

Future of Healthcare : 3D Printing for Personalized Medicine

Ho Chaw Sing (Ph.D)
3 August 2021

NAMIC 
NATIONAL ADDITIVE MANUFACTURING
INNOVATION CLUSTER



**Singapore Healthcare
Management 2021**

**3rd - 4th
August**

Featuring:

-  Singapore Healthcare Management Congress 2021
-  Singapore Healthcare Supply Chain Management Congress 2021
-  Singapore Healthcare Enterprise Risk Management Congress 2021

Join us
at the premier congress
for healthcare
management!

© Copyright 2021 - NAMIC Singapore. The information contained herein is subject to change without notice. All rights reserved.

Agenda :

- **Introduction**
- **RIE2025 Priorities – Why 3D Printing?**
- **Impact of Black Swan Events : COVID-19**
- **Stretching the Boundaries with 3D Printing : Point of Care Model**
- **AM Development in Singapore**
- **Conclusions**

Our Mission

We aim to transform and enhance our industry competitiveness by orchestrating breakthrough strategies for the future of production, jumpstarting public-private collaborations, developing the AM ecosystem, and helping companies lower barriers for hybrid and additive manufacturing technology adoption.

We have built a global interconnected network of thought-leaders, research performers and industry players to develop and deploy industry-relevant AM technologies and solutions, building towards Singapore's status as a future leading digital manufacturing hub.

**Enable Industry
4.0 Transformation**

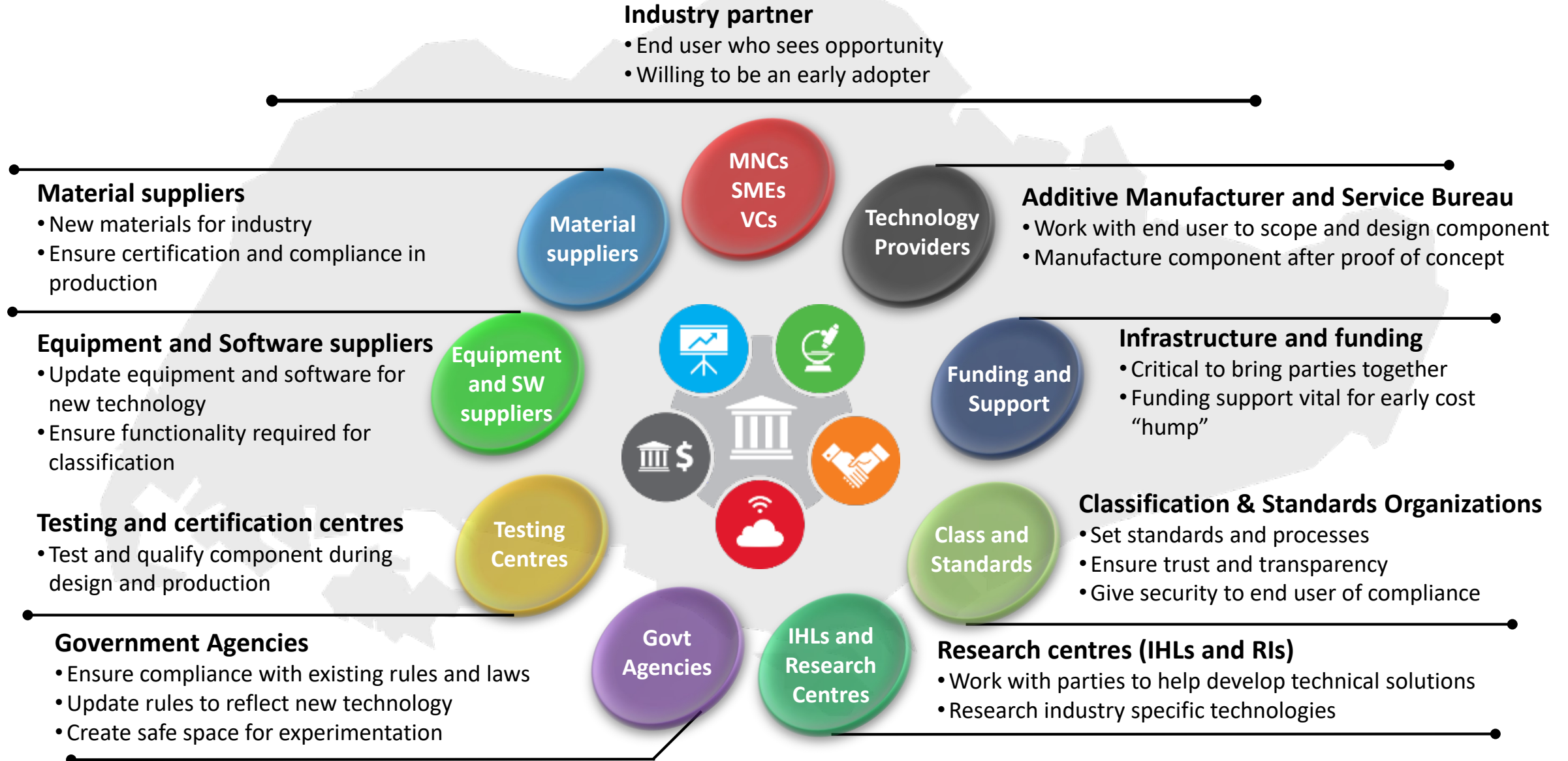
**Translate and
Commercialise 3D
Printing technologies**

**Digital Manufacturing
in a Digital Economy**



NAMIC : Connecting the dots for the Industry

Enabling the Digital Manufacturing Future



AM Ecosystem in Singapore – Full Value Chain

Beyond OEMs and TICs, more startups and MNCs adopting AM for product development and on-demand manufacturing

March 2021 : >170 companies across value chain*

62 SGP startups (incl 9 foreign) and ~30% global AM companies in SGP

Anchoring **Equipment** and **Software** companies' RHQs
and regional engineering centres



Building the APAC **Materials** supply
chain and R&D network



Grooming **product startups** & highly-
specialized **Service Bureaus**



END-USERS



25% of the APAC MRO
market



Global leading trans-
shipment hub and
jack-up rigs



RHQs by 9 of top 10
companies

Engaging **Standards and TICs**
to support adoption



*AM Business Network Online Directory, [NAMIC Singapore](https://www.namic.sg)

Agenda :

- **Introduction**
- **RIE2025 Priorities – Why 3D Printing?**
- **Impact of Black Swan Events : COVID-19**
- **Stretching the Boundaries with 3D Printing : Point of Care Model**
- **AM Development in Singapore**
- **Conclusions**

Confluence of Healthcare & Technology

The evolving world of healthcare intersecting with a new world of technology

Current State of Healthcare



Emerging Technologies



As health needs and expectations evolve,

WE MUST ANTICIPATE WHAT'S NEXT AND INNOVATE NEW SOLUTIONS

RIE2025 : Human Health and Potential



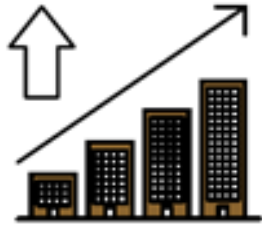
\$32B manufacturing output from the BMS sector in 2019



4% contribution to SG's GDP from pharmbio and medtech in 2019



>24,000 workforce in 2019



>330 BMS startups in SG (x2 since 2014)



>US\$250M raised by BMS startups in 2019



5x increase in industry R&D spending from 2013-2018

Source : National Research Foundation, RIE Strategies

Under RIE2025 Human Health and Potential domain, **Precision Medicine** is a key focus.

Singapore's rapidly ageing population and rising chronic disease burden require that the health system become more **data-driven and patient-centric** to deliver value-based care. Innovative use of technology and digital solutions at scale will be needed. Cross-domain technologies, such as **additive manufacturing** can be deployed for patient-centric solutions, resulting in enhanced patient outcomes.

3D Printing | Additive Manufacturing : An Umbrella Term

Material Extrusion

FDM: Heated nozzle used to extrude mostly thermoplastics to create successive object layers.

Vat Photopolymerization

SLA: Laser or other light source to solidify successive object layers on the surface or base of a vat of liquid photopolymer.

Material Jetting

Polyjet: Uses multiple print heads to spray liquid layers that are solidified by exposure to UV light

Binder Jetting

Binder Jetting: Uses a print head to selectively spray a binder (glue) onto successive layers of powder

Powder Bed Fusion

SLS: EBM: uses a laser, electron beam or other heat source to selectively fuse successive powder layers. Plastics and Metals

Direct Energy Deposition

Metal Printing: laser or other heat source to fuse a powdered build material as it is being deposited.

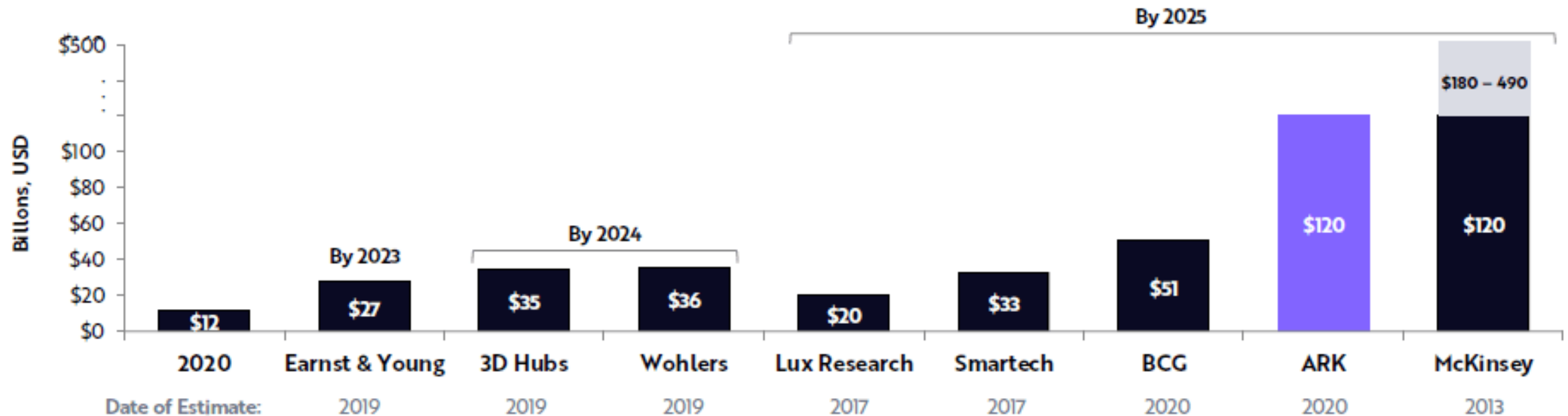
Sheet Lamination

Paper Printer, Metal Printer: sticks together sheets of cut paper, plastic or metal.

Sizing the Opportunity : Additive Manufacturing

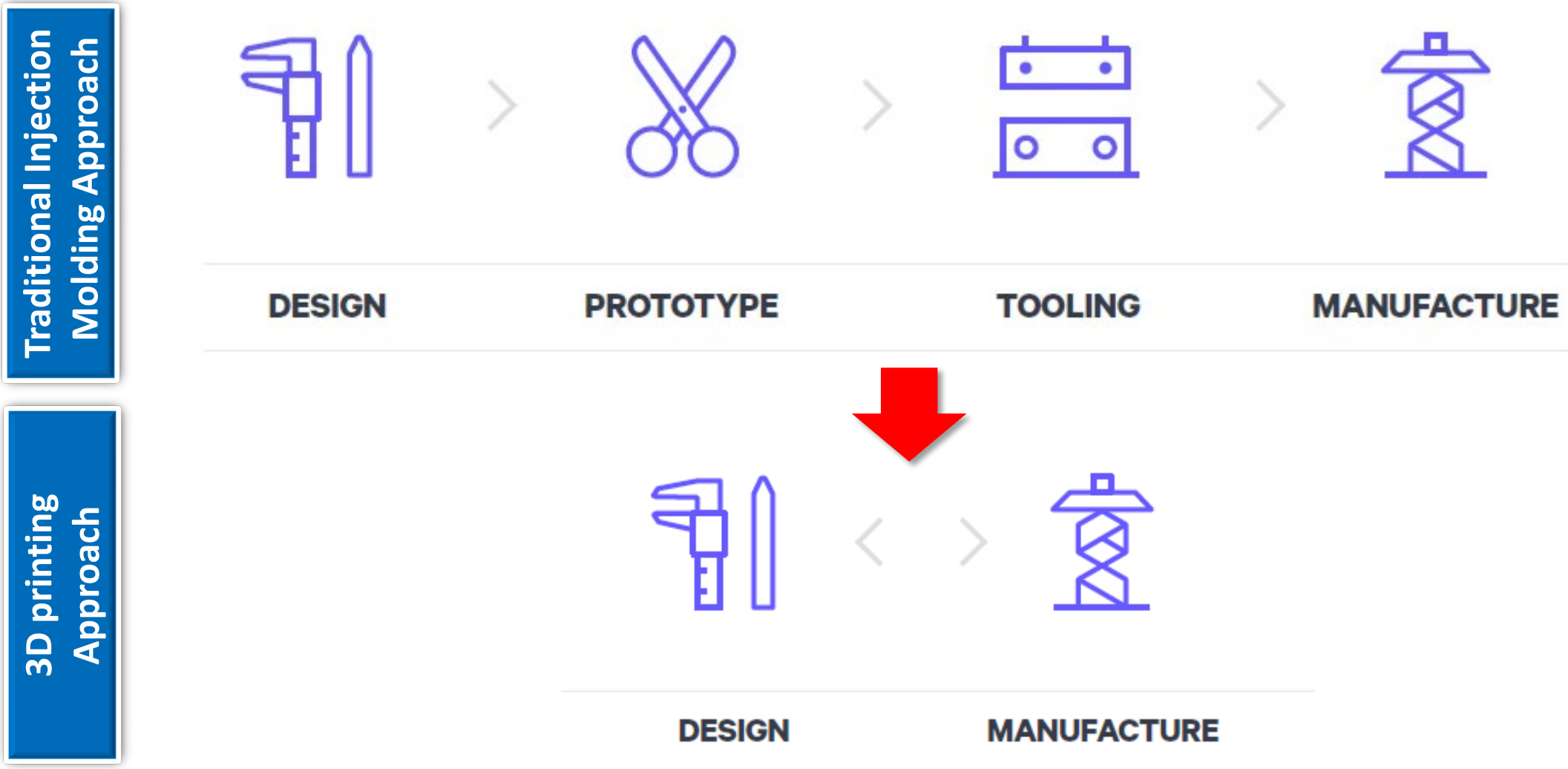
Global 3D Printing market will scale at a compound annual rate of **20-60%** during the next 5 years, from \$12 billion in 2019 to approximately \$120 billion by 2025. Global AM products and services grew by 7.5% in 2020 [Wohlers 2020], despite the pandemic.

Global Estimates for 3D Printing Market 2020 to 2025



3D Printing – Going Digital

Dis-intermediation of Product Development Cycles | Personalization | On-demand Production



Process



Patient data
acquisition



Data Transfer



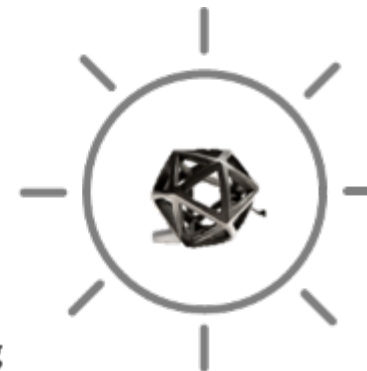
Design
preparation



3D
printing



Post processing
(machining & cleaning)



Agenda :

- **Introduction**
- **RIE2025 Priorities – Why 3D Printing?**
- **Impact of Black Swan Events : COVID-19**
- **Stretching the Boundaries with 3D Printing : Point of Care Model**
- **AM Development in Singapore**
- **Conclusions**

COVID-19 RESPONSE

[NAMIC Covid-19 Response Site](#)

FEATURED INITIATIVES FOR THE COMMUNITY



FACE SHIELDS FOR
FRONTLINE WORKERS



AM EAR GUARDS



NP SWABS



VENTILATOR
COMPONENTS



GLOBAL
PARTNERS



RESOURCE MATCHING
PLATFORM



GUIDELINES AND
STANDARDS

Asia Pacific's
COVID-19
Resource Site –
launched 15 Apr
2020

Over 70
enterprises
and
institutes
featured

PARTNERS



3D Printed NP Swabs : Global Overview



HP | Abiogenix (US)
(Binder-Jet, PA11/PA12)



Carbon | Resolution Medical (US)
(SLA, Biocompatible certified Resin)



EnvisionTECH (US)
(SLA, Biocompatible certified Resin)



Northwell | Formlabs (US)
(SLA, Biocompatible certified Resin)

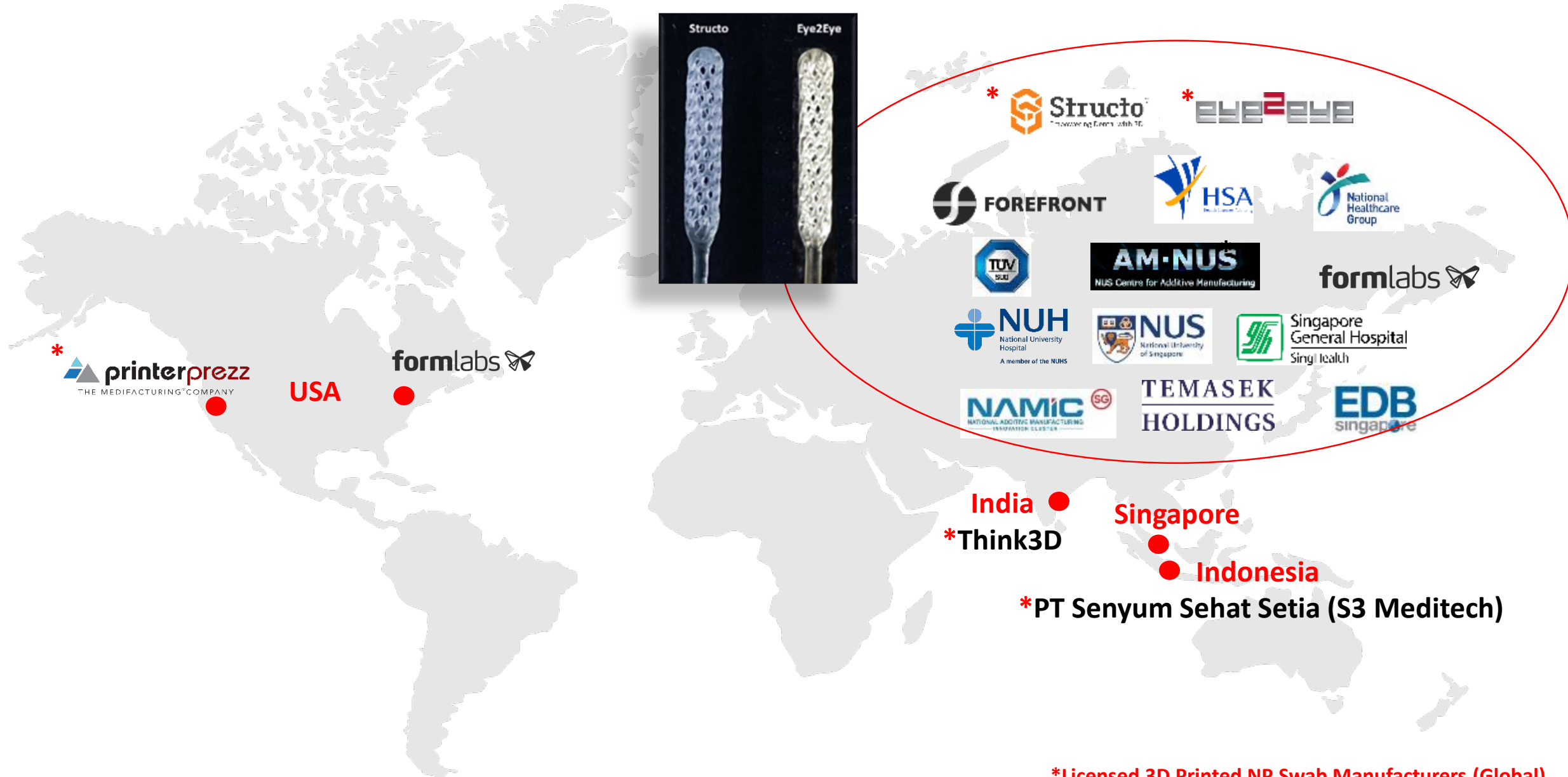


Origin | Henkel (US)
(SLA, Biocompatible certified Resin)



Eye2Eye, Structo | NUS (Singapore)
(SLA, Biocompatible certified Resin)

Vibrant Innovation Ecosystem : Singapore Inc.



*Licensed 3D Printed NP Swab Manufacturers (Global)

Agenda :

- **Introduction**
- **RIE2025 Priorities – Why 3D Printing?**
- **Impact of Black Swan Events : COVID-19**
- **Stretching the Boundaries with 3D Printing : Point of Care Model**
- **AM Development in Singapore**
- **Conclusions**

3D Printing

in Medical devices enables

Personalised &

Custom made, Patient specific, individualised

Standard

Off-the-Shelf, Stock

Newer Possibilities

**Superior Clinical
Outcomes**

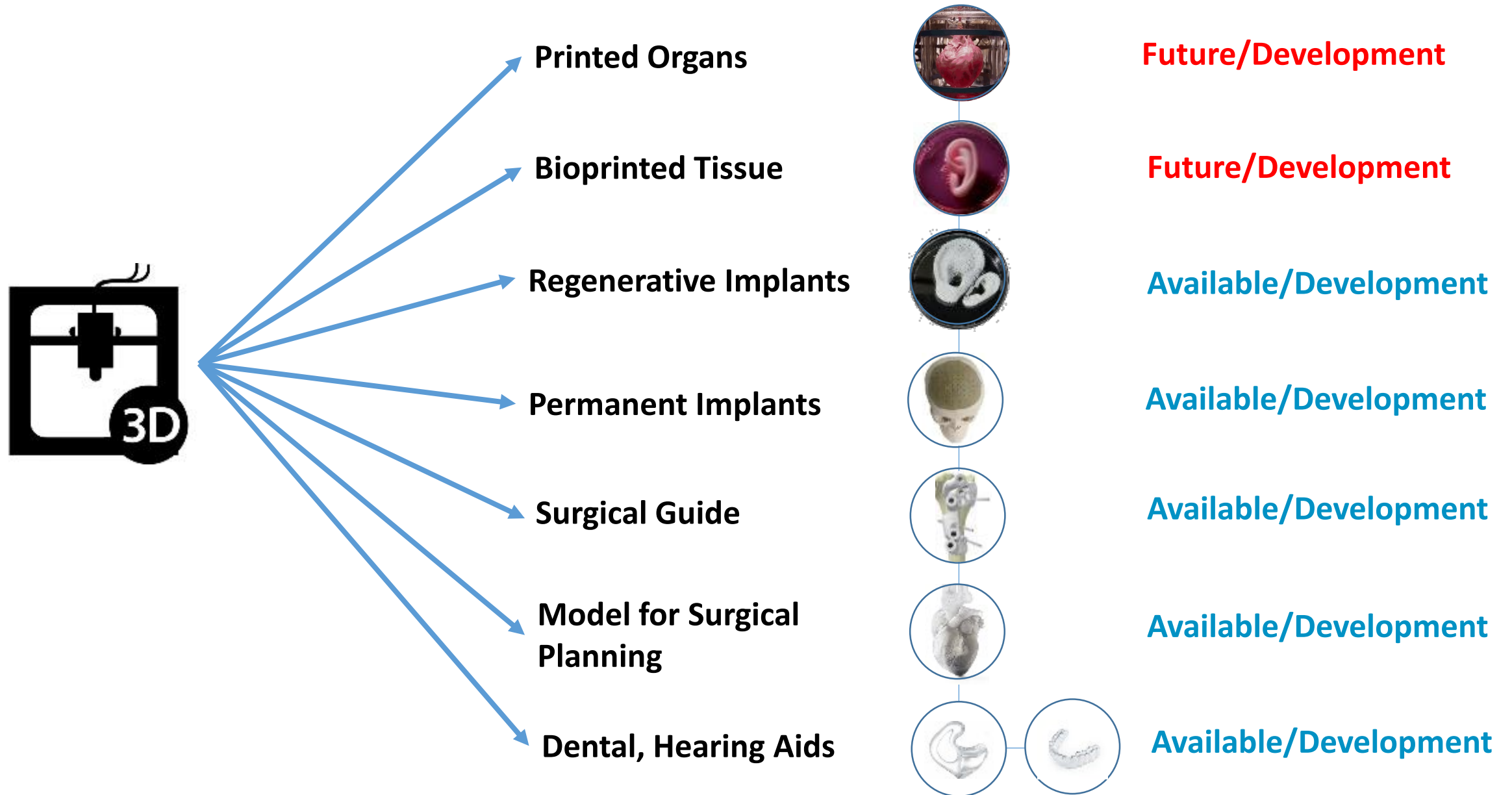
**Better value to
healthcare systems**

Why Personalize?

- Every person is different 😊
- Fit the product to a Patient, not fit a Patient to the product
- Get it right the First-time
 - ✓ Avoid excessive bone removal and unnecessary manipulations
 - ✓ Avoid multiple surgeries
 - ✓ Save OT time and increase efficiency
 - ✓ Empowers surgeons to decide what solution is best for their patients and innovate rapidly and not be solely dependent on standard products available



Pushing the Boundary of 3D Printing Technology

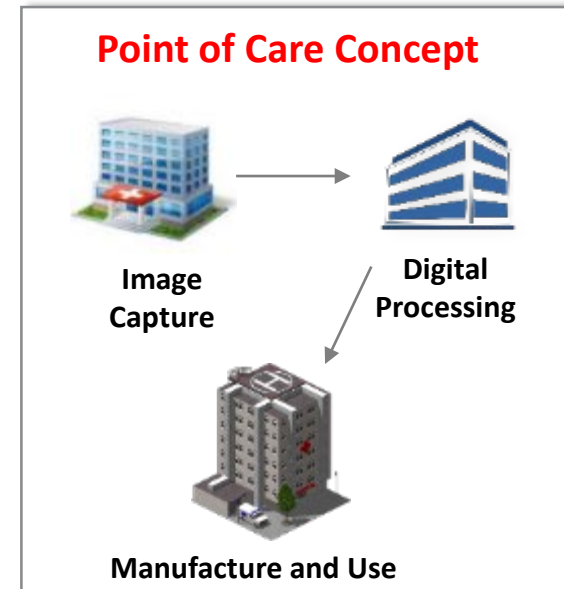
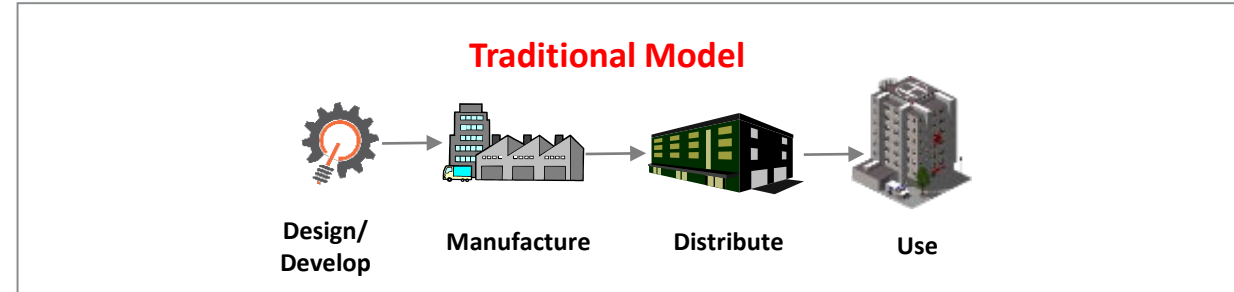


Point of Care Delivery has the potential to Transform Healthcare

A transformation in healthcare is anticipated with the shift from traditional manufacturing and distribution models to integrated end-to-end business models centered on patient outcomes.



Hospital or near-hospital based 3D Printing can provide clinicians or surgeons across surgical disciplines, image-based surgical planning and medical 3D printed products such as anatomical models, surgical templates, instruments, implants and smart prosthetics.



X-Ray 2D to 3D Applications



Customized Instrumentation



Transform Procedure & Business Model



Pivoting to Just in Time Manufacturing

Is it REAL?

- ~100 3D printed medical devices have been FDA approved
- Est. market size of \$2.1billion (2020)
- Several hundreds of thousands of anatomical models clinically used
- **Millions** of non-custom metal implants used
- A rapidly growing list of new clinical applications in different areas

Source : Sivantos, Materialise, Phonak

- In 2015, >15million 3D printed hearing aids were in circulation
- In the US, >98% of hearing aids use custom 3D printing
- Materialise & Phonak (Sonova group) – custom Ti hearing aids
- 1/3rd of all hearing aids by Sivantos are made in Singapore

"Molds for ~17 million teeth aligners are 3D printed every year"



STEP 1

STEP 2

STEP 3

STEP 4



Impression



Treatment
Planning



3D Printing
Models



Thermoforming



Source : Align Technologies, 3D Systems, Structo

Surgery Applications

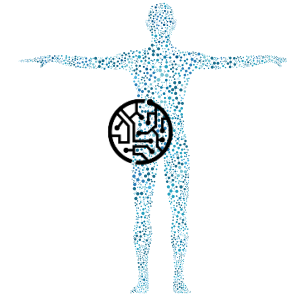
2020



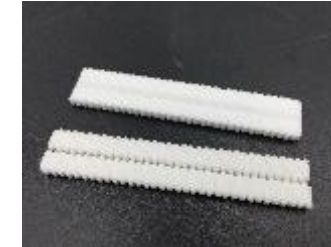
Highly
Differentiated
Products



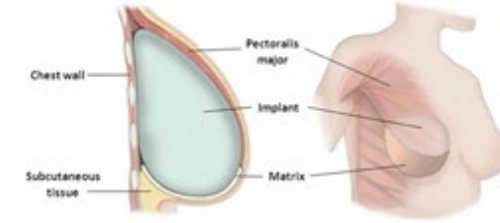
3D printing enabled
Complex Geometries



Electronics for sensing
and feedback



3D Printed
Resorbable buttress



Bio Materials: Extracellular
Matrix Scaffold

Long Term
Disruptions



Transform surgical care business model
via 3D printing and Data Analytics



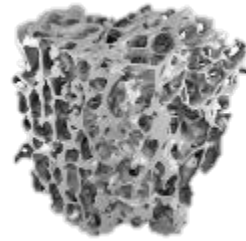
Postponement Strategy:
Just in time regional value-add to products T

2030

Orthopedics Applications

2020

Highly
Differentiated
Products



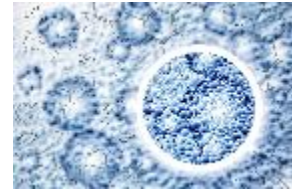
Unique Bone Growth
Structures & Coatings



Expandable Cage Technology
Enhancements
including 4D Printing



Inclusion of Sensors
for biofeedback



New Materials
promoting Wear
Resistance while
maintaining Strength

Long Term
Disruptions



Point of Care
Printing
(Rapid Deliver)



Customized &
Single Use
Instrumentation



3D Bio-Printed
Cartilage Meniscus
& Soft Tissue



Hard Tissue/Bone 3D Bioprinting
Targeted Biologics & Drug Delivery
Implants

2030



Pharmaceuticals & API's Applications

2020

Highly
Differentiated
Products

Long Term
Disruptions

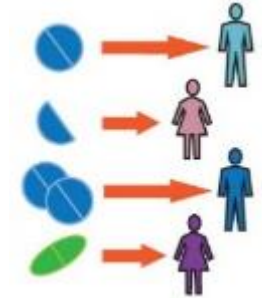
2030



3D Printed Dosage Forms
(multiple API's/shape/release profile)



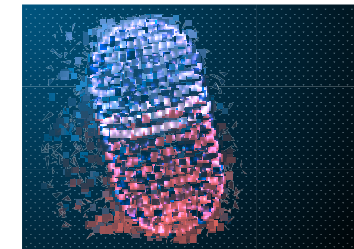
Bioprinted tissues & organs for
drug testing & screening



Non-Genomic- Personalized
Medicines



Point of Care of Personalized
Medicines



Inclusion of Sensors for Bio-
Feedback and Improved Outcomes



Scan2Health Genomic
Targeted Personalized
Medicines

Consumer Applications

2020

Highly
Differentiated
Products



Personalized
Oral Care Devices



Personalized
Skin Care / Beauty Products



Single Use
Personalized Products



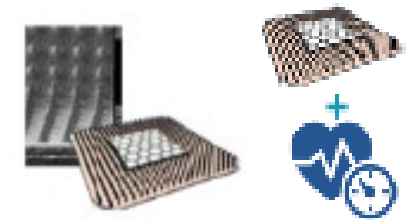
Long Term
Disruptions



Consumer Controlled
Scan to Design Product
Personalization



Inclusion of Sensors for
biofeedback
Health Monitoring / Predictive Care



Drug Delivery Self Care
Treatment Products

2030

Vision Care Applications

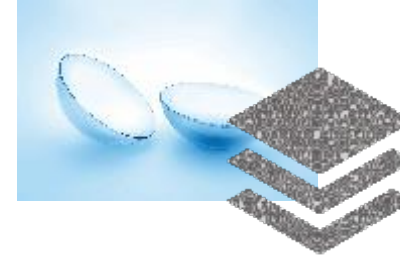
2020

Highly
Differentiated
Products

Long Term
Disruptions



Custom Surgical
Devices



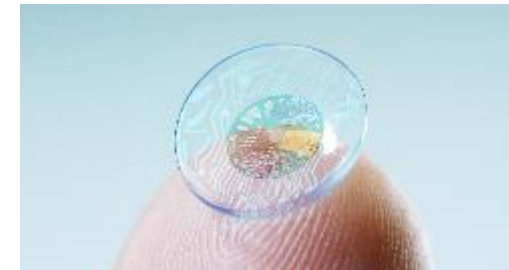
Multi-layered lens
material constructs



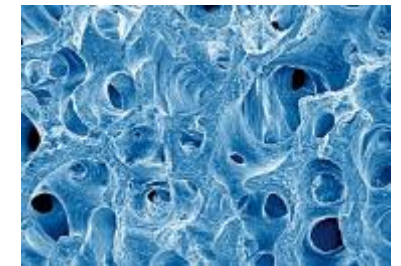
Resorbable Therapeutic
Patches



3D Printed Lenses at
Point of Care

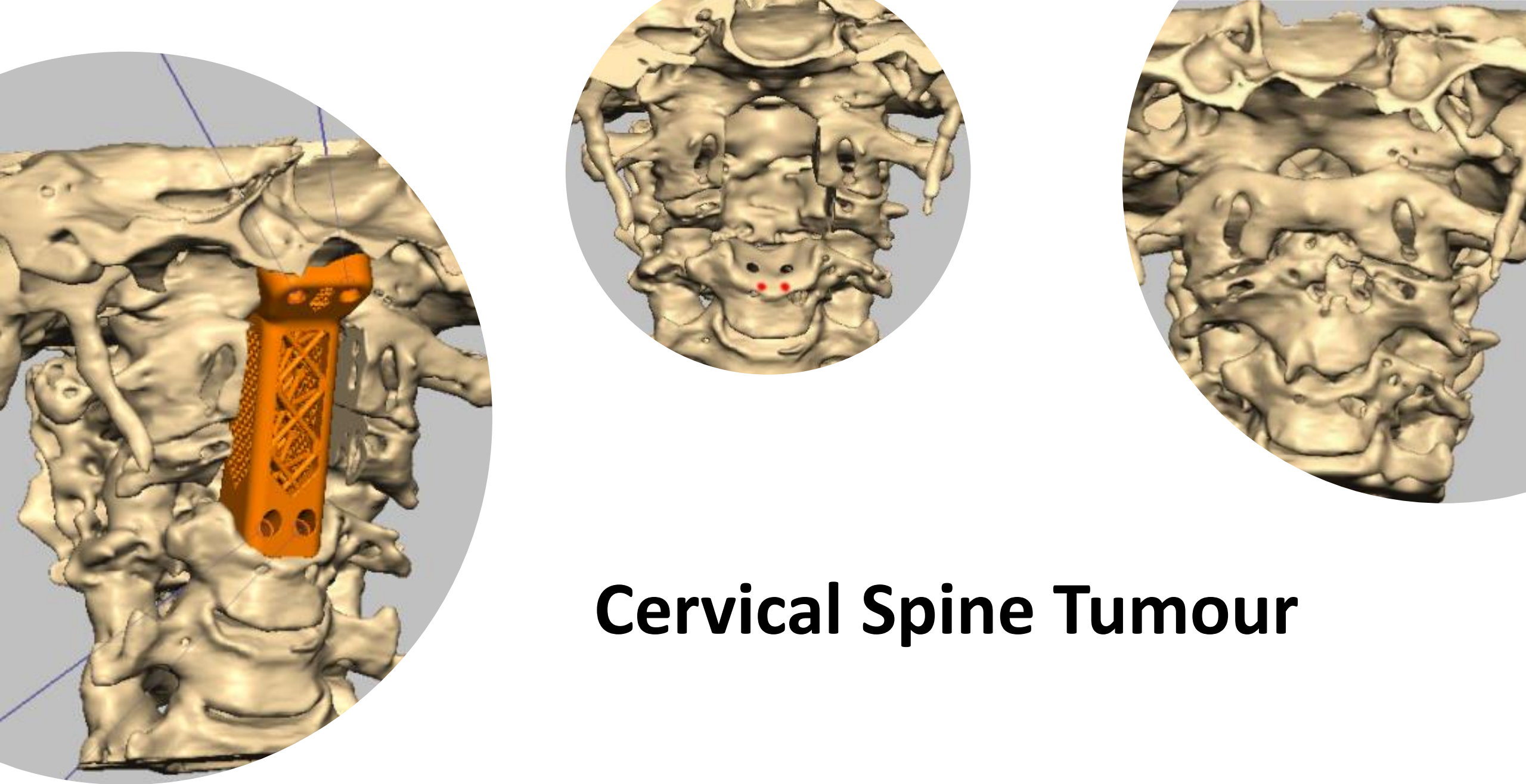


Contact Lenses with
inclusion of Sensors & Actives



Bio-Material Ocular
Solutions

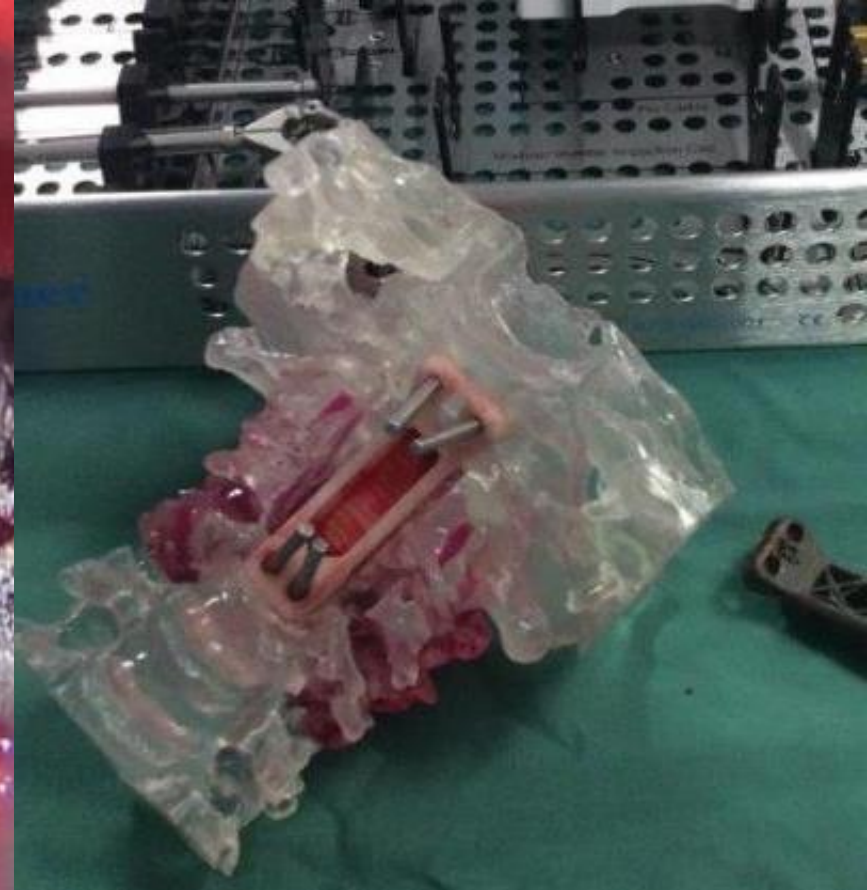
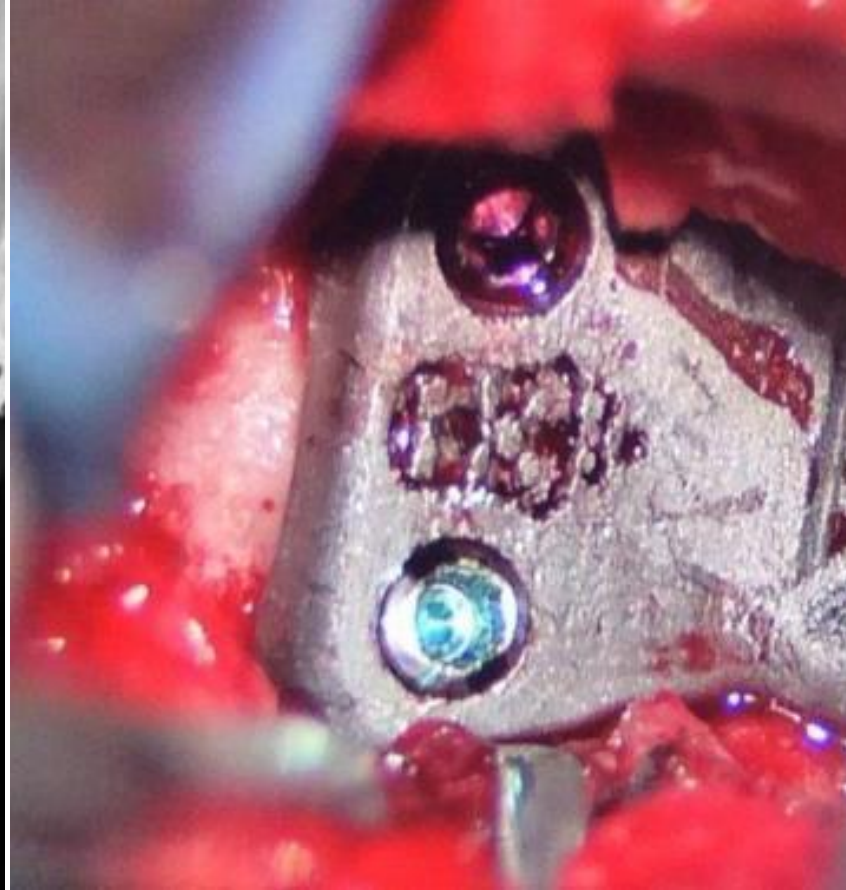
2030



Cervical Spine Tumour



Cervical spine implant and drill guide



Intra-operative view & Post-op imaging

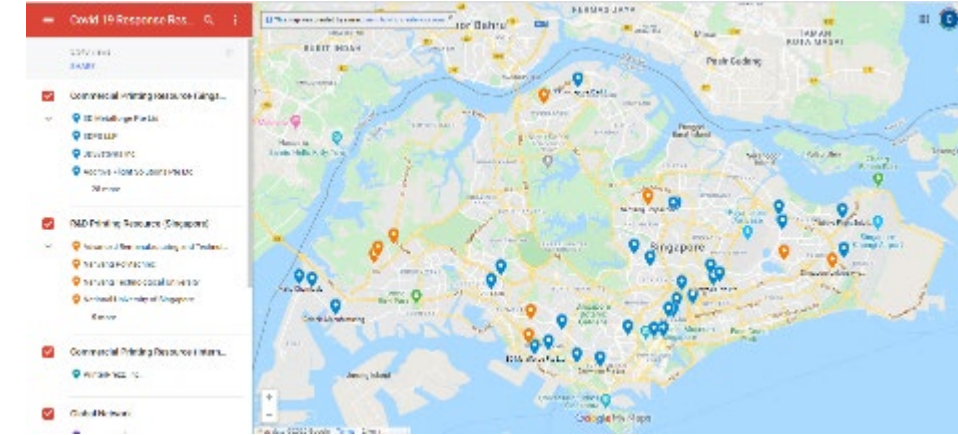
Agenda :

- **Introduction**
- **RIE2025 Priorities – Why 3D Printing?**
- **Impact of Black Swan Events : COVID-19**
- **Stretching the Boundaries with 3D Printing : Point of Care Model**
- **AM Development in Singapore**
- **Conclusions**

AM Development : Singapore's Biomedical sector

Status Summary

- HSA has released Singapore's [regulatory guidelines](#) on 3D Printed Medical Devices, in consultation with NAMIC and its stakeholders.
- An APEC effort led by [ASTM](#) (NAMIC is a partner) to develop joint standards on convergent regulations to address the last mile of Additive Manufacturing Use for PPE – Assisting Regulators, has commenced.



Guidance documents for medical devices

Here is the list of guidance documents with relevant forms and templates to help you meet the regulatory requirements for dealing in medical devices.

- Regulatory Guideline For 3D-Printed Medical Devices 601 KB
- FAQ (3DP Medical Devices) 2021 804 KB

3D Printed Medical Device
Regulatory Guidelines



ASTM CENTER OF EXCELLENCE

COVID-19 ABOUT R&D TRAINING CONSORTIA & COLLABORATION

- ASTM Response to COVID-19
- AM Guide for Part Designers
- AM for Supply Management During Disruptions
- Additive Manufacturing Community Response

Standard Guidelines for part
designers, supply chain and
community response



NAMIC

SG UNITED IN THE FIGHT AGAINST COVID-19
JOIN US IN THIS TIME OF CRISIS

TUV SUD **TUV SUD**

For Face Shields **Download Checklist**

For NP Swab **Download Checklist**

Checklists for 3D Printing
Manufacturers



CHEMTRON **ZELTA3D**

SIEGE **SIEMENS**

DesignTech **TEEHEE**

Structo **EYE2EYE**

FOREFRONT **formlabs**

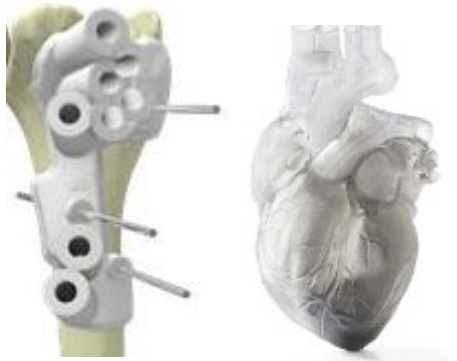
printerprezz **meiban**

Enabling enterprises

NAMIC AM Initiatives : Healthcare

Enabling personalized solutions to improve patient outcomes at a lower cost

64 projects supported to develop clinically tested and certified 3D printed medical device solutions



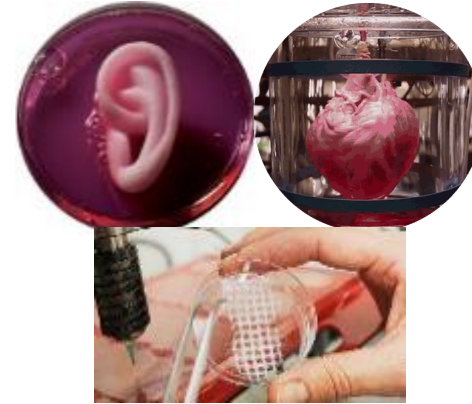
3D Printed Surgical Guides and Models



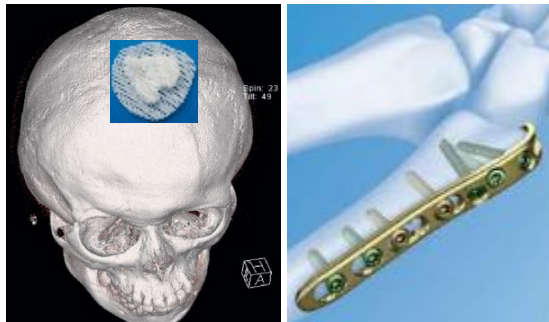
Personalized supplements

3D printed tablets

3D Printed Drugs



Bioprinting for Tissue Repair



Restorative Repair & Regenerative Implants

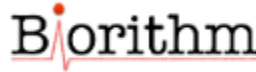


Oral Health and Craniofacial Applications



AM Enabled Design and Prosthetics

Collaborators



NAMIC AM Initiatives for Healthcare

Targeting 3D printed medical solutions for patient-specific solutions and enhanced clinical outcomes

Developed
for 3DP



Successfully
designed and 3D
Printed



Animal
Tests

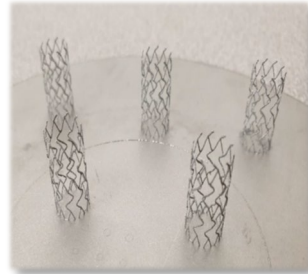


Patients

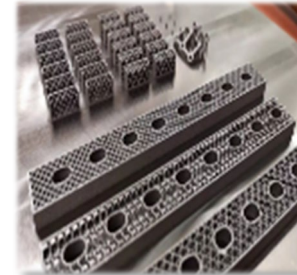
Titanium Rod and
Pedicle Screws for
Spinal Implant



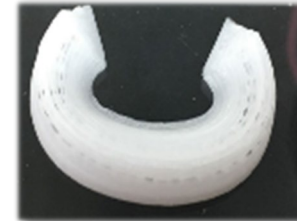
Nitinol
Stent



Orthopaedic
Implants
Bone Plates



Bioprinted
Tissue Implant
Knee cap
Meniscus



PEEK composite for
Spinal Implants



Implants for
Mandible Defects



Dental
Metal Implant
One Piece Dental
Implant



Customized
Prosthesis



Bioresorbable
implants



Ocular
Prosthesis



Start-up : Structo

Singapore-based Dental 3D printing solutions provider

- Start-up by NUS Student
- Patented Mask Stereolithography (MSLA)
- Velox : Integrated autonomous post-processing
- Fastest production system for this segment
- 30 dental moulds in 2.5hrs (compared to 8)
- NRF RIE 3D printing Dental Start-up Feature
- Recognized as "Leading Suppliers of Dental 3D Printers" by GHP as part of Global Excellence 2018 awards.



Structo



GHP Global Excellence 2018
The Leading Suppliers of Dental
3D Printers 2018

Structo 3D
WINNER



spotlight on startup

...DENTAL REVOLUTION



Structo's Chief Technology Officer Boyle Sorensen and Co-founder Hui van Eiden with NRF Chairman GPM Tan Chai Hon during a visit to Structo's premises. Photo: Ministry of Communications and Information

This is something that Hui described as a true testament of the team's hard work, and validation that Structo is delivering products that meet the industry's needs. In 2017, besides increasing its revenue, the startup also more than doubled its staff strength to 40. It now has its premises situated in five continents around the world.

Structo has obtained investments from SPRING Singapore's investment arm Spring Seeds Capital and early stage venture capital firm Waveventures Partners.

Despite their success, the team views Structo as a constant work-in-progress, and have found ownership to be an incredibly important aspect of their entrepreneurship journey.

"For us, this has been really helpful in avoiding preventable mistakes along the way that we would definitely have made without the guidance from more senior and experienced officers," Hui said.

Hui also recalled that in the beginning, it was through an innovation grant from the university that allowed them, as students, to explore the technology and develop a prototype that demonstrated some business viability. He said that the grant was a stepping stone for them to be able to raise more funding from investors to continue building the company.

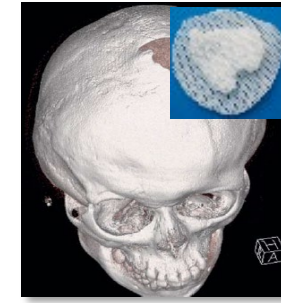
What's next for Structo? Hui shared that the team hopes to continue helping dental professionals be more efficient with the dental appliance manufacturing process, as this leads to lower production costs, thus making dental treatment more accessible to a wider demographic.

He said: "The best part about 3D printing and the dental industry is that it is only getting started. There is still so much room for innovative and novel ideas. With the help of our stakeholders, we will continue to innovate and hopefully deliver more products that will be able to solve more problems."

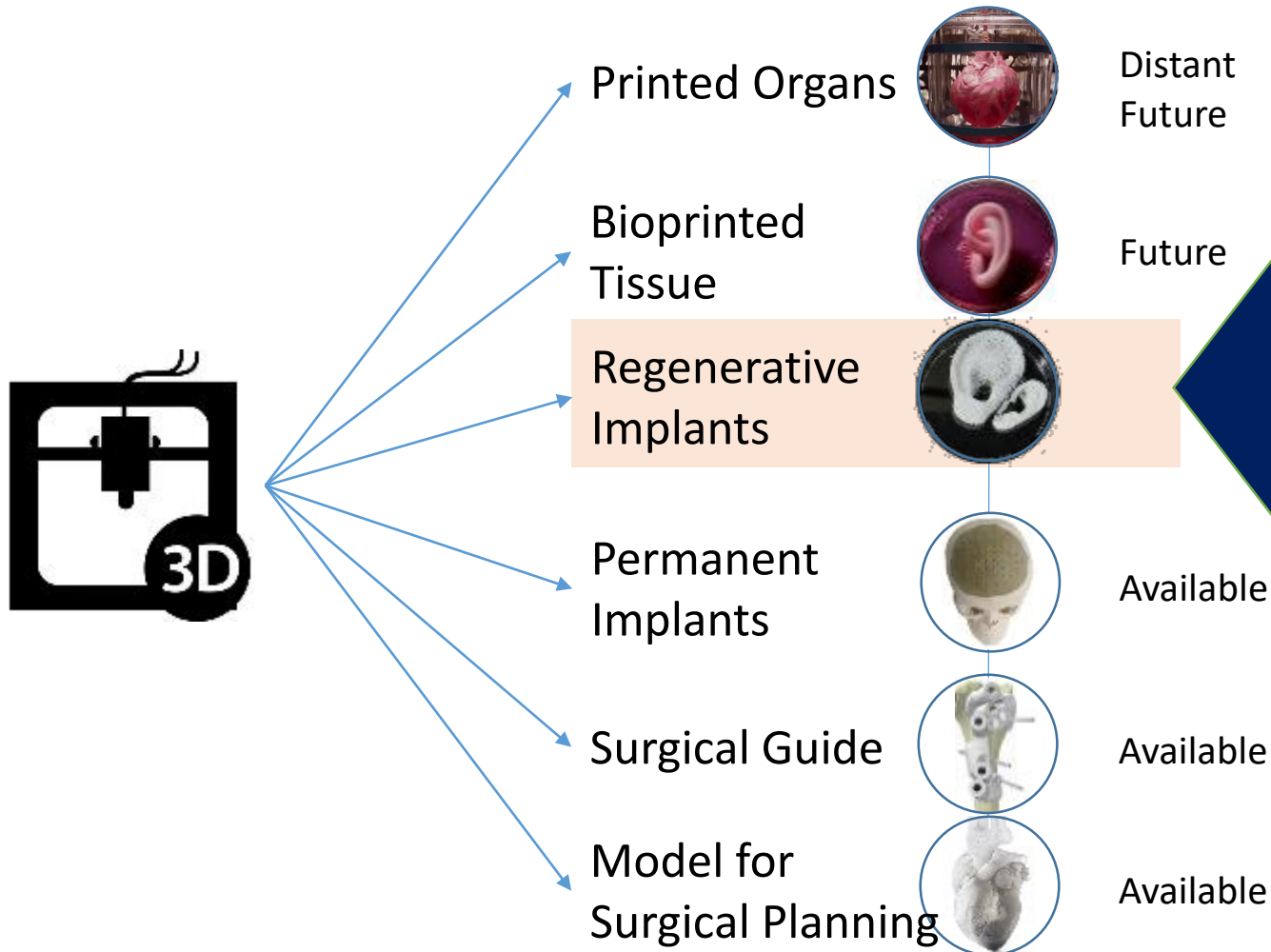


Osteopore Technological Position

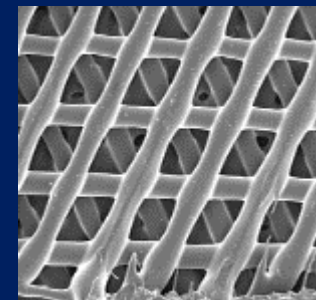
Pushing the Boundary of 3D printing technology



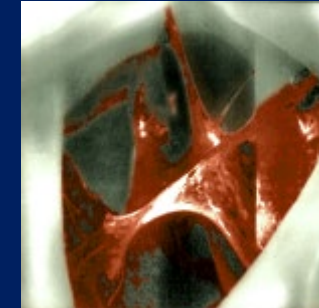
**Cranio-facial
Implants**



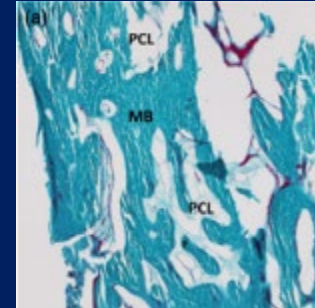
Osteopore pushes the technological boundary of 3D printing to develop & commercialise biomimetic microstructure that facilitates natural tissue regeneration



**Biomimetic
Microstructure**



**Stem Cells
Propagation**



**Tissue
Regeneration**

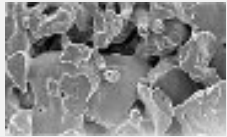
Regenerative Implants

[video](#)

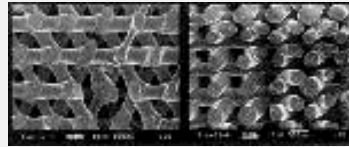
Permanent Implant Landscape

Biomimetic bioresorbable space

Biomimetic
microstructure



- MedPor (Stryker)

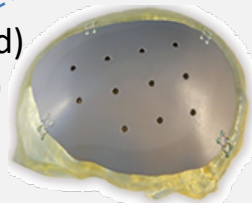


Osteopore™
Biomimetic microstructure
& Bioresorbable

Improving Tissue Regeneration

Solid
Structure

- Anatomics
- AccuShape (MedCad)
- TiMesh (Medtronic)
- KLS Martin
- Depuy Synthes



- Rapidsorb (Synthes)
- Lactosorb (Biomet)
- Macropore (Medtronic)
- Osteotrans (Takiron)
- Inion CPS

Permanent
Implant

Bioresorbable

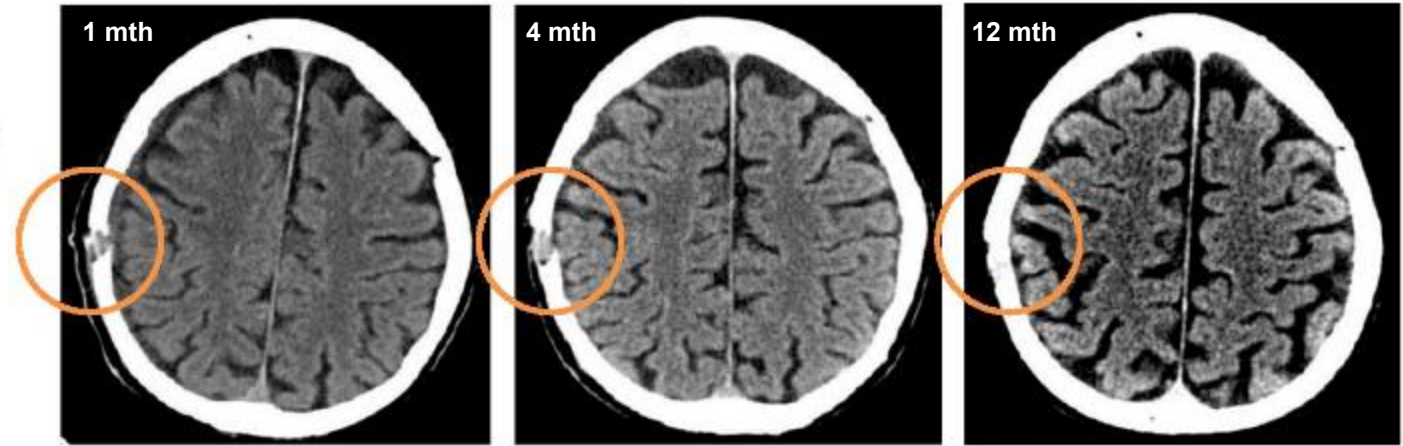
Competitive Advantage

- Ability to integrate with surrounding bone and/or tissue
- Bioresorbability with no documented long term regenerative problems
- 3D printed to specific patients needs when required to achieve clinical advantage

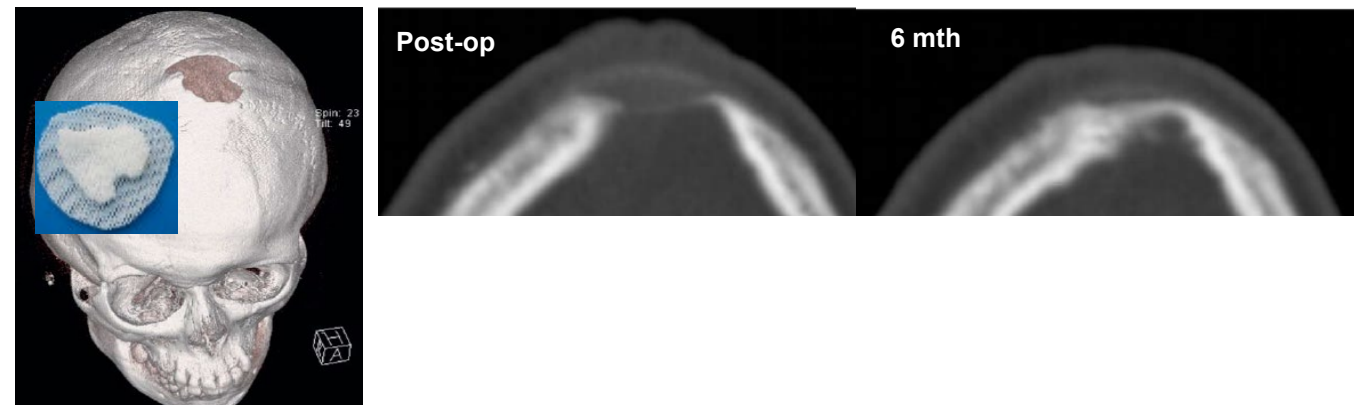
Material Resorption in Tandem with Tissue Regeneration

- Biomimetic devices facilitate the body's natural healing process. Once the healing is complete, no foreign materials should remain in the body to **minimise or eliminate late complications** such as infection, extrusion, dehiscence or fracture.
- Through a combination of 3-D printing and bioresorbable material, Osteopore International manufactures devices that biomimic the cancellous bone microarchitecture that facilitates the natural stages of bone healing.

Post-Operative CT: Burr Hole Reconstruction



Post-Operative CT: Cranioplasty



Project Title:

A novel technique using patient-specific PCL-TCP scaffold with AD-MSC stem cells for alveolar ridge augmentation

Industry Sector

Healthcare

Collaborators

OsteoporeTM
Empowering Natural Tissue Regeneration



Objective

- Development of 3D-printed bioresorbable polycaprolactone-tricalcium phosphate (PCL-TCP) scaffold for alveolar ridge augmentation with Adipose-Derived Mesenchymal Stem Cells (AD-MSCs) to **enhance bone regenerative capability** of the construct

Innovation Applied

- Novel 3D-printed 3-angle layering (0°/60°/120°) PCL-TCP scaffold design and combination of AD-MSCs

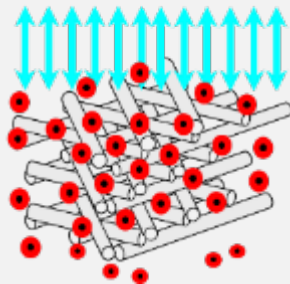
Images & Implementation Approach

Our proposition

3D-printed bioresorbable polycaprolactone-tricalcium phosphate (PCL-TCP) scaffold



Concentrated Autogenous Adipose-Derived Mesenchymal Stem Cells (AD-MSCs)



Development approach of novel 3D-printed PCL-TCP scaffold with AD-MSCs

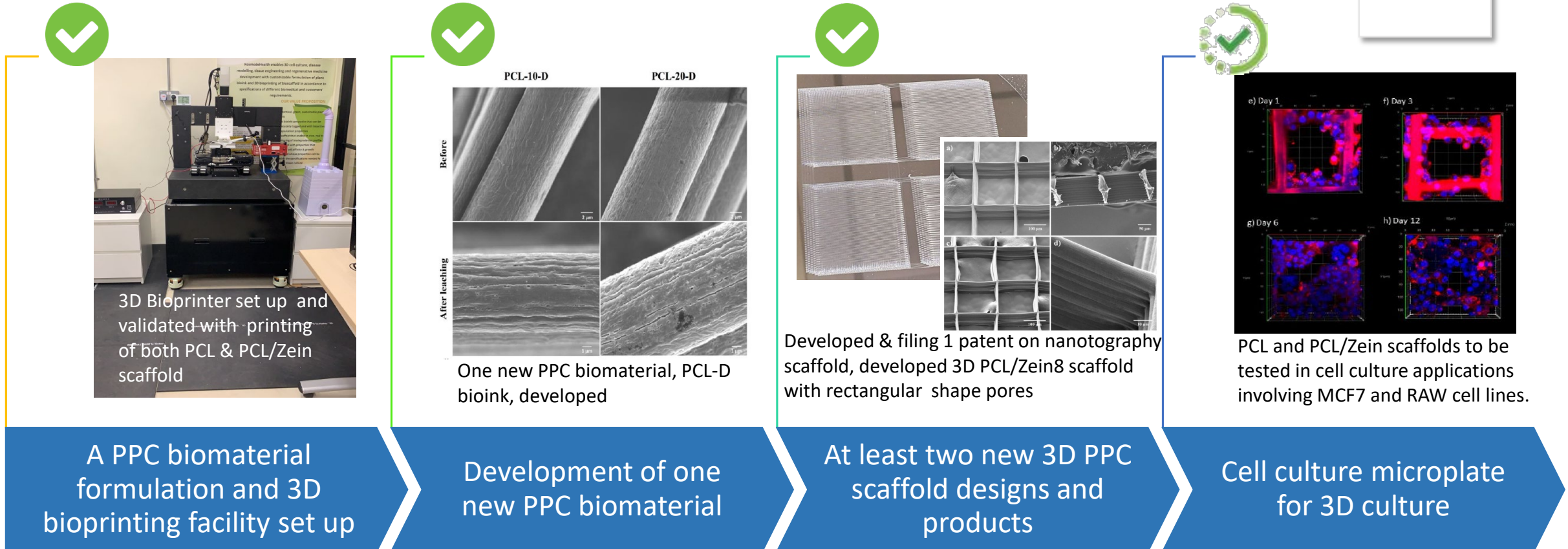
Key Benefits / Outcomes

- Enable Point-of-care, patient-specific customization according to defect size
- Replace traditional bone substitutes have been unpredictable and limited to smaller sized defects
- Eliminate the need to go through another surgery to harvest autogenous bone
- Combination of PCL-TCP **Provide a simplified and less invasive process that saves time and costs**
- The project has led to an **IAF-ICP funded initiative**

POV : NUS | Kosmode Health

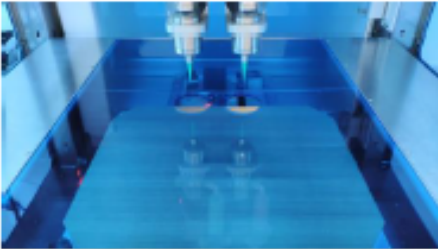
With the successful development of **plant-based bio-inks**, Kosmode Health went on to **develop its 3D bio-printing platform capabilities**. It has since set up a platform to **develop and commercialize the plant protein composite (PPC) scaffold** for cell culture applications.

Milestones & Achievements

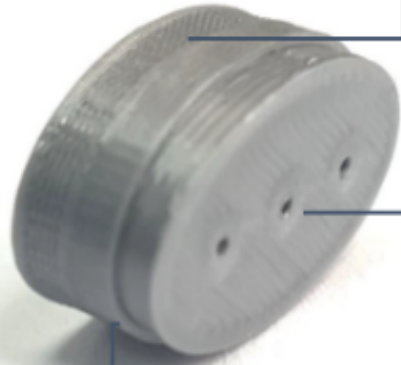


About Craft Health

**Craft
Health**



- Privately held company
- Research & Developmental stage
- Founded in 2019
- Headquartered in Singapore
- 8+ employees
- Patent protected technologies in 3D printing of nutraceuticals and pharmaceuticals



3D printed hollow cap

- Confers buoyancy to 3D printed pill, floating the pill at the top of the stomach regardless of the position/posture of user.

3D printed body

- Houses the active ingredient.
- Controls the rate of active ingredient release and provide a zero-order release kinetics through pre-specified openings.
- 3D printed SLR body is smaller than the opening of the stomach, reducing risk of blockage.

Material Composition of SLR Capsule

- Using Food and Drug Administration (FDA) approved materials that are safe, and will be digested in the stomach after a specified period of time

Day 1

- SLR capsule is consumed, floats at the top of gastric juices due to floatation chamber.
- API is released slowly.



Day 2-7

- API continues to be released following zero order kinetics
- SLR capsule is slowly eroded.



Day 8

- API is completely released
- SLR capsule is eroded to the extent it no longer floats.
- Capsule sinks and is removed by the body.



Agenda :

- **Introduction**
- **RIE2025 Priorities – Why 3D Printing?**
- **Impact of Black Swan Events : COVID-19**
- **Stretching the Boundaries with 3D Printing : Point of Care Model**
- **AM Development in Singapore**
- **Conclusions**

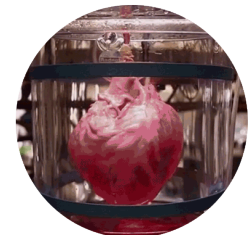
Summary

3D Printing has the potential to provide enhanced patient care, greater accessibility to underserved patient populations and reduced healthcare costs through new business models.

Global Regulators are dedicating resources and working collaboratively with industry and technical experts to create guidance and policy for 3D printed devices.

NAMIC is actively engaging with all the university-hospital cluster groups in Singapore to understand, apply and collaborate on:

- Point of Care Model Deployment
- Growing clinical applications
- Developing Patient-specific Products
- Research in Emerging space i.e. Bioprinting



A photograph of a road blocked by a large rockslide. A yellow bulldozer is positioned on the road further back, facing the rock. The scene is set in a mountainous area with steep cliffs and some greenery. The sky is overcast.

*“If you can find a path with no obstacles,
It probably doesn’t lead anywhere”*

Frank A. Clark



Enabling the Next Frontier



NTU Innovation Centre
71 Nanyang Drive, 04-01
Singapore 638075