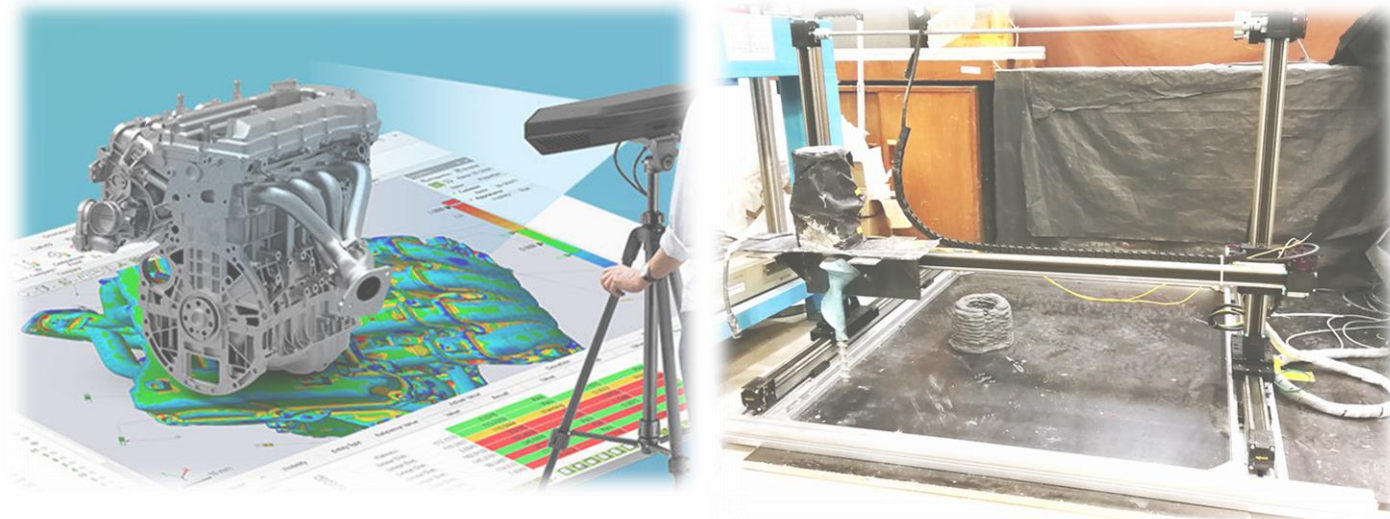


Geopolymer Cement-based 3D Printing Concrete Technology

基於地聚物水泥的3D混凝土

Annual Concrete Seminar 2019

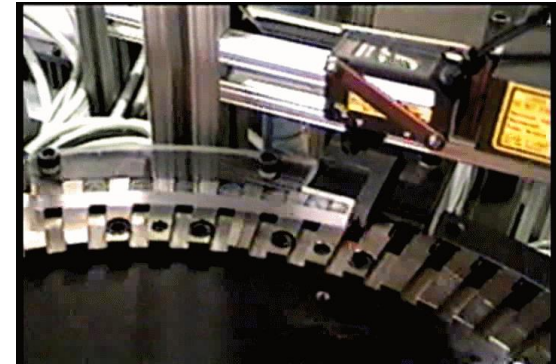
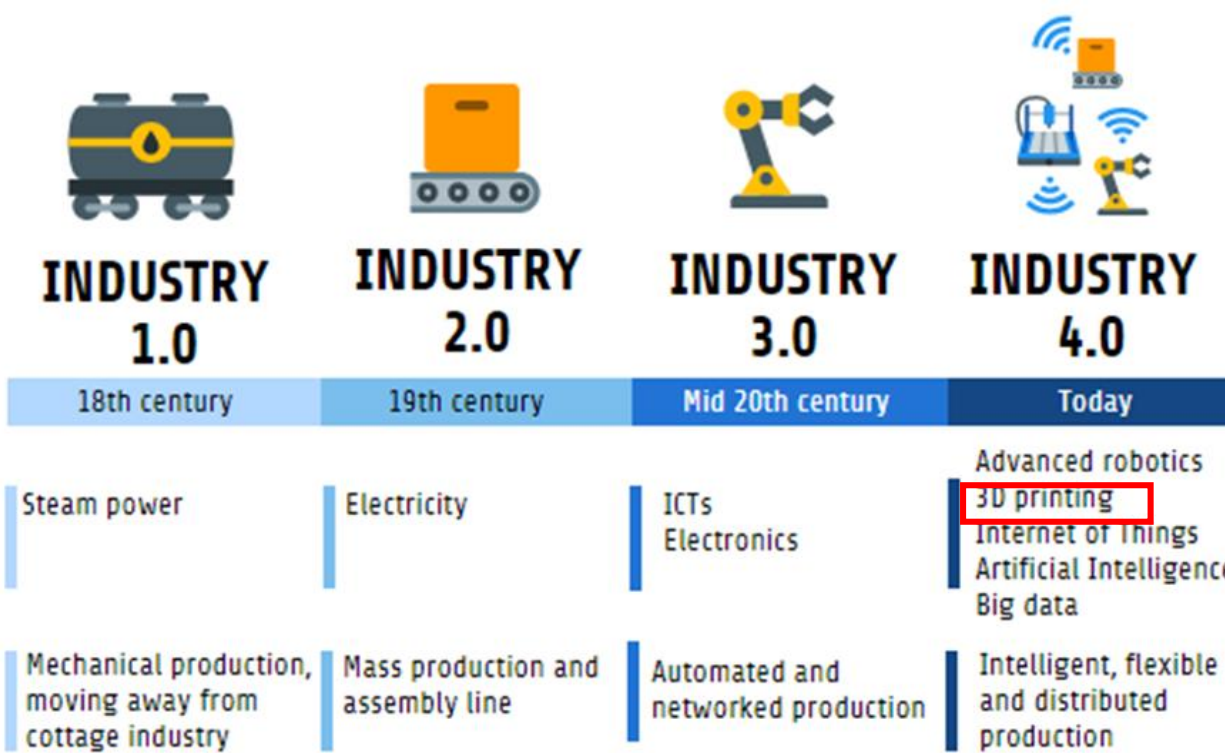


Prof. Jian-Guo DAI
(戴建國 教授)
(FIIFC, FHKIE, FHKCI)

Department of Civil and Environmental Engineering
The Hong Kong Polytechnic University

Hong Kong, 2 April 2019

1. Construction Industry 4.0
2. 3D Concrete Printing Technology
3. Geopolymer Cement-based 3D Printing
4. Conclusion

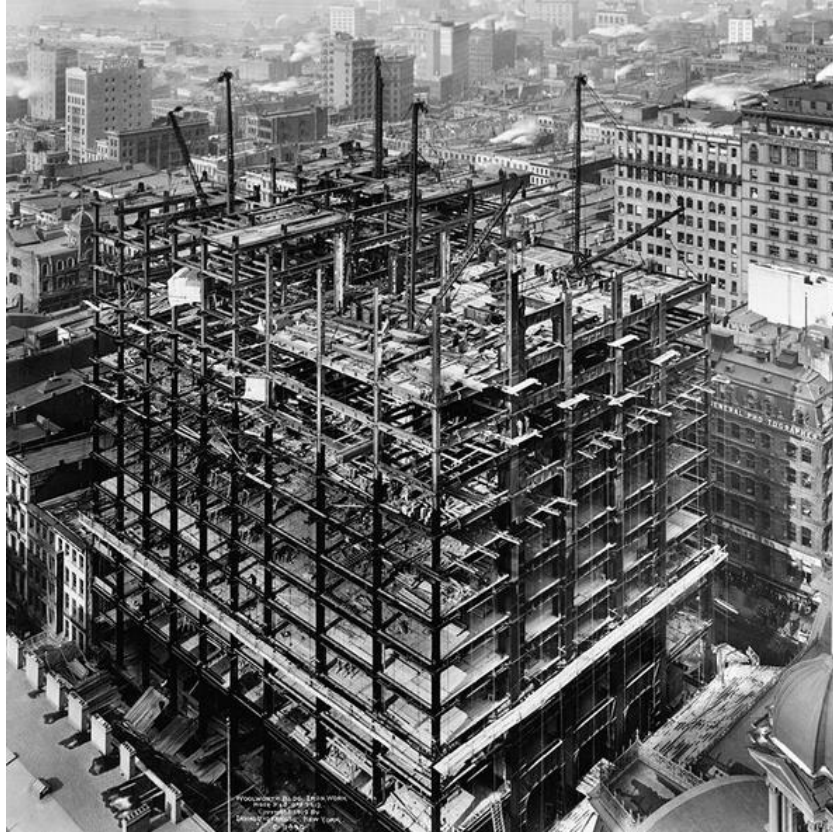




Prefabricated Construction



Modular Integrated Construction

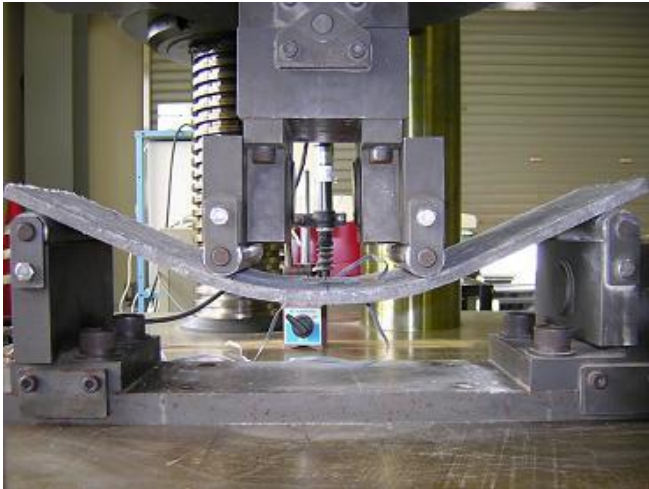


Woolworth Building, 1912

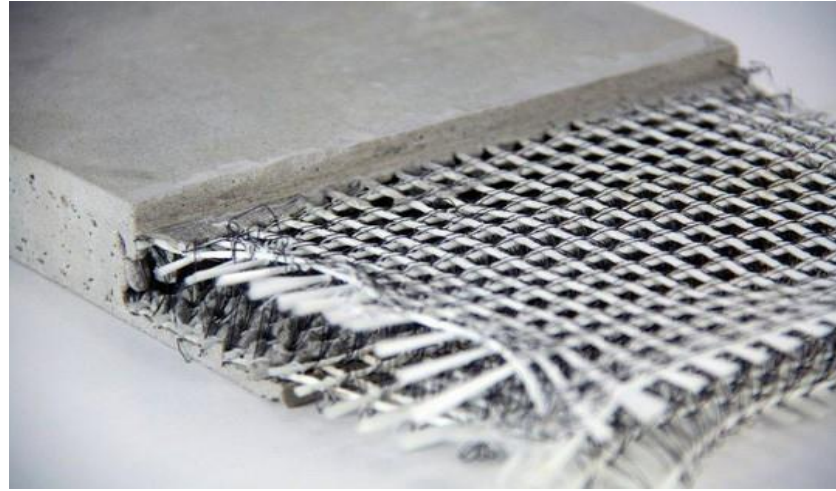


Hollow core slabs

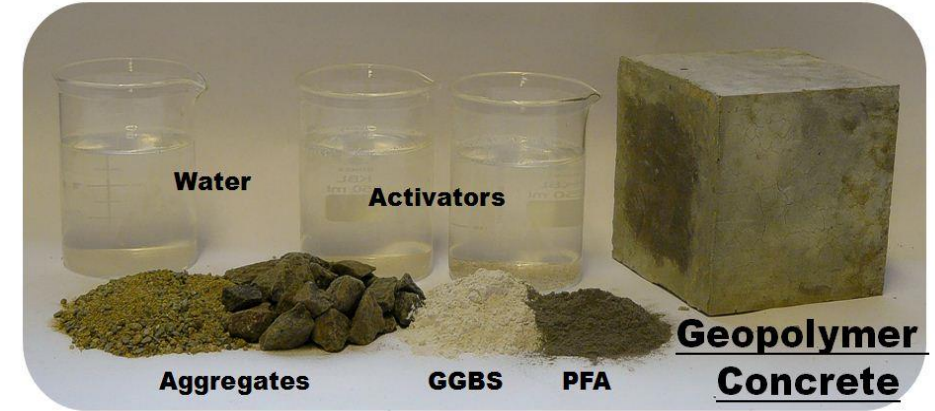
https://upload.wikimedia.org/wikipedia/commons/thumb/6/6a/Woolworth_Building_2_Feb._1912_LC-USZ62-105567.jpg/800px-Woolworth_Building_2_Feb._1912_LC-USZ62-105567.jpg



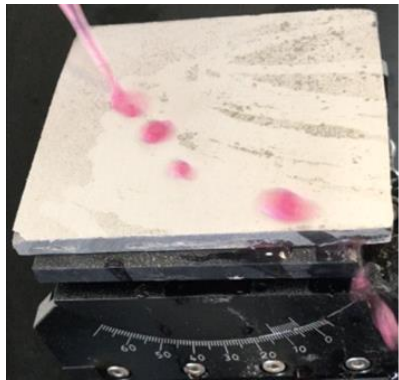
HPFRC



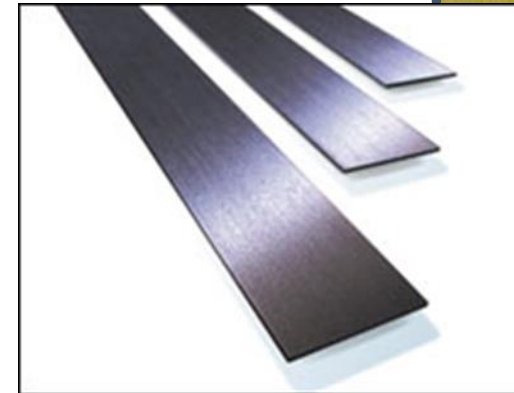
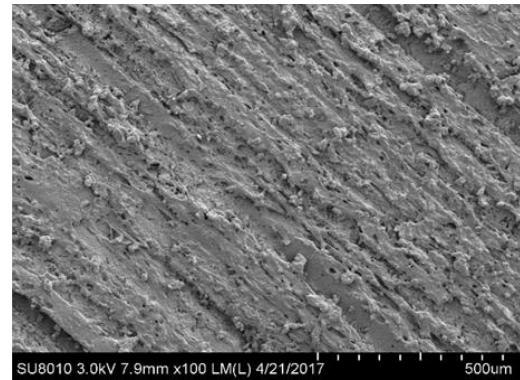
TRC



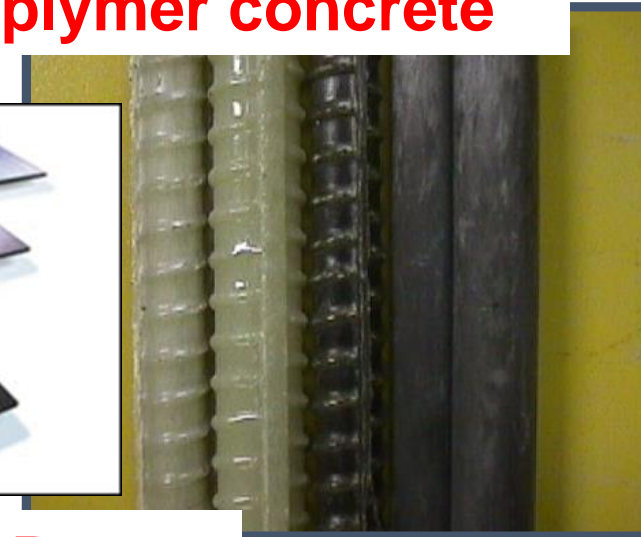
Geopolymer concrete

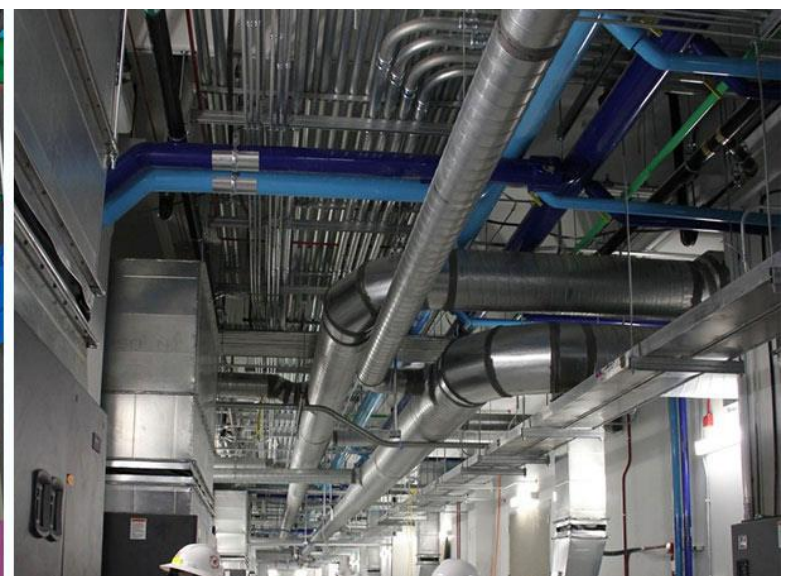
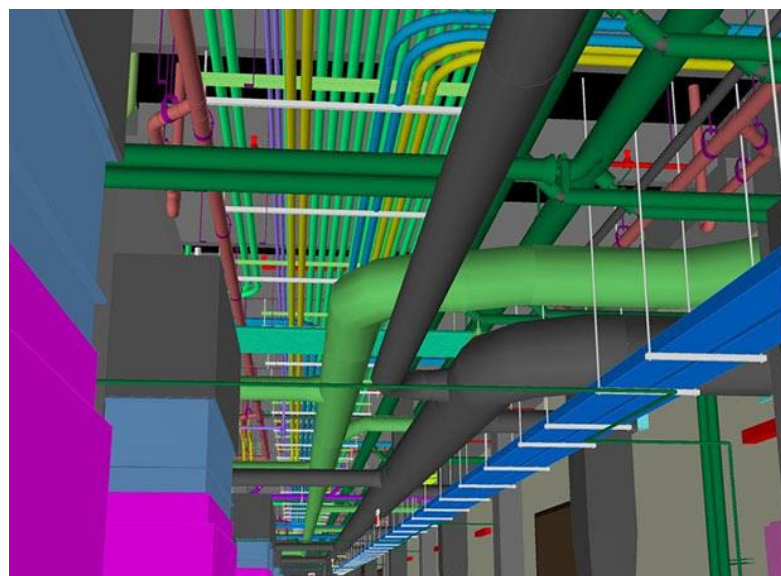
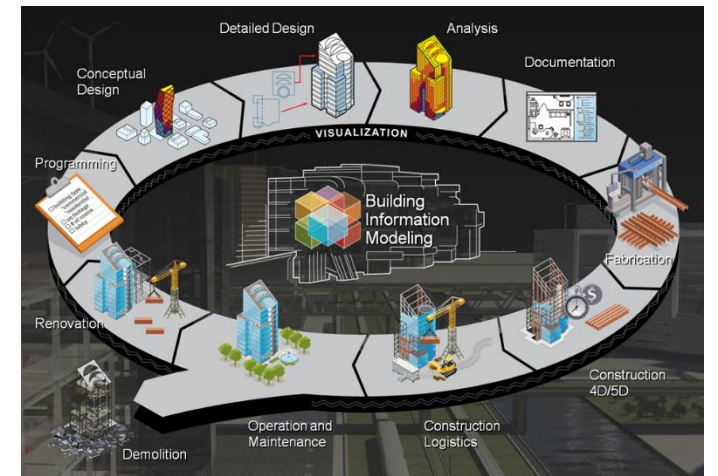
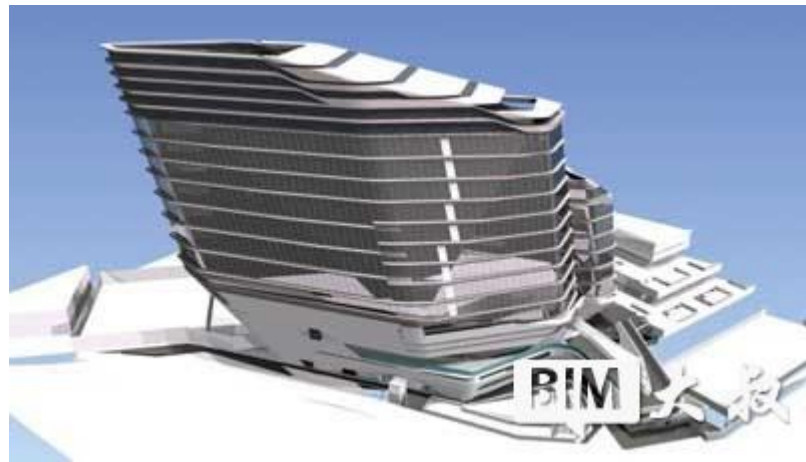


Super hydrophobic coating



FRP





Building Information Modeling (BIM)



Gable Frame Assembly



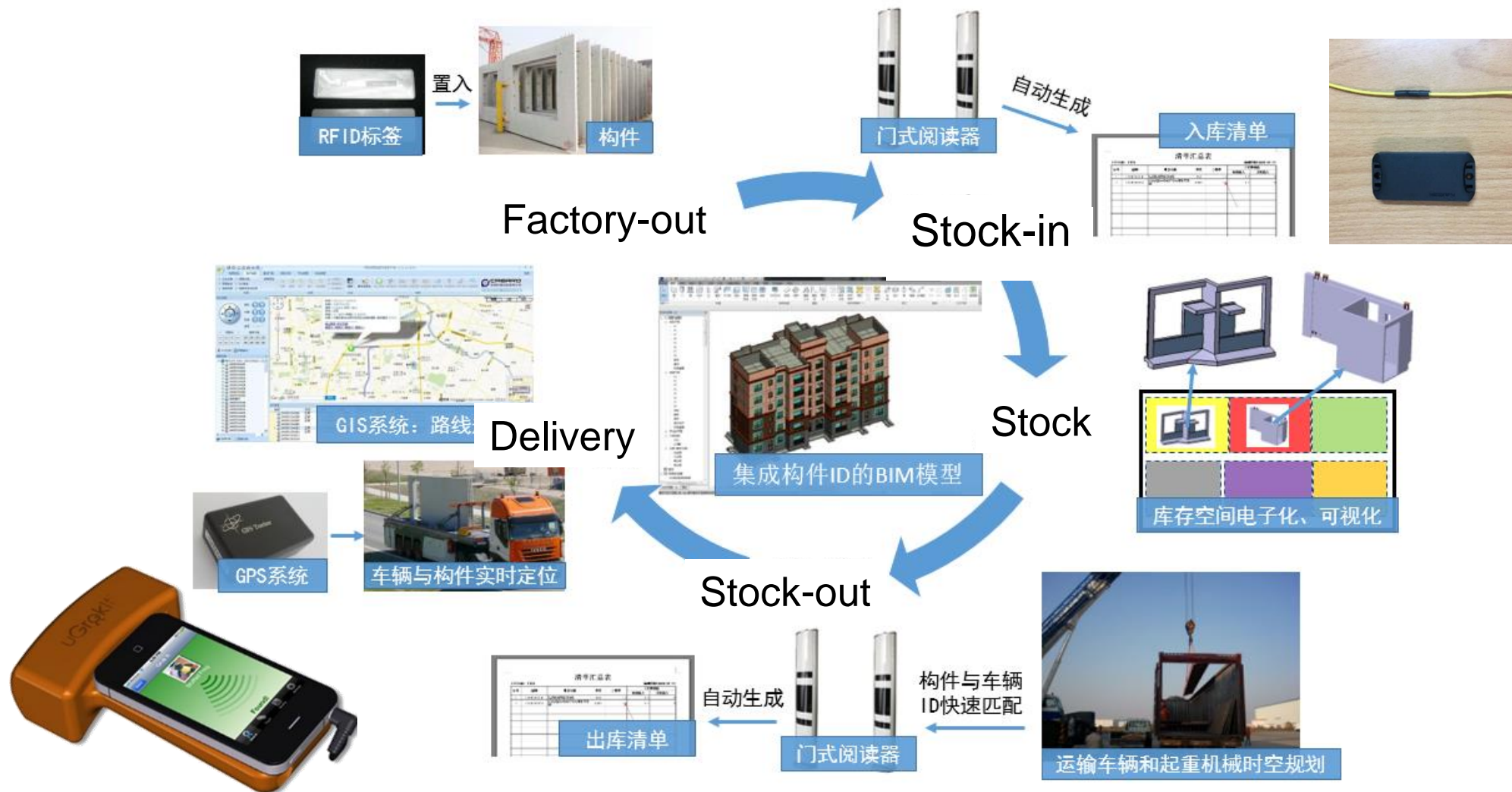
Assembly of Structures



Exterior wall Assembly



Module Finishing Line





Robotized Construction SMART Automated Construction, SHIMIZU Co. Ltd.

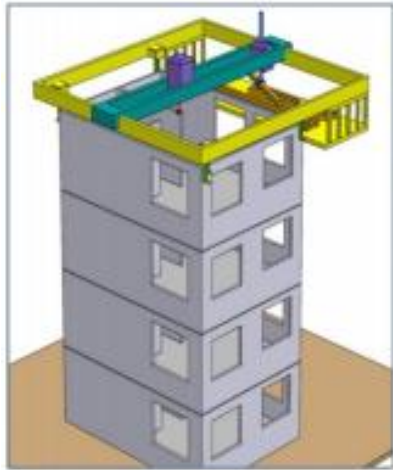


Big data and smart city



Monitoring, Pre-warning, Optimization, Emergency Treatment etc.

Industrialized building construction (IBC)

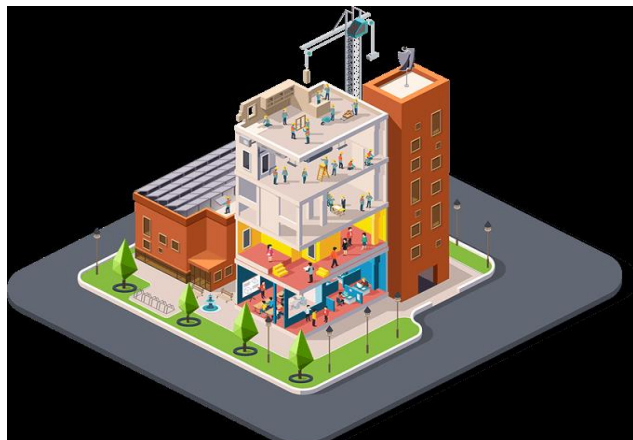


- Digitalization (数字化驱动)
- Customization
- Formwork free and zero construction waste



3D print technology

Building Information Technology (BIM)



- Prefabrication
- Mechanisation
- Automation
- Informationisation
- Customisation



<https://www.psfk.com/2014/12/concrete-3d-printer.html>



Traditional Numerical Control Manufacturing

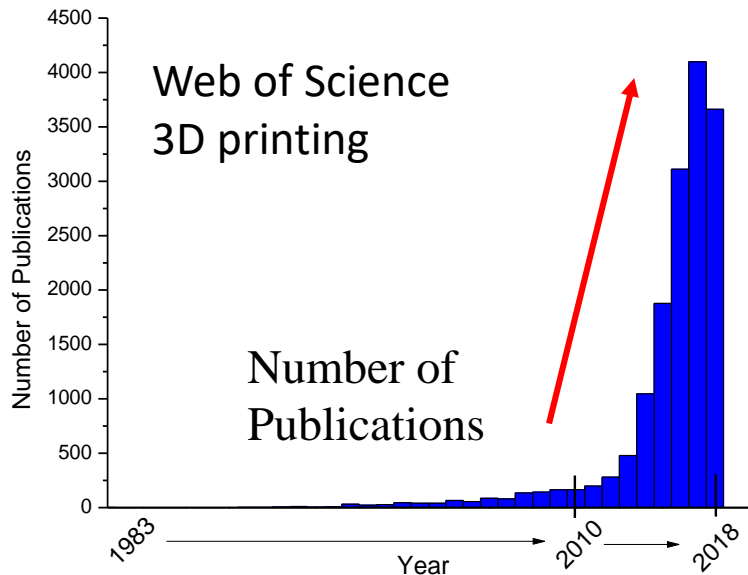
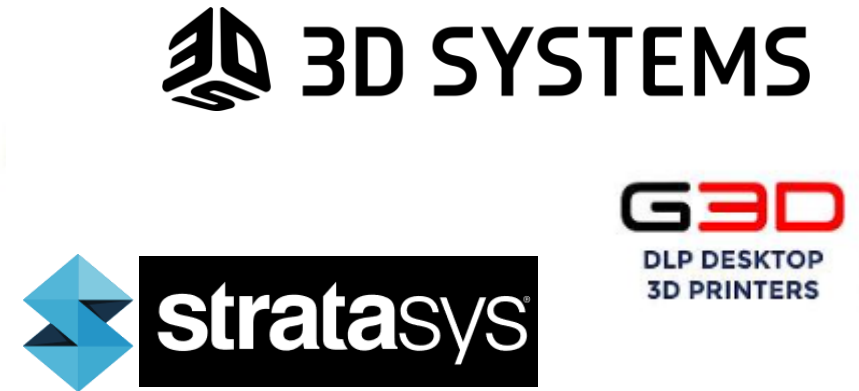
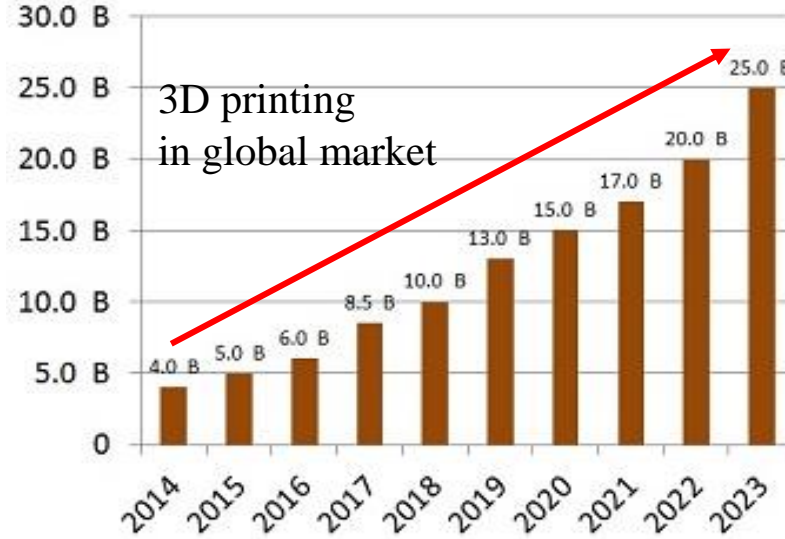
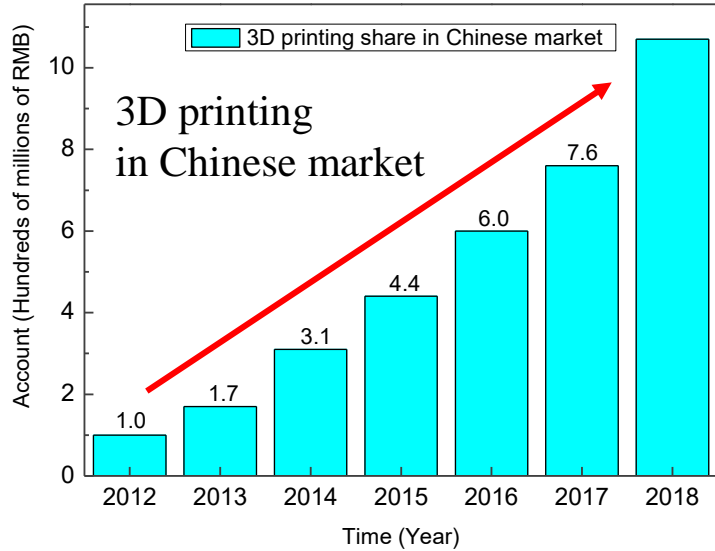
Industry 4.0 - 3D Printing in Manufacturing Industries



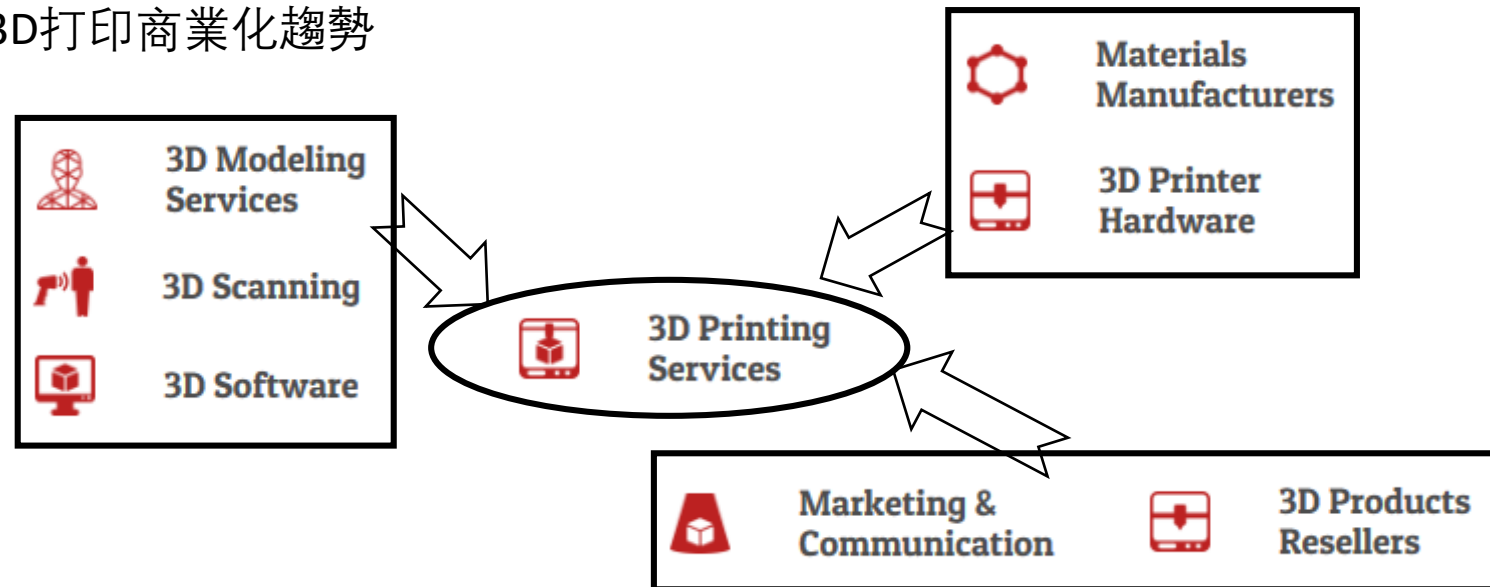
Posted on: **March 26, 2018** by **Stefan Zimmermann**

Head of Global Center of Excellence Industry 4.0

3D printing is one of the potential game changers that could completely disrupt the manufacturing value chain, allowing a shift from mass production to full customization, from centralized to distributed production. In the future 3D printing technologies will provide an alternative to “conventional” manufacturing technologies in many situations. It will deeply impact the way products are manufactured, delivered and maintained.



3D打印商業化趨勢

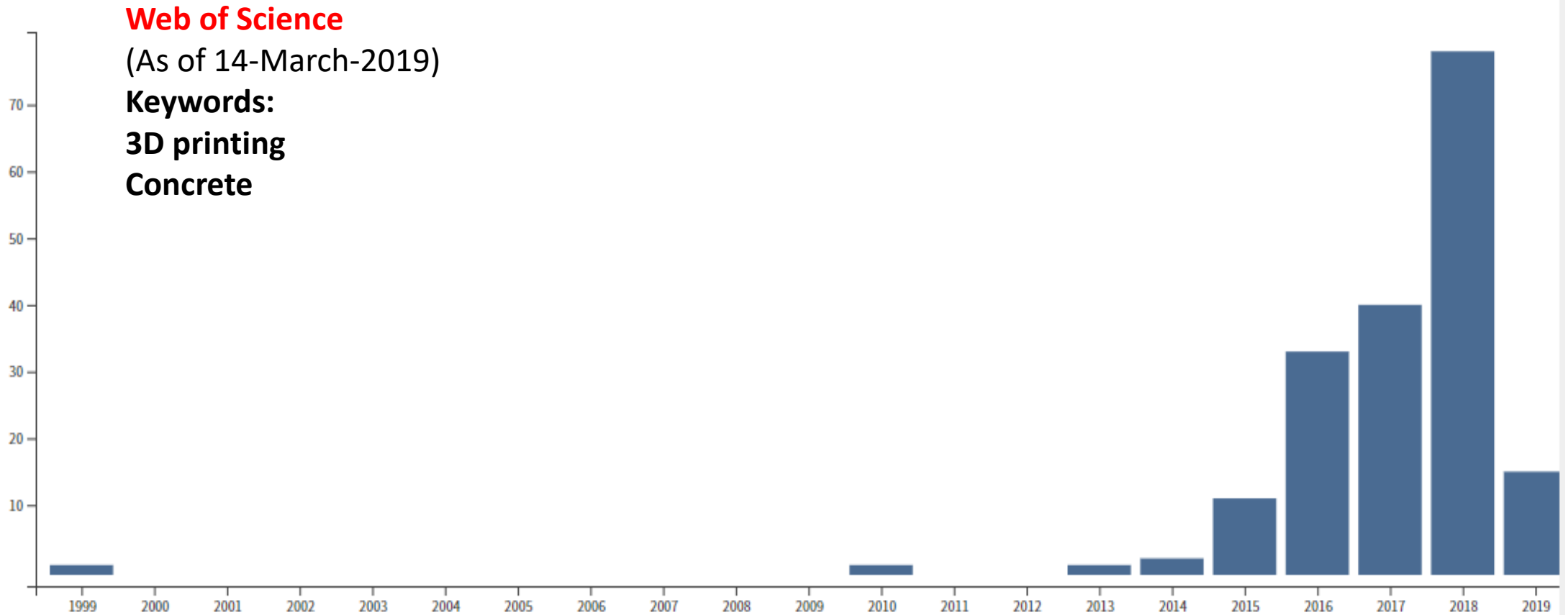


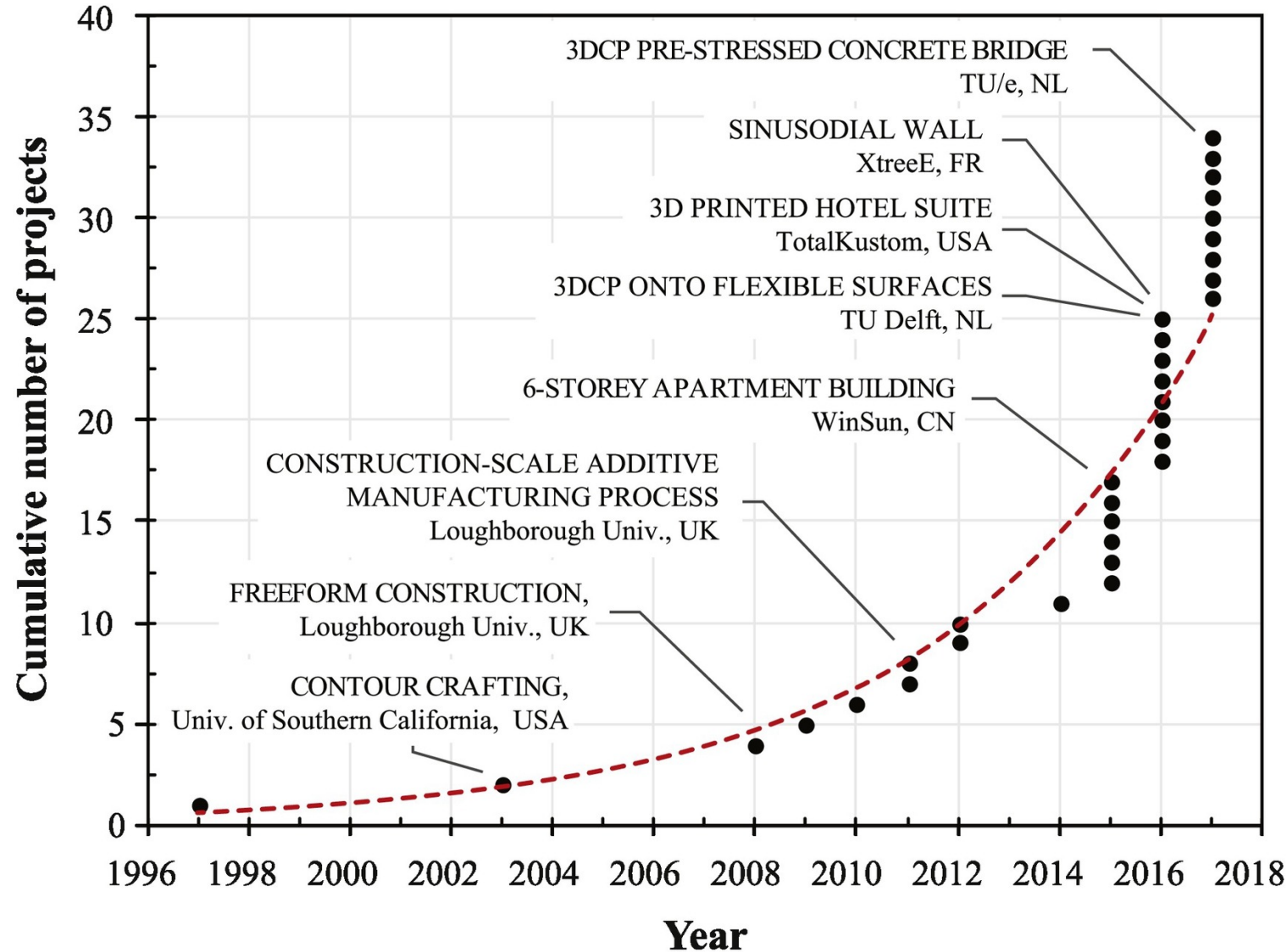
Total Publications

182 Analyze

Save to Excel File

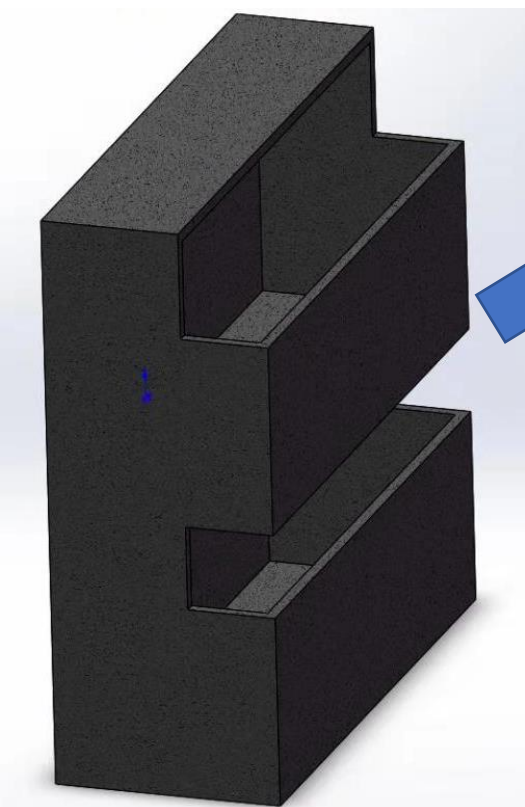
Save to Text File



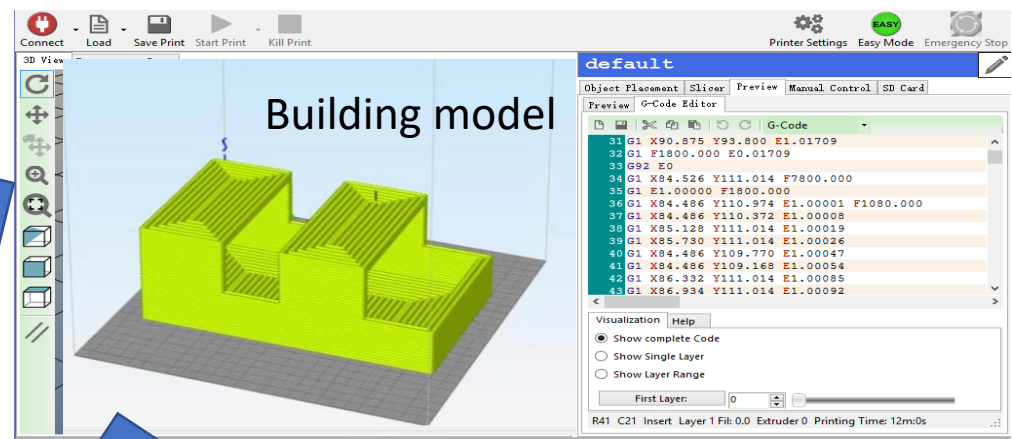


Buswell 2018, CCR

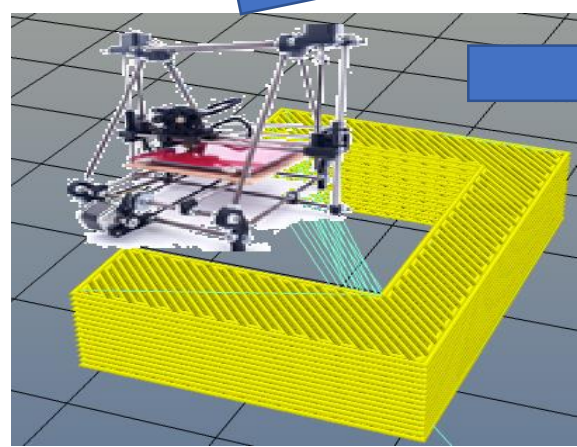
3D Printing Concrete Technology



required object



Building model



Printing Simulation



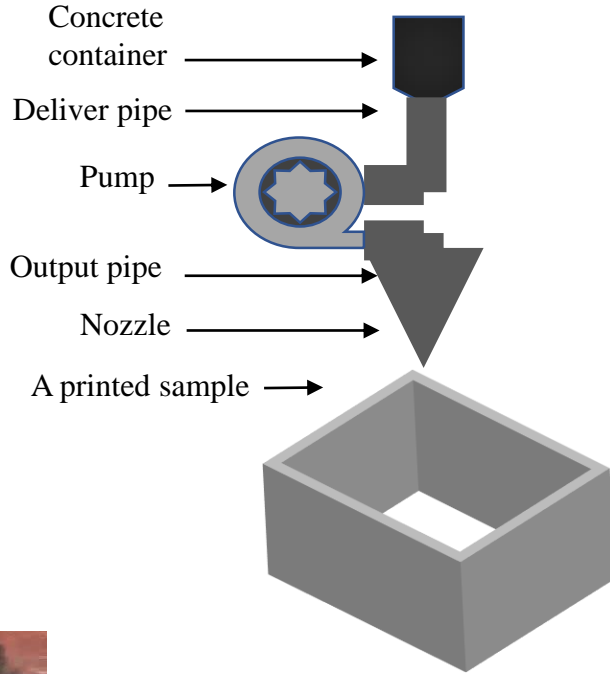
Printing



3D Concrete Printing Technology

Extrusion Printing

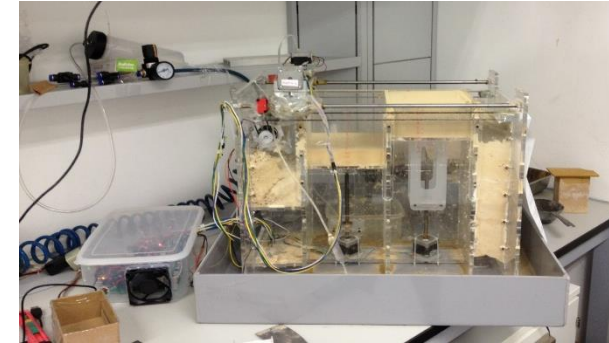
Direct Deposition



- Well-mixed slurry
- Control rheology, viscosity, setting time
- Control extruding rate, slurry continuity
- Printing time per layer

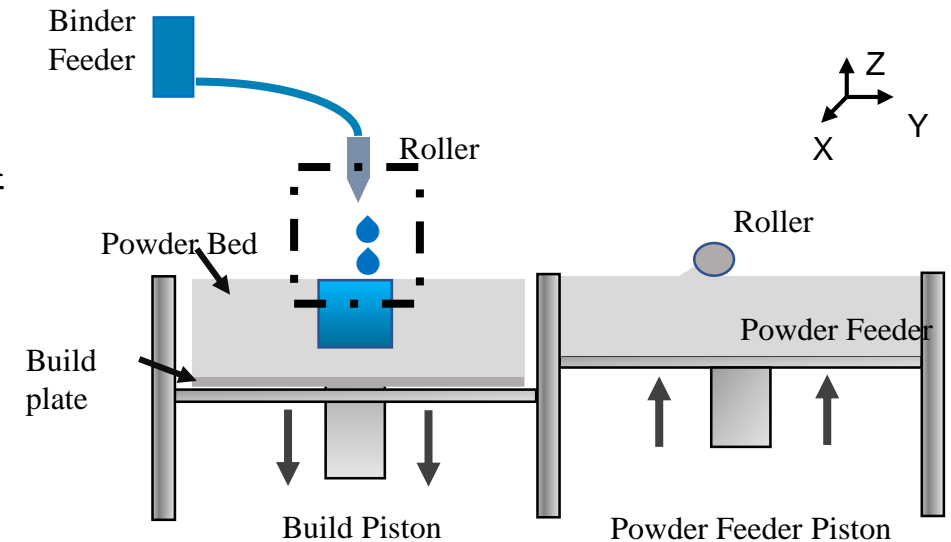


- Well-homogenized particles
- Control setting time
- Accurate Positioning

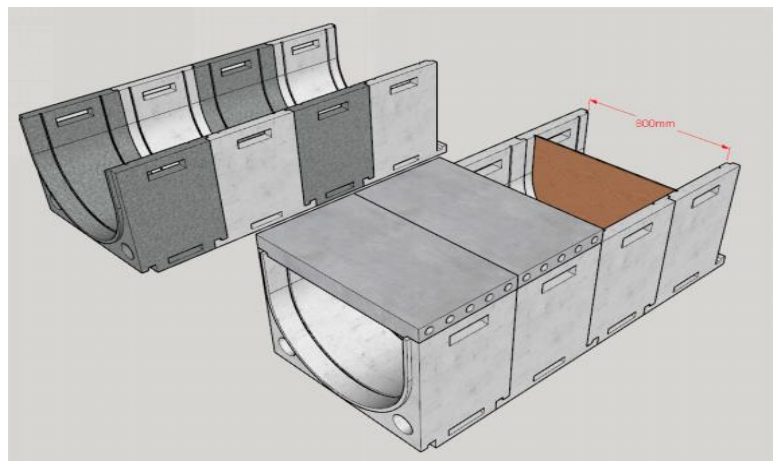
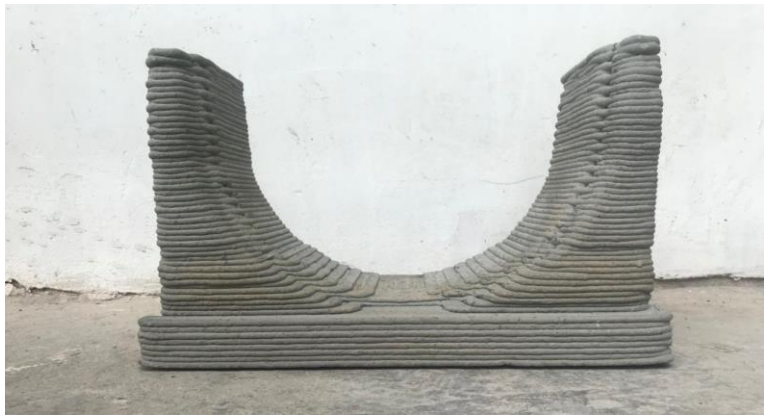


Powder-bed Printing

Selective Reaction



3D Concrete Printing Technology



Advantages

- Reduce need for labor and improve the construction safety
- Create mid-size homes in low cost;
- High Handle geometries that would be difficult for traditional construction techniques to handle. The modern building design has made features like exposed concrete walls and geometrically complex roofs more popular;
- High build speed: designing and building a home can be an expensive and time-consuming task;
- Nearly no material is wasted during the production process, making it more environmentally friendly than traditional techniques;
- No need for construction companies to make molds to actualize their structures, saving time, money and energy.

3D Concrete Printing Technology



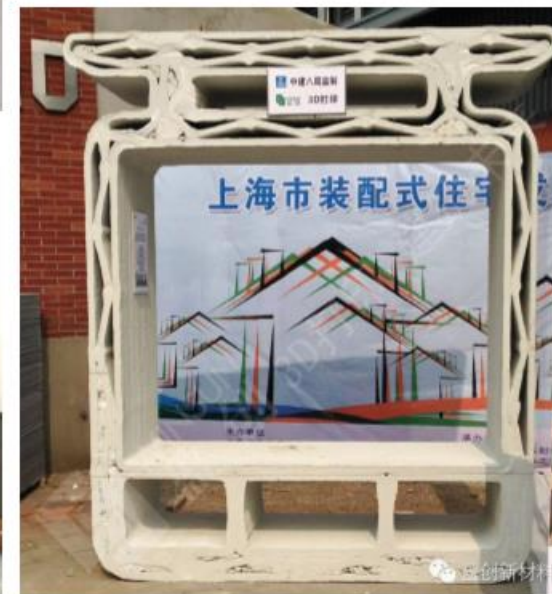
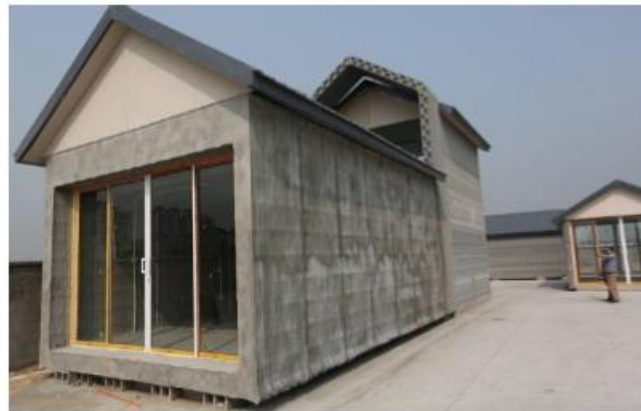
Gantry: 4 degree of freedom

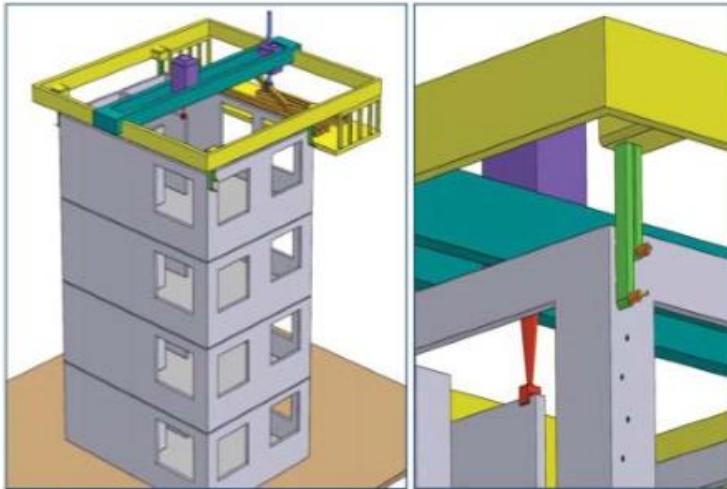


Robotic arm: 6 degree of freedom

Extrusion based 3D Printing system is composed of two parts: pumping system and printing system.

上海盈创 2016





Construction of multi-story buildings using Contour Crafting method (Zhang and Khoshnevis 2013)



A 3D printed five-story apartment block (Charron 2015)



A Decorated 3D printed house (Charron 2015)

Raw materials



This block contains four images of raw materials for alkali-based geopolymer. From left to right: a pile of grey fly ash, a pile of grey slag, a white plastic jug of NaOH solution with a label, and a yellow plastic jug of Sodium Silicate solution with a label. A large white arrow points from this group towards the right.

One-part geopolymer
Two-part geopolymer

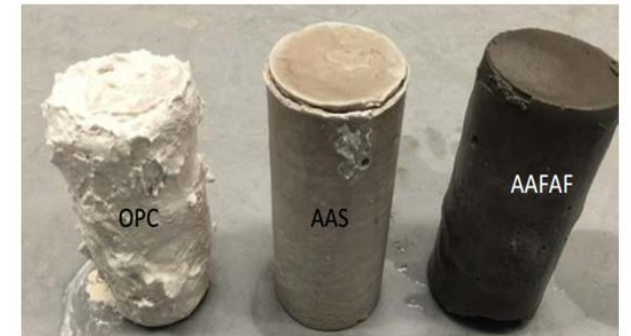
- Utilization of industry waste
- Low carbon
- Fast strength gain
- Good chemical resistance
- Good fire resistance

Alkali-based

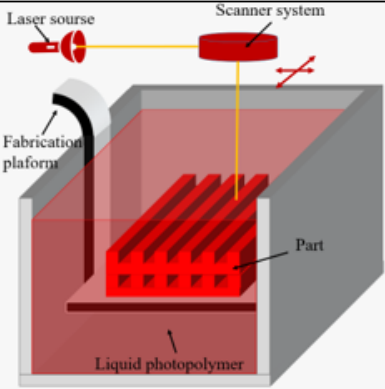
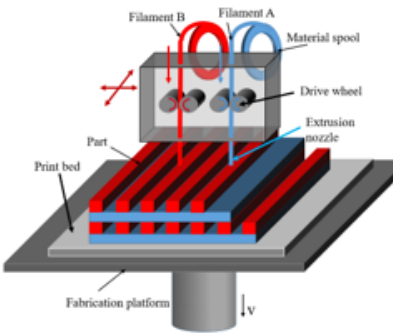
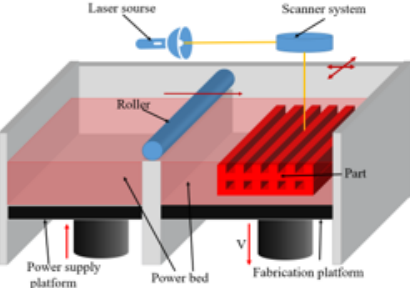
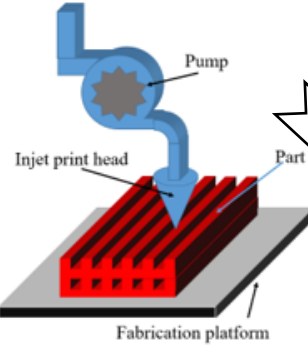



Acid-based



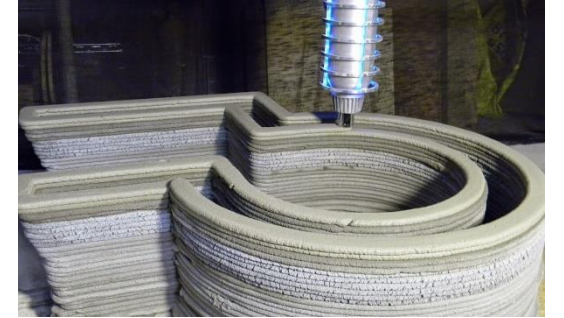
This block contains four images of raw materials for acid-based geopolymer. From left to right: a pile of white metakaolin, a pile of grey fly ash, a pile of white MgO powder, and a blue plastic jug of phosphate solution. A large white arrow points from this group towards the right.



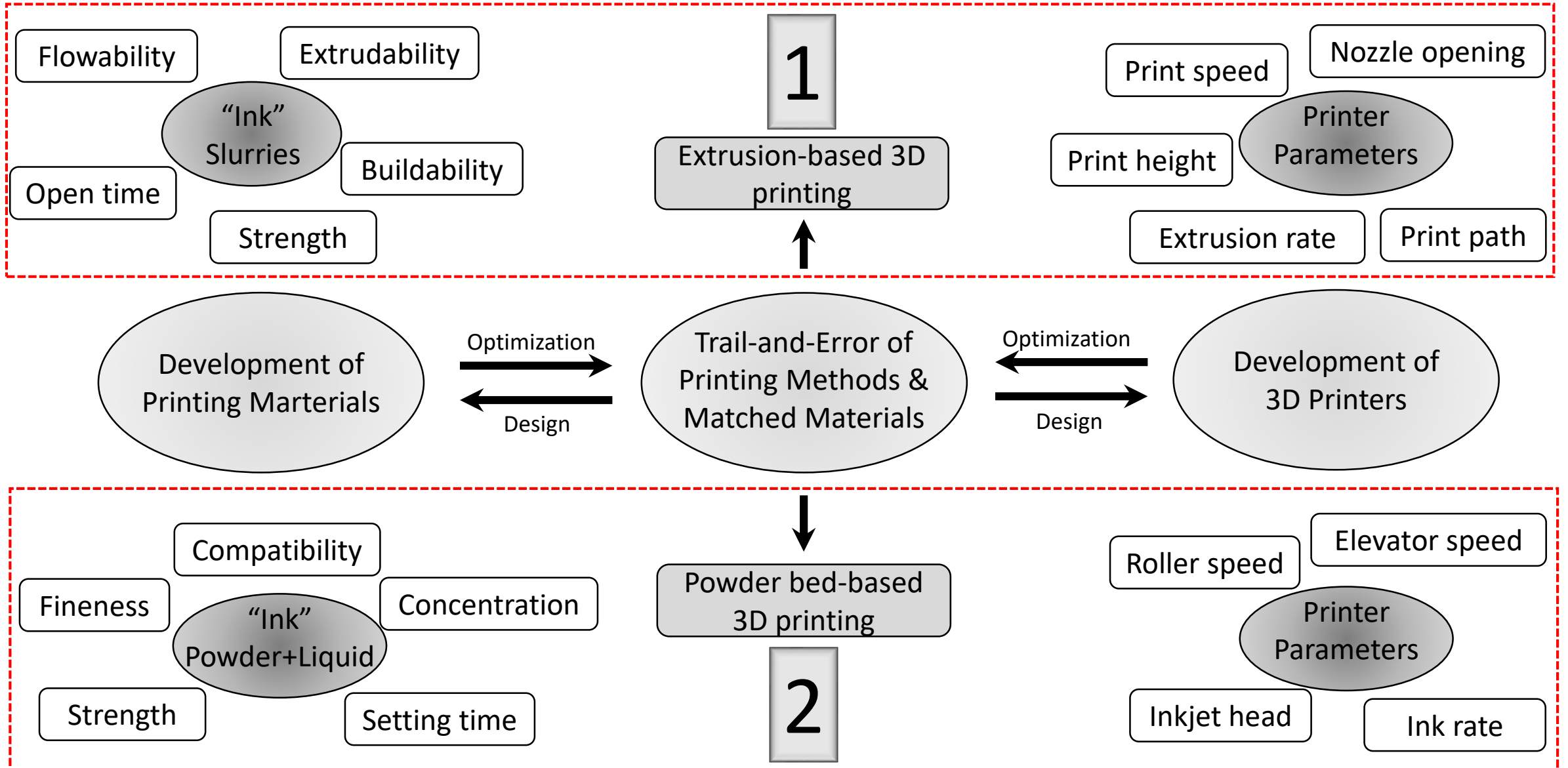
Solico-aluminophosphate geopolymer

Printing Type	Stereolithography (SLA)	Fused deposition modelling (FDM)	Powder bed fusion	Extrusion
Sketch Map				
Printing Materials	resins with photo-active monomers	Continues filaments of thermoplastics polymer	Compacted fine powders (e.g., Metal, Alloy, Gypsum, Polymer) and setting solution	A concentrated dispersion Cement Mortar/Paste, Ceramic
Benefits	Fine resolution High quality	Low cost High efficiency Simplicity	Fine resolution High quality	Low cost High efficiency Large products
Disadvantage	<u>Very limited materials</u> Slow printing Expensive	<u>Limited materials (only thermoplastics)</u> Layer-by-layer finish	Slow printing Expensive Low compactness Low strength	Maintaining workability Coarse resolution Weak inter-layer adhesion Layer-by-layer finish
Applications	Biomedical Prototyping	Rapid prototyping, Toys, advanced composite parts	Biomedical, Electronics, Aerospace, Lightweight structures (lattices)	Biomedical, Large structures Buildings
Suitable for Construction Industry?			Need to be modified	

Extrusion-based



Powder-based



1. 流動性測試 (flow)

The fluidity was further assessed by comparing the relative slump values calculated by the following Eq. 1:

$$\Gamma_p = \left(\frac{d}{d_o}\right)^2 - 1 \dots\dots \quad (1)$$

where Γ_p is the relative slump, d is the average of 3 measured diameters of the spread and d_o is the cone bottom diameter.

2. 粘度及剪切應變測試 ()

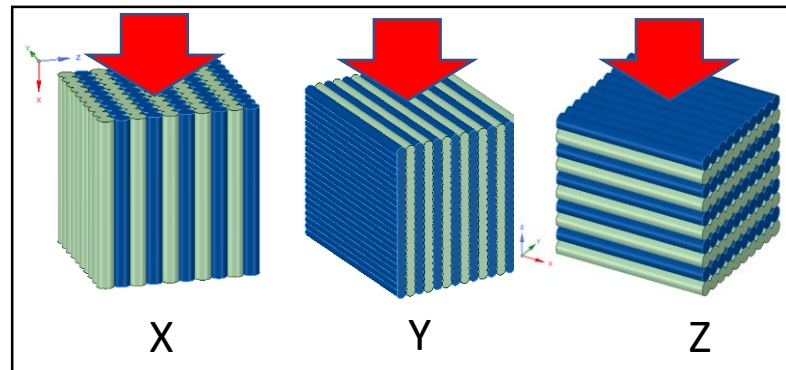
A rotational and oscillatory rheometer (Anton Paar MC302)

3. 凝結時間測試

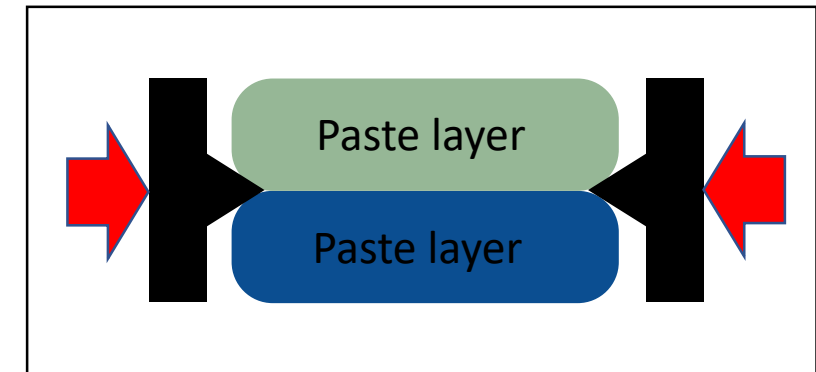
ASTM C191-13

4. 機械性能測試

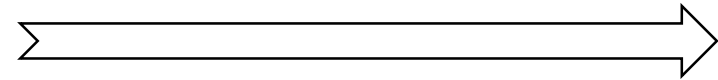
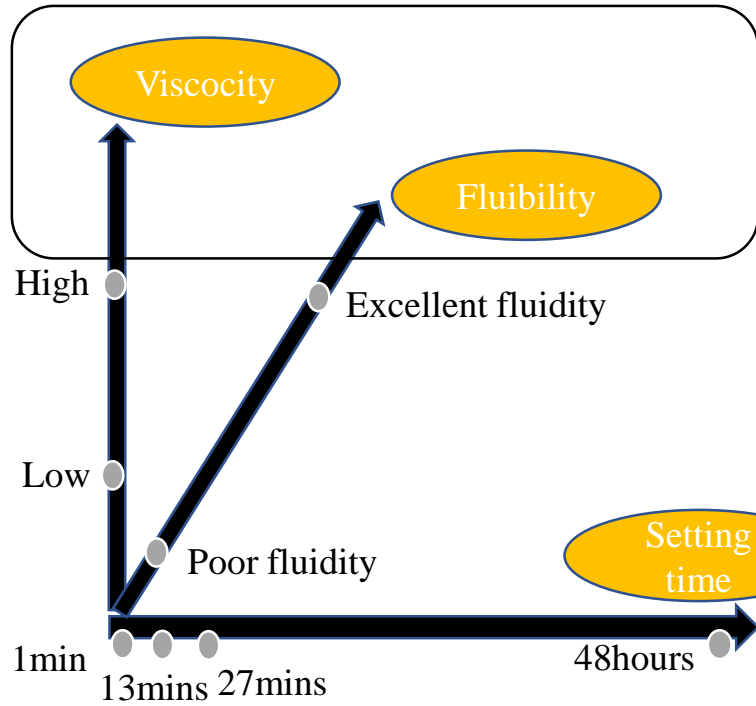
ASTM C109/C109M-16a



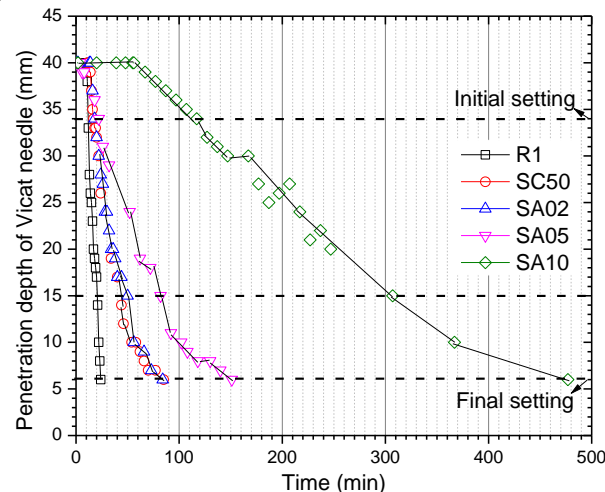
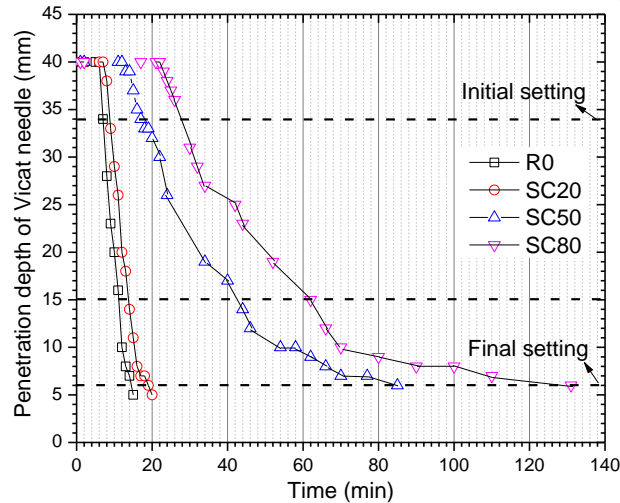
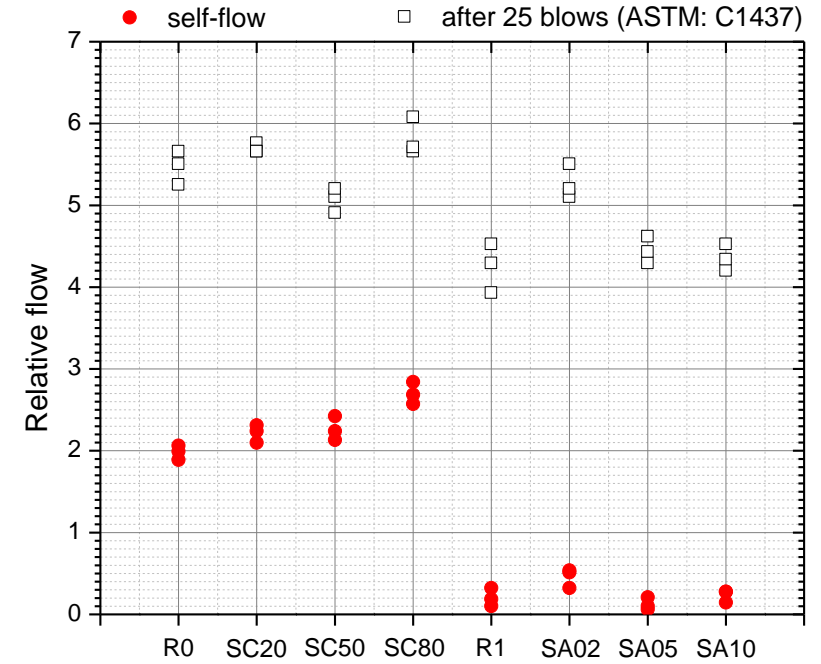
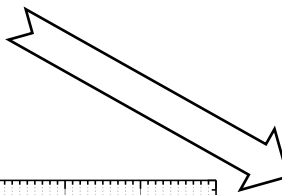
抗壓強度測試



層間粘結強度測試

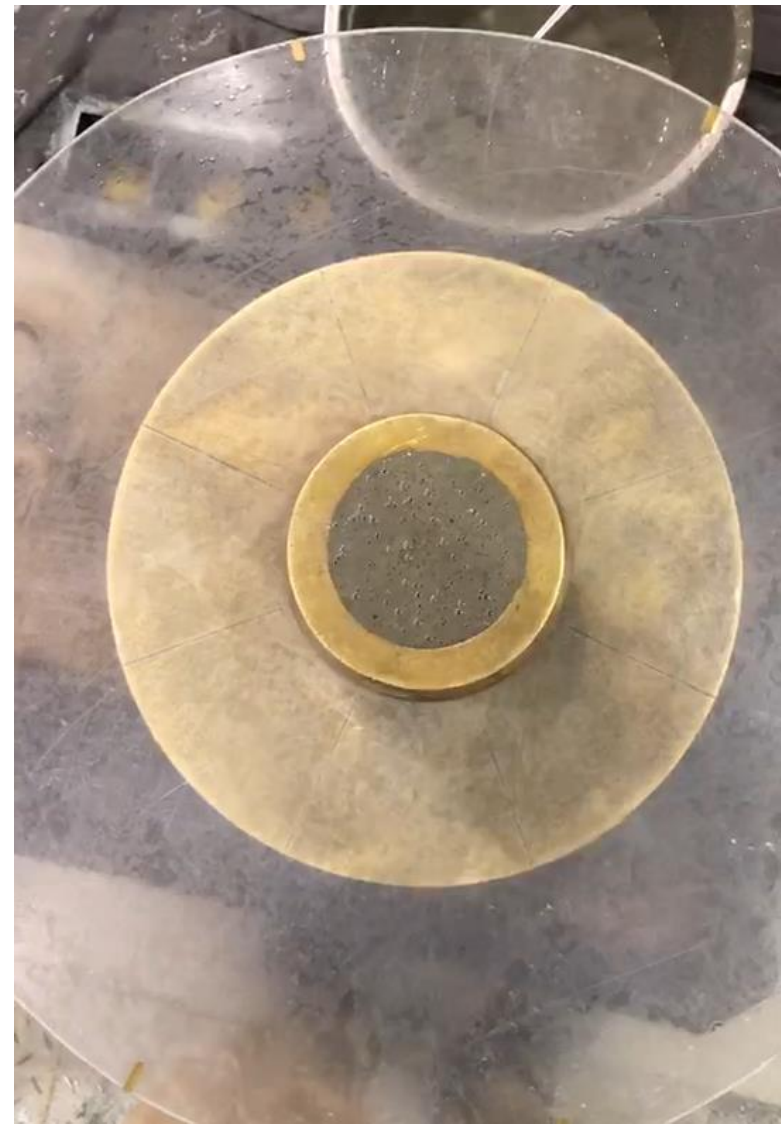


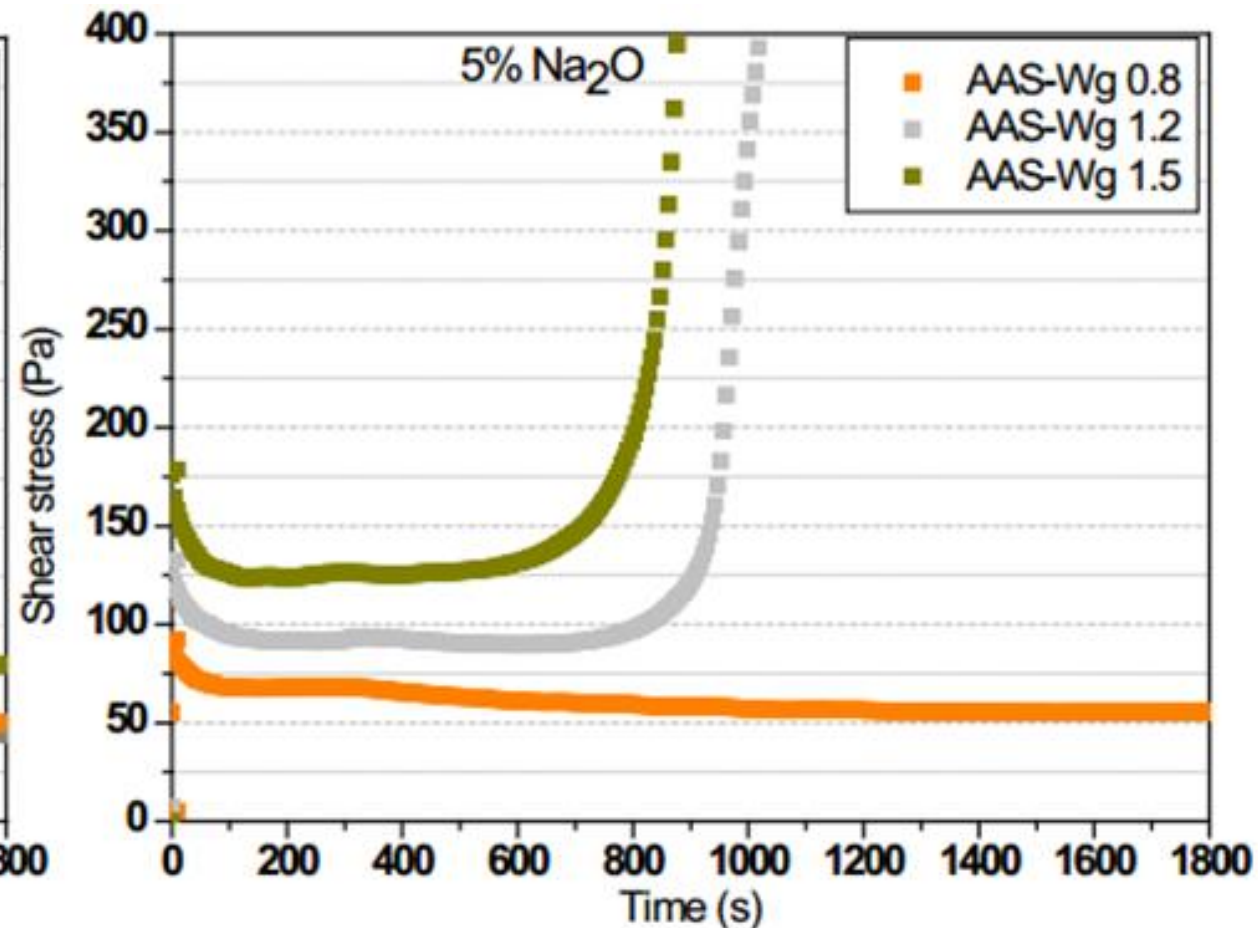
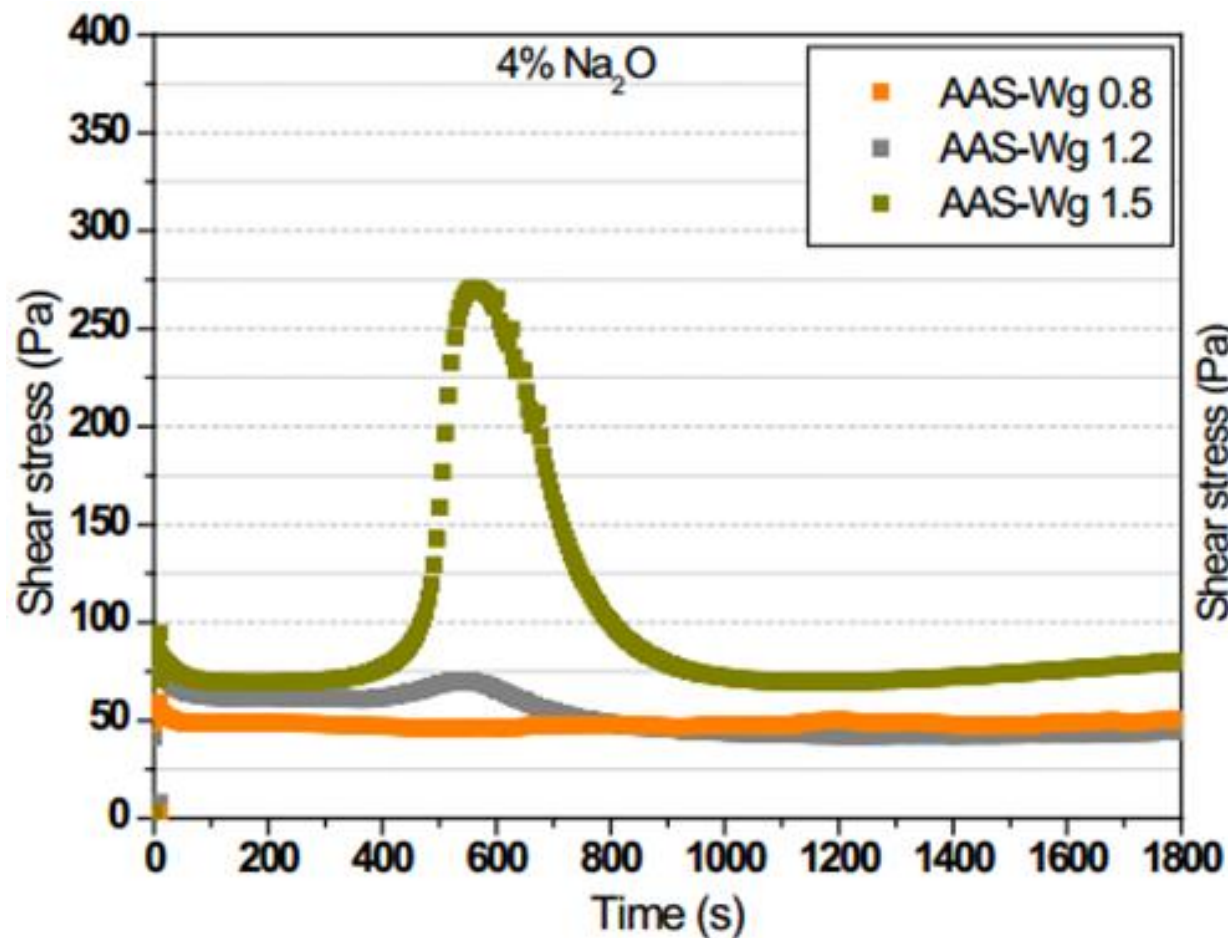
A wide range of parameters

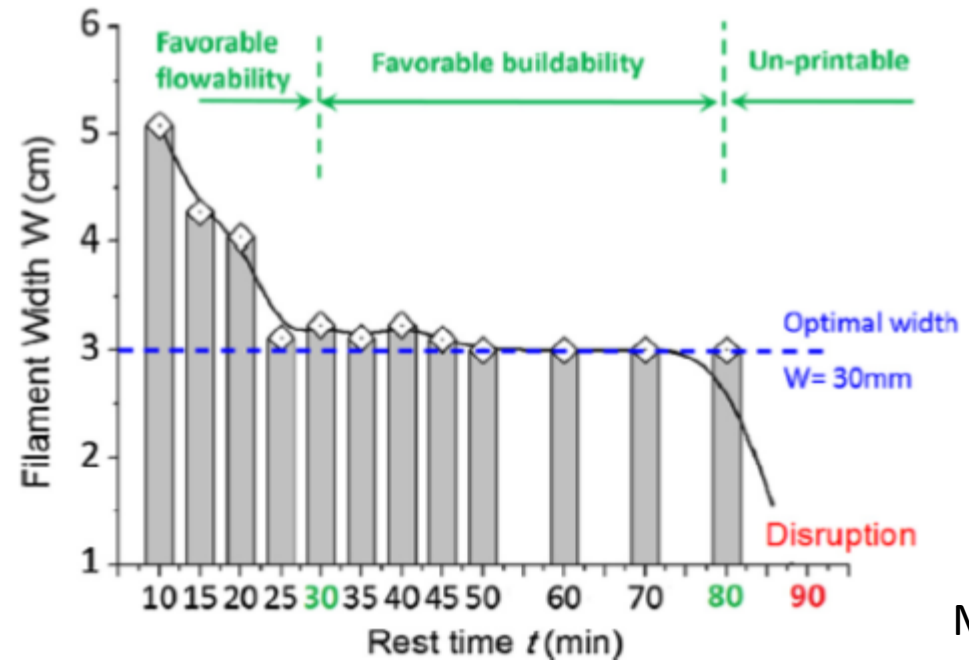
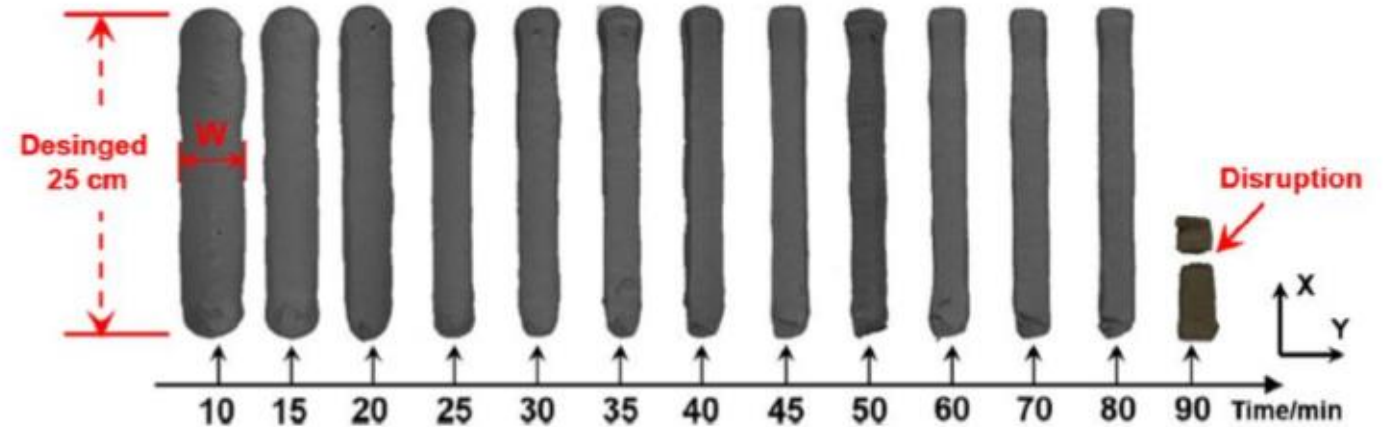
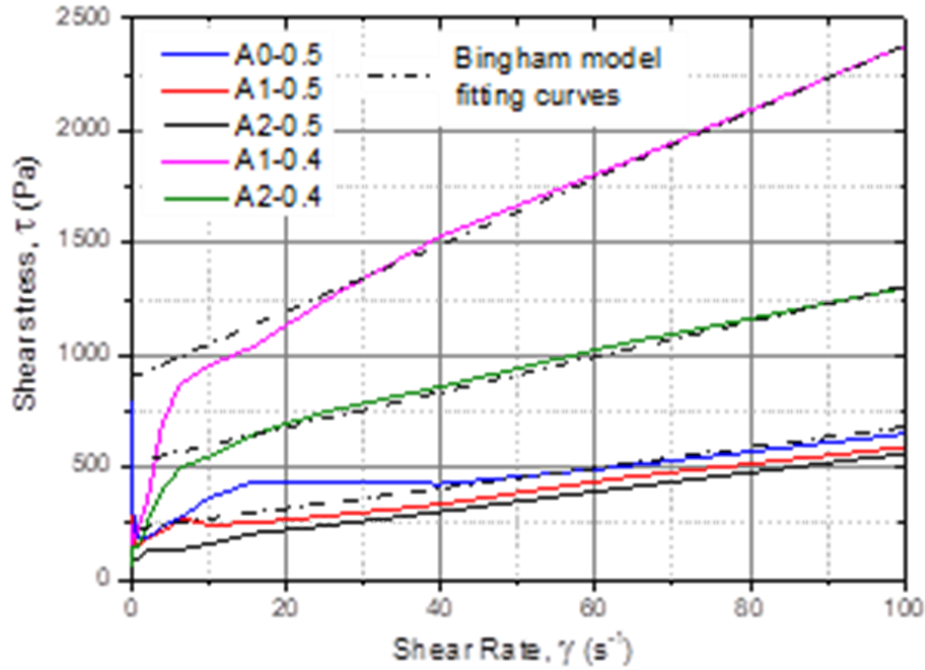


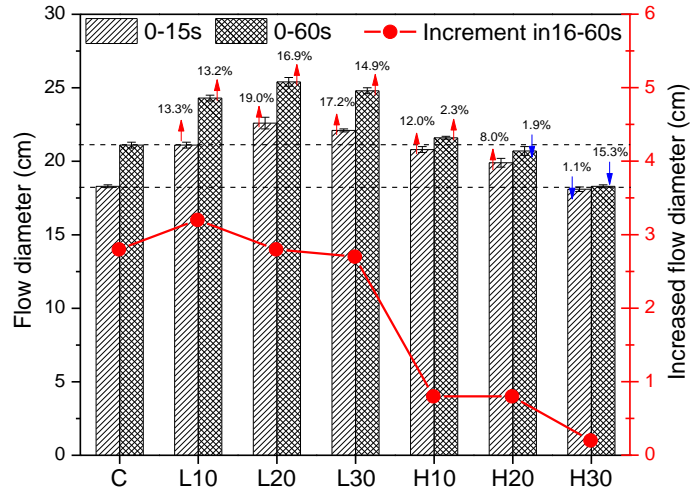


Two
extreme
cases for
instance

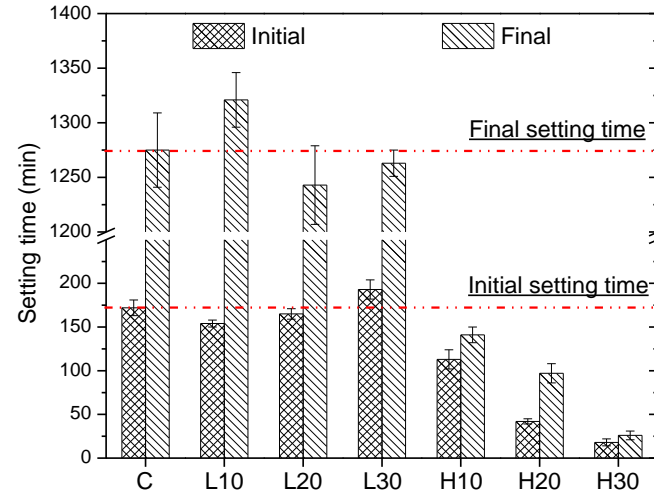




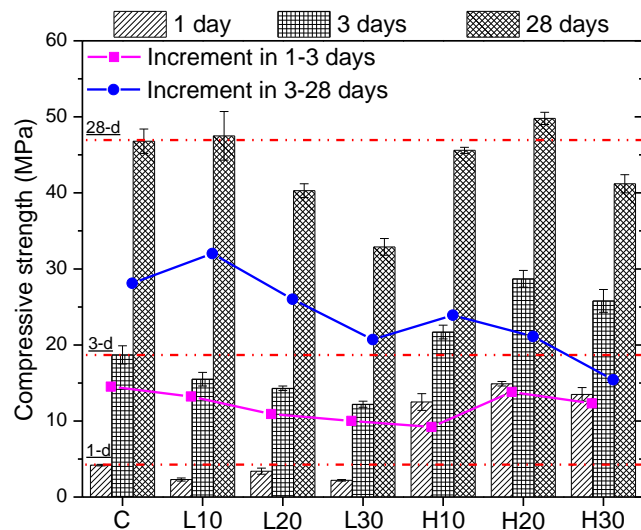




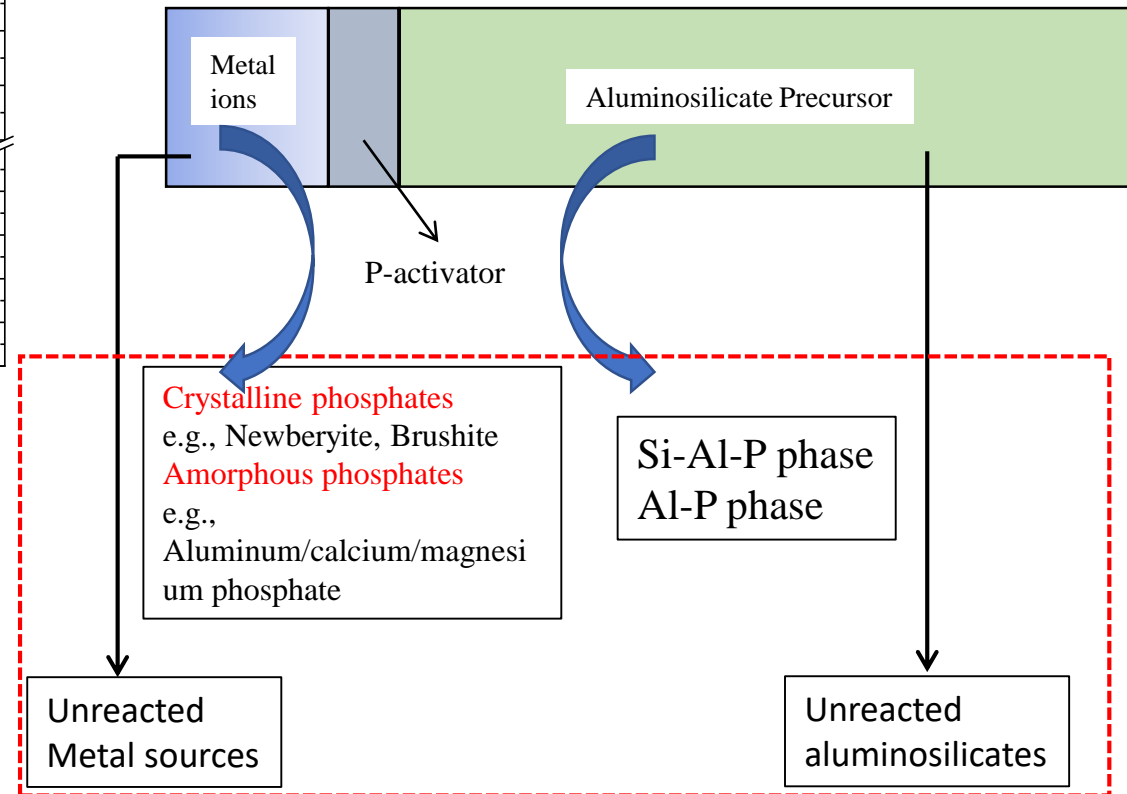
Flow

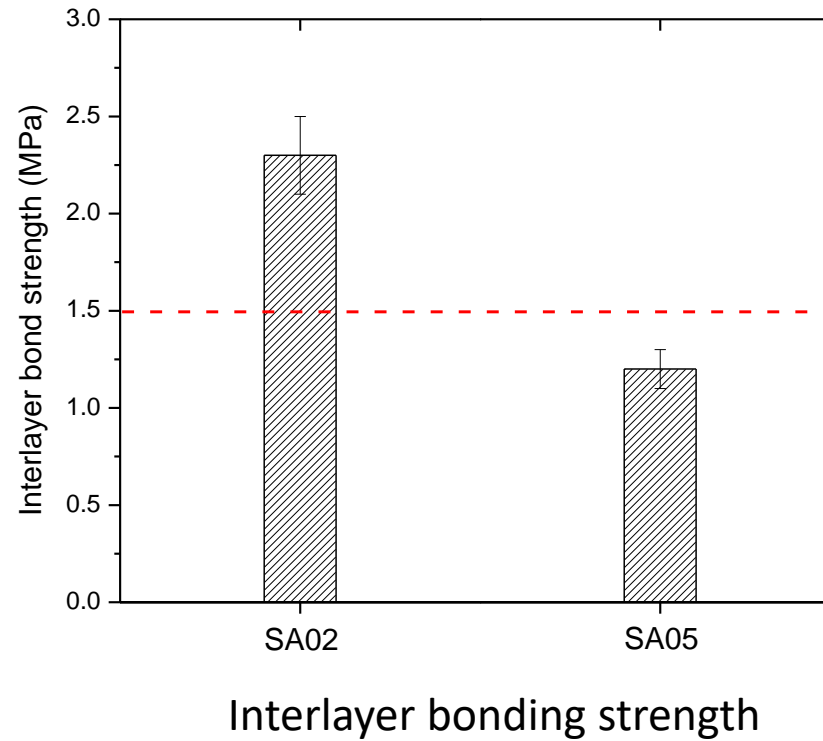
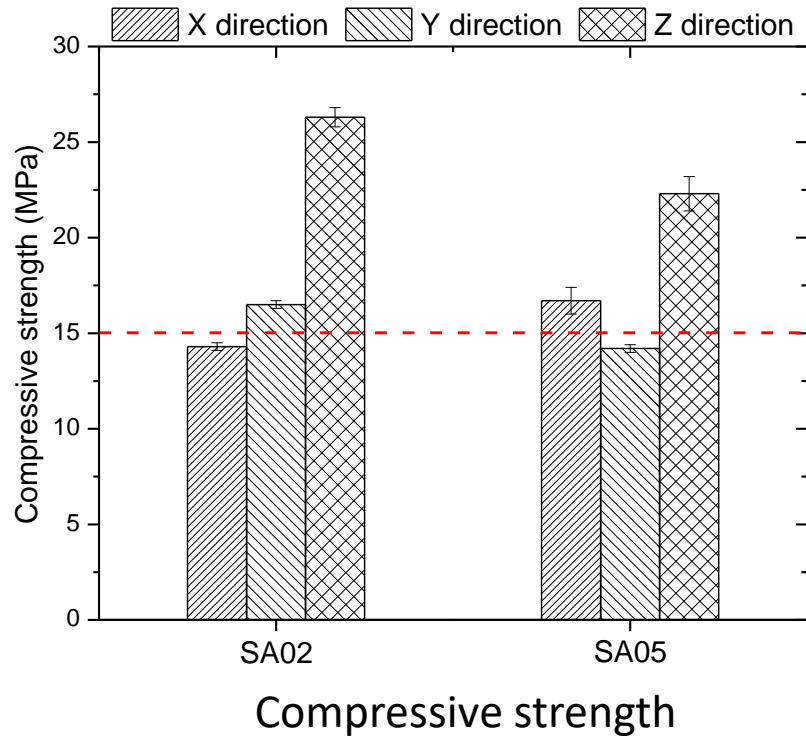


Setting time



Compressive strength

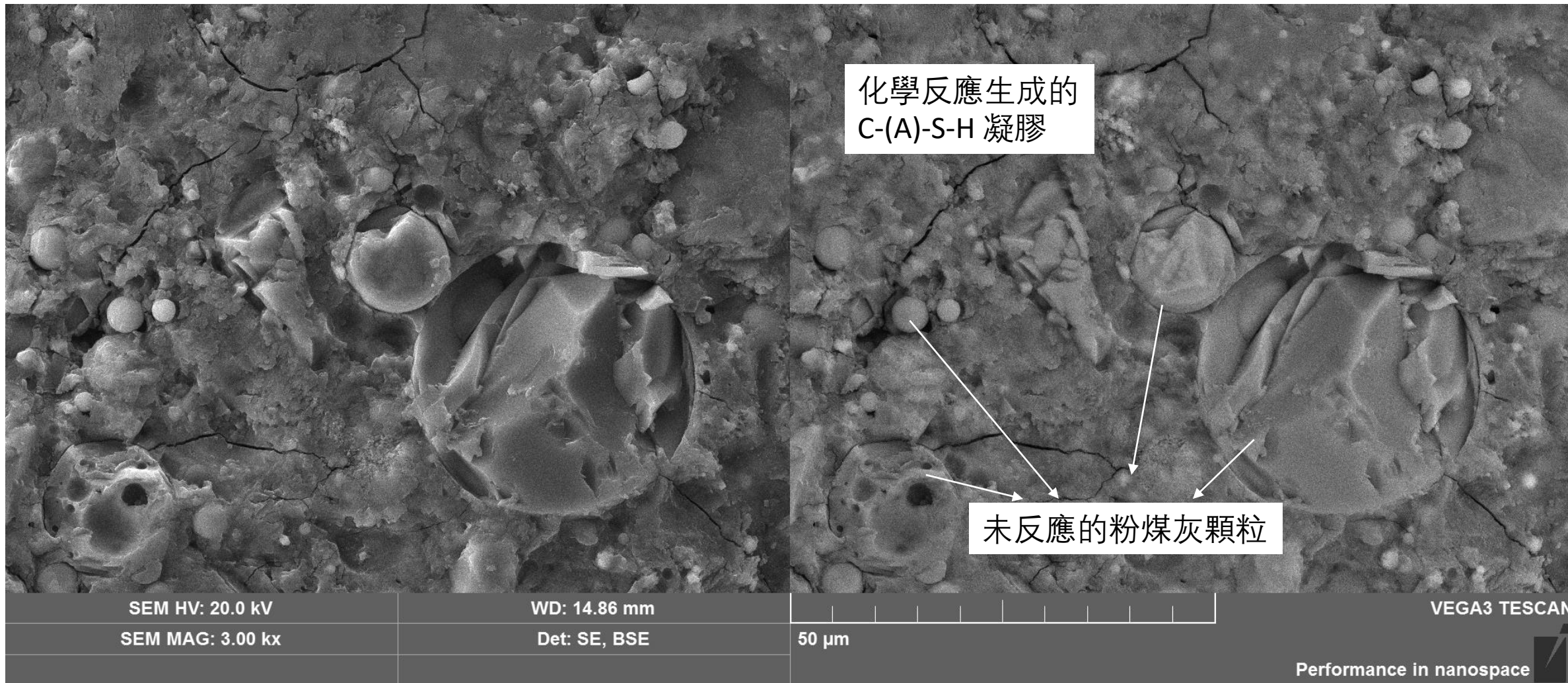


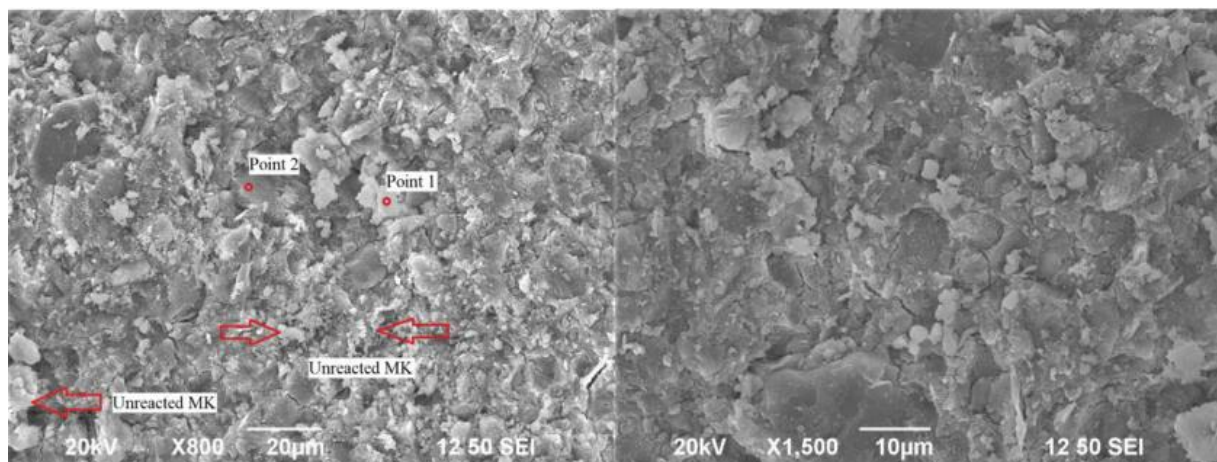


sample



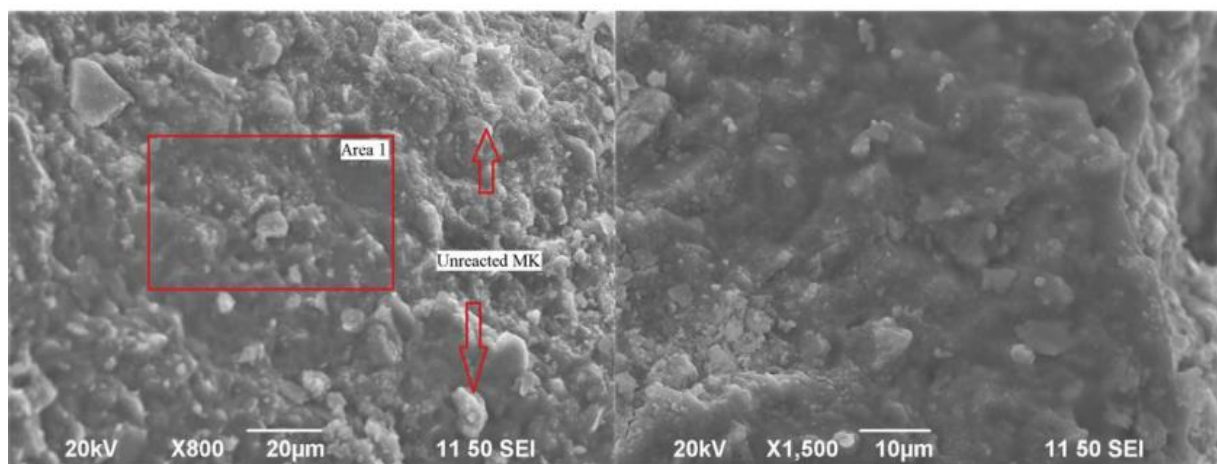
Failure of sample





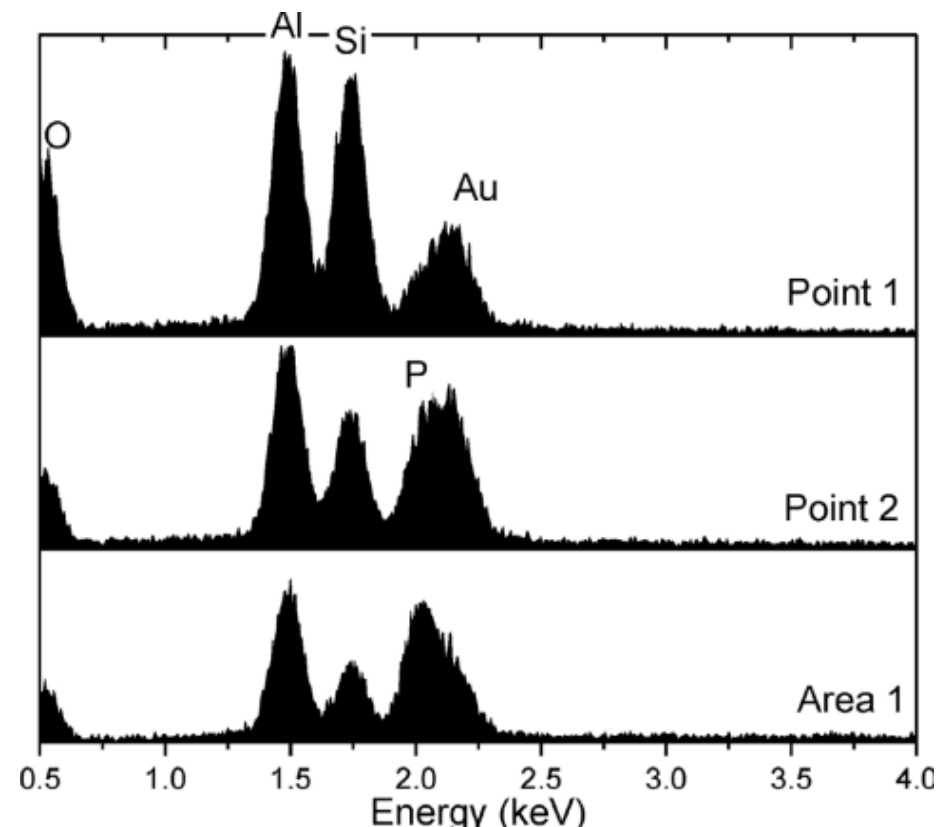
(a) x800

(b) x1500

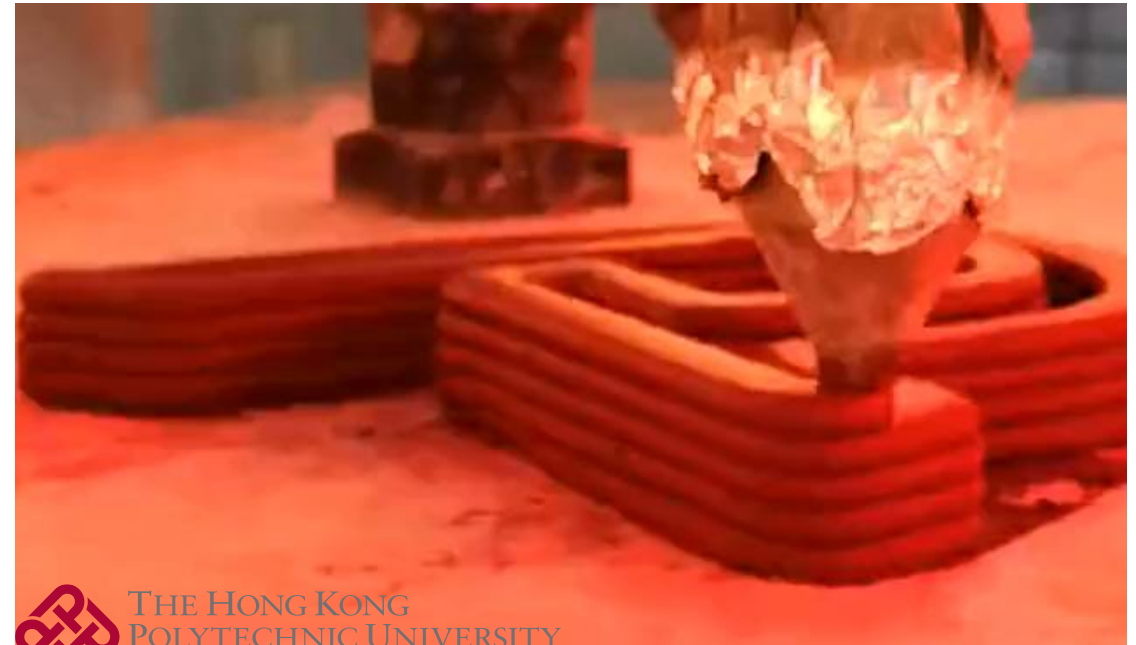
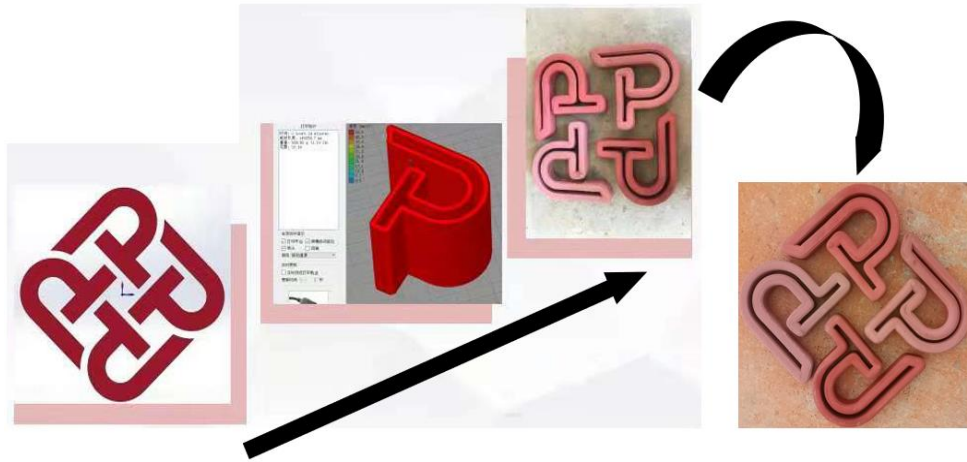


(c) x800

(d) x1500



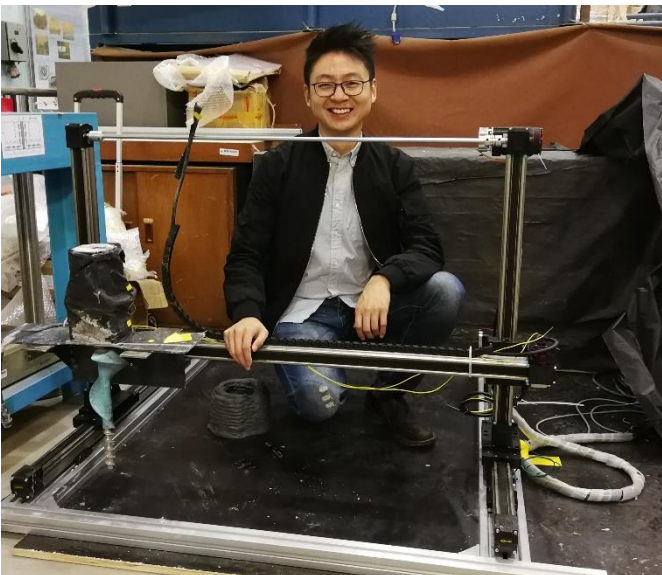
化學反應生成的 S-A-P-(H) 凝膠

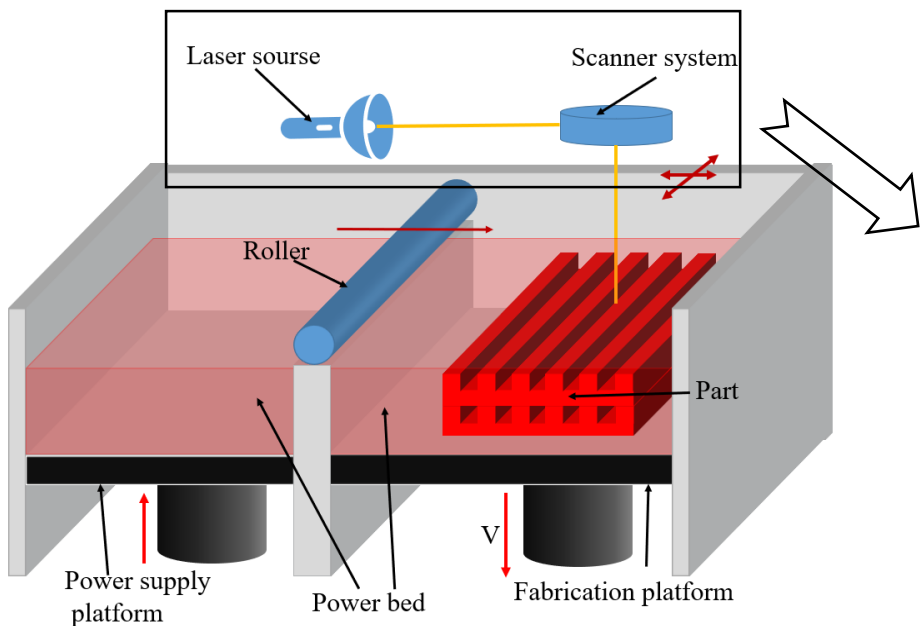
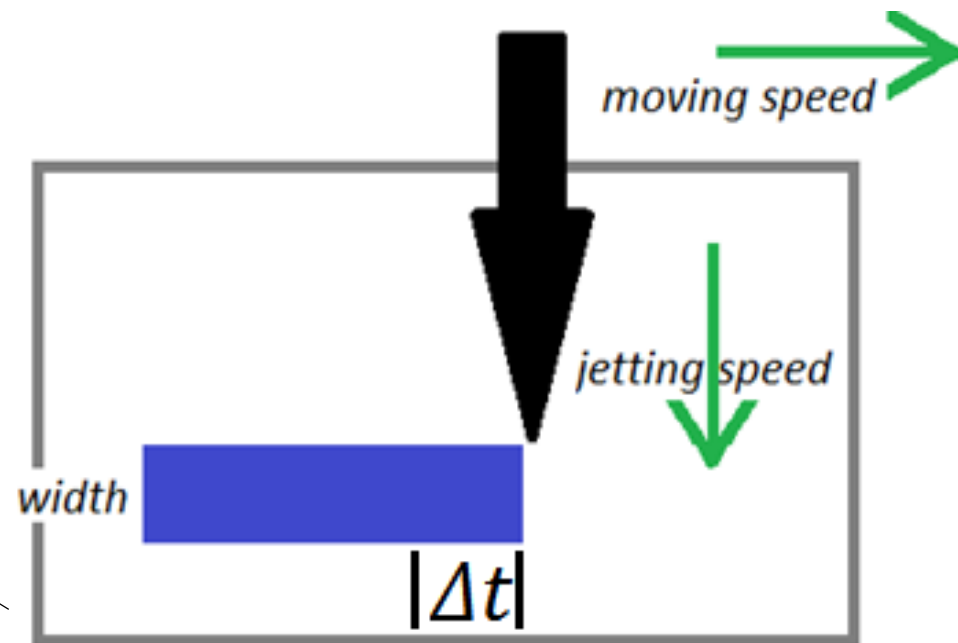
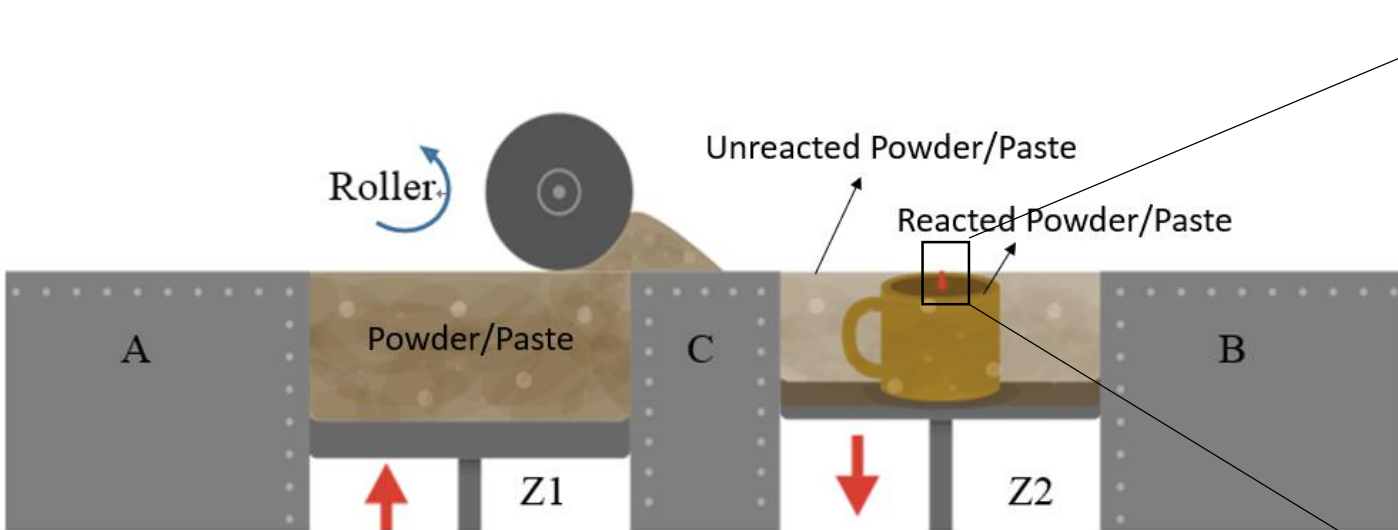


 THE HONG KONG
POLYTECHNIC UNIVERSITY
香港理工大學

PolyU Logo

- CAD Modeling
- Slicing 3D → 2D → 1D
- Printing 1D → 2D → 3D

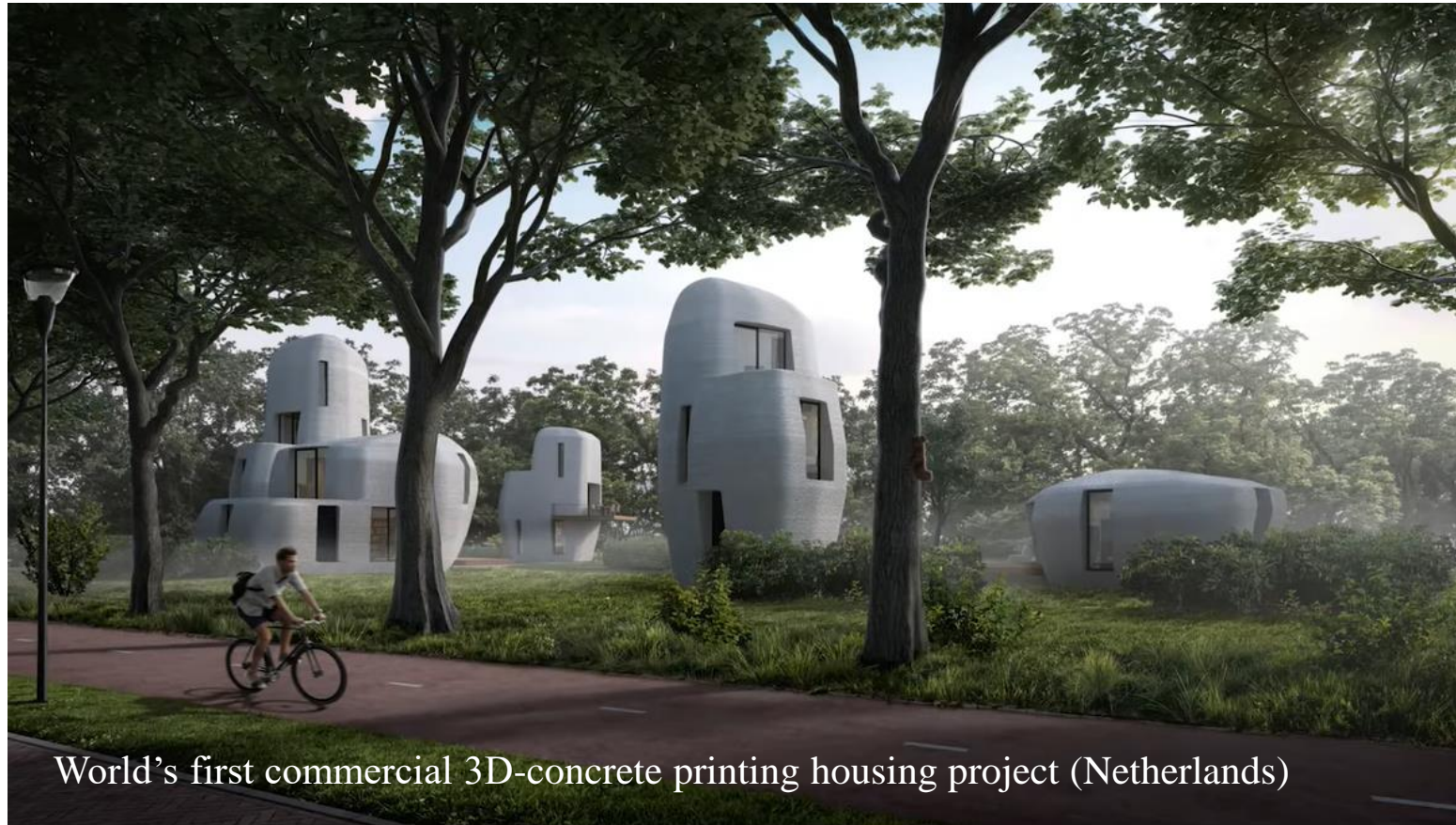




1. 粉床材料激光硬化機制改為化學反應機制
2. 激光激發方式改為化學激發方式

在某一點的打印體積 =
 注射速度 * Δt * (移動速度 * Δt) * 打印厚度

- 3D printing concrete is an important dimension for building industry 4.0.
- More and more successful projects have been completed with concrete 3D printers, the legal obstacles that may hinder the technology will ease up as time progresses.
- As time goes, more and more cities will adopt new rules and standards that will support the use of concrete 3D printing technology.



Thank you for your attention.