Analyse local labour employment.
- Analyse local economic contribution.
- Make final recommendations.

PRELIMINARY PERCEPTIONS ON 3D PRINTING OF HOUSES

Dr Luxien Ariyan, Senior Research Associate, University of Johannesburg, UJ

The construction sector has not kept up with trends in the communication sector or the transport sector, for example, and needs to consider new terminology to accommodate the new trends in construction, such as 3DCP.

The housing backlog in South Africa has been growing exponentially and the rate of construction has not been able to keep up with the demand. The high cost of conventional methodologies, technologies and materials, the shortage, poor quality and inaccessibility of raw and processed materials, as well as overly complex processes contribute to the backlog in affordable housing. A solution is needed that takes into account that certain trade-offs will have to be made.

The research design addresses three phases: pre-production, production and post-production, looking at social acceptance and technical assessments. The pre-production phase is largely exploratory through an indicative study that is based on eliciting perception responses. A structured questionnaire focussing on conventional house building, 3D printing in general and 3D printing of houses was disseminated online to 200 people. Respondents were built environment professionals and artisans, contractors and developers, homeowners and home seekers, government officials and bankers. The responses revealed a better-than- expected awareness of the existence of 3D printing of houses and the relevant technology, and that the idea of alternative construction systems has been embraced. People's perceptions must be taken seriously when introducing new systems and house designs. It is important to note that 81% of respondents indicated 'yes' to a question about whether only house built of bricks and blocks should be allowed in South Africa. Experience has shown that, no matter how good the structural integrity of a building is, people disapprove of how it looks if alternative materials are used and if the design is unfamiliar. Government needs to consider this aspect when innovative building systems are referred to as a 'solution for low-income housing'. Research has shown that poor people want exactly what rich people want and the reality is innovative building systems elsewhere in the world are embraced more by the richer people than the poorer people. This is a communication issue.

With regard to general knowledge of 3D printing, 44% of respondents indicated that they have seen a 3D printer in real life. More people liked a bigger house. As much as the project is aligned to the BNG, the size of the house can vary between 40m^2 to 50m^2 depending on the relevant municipality. If there is densification due to the lack of developable land, the biggest population lives on the smallest land portion. It is necessary to look for solutions that go beyond a stand-alone 40 to 50m^2 BNG house. Densification becomes an issue when it comes to 3DCP houses. Past research in rural areas found that people liked the rondavel (traditional hut) shape and were less keen on the square shape, and were of the view that brick and mortar houses did not blend in with the natural environment. The majority of respondents believed that 3DCP houses would be easier, cheaper, faster, better and safer to build, and would gladly live in such a house.

Respondents seemed to be very excited about the pilot project and were keen to know more about 3D houses and to see these during the project implementation phase. However, they were very concerned

about job losses and were sceptical about the durability of the 3DCP houses. Overall, respondents felt that 3DCP houses have more to offer than the conventionally built houses.

Dr Mahachi mentioned that a number of post-graduate students were working on the 3DCP housing project. He emphasised that a lot of work still needs to be done and that the UJ research team was working hard to ensure that the results are produced. The launch of the first 3D printing of a house would take place in around three months' time.

Q&A AND DISCUSSIONS

Question

Marchant van den Heever, Stellenbosch University, SU

If we have 3DCP technology that is ready for adoption, who does one speak to, to take this to the next level of implementation?

Responses

Dr Jennifer Mirembe, National Department of Human Settlements, NDoHS

Nothing can be done as yet because we are in the process of implementation. The project is in partnership with the DSI, and the DSI is busy procuring 3DCPs and getting the work started. The NDoHS will link its programmes (such as upgrading informal settlements or emergency housing) to the DSI so that houses can be built quickly.

Dr Jeffrey Mahachi, University of Johannesburg, UJ

There are still a number of processes to follow (such as compliance of the technology to the National Building Regulations and so on) before implementation can take place.

Mr Tshepang Mosiea, Department of Science and Innovation, DSI

We need to take a programme and build a systemic capability. This means the participation of private sector and SMME role players, as well as universities, to deliver a country capability in this space. The DSI would welcome other actors who can work with us.

Comment

George Onatu, University of Johannesburg, UJ

The challenge is usually affordability, acceptability, cultural, adequacy and choice.

Response

Dr Jennifer Mirembe, National Department of Human Settlements, NDoHS

The department has launched a massive communication campaign together with the Housing Development Agency. We will talk on TV about innovation in human settlements, the affordability and the concept, and to break the ice and show that a house with alternative technology is equally habitable. In terms of affordability, the department has taken the approach relating to funding for innovation that service providers will have to stick to.

Mr Tshepang Mosiea, Department of Science and Innovation, DSI

Mr Patel mentioned that we need to take cognisance of the fact that things will not happen unless the policies, norms, routines and standards are dealt with. There are established norms and routines, as well as social attitudes and so on, in the human settlements sector. These need to be looked at from a quantum allocation point of view and be designed to enable and open up for innovation is a question that needs to be answered. The focus should not be on a programme or a specific technology, but on how to transform sustainable human settlements social technical systems in its entirety by including the norms and standards. All the aspects need to be addressed holistically.

Question

On the LCC, there might be unforeseen costs that could escalate the cost of construction. People also expect to be able to expand their houses. How will 3DCP allow this?

Response

Mr Khululekani Ntakana, University of Johannesburg, UJ

I think that it is obviously possible to do extension on a 3DCP house if the plot is big enough. I do not see any cost implications due to extensions apart from possible structural aspects. Looking at the finishes, it will depend on whether or not people like their houses unplastered.

Question

Ellis Chitakatira, University of Cape Town, UCT

I am very interested in this. We are doing Construction Management research at UCT on 3D printing and are part of the African Research

University Alliance and we received funding in 2020 on converting plastic waste into filament used for 3D-printing. Our research is on making a sustainable housing material from 3D printing material. How can the department of housing rally with our cause?

Response

Mr Tshepang Mosiea, Department of Science and Innovation, DSI

You can share your details with me: Tshepang.mosiea@dst.gov.za. The DSI is the sponsor of the project and UJ is our appointed implementing entity.

Comment

Dr Bethuel Sehlapelo, Council for Scientific and Industrial Research, CSIR

The ultimate implementer of the 3D printing is the private sector. We should ensure that they are at the centre of the discussions. Also, discerning industry readiness for 3D printed housing is critical.

Response

Mr Tshepang Mosiea, Department of Science and Innovation, DSI

I agree Dr Sehlapelo, we need to involve SMME's and the private sector and stimulate a small-scale industrial activity in this niche area, especially for socio-economic infrastructure.

Question

Marchant van den Heever, Stellenbosch University, SU

Mr Patel mentioned that one should consider the social-technical aspects of 3DCP from a systems approach: What does automation in construction mean for a largely unskilled work force?

Response

Mr Tshepang Mosiea, Department of Science and Innovation, DSI

We want to use the pilot to answer exactly the question you are asking.

Question

Coralie van Reenen, Council for Scientific and Industrial Research, CSIR

Please elaborate on how 3D printed houses are environmentally friendly.

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

There is potential of using waste materials as an input material to 3D printing and other environmentally friendly materials.

Question

Elijah Djan, Nubrix

How can local SMME's partake in the transfer of the "know-how" process?

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

We are identifying SMMEs in the pilot study to be involved in 3D printing and we will train them in both the technology and materials. Support systems will also be provided.

Question

Elijah Djan, Nubrix

Another challenge is the certification process. How is the human settlement department aiming to assist to ease the process and the costs related to this process? How has UJ experienced this process thus far?

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

Pre-assessment tests can be conducted at UJ or any other university. This will reduce your cost and time for certification by Agrement SA.

Comment

Dr Bethuel Sehlapelo, Council for Scientific and Industrial Research, CSIR

A group from the CSIR had an opportunity to visit Shaoxing-Keqiao in China. There is a company that is using 3D printing extensively in building high-rise residential buildings at a massive scale.

Question

Tshiphiri Tshivhasa, National Department of Human Settlements, NDoHS

Was the SA housing delivery landscape and its matrix explored with regards

to the use of 3D printing, more specifically considering the difficult terrain of the Eastern Cape Province with the likes of Port St Johns. What would be the best mechanism considering the Girder System and Robotics?

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

There are various types of 3D printers. There is a 3D printer with crawler base, capable of going through difficult topographies.

Question

Tshiphiri Tshivhasa, National Department of Human Settlements, NDoHS

Would the 3D printers accept some changes and modifications, giving example of Girder that build curvy corners than sharp 90-degree corners as in traditional bricks and mortar houses, which are common practice? Can this also build rondavels which may be favoured by some beneficiaries to keep trend of their traditional homes?

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

3D printers have the advantage of printing exactly (with tolerances) any shape. It's a robot, so the precision is excellent, like printing a car. The consistency is also uniform.

Question

Tshiphiri Tshivhasa, National Department of Human Settlements, NDoHS

4IR is maybe generally perceived as threat to local job creation, what would be the best approach towards ensuring that the 3D printing approach improves the local market especially with local skills development and material availability at local, specifically at project level?

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

You are right on the perceptions. But 3D does not contribute to job losses. Jobs are moved from one area to another. One needs to look at the whole value chain. More jobs will be created in material characterisation and technical skills.

Question

Mahadi Mofokeng, Department of Water and Sanitation, DWS

How is the energy installed, and what is the risk of using different types of energy?

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

You can embed anything (conduits etc) in the wall before you start printing. Even rebars.

Question

Dr Maryam Amra Jordaan, SA Rebuilders

Please kindly specify filament used for printing and type of 3D printers used?

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

Are you specifically asking the material composition because there are various types of materials including waste materials?

Comment

Dr Maryam Amra Jordaan, SA Rebuilders

Yes, correct I am from SA Rebuilders and we specialise in the production of filament for 3D printing from waste.

Question

Kwena Prince Mashita, South African Local Government Association, SALGA Do these 3D printing machines/technologies start from foundation or they start from the slab?

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

For now, our focus is on walling structure. However, we will look at foundations in the future. Other researchers have started looking at foundations and roof.

Comment

Carin Van Zyl, Department of Planning, Monitoring and Evaluation, DPME

I saw a video of 3D house printing about 3 years ago. I'm absolutely thrilled that we are now having these discussions.

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

We are always open to collaborations and discussions with industry and other academic institutions.

Question

Tshiphiri Tshivhasa, National Department of Human Settlements, NDoHS

Permanent/full time employment driven by the innovation is also reactive to the demand for such innovation. Considering the housing development nature of our country, can we confidently say the permanent job creation is possible with 3D printing? What would be the possible factors of that?

Response

Mr Khululekani Ntakana, University of Johannesburg, UJ

There is a separate study that it being presented currently, which looks in at social acceptability. If this system is accepted in our markets, there will definitely be a demand for it thus resulting into job creation. With regards to permanent/short-term employment, I agree that depends on the demand.

Question

Marchant van den Heever, Stellenbosch University, SU

How is it that a robotic system would require less material used as opposed to a gantry system? Surely, if you are creating the same building topology with the same infill pattern you would require the same amount of material?

Response

Mr Refilwe Lediga, University of Johannesburg, UJ

The printing pattern approach is different as was displayed in the LCC presentation.

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

Possibly, but you need to look at a number of other factors, such as the speed of construction. However, it is unlikely that the material used for 3D printing is the same as for conventional. There are a number of properties required for 3D printing (extrudability, flowability etc).

Question

Tshiphiri Tshivhasa, National Department of Human Settlements, NDoHS

What would be the profit margin for the service providers/contractors contracted by government for Integrated Residential Development Programme (IRDP) and any other government programmes?

Response

Mr Khululekani Ntakana, University of Johannesburg, UJ

At this point of our preliminary study, we have not done the analysis from the builder's perspective. It is a very important aspect that we need to look at.

Comment

Dr Maryam Amra Jordaan, SA Rebuilders

Additionally, as requested by another attendee on options for local SMME's to take part in the transfer of the "know-how" process.

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

We are open to suggestions from SMMEs on how we can assist in knowledge transfer.

Question

Dr Bethuel Sehlapelo, Council for Scientific and Industrial Research, CSIR

Thanks for illuminating on the cost-comparisons. Is the assumption that the same materials were used with the quantity being the only variable?

Response

Mr Khululekani Ntakana, University of Johannesburg, UJ

Not at all. The quantity is the same with different materials and costs. We have looked at the available materials being used currently and at what

cost. Some of the companies that developed these machines actually have materials in stock available for sale with the machines (pre-mixtures).

Comment

Dr Bethuel Sehlapelo, Council for Scientific and Industrial Research, CSIR

The CSIR has developed a "green cement" from geopolymers. This reduces the cost of cement drastically and reduces the carbon footprint.

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

Great. There is a lot of work on geopolymer cement, and UJ is also working on green cement. Let's explore collaborative work.

Comment

Alireza Moghayedi, University of Cape Town, UCT

UCT can assist with the project by evaluating the sustainability assessment of 3D printing of SA Human Settlements.

Response

Dr Jeffrey Mahachi, University of Johannesburg, UJ

We welcome collaborations with other institutions. I know UCT is working on some sustainability research.

WAY FORWARD

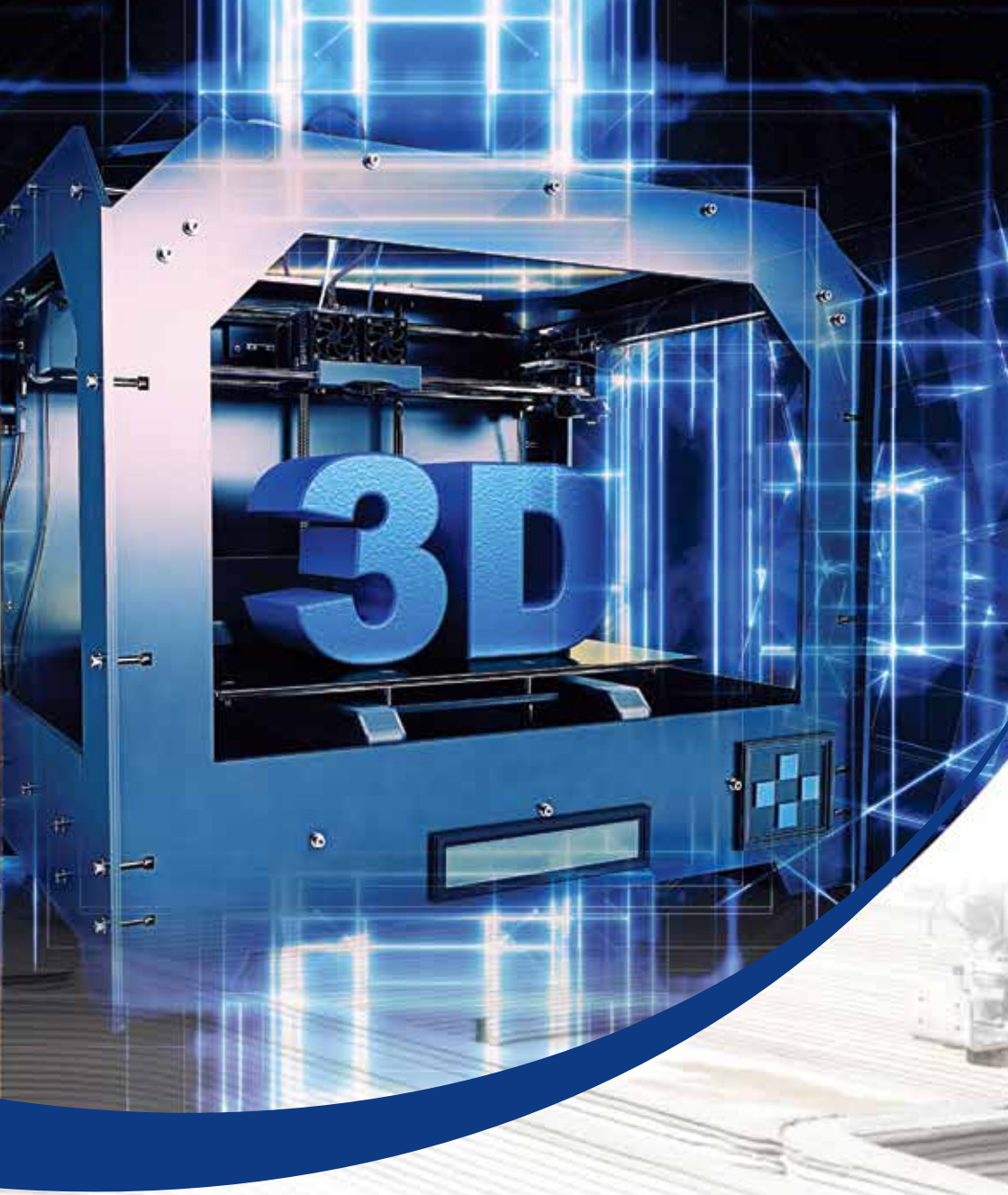
Mr Ephraim Phalafala, Deputy Director, Department of Science and Innovation, DSI

The first phase of the project focussed on investigation of the 3D printing concept for human settlements. The next phase will involve the procurement of a 3D printer and beefing up the initial research in a pilot project. The DSI has negotiated with the KZN Department of Human Settlements to identify a site for the pilot project. The project launch will take place as soon as the 3D printer has been delivered. The DSI has indicated to UJ that it should partner with an SMME to transfer skills during this process in order to ensure that empowerment takes place.

The presentations at this webinar will be made available and the proceedings report will be disseminated to all participants once finalised.

Thank you to Mr Patel for providing a very clear purpose for this webinar and the project as a whole. Thank you to ASSAf, represented by Dr Mabotha and Dr Maphosa and led by for your strong partnership with the DSI on this and other projects. We thank the NDoHS, particularly Dr Mirembe, for being part of the webinar, and the project implementing team from UJ, under the leadership of Dr Mahachi for their good work and fruitful working relationship with the DSI.

Thank you to all the participants for your valuable contributions to the discussions, which would be useful to inform the implementation of the project.



ANNEXURE

ANNEXURE A: LIST OF ACRONYMS

3DCP	3D Concrete Printing
ASSAf	Academy of Science of South Africa
BNG	Breaking New Ground
BoQ	Bill of Quantities
COVID-19	Coronavirus Disease of 2019
CSIR	Council for Scientific and Industrial Research
DPME	Department of Planning, Monitoring and Evaluation
DSI	Department of Science and Innovation
DWS	Department of Water and Sanitation
IID	Innovation for Inclusive Development
KZN	KwaZulu-Natal
LCC	Life Cycle Costing
NDoHS	National Department of Human Settlements
SALGA	South African Local Government Association
SMME	Small, medium and micro enterprise
SU	Stellenbosch University
UCT	University of Cape Town
UJ	University of Johannesburg
WLC	Whole Life Costing

ANNEXURE B: LIST OF PARTICIPANTS

Name	Surname	Organisation
Oluwafemi	Adebo	University of Johannesburg (UJ)
Stephen Adeyemi	Alabi	UJ
Christopher	Allen	Nelson Mandela University
Luxien	Ariyan	UJ
Michael-Lee	Aucamp	Pi Creations
Mabel	Ben	UJ
Ezee	Blackchildunite	Ezee
Sello	Borephe	UJ
Mmampei	Chaba	Department of Science and Innovation (DSI)
Brian	Chasi	E-Square
Ellis	Chitakatira	UCT
Harsha	Dayal	Department of Monitoring, Planning and Evaluation (DPME)
Wesley	Diphoko	The Infonomist
Elijah	Djan	Nubrix
Senzo	Dlamini	DSI
Mqhele	Dlodlo	National University of Science and Technology
Takudzwa	Dodzo	E-Square Engineering
Lisa	du Toit	DSI
Ashutosh	Dwivedi	Council for Scientific and Industrial Research (CSIR)-Central Building Research Institute
Colin	Elliott	Walter Sisulu University
Heather	Erasmus	Write Connection
Lindiwe	Gama	DSI
Sadiyah	Geyer	UJ
Hardus	Greyling	CSIR

Name	Surname	Organisation
Trynos	Gumbo	UJ
Isaac	Hartley	Heartly Consulting and Engineering
Mphakiseng	Hlungwane	RBR Enterprise
Felix	Holm	Maker Station HQ
Maryam Amra	Jordaan	SA Rebuilders
Barwa	Kanyane	Human Sciences Research Council (HSRC)
Ndapandula	Kawalu	UJ
Khanyisa	Khomani	Agrément SA
Timothy	Laseinde	UJ
Refilwe	Lediga	UJ
Mapule	Letshweni	South African Local Government Association (SALGA)
Colin	Logan	GIBB Capital
Omowunmi	Longe	UJ
Stanley	Luvhengo	Mudengu Studio
Tebogo	Mabotha	Academy of Science of South Africa (ASSAf)
Nkosinathi	Madushele	UJ
Daniel	Madyira	UJ
Aleck	Magora	Calliper
Mandisa	Magwaza	DPME
Jeffrey	Mahachi	UJ
Choeu	Makabate	Private
Bennet	Makwakwa	UJ
Kholo	Mali	Housing Company Tshwane
Stanley	Maphosa	ASSAf
Khomotso	Maponyane	Versatile Consulting
Precious	Maputle	UJ
Denislav	Marinov	University of Cape Town (UCT)

Name	Surname	Organisation
Tebogo	Mashifana	UJ
Kwena Prince	Mashita	SALGA
Thabiso	Matenchi	IIE Rosebank College
Iris	Mathye	Department of Water and Sanitation (DWS)
Hayley	McKuur	National Department of Human Settlements (NDoHS)
Mongezi	Mdhluli	South African Medical Research Council (SAMRC)
Jennifer	Mirembe	NDoHS
Euricia	Mkhonto	UJ
Mahadi	Mofokeng	DWS
Alireza	Moghayedi	UCT
Kagisho	Mojapelo	Lentilex
Tebogo	Mokgobi	The South African Nuclear Energy Corporation (necsa)
Amanda	Molete	MandaLip Development Agency
Mogorosi	Monama	Private
Tshepang	Mosiea	DSI
Lufuno	Mudau	Fulufhedzani Audit and Advisory Services Inc
Anne	Mufamadi	Mintek
Unathi	Munyai	DSI
Mukundi	Mushaphi	Vhembe District Municipality
Innocent	Musonda	UJ
Nqaba	Mweli	Private
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Abdolhossein	Naghizadeh	University of the Free State (UFS)
Sibusisiwe	Ndamashe	Agrement SA
Johan	Neethling	DSI

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Mbacké	Niang	Agence d'Architecture et de Recherche MBN
German	Nkhonjera	UJ
Koketso	Nkoana	TselaTema
Khululeka	Ntakana	UJ
Bernd	Oellermann	The Department of Trade, Industry and Competition (the dtic)
George	Onatu	UJ
Daniel	Palma	Cloud2Africa
Imraan	Patel	DSI
Ephraim	Phalafala	DSI
Tankiso	Phidza	Gemini GIS and Environmental Services
Farrel	Pillay	3D Wax Worx Pty Ltd
Colin	Pollock	Pinacle Projects
Sibongile	Radebe	Technology Innovation Agency (TIA)
Vusi	Radebe	GIBB Pty Ltd
Thabang Lisbon	Rakoena	Broadside Konsult
Stephan	Ramabodu	UJ
Mahlatsi	Ramasobane	LDM GLOBAL PROJECT
Pelonomi	Ramatlhatse	NECSA
Mamokete	Ramphisa	DSI
Aluwani	Ramudzuliza	UJ
Takalani	Ramuthaga	the dtic
Dimpho	Rapudi	D Imperium Group
Nicky	Reynecke	UJ
Bethuel	Sehlapelo	CSIR

Name	Surname	Organisation
Thato	Sekgoele	UJ
Sonia	Sequeira	University of the Witwatersrand (Wits)
Lebogang	Setabola	Mechanical engineering
Hamilton	Sithole	E Square Holdings (Pty) Ltd
Thandiwe	Sithole	UJ
Himla	Soodyall	ASSAf
Tshiphiri	Tshivhasa	NDoHS
Marchant	van den Heever	Stellenbosch University (SU)
Charlotte	van der Merwe	CITEPLAN
Hennie	van der walt	UJ
Gerdus	van der Watt	SU
Louise	van Heerden	ASSAf
Alexandre	van Niekerk	Mintek
Coralie	van Reenen	CSIR
Carin	van Zyl	DPME
Renate	Venier	ASSAf
Kevin	Wall	University of Pretoria (UP)
Benson	Wekesa	UJ
Jan	Wium	SU
Dieter	Zimolong	necsa
Fungai	Zinyandu	Tobacco Research Board
Hlengiwe	Zondi	UJ
Asandile	Zothe	UJ
Sinethemba	Zungu	UKZN
Bongiwe	Zwane	ASSAf

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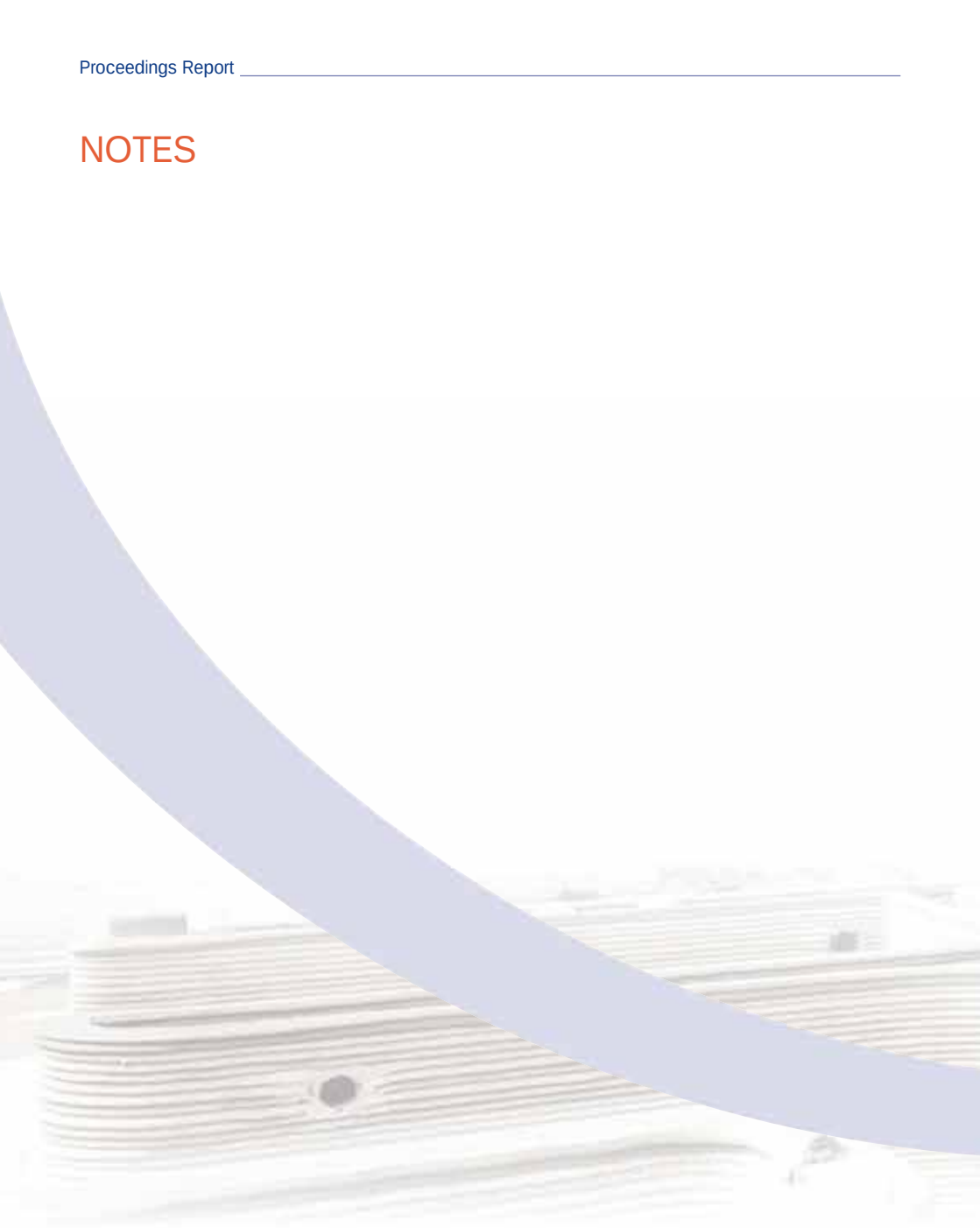

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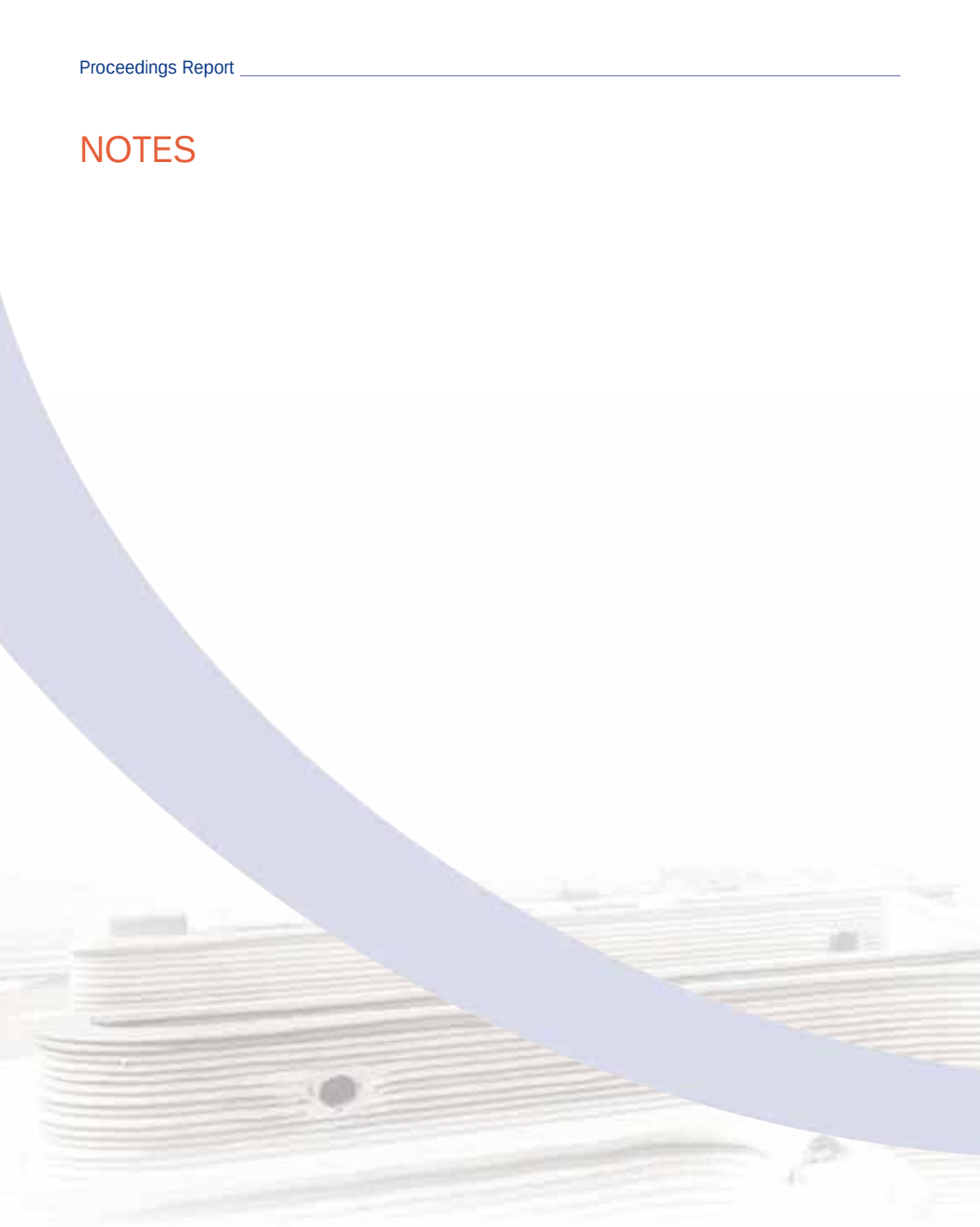

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2021

Exploring the Prospects of Using 3D Printing Technology in the South African Human Settlements

Academy of Science of South Africa (ASSAf)

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