# Development of 3D-printed geopolymer cement for sustainable construction

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# Consolidating Capabilities in 3D Printing

## Singapore Centre for 3D Printing

### Future of Manufacturing

- Modeling & Prototyping
- Sustainable Manufacturing
- Precision Engineering

### Aerospace & Defence

- Lightweight UAVs
- Parts on demand
- Part certification for Quality System Management

### Building & Construction

- New printable materials
- Modular systems for multiple build materials
- Novel robotic 3D printers for construction

### Marine & Offshore

- Novel process for large joints
- Printing of high aspect ratio structures
- Large scale laser cladding for component repair

### Bio & Food Printing

- Bioprinting – bionic constructs, retina tissue, organs
- Medical Implants
- Food printing – meat, chocolate, etc.

## NAMIC @ NTU

Innovation Cluster to perform ***translation of upstream research*** into applications for commercialization, and to ***collaborate with key partners*** for industry development

# Content:

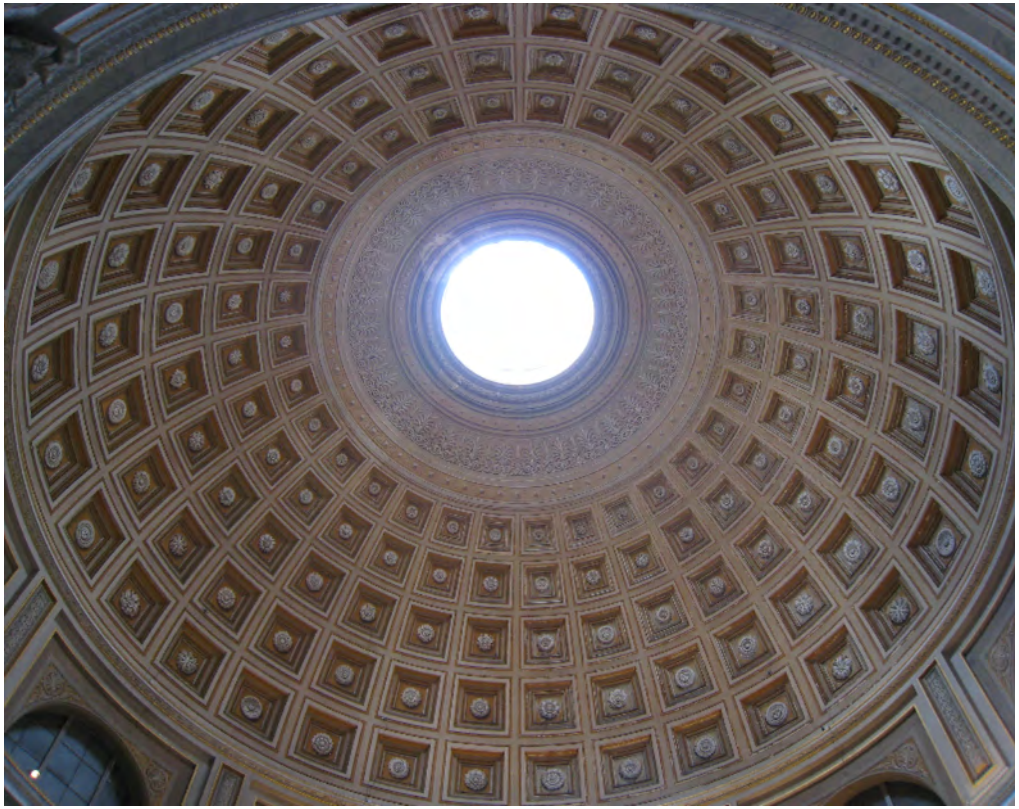
**Part 1**
Challenges for sustainable construction

- Design and architecture
- Sustainability
- Productivity

**Part 2**
Opportunities of 3D printing and Geo-Polymer

- Introduction & Printer
- Geo-Polymer
- Benchmarking properties

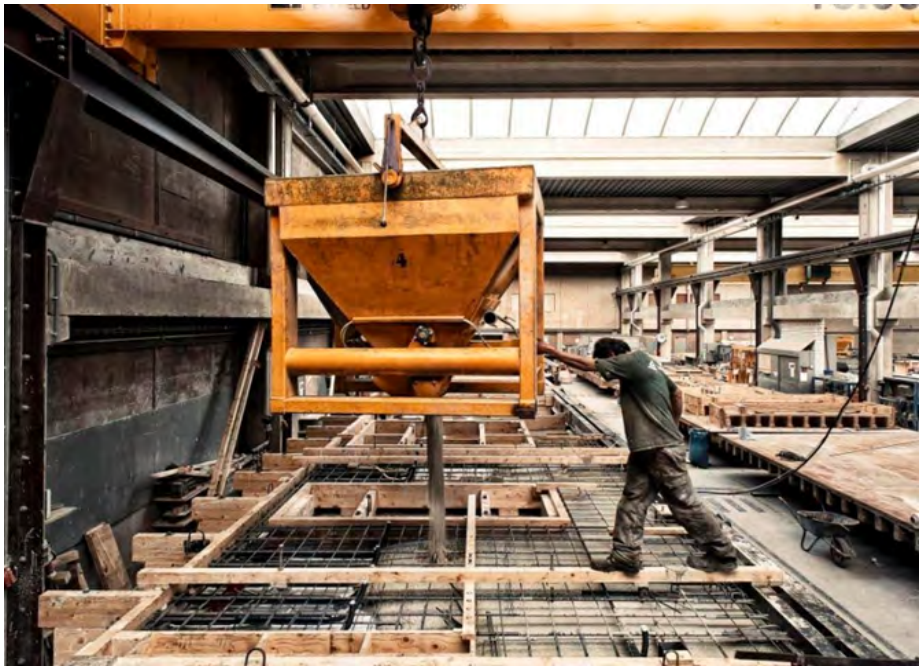
# Part 1: Design and architecture



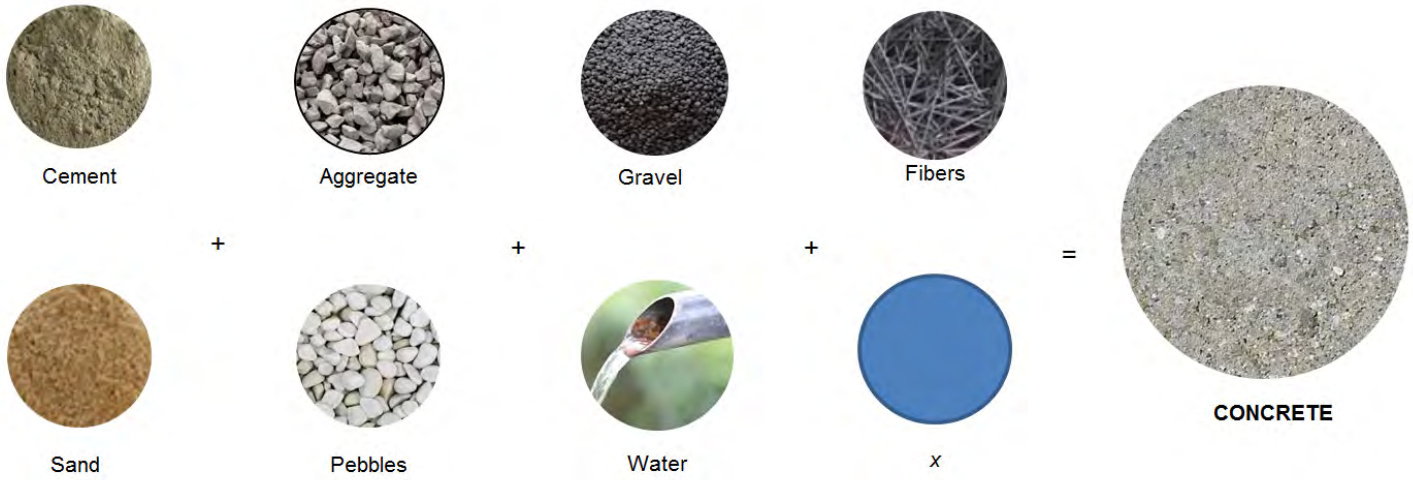
**Pantheon Rome (126 AC)**
Example of superb architecture and a sustainable concrete structure

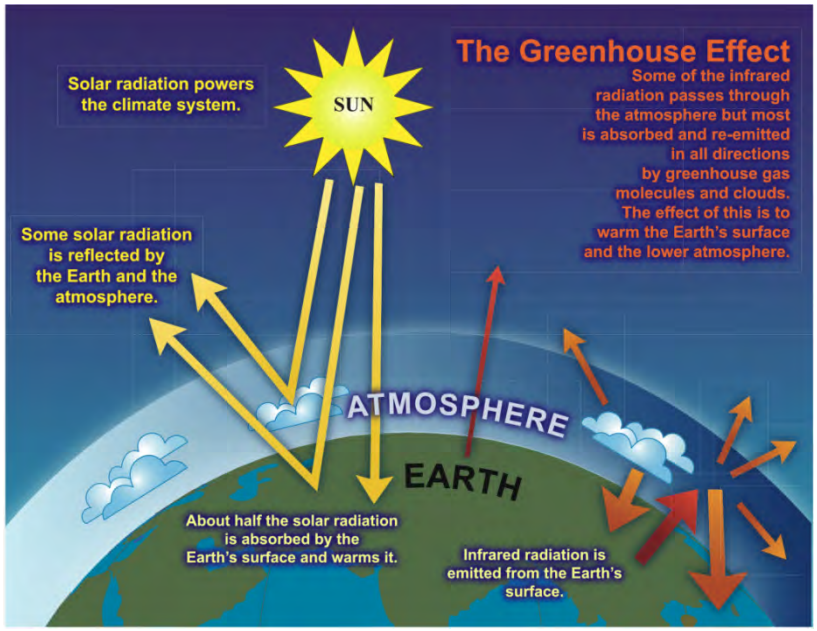
**Philips pavilion**
Example of free form architectural design at the World's fair 1955 in Brussels

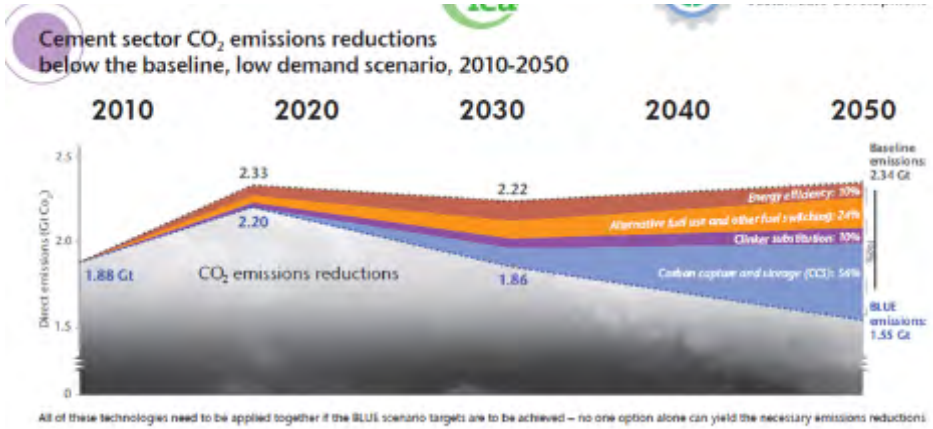
***Parabeton***
*Pier Luigi Nervi and Roman Concrete* (2012



# Sustainability:

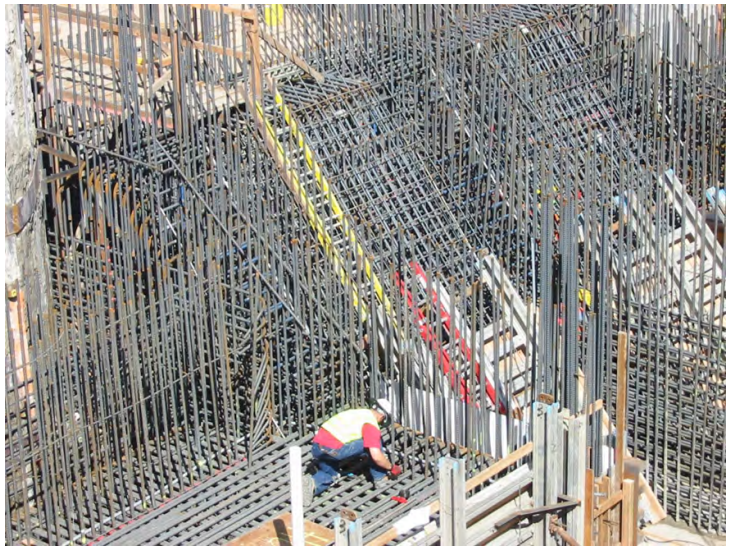


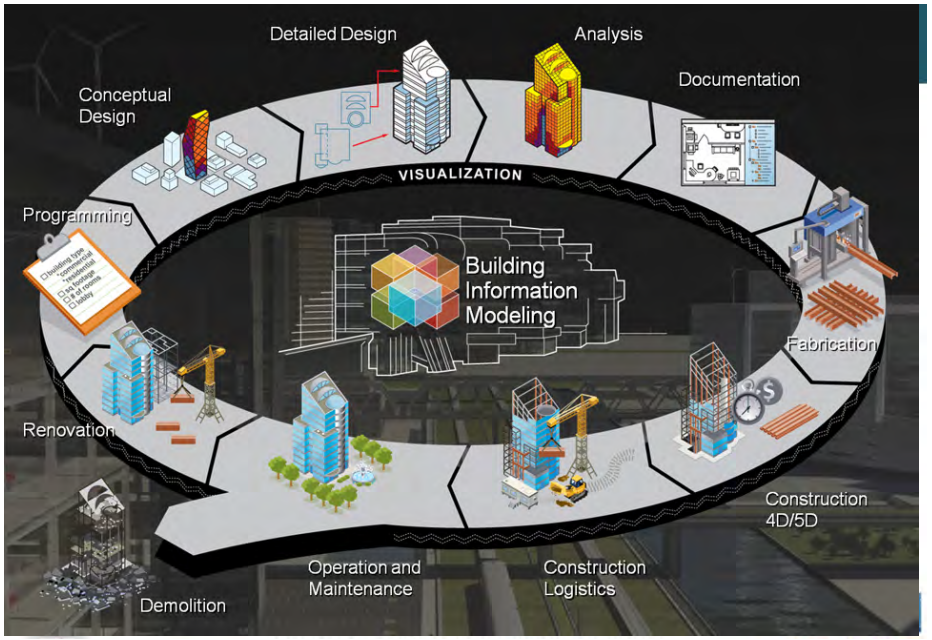



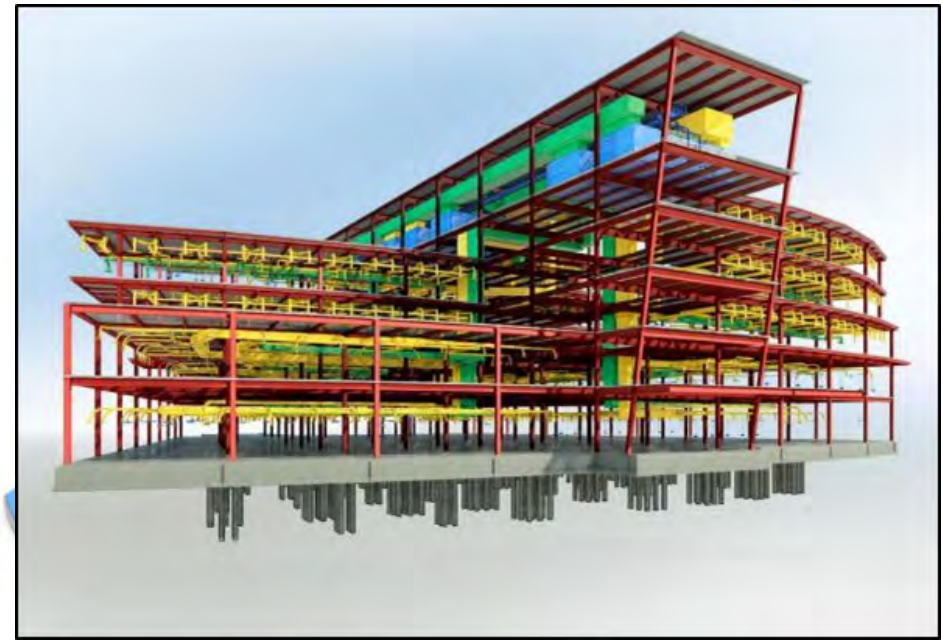

(Source: www.**iea**.org)

# Productivity:



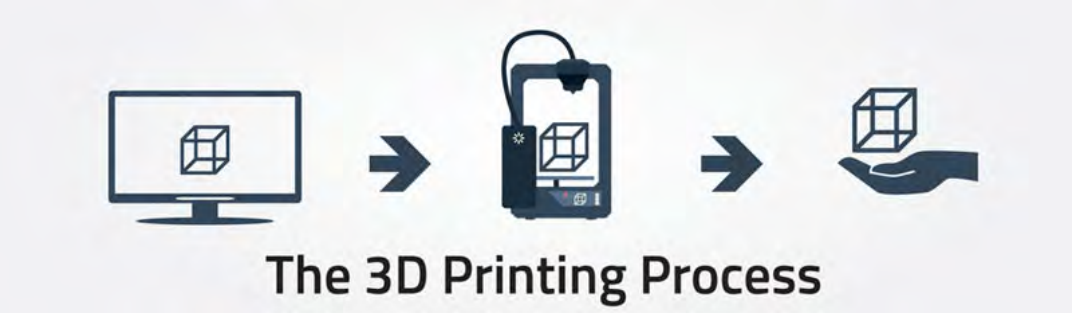
**Health**
The preparation of rebar is labour intensive and a major cause of illness.

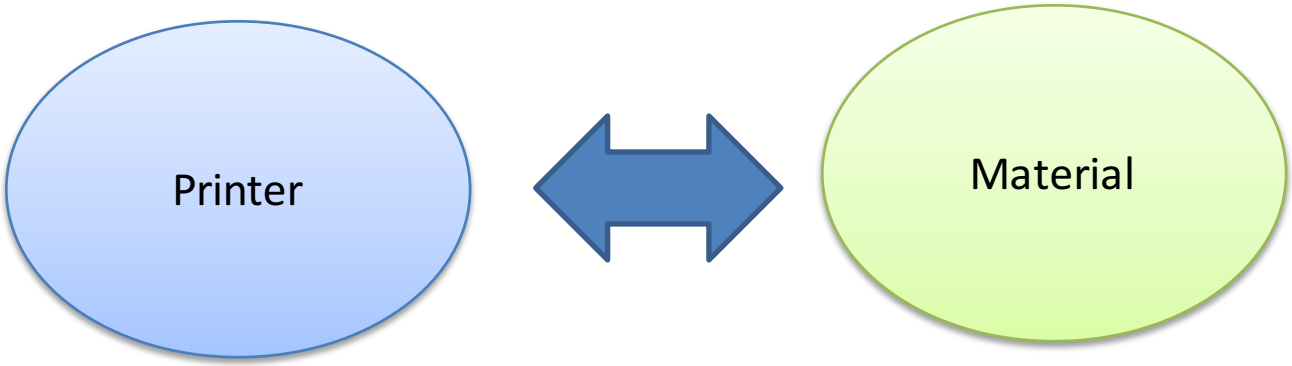


**Part 2: Digital manufacturing via 3D printing**

# Part 2: Introduction & Printer




- Printing speed
- Rate of deposition
- Layer thickness
- Time gap between layers

- Setting time
- Extrudability
- Shape retention
- Thixotropic

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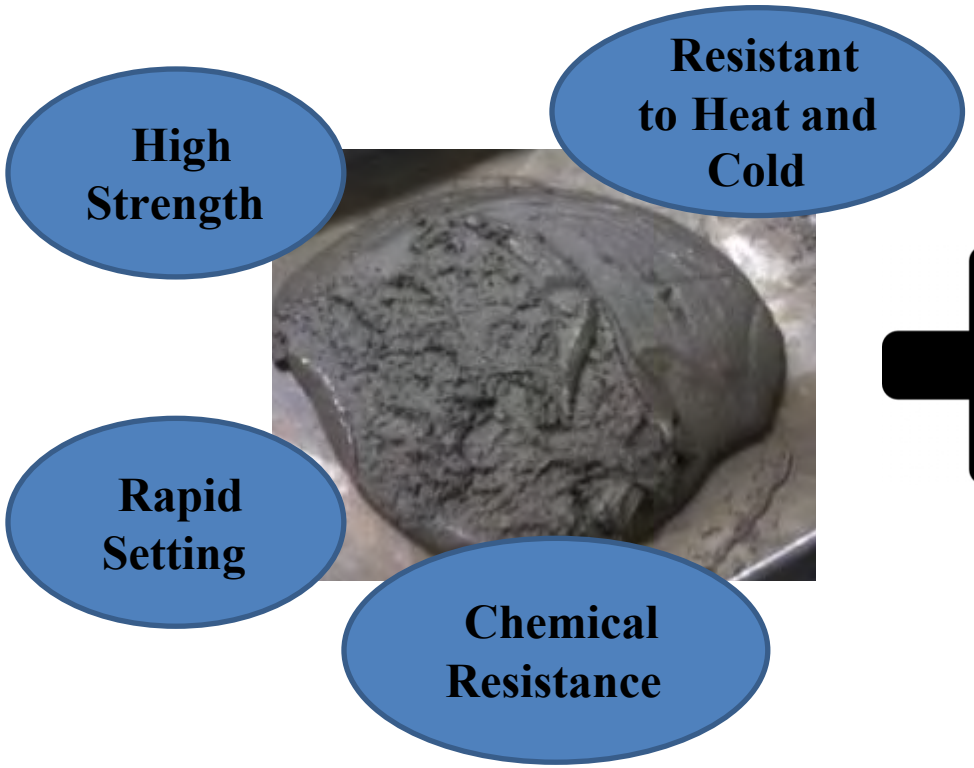
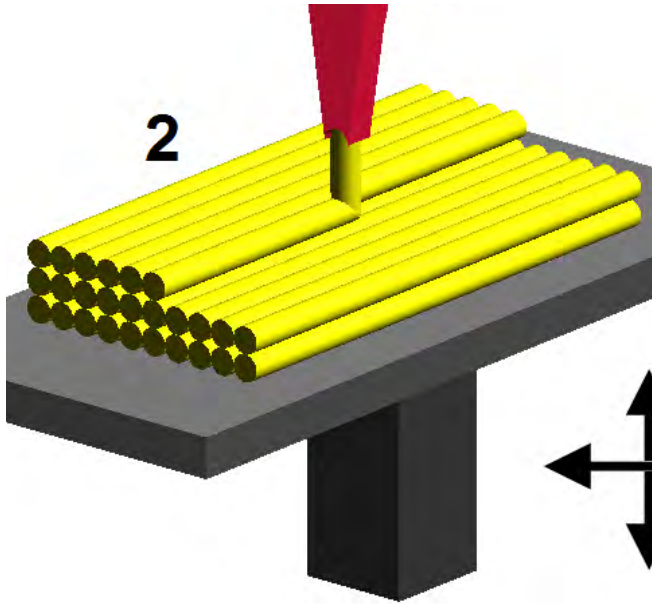
- ✓ Design and architecture
- ✓ Sustainability
- ✓ Productivity

# Part 2: Geopolymer

**Definition:** Geopolymer is an inorganic alumino-silicate polymer synthesized from alkaline activation of various aluminosilicate materials of geological origin or by-product materials like fly ash, metakaolin and blast-furnace slag.

**Goal:** Development of 3D-printed geopolymer binder for Sustainable Construction

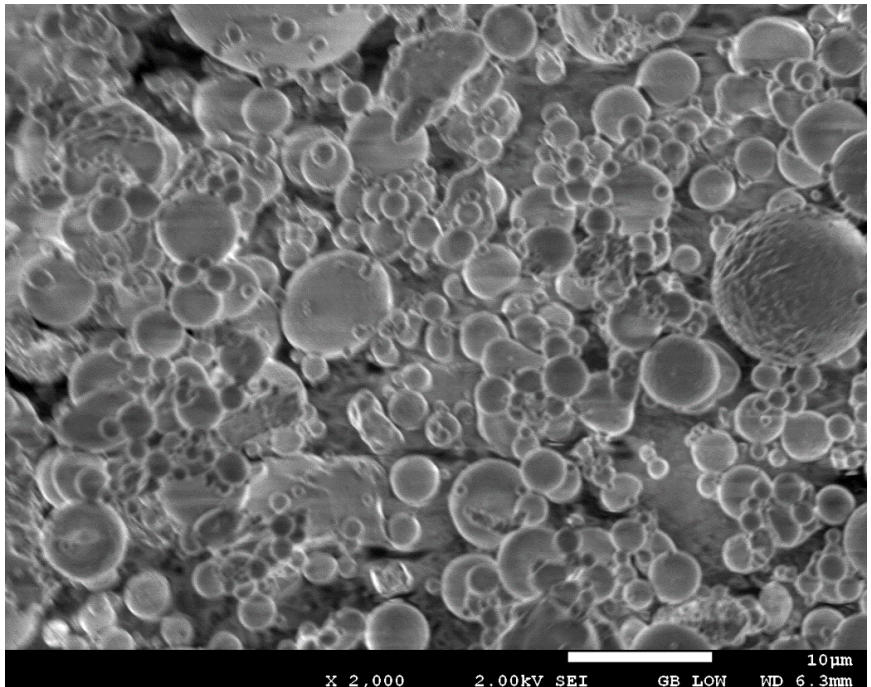


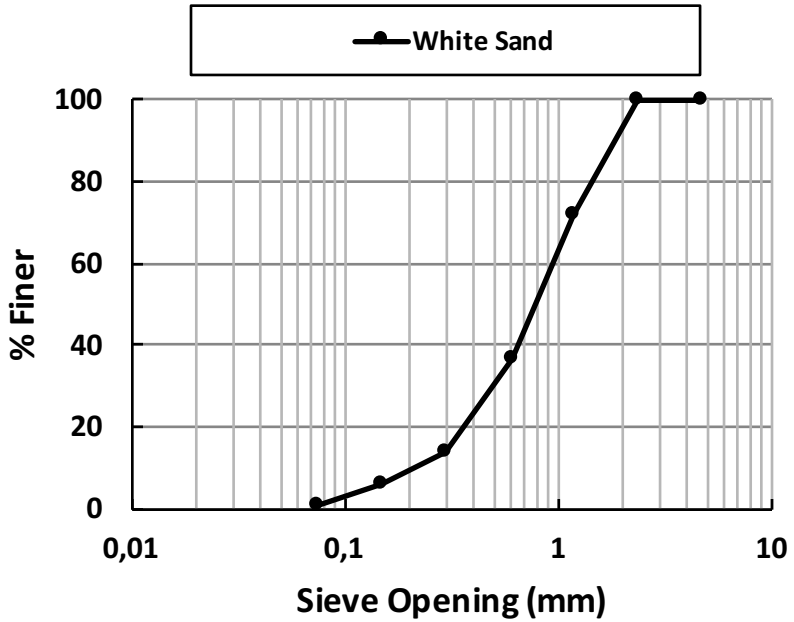



| Properties | | Test | Targeted parameter | | Remark |
|---|---|---|---|---|---|
| **Fresh properties of printed concrete** | Extrudability/printability | Nozzle | Ability to print bead layers without any surface breakage | | Related to workability |
| | Workability | Slump flow | Flow without segregation | | Related to matrix design |
| | | Rheological test | 0.55KPa for initial shear strength | | |
| | Open time | Vicat apparatus | 100 minutes | | Ending of open time: shear stress increased by 0.3MPa in comparison with initial value |
| | | Shear stress changed with time | | | |
| | Buildability | No of layers could be built | Ability to print multiple bead layers without any collapse | | Depends on workability and open time |
| **Curing dynamics** | Curing test | Need to develop* | Hardening behaviors of materials with time | | Influence the hardening behavior of concrete |
| **Hardened properties of printed concrete** | Compressive stress | Direct compressive test | As per types of structure /structures need | | Depends on testing direction, e.g., printing surface, cut surface, side surface |
| | Flexural stress | Four point bending test | | | |
| | Tensile bond stress between layers | Direct tensile test | Printing gap | Tensile bond stress | Reduce with increased printing gap |
| | | | 8 hours | 0.8MPa | |
| | | | 3 hours | 1.0MPa | |
| | | | 1 hour | 1.2 MPa | |
| | | | 15 min | 1.5MPa | |
| | Void structure between filaments | Image analysis for large voids (0.2-4mm) | 4.8% for poorly printed | | Less voids less permeable |
| | | | 1.0% for well printed | | |

# Rheology of Fly-Ash/Slag-Based Geopolymer Concrete

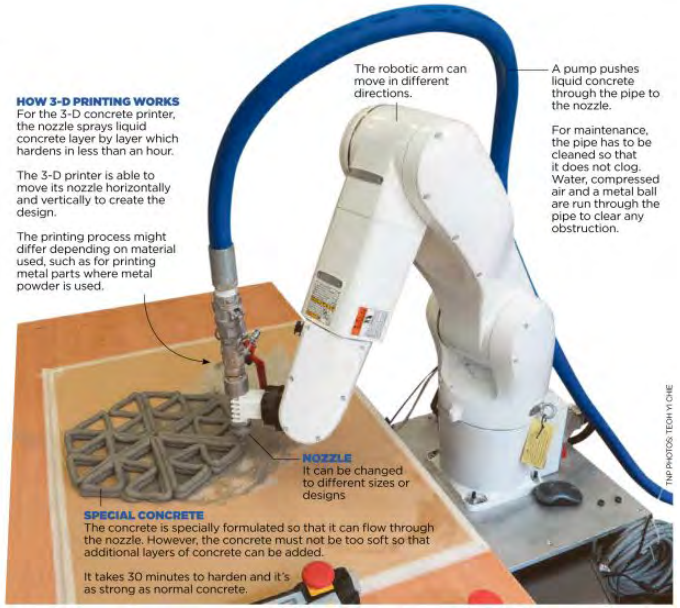
| Run | Slag/Binder | Alkaline/binder | Sodium silicate/NaOH ratio |
|---|---|---|---|
| 0 | 10 | 35 | 1 |
| 1 | 10 | 35 | 1.5 |
| 2 | 10 | 35 | 2 |
| 3 | 20 | 35 | 2 |
| 4 | 20 | 40 | 2 |
| 5 | 20 | 45 | 2 |
| 6 | 30 | 35 | 2 |



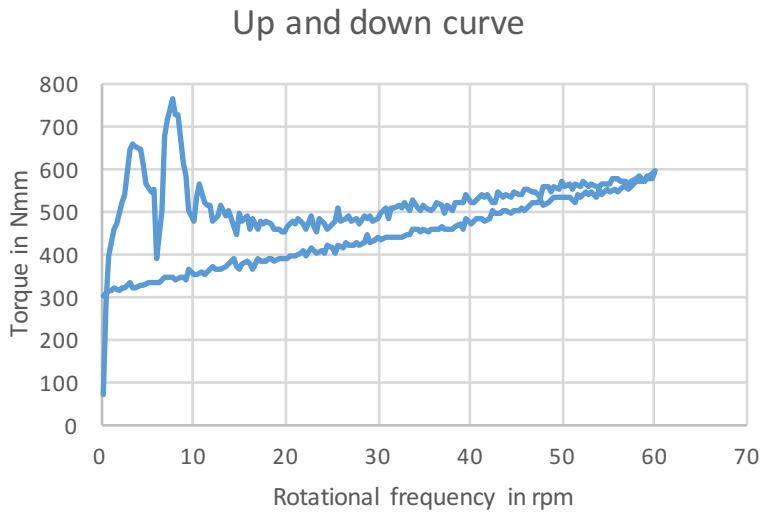



Rheometer

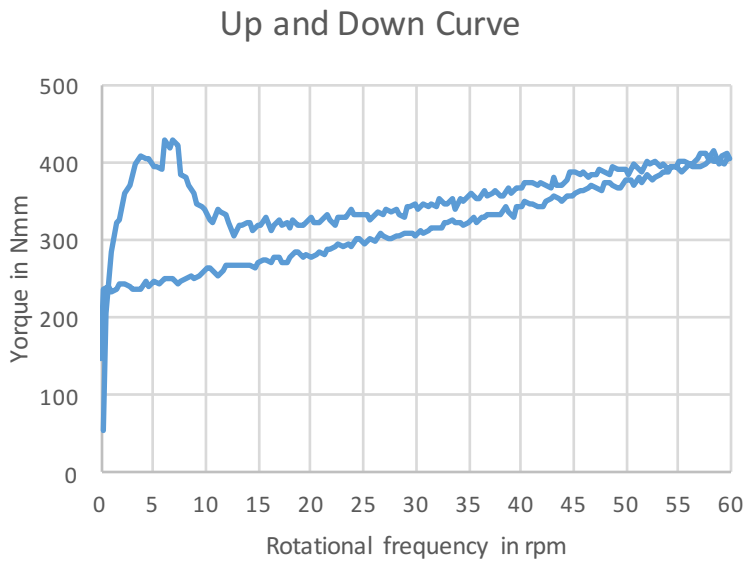
Pump



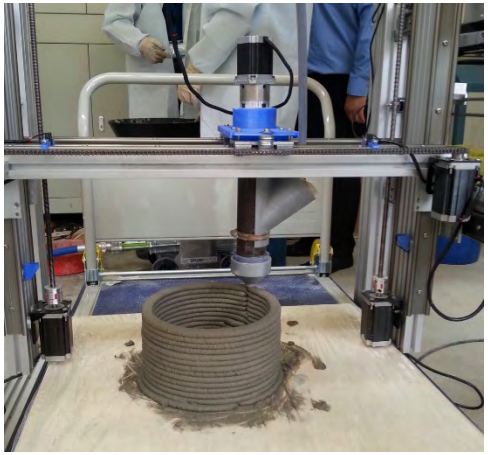

Robotic Printer

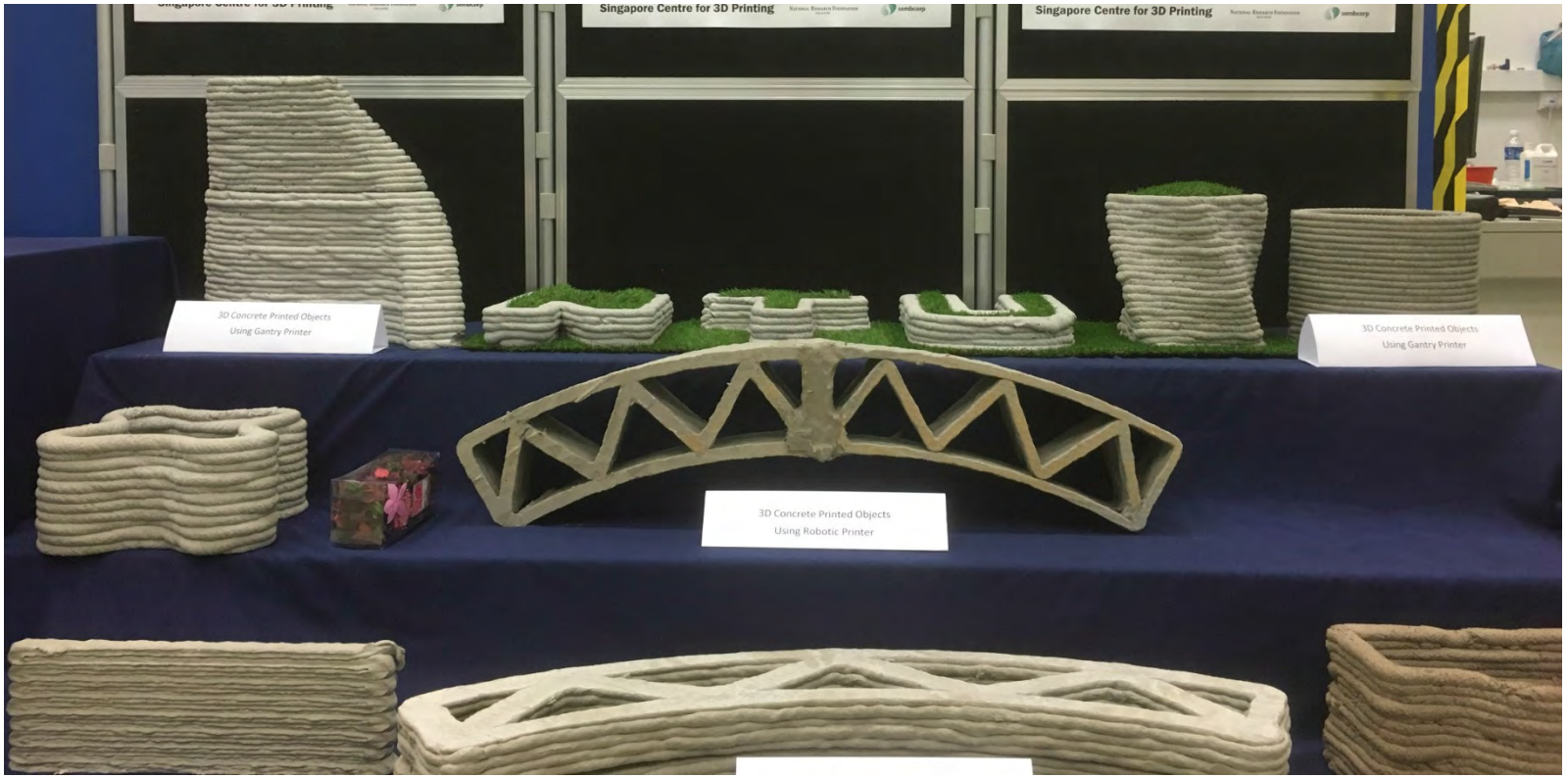



*Up and down curve of Run 2*




*Up and down curve of Run 5*




Singapore Centre for 3D Printing
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3D Concrete Printed Objects
Using Gantry Printer
3D Concrete Printed Objects
Using Gantry Printer
3D Concrete Printed Objects
Using Robotic Printer

# Conclusion

- Increase of GGBFS in the fly ash based geopolymer mixture reduces the workability and setting time. Slump of concrete and flow of mortar decreased with the increase of slag.

- Rheological parameters yield stress is more sensitive to changes in the molar strength of the NaOH solution and is comparatively less sensitive to the quantity of the sodium silicate solution in the mixture. Plastic viscosity, on the other hand, is sensitive to both the molar strength and the quantity of the sodium silicate solution in the mixture

## References


- Davidovits J. Geopolymer chemistry and application. 2nd ed. Saint-Quentin (France): Institut Géopolymère; 2008
- Nath, P. and Sarker, P.K., 2014. Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition. *Construction and Building Materials*, *66*, pp.163-171.
- Laskar, Aminul Islam, and Rajan Bhattacharjee. "Rheology of Fly-Ash-Based Geopolymer Concrete." *ACI Materials Journal* 108, no. 5 (2011).
- http://www.3ders.org/, http://3dprintingindustry.com/


Thank
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