THE FUTURE OF THE WESTERN CAPE AGRICULTURAL SECTOR IN THE CONTEXT OF THE 4TH INDUSTRIAL REVOLUTION

Review: Biofabrication

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University of Stellenbosch Business School

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1. What is Biofabrication?

Introduction

Biofabrication(BF) refers to the production of tissues and organs, predominantly to address health challenges in medicine. It uses the principles of additive manufacturing to combine cells, gels, and fibres into a single construct that can replace a diseased or injured tissue. Typically products of BF include a broad range of tissues such as skin, nervous, cartilage, vascularized bone and blood vessels, as well as complete organs such as the heart, kidney, liver and bladder.[1] BF is generally divided into Bioprinting and Bioassembly.

For the purposes of understanding the context of BF in agriculture, we believe it is useful to include synthetic biology. Synthetic biology is an emerging area of research that can broadly be described as the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems.[2] Essentially this report will review the role of humans engineering biological materials in order to improve the world around us.

Why does Biofabrication exist?

There are numerous inefficiencies in the biological world around us. For example, human beings are prone to illness. Whilst medical science has made huge steps forward in terms of diagnosing, curing and preventing illnesses in both humans and other animals, there are still many inefficiencies in healthcare which need to be addressed. In order to reduce these inefficiencies, humans have typically looked to chemistry to create medicines to combat illness. However, with today's technological innovations, we are able to manufacture biological materials in order to reduce inefficiencies and improve life on earth.

Another example of inefficiency is the negative effect of animals, such as cows, on our environment. Humans need cows predominantly for food and leather. The sheer number of cows required produces greenhouse gases which threaten the earth's climate stability. This inefficiency can be addressed through biofabrication of tissues needed from cattle without growing those tissues in a living organism.

2. Why is Biofabrication important now?

Reducing Device Costs

Biofabrication is a rapidly growing field with large steps forward being made each year in terms of performance and cost. This is partially due to the expiration of patents which has rapidly made 3D printing equipment more affordable and widely available. Affordability has also lead to increased demand which in turn leads to economies of scale and competitive pricing as new manufacturers produce new equipment at lower prices.

In concert with this lowered cost of equipment has been the transformation of rapid prototyping into rapid manufacturing. Additive Manufacturing methods have also made rapid advances and are now used for the production of high value parts with complex geometries, such as fuel nozzles in gas turbines, and also for low number serial production in medical engineering, as highlighted by the recently FDA approved titanium hip implant components. A similar evolution and expansion of applications has occurred in BF especially for the fields of Tissue Engineering (TE) and Regenerative Medicine (RM).[3] Increased access to equipment drives innovation on a much wider scale as more and more scientists and entrepreneurs are able to innovate around BF.

Ever Improved Processing Power

The exponential improvement in price vs performance of computing power has also been a major driver of BF. Analysing models built to mimic biology requires massive amounts of processing power. Increased computing power both locally and through cloud computing have dramatically improved computer-aided design. Each passing year provides cheaper processing power, reducing the barriers of entry to participating in BF. Once the sole province of universities or large pharmaceutical companies, fields such as BF have opened to innovation from the crowd as competitions such as the XPrize, iGEM, and Biodesign Challenge encourage anyone from leading scientists, to school children to participate in scientific discoveries without needing access to a lab.

Necessity

BF can provide solutions to many of humanity's most pressing problems. Climate change, a larger world population, diminishing natural resources, antibiotic resistant pathogens and many other issues have risen to the fore as humans change the face of the earth. BF has the power to solve many of the world's greatest challenges by enabling us to fabricate biological resources in a less harmful manner, and reduce efficiencies in current organisms. Solving the world's largest challenges is also extremely profitable, and thus billion dollar businesses are being borne out of BF breakthroughs.

3. Biofabrication, Today and Tomorrow

BF whilst advancing at an increasing rate, is still in its relative infancy. Thus we have combined applications of today and tomorrow into one section and analysed those applications by sector. New companies operating in BF and synthetic biology are opening every day, fueling the pace of innovation in this space.

Medicine

Biopen

The extraordinary BioPen, which lets surgeons use 3D printing technology to draw missing tissue into patients, both human and animal, was developed by the University of Wollongong and the ACMD, which is based at St. Vincent's Hospital Melbourne. It uses an ink that's similar to toothpaste, which mixes a gelatine substance with pluripotent stem cells, which are taken from the patient on the day of the surgery and put into special ink cartridges inside the pen.

Growth factors will actually spur the stem cells to grow into the exact kind of tissue that's necessary – for now, it's knee cartilage. Then, an ultraviolet light, affixed to the pen, dries the ink mixture on contact so surgeons can fill in the damaged area of the knee and build up layers. The BioPen was recently tested by treating 1 cm cartilage tears in six sheep, which were suffering from knee injuries not unlike those common to Australian football players.[4]

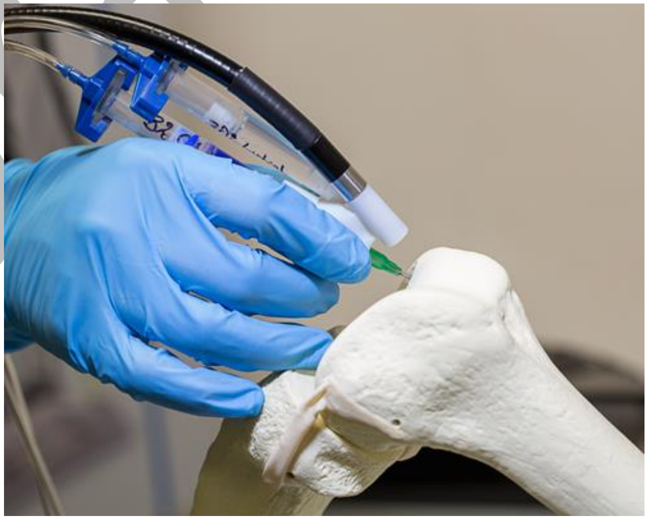

Figure 1: A Biopen. Source: Plasticstoday.com

3D Printed Organs

One of the leading BF companies, Organovo, currently creates 3D Bioprinted Human liver and kidney tissues fabricated using proprietary 3D bioprinting technology. The resulting tissues contain precise and reproducible architecture that can remain fully functional and stable for up to 28 days. Organovo's products allow pharmaceutical companies to test drugs for toxicity far more accurately than before. In the past, these tests would have been conducted on animals which can never truly mimic human bodies. By biofricating human tissue, companies like Organovo allow perfect testing conditions to rapidly improve the manufacturing process for drugs.[5]

Scientists from the Universidad Carlos III de Madrid (UC3M), CIEMAT (Center for Energy, Environmental and Technological Research), Hospital General Universitario Gregorio Marañón, in collaboration with the firm BioDan Group, have presented a prototype for a 3D bioprinter that can create totally functional human skin. This skin is adequate for transplanting to patients or for use in research or the testing of cosmetic, chemical, and pharmaceutical products.[6]

Computing

Biocomputers

Supercomputers are impressive in terms of raw power, but it comes at a price: size and energy consumption. A multi-university team of researchers are trying to solve this problem with protein-powered biocomputers. Lund University notes that where this should really be helpful is with cryptography and "mathematical optimization" because with each task it's necessary to test multiple solution sets. Unlike a traditional computer, biocomputers don't work in sequence, they operate in parallel, leading to much faster problem solving. They also require less than one percent of the power a traditional transistor does to do one calculation step.[7]

The model biocomputer used in the experiment is only about the size of a book, compared to IBM's Watson which is comprised of some 90 server modules. The ATP-powered biocomputer is admittedly limited at present, but the scientists involved say that scalability is possible and we might not be far off from seeing the tech perform more complex tasks.

DNA Data Storage

Microsoft Research computer architects say they want to start storing their data on strands of DNA within the next few years, and expect to have an operational storage system using DNA within a data centre by the end of the decade. While strings of nucleic acid have been used to cram information into living cells for billions of years, its role in IT data storage was demonstrated for the first time just five years ago, when a Harvard University geneticist encoded his book – including jpg data for illustrations – in just under 55,000 thousand strands of DNA. Since then, the technology has progressed to the point where scientists have been able to record 215 petabytes (215 million gigabytes) of information on a single gram of DNA.[8] This is a colossal improvement.

The cost of storing data using DNA is still preclusively high. However, DNA is so much more space efficient and longer lasting than current data storage, that the benefits of developing the technology will incentivise companies like Microsoft to drive down the costs, making DNA data storage a reality in the future.

Construction

Growing Bricks

U.S. based startup bioMASON, has developed a technology using microorganisms to grow biocement™ based construction materials. The Company's products include proprietary manufacturing process and materials used by customers for incorporation in existing facilities or on-site manufacturing. The strength of biocement™ materials is comparable to traditional masonry, and can be used as a green alternative. bioMASON's products make it possible to manufacture on-site in ambient temperatures using locally available materials, without using fuel for firing the material. bioMASON enables savings in energy costs and a large reduction of carbon emissions.[9] bioMASON essentially grows its brick around grains of sand, recycled plastic or glass and a number of other substances which give its bricks various other properties such as the ability to insulate buildings and absorb pollution.

Figure 2: bioMASON Bricks. Source: biomason.com

Textiles

3D Printed Shoes Using Biofabricated Spiderweb Silk

Probably the most exciting announcement at the 2016 Biofabricate conference was the advancement made in the production of spider silk protein using genetically modified bacteria, avoiding fossil fuels and using only a fraction of the energy that is required for the production of plastic. The production process has improved so much that NorthFace is going to be presenting the first spider silk-made Moon Parka. The prototype will be displayed on 5th Avenue later in November. Adidas, instead, uncovered their new product at the conference: Adidas Futurecraft Biofabric, a pair of running shoes the tissue of which is made entirely of spider silk (the sole instead is still made of recycled plastic). Spider silk is fully biosourced and biodegradable, while maintaining an excellent tensile strength. For the Moon Parka, NorthFace has partnered with Spiber, a Japanese company, while Adidas' partner is the German company AMSilk, producer of Biosteel spider silk.[10]

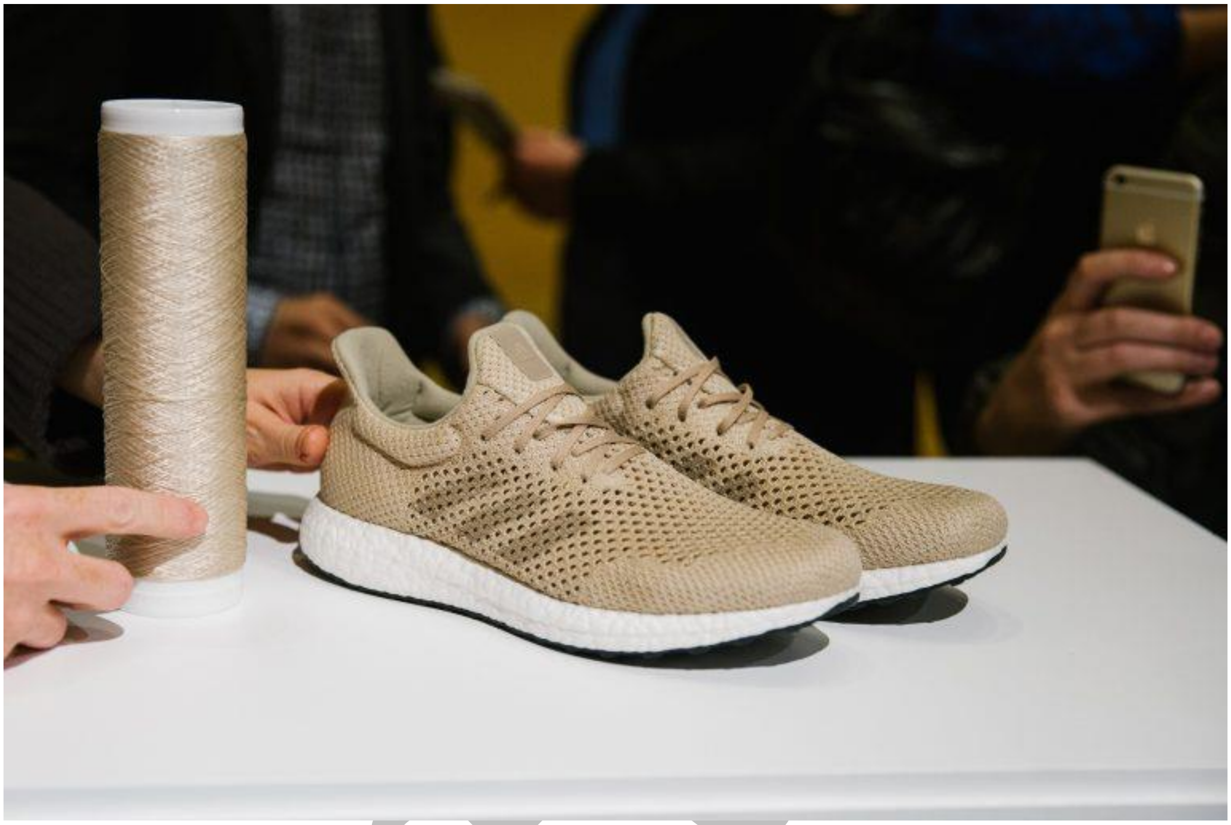

Figure 3: Shoes made out of biofabricated spider silk. Source: blogs.plos.org/synbio

Biofabricated Leather

U.S. based Modern Meadow has received a lot of press for fabricating cow meat. However, the company is now firmly focussed on the biofabrication of leather. Modern Meadow works off of skin cells that have been programmed to produce collagen identical to that of a cow or another desired animal. CEO Andras Forgacs: "We start with what leather is in its end state," he explained. "We can produce cow collagen, alligator collagen — any kind of collagen using the tool kit of biotechnology. We've developed a way to organize this collagen to get it to recapitulate into the full biological structure of that collagen in hide that we then treat to become leather."[11]

Food

Lab Grown Meat

There are at least seven companies trying to commercialize lab-grown beef, chicken and seafood cultured from animal cells. The keyword here is "trying," as the current prices are still out of range for widescale consumption. For example, it costs Memphis Meats about $6,000 per pound for its test tube chicken. That represents progress: Back in 2013, Mosa Meats in the Netherlands produced a beef patty at $330,000. That is an exponential reduction on cost.[12]

These startups, most taking their cues from the regenerative biotech medical industry, claim their products will represent a better alternative to industrial livestock, which accounts for about 14.5 percent of greenhouse gas emissions. Lab-grown meat, often referred to as clean meat, may also be healthier, without antibiotics and diseases that currently plague the conventional food system. Lab-grown meat also opens up new markets to those who currently abstain from eating meat due to ethical reasons. Should meat produced in a lab become economically viable, the implications for the agricultural industry would be significant.

Figure 4: Biofabricated meat. Source: modernmeadows.com

4. Biofabrication Application Life Cycle

Biofabrication is very much in its innovation phase. Whilst there is a great deal of progress being made in the field, biofabrication is not yet on a scale where widespread adoption for agricultural purposes in the Western Cape is feasible.

5. Business Eco-System View

Due to the early stage of biofabrication, the business ecosystem for the technology is still very immature. The majority of participants are large research and development divisions in corporate companies, universities and research institutes. This ecosystem is sure to flourish once biofabrication reaches a more accessible price point.

6. Benefits and Risks

The benefits of biofabrication are almost as wide as the human imagination. If we can fabricate biological matter to our own specifications, we can eradicate many of the issues encountered in the natural world such as disease. Animal husbandry in particular will benefit from this. The most important risk to mitigate will be the potential to engineer biological matter that has an unexpected negative effect on the natural world around us. Biological warfare and terrorism are also far more of a threat to society once biofabrication becomes a mainstream technology. Agricultural adopters will need to be sure that biofabricated matter does not have adverse effects depending on the region they are implemented, as technology could be tested in the US before wide-scale rollout to areas such as Africa.

7. Potential Economic, Social, Ecological and Political Developments and Impacts

Probably the most topical issue on biofabrication is the question of whether it is ethical or not. Our ability to manipulate the natural world has always caused consternation amongst certain members of society. For example, many people are not supporters of genetically modified crops. Biofabrication has the propensity to greatly improve human healthcare and this will probably ensure its adoption in most countries. However, this technology will not go unopposed and cognisance should be taken of that fact.

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