THE BIG IDEA: Print your own body parts

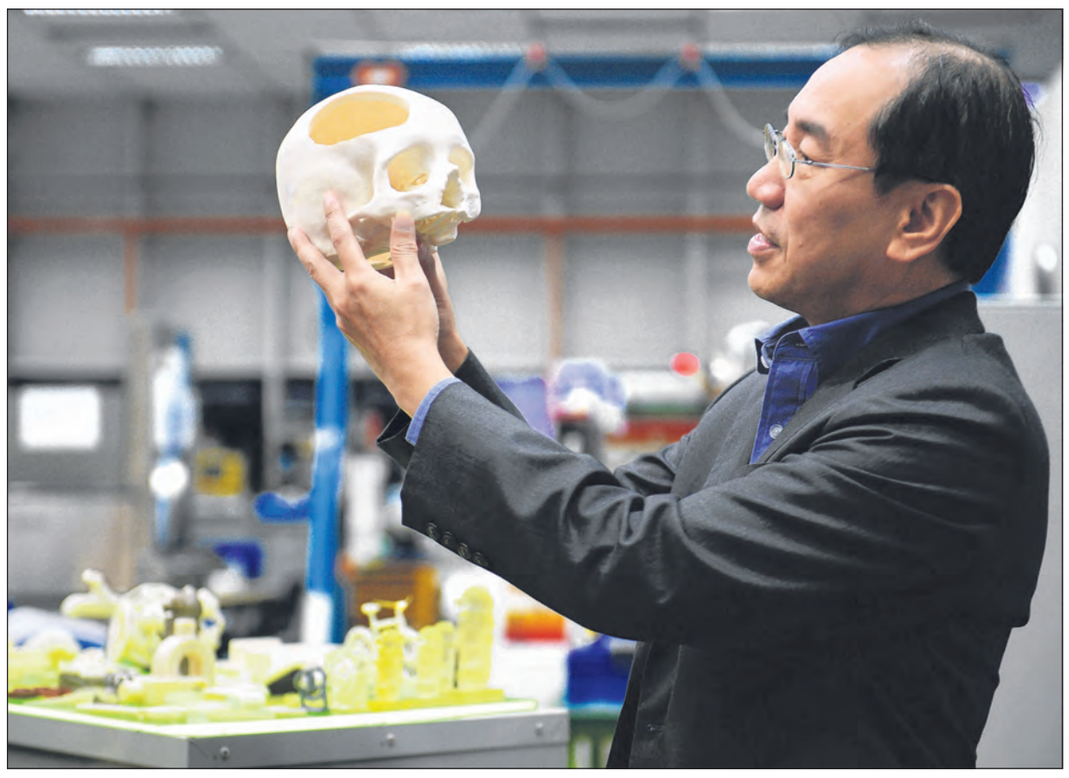
Engineering don Chua Chee Kai has mastered the technology called additive manufacturing, or 3-D printing, in which an inkjet-like printer builds an object layer by layer according to a computer-aided design.

Professor Chua has gone so far in this field that he can produce the following:

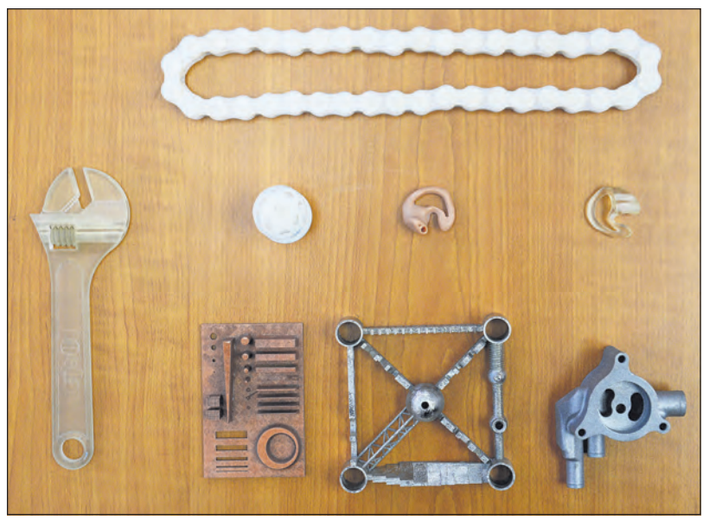
- Tissue scaffolds, which are tiny biodegradable grids implanted into a person for the person's cells to latch on and grow new tissue. Once the tissue is grown, the grids will dissolve;
- Body parts such as corneas, skin and heart tissue. For this, Prof Chua uses stem cells, proteins and other biological material as the "ink" for his printer. He will need more research with doctors and biologists to print vital organs;
- Replicas of body parts, such as artificial limbs and artificial bones. He has printed out a curved section of cranium to restore the forehead of an injured woman.

Broken heart? Print a patch to mend it

Singaporean taking 3-D tech a step further by 'printing' tissue, organs



Prof Chua with a 3-D printed replica of a human skull he made. He will be using stem cells, proteins and other biological material as "ink" in his new 3-D bioprinter to make corneas, skin and heart tissue. ST PHOTOS: MUGILAN RAJASEGERAN



Some of the items that Prof Chua has made using a 3-D printer in his laboratory. He will be getting a new 3-D bioprinter by the end of the year.

By CHEONG SUK-WAI
SENIOR WRITER

SINGAPOREAN engineer Chua Chee Kai dreams of the day when you can walk into a shop here on Valentine's Day and ask its minders to print out a chocolate rose for your spouse on the spot.

Or if you need replacement soles for sneakers, you can get them to print them out pronto.

Now, what if you needed a cornea, a bladder or heart tissue? Well, Professor Chua will be able to print all these out for you too by the end of the year.

That is when his new million-dollar 3-D bioprinter will arrive at his new $30 million centre at the Nanyang Technological University (NTU) to research the technology known as additive manufacturing. The centre is funded by the Economic Development Board and will officially open in May next year.

Two Sundays ago, Prime Minister Lee Hsien Loong gave Singaporeans a peek into one possible future for Singapore manufacturing during his National Day Rally speech, showing slides of the dental implants and artificial bones made with such technology.

Additive manufacturing, known popularly as 3-D printing (3DP), was a Western breakthrough some 30 years ago to address the industry's need for first-cut models, or prototypes, of designs so that manufacturers could keep testing how viable their designs were.

So, for example, if you wanted to make a most comfortable office chair, you would need to keep adjusting the design of its armrests until it was ideal for customers of all shapes and sizes.

With 3DP, you can generate and tweak model after test model of your office chair design quite cheaply, until you perfect the design. The 3-D printer that enables this has a built-in computer which directs a souped-up inkjet printer to lay one filmy slice of molten material, usually a plastic, atop another as one would stack pancakes. When these slices cool down, they harden into a solid object.

Prof Chua, 53, chairs NTU's school of mechanical and aerospace engineering, and has distinguished himself globally in this field of building things up layer by layer, similar to how a plant or person grows.

His biggest idea to date has been to crack the computer formulae needed to direct a 3-D printer effectively to make tissue scaffolds.

These scaffolds are tiny biodegradable grids that can be implanted in a person so that the person's cells can latch onto the grid and grow into tissue. Once the new tissue holds together well, the grid will dissolve harmlessly.

American industry consultant Terry Wohlers, who is a globally respected 3DP industry expert, says: "Without a doubt, Chee Kai has contributed favourably to 3DP, especially in academia."

Now, Prof Chua will be taking the possibilities of such printing further by using stem cells, proteins and other biological material as "ink" in his 3-D bioprinter to make replacement corneas, skin and even heart tissue.

He has just submitted a proposal to the Government for $25 million to print a lung.

Then again, as he himself notes, printing out vital organs such as a heart, lung or kidney is far more complex than creating ears and bladders, which others have done.

He says: "It's not the geometry that's complicated but the biology. If the cell is meant to be a kidney cell, you cannot simply print something that looks like a kidney and assume that it would function like one.

"That knowledge is beyond an engineer, and so the engineer would need to work with doctors and biologists to widen this field."

That said, he points out that putting a 3-D printed vital organ into a person is less hazardous than organ transplants because the cells used to print the organ would have come from that person, and so the risk of rejecting the printed organ is low.

Some might consider such innovations too invasive, but Prof Chua says he is not in the business of only scoring breakthroughs. "This technology can save lives, and that makes me even more passionate about it," he insists.

He knows a lot about that. In 2003, he used 3DP to save a 27-year-old Singaporean man with nose cancer.

The man's surgeon at the Singapore General Hospital sent Prof Chua and his team a CT scan of the man's face on a Friday.

From that scan, Prof Chua and his colleagues used the computer to digitally reconstruct the man's skull and printed it out over the weekend.

The result was a precise replica of the unique contours and bumps of the man's skull.

The surgeon rehearsed the operation on that the next day, and the day after that, excised the man's tumour cleanly and far more quickly than if he had not had the chance to practise on the replica. The man recovered well.

Despite how disruptive 3DP is to conventional ways of making things, Prof Chua is quick to stress that it will not replace mass manufacturing any time soon.

He says: "This technology is effective only for high-mix, low-volume industries like aerospace engineering. That's because you don't make one million airplanes at one go, but you do make 10 to 15 different airplane spare parts at a time and 3DP can do this very well."

The married father of three was first fascinated by 3DP in 1989, when he was doing part of his PhD at the Karlsruhe Institute of Technology in Germany.

He recalls: "I found it strange even back then that people were manufacturing by taking a block of material and then chipping away at it. Such subtractive technology wasted a lot of materials.

"So I got to thinking: What if there was a way to build things layer by layer, just like how nature grows living things?"

This National University of Singapore and NTU alumnus went on to co-author a critically acclaimed book on 3DP in 1995, with NTU don Leong Kah Fai and their former colleague Lim Chu-Sing.

With growing interest worldwide in 3DP today, Prof Chua says that it would be wise if the Government set up a national institute soon to educate all Singaporeans on the dangerous pitfalls of 3DP, such as:

- copyright concerns, as 3DP has made ripping off another's designs only too easy;
- Security concerns, as this enhanced power to make things has made it very easy to produce guns and other weaponry;
- Quality concerns, as there are more than 40 different 3DP techniques but few, if any, product standards in place; and
- Social concerns, as people's attitudes may change now that they can technically make any object or body part they desire.

Already, he has run workshops on that for senior officers of the health, home affairs, finance and trade and industry ministries in Singapore.

Earlier this month, he also launched an international competition for all to design and 3-D print clothes and abacuses, and will announce the winners in November.

He muses: "The key thing is to understand the limits of 3DP and use it to spark the creativity of younger Singaporeans so they will innovate to satisfy their curiosity about many things, be they chocolate roses or sneakers."

suk@sph.com.sg

Cheong Suk-Wai meets a thinker in this fortnightly column, which alternates with The Big Read, in which she reviews a book of ideas.

Chua Chee Kai on...

HIS BIGGEST REGRET ABOUT HIS BIG IDEA

"That I could not save a very good friend who died recently from lung cancer. If I could have printed out a lung for her, it could have saved her."

HOW HARD IT WAS TO CONVINCE OTHERS OF HIS IDEA

"When I first tried to get funds from the Ministry of Education to buy a 3-D printer for metals, I got shot down. The next year I tried, I got shot down... I hope the Government will give us money to educate people now because I don't want to be following others always."

HOW HE FEELS NOW THAT HE'S GOT THE MULTIMILLION-DOLLAR MACHINE

"I was joking the other day that I should collect admission fees, as people now come to see it every week."

WHAT ABOUT 3-D PRINTING EXCITES HIM CURRENTLY

"I don't know about roti prata or kuih lapis, but I'll be able to print out chocolates soon when I perfect the printer."

WHAT ABOUT 3-D PRINTING WORRIES HIM MOST

"That if most people do not understand it properly, someone might die one day, you know, by pouring water into something toxic he has printed and drinking it all up."

HIS MOTIVE IN PROMOTING 3-D PRINTING

"Too many of our young today are going into the soft sciences, humanities and business, so I hope 3-D printing can excite them about engineering again."

THE PROLIFERATION OF CHEAPER 3-D PRINTERS IN THE MARKET NOW

"As the Chinese saying goes, *yi fen qian, yi fen huo* – if you buy something for a few thousand dollars, don't expect great results."

HEAR IT

www.straitstimes.com

Prof Chua Chee Kai explains why you should not rush to buy a 3-D printer

Download a QR code reader app on your smartphone and scan this code for more information.

THE BIG IDEA IN HISTORY: Creating layers with lasers

THERE are currently more than 40 ways to use a 3-D printer to make things but they all started with the same idea – using lasers to turn a molten, liquid or powdery substance into a solid object.

In a 2011 report, American 3-D printing advocate Terry Wohlers traced the initial innovation to the late 1960s, when researchers at the Battelle Memorial Institute in the United States aimed two lasers at a special resin and created a mass out of it.

Then in 1970, Mr Wohlers writes, US company Dynell Electronics perfected a way to control a laser cutter via a computer so that a rough chunk of material could be sliced as wafer-thin as possible, like salami.

The computer would then stack each filmy slice atop the other, to cool and harden into a specifically shaped item. Researchers continued improving on these methods until 1980, when Japanese engineer Hideo Kodama found a way to use a single laser beam to carve out and harden slices of resin.

But it was the US that soon surged ahead in innovating 3-D printers. In 1984, Mr Charles Hull, co-founder of a California start-up called 3-D Systems, registered a patent for using a computer-controlled laser beam to harden slices of plastic into an object.

Today, the US remains the clear leader in this field, especially 3-D printing (3DP) with plastics. Germany is best at 3DP with powdered metals.

Researchers at the Massachusetts Institute of Technology, however, are now trying to supersede 3DP with what they call "smart sand", or special grains that can automatically sense shapes.

If you drop, say, a cup into this sand, the grains will automatically bond themselves such that they make a usable replica of that very cup.

THE BIG IDEA IN ACTION: Customising precisely and speedily

WHEN tinned food maker George Huang first saw the technology known as additive manufacturing abroad in the 1980s, he wondered: "What would be the point of such sci-fi technology when translated into reality?"

Additive manufacturing, also known as 3-D printing, was then used to generate first-cut designs such as mini architectural models of buildings.

Now, he considers that concept of building an object layer by layer with a molten substance a "strong" idea with potentially lots of applications.

Mr Huang, 63, who is chairman of Amoy Canning here and president of the Singapore Manufacturing Federation (SMF), says: "As a country, Singapore cannot risk not looking into the possibilities of this technology.

"It is part of the future of manufacturing, but not the future of manufacturing because it might be superseded in time to come."

The rub, he notes, is finding a way to "jump across the chasm between prototyping and full manufacturing".

Also, for now, few small and medium-sized enterprises can make the jump because it costs too much to research such technology.

He says the SMF is monitoring developments in this technology closely with a view to applying it generally to various assembly lines. He estimates, however, that it will take at least 10 years to do so. At the moment, he says, additive manufacturing cannot replace mass manufacturing because:

- Its printers are too expensive and still too small to build entire products such as cars or airplanes;
- Each 3-D printer can print with only one substance at a time, so it cannot make, say, an entire car at once because a vehicle is made up of steel, plastic, cloth, leather and other materials;
- The materials used as "ink" in the printers are not of solid enough quality for large-scale construction, being mostly in powdered form; and
- It is still much slower to print an object layer by layer than it is to make it conventionally in factories.

Mr Huang says: "3-D printing is a very good research tool because you can print many iterations of a design fairly inexpensively to test which design holds up best."

The strength of this technology is its ability to customise an object with precision, he notes. So it is particularly effective in making body parts such as dental, hip and knee implants and bones, he points out. It helps that the powder used in 3-D printers makes functionally porous bones.

So, he notes, 3-D printing is useful if a multinational company wants its branches all over the world to test or sell a product. Each branch need only be given the computer file of the design to print out the product in question instantly in its office.