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3D printing in construction: growth, benefits, and challenges

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3D Printing in Construction: Growth, Benefits, and Challenges

Khalil Almbaidheen

Concrete talk , 20/02/2023

www.thebig5saudi.com

Overview

- Introduction
- Projects in Gulf region
- Main components of 3DCP
- Challenges
- Materials

ACI –UAE chapter / 3D Printing Committee

Vision :

➢To be a leading group in 3D printing technology with Cementitious material in the UAE and a place where everyone who is interested in this technology can find connections, support and resources.

Mission:

➢Develop and disseminate information on 3D printing with Cementitious material based on local and global resources.

ACI –UAE chapter / 3D Printing Committee

Goals:

1. Support research of locally produced 3D printing materials and develop publications in this regard.

2. Collaborate with local municipalities, key regulators and related technical organization to provide the needed expertise to instill confidence with the technology and promote its use.

3. Develop a mix design guideline for 3D printing material that optimizes required properties such as sustainability, strength, setting time, etc.

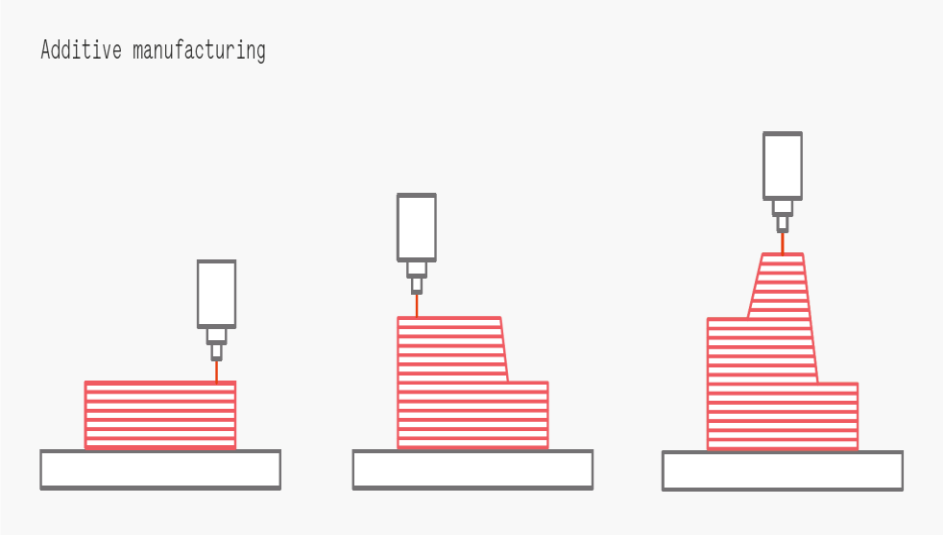
- The guideline will be built on the thorough understanding of relationships between the different material properties and will also provide guidance on testing & acceptance criteria.

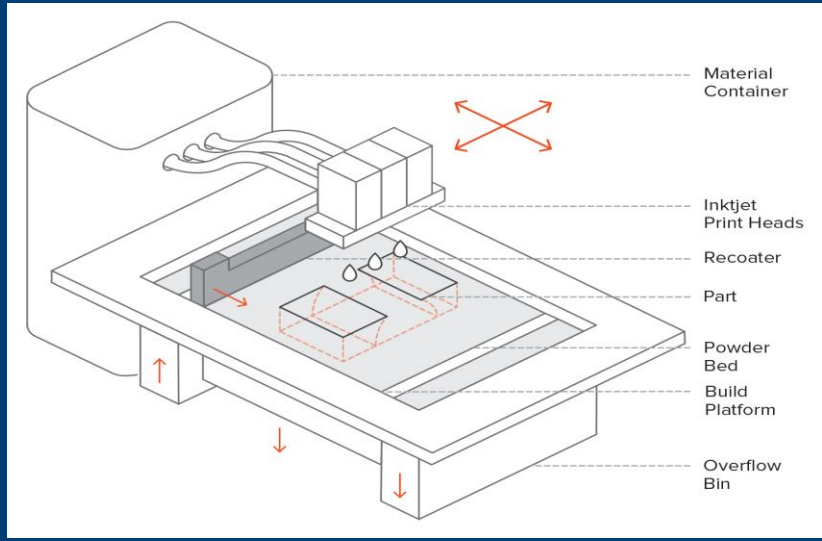
Introduction

Additive Manufacturing

Principle : Add 2D layers of materials one at a time to build the solid 3D part.

Definition : Fabrication of objects through the deposition of a material using a print head, nozzle or another printer technology





Projects in UAE






Projects in KSA

THE TALLEST 3D PRINTED BUILDING IN THE WORLD IS NOW IN SAUDI ARABIA

Projects in KSA

- 3 story 3D printing concrete building with area around 345 m2 .
- The building has a total height of 9.9m and is therefore also the tallest on-site 3D printed building in the world.
- The building was made without the use of a tent just after the summer in a hot dessert where temperatures run as high as more than 40 degrees

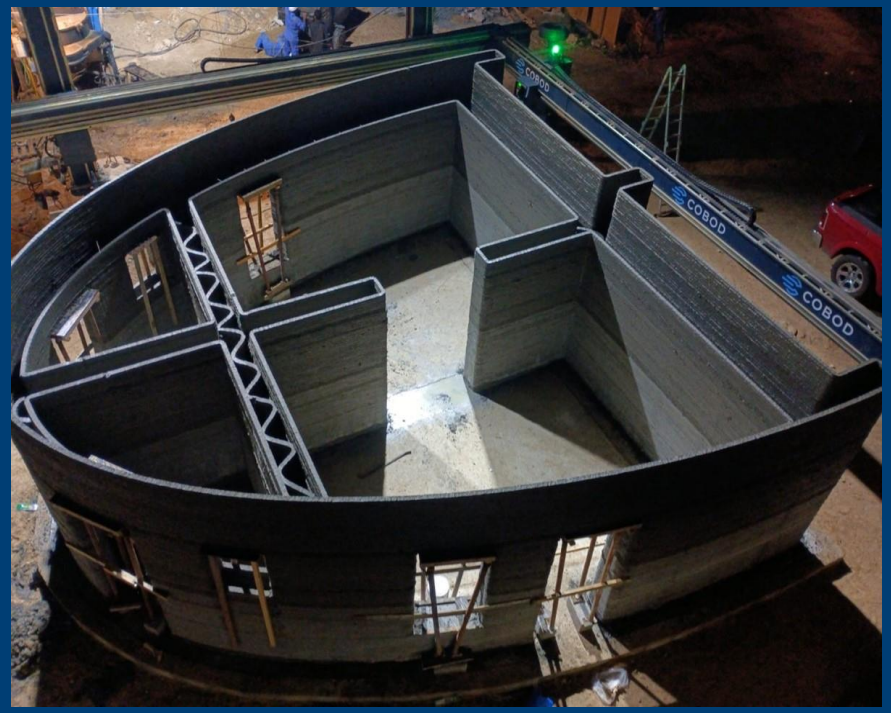
Projects in Oman

- GUTECH in oman has built 3 buildings in just 8 days in Duqm, Oman. The buildings was ready in 8 days only which recorded as the fastest record .

- The first 3D printed coffee shop in the world, a public restroom and a Fisherman's house was 3D printed in respectively 22, 13 and 19 hours and the total duration including movements of the printer was 8 days.

- A total of 173 m2 (1,851 SF) of buildings were made with a cost for the concrete of only 3,600 USD.

Projects in Oman



Benefits & challenges of 3DCP

Benefits of 3DCP

1. Reducing construction costs by eliminating the need of formwork;
2. Creating new high-end-technology-based jobs;
3. Saving of on-site construction time and avoiding frequent time delays by operating at a constant rate;
4. Minimizing the chance of errors and increasing efficiency by highly precise material deposition which would create tailored 3D components optimized based on functionality;
5. Increasing sustainability in construction by reducing wastages of formwork;
6. Increasing architectural freedom, which would enable more sophisticated designs for structural and aesthetic purposes;
7. Enabling potential of multifunctionality for structural/architectural elements by taking advantage of the complex geometry;

Benefits & Challenges of 3DCP

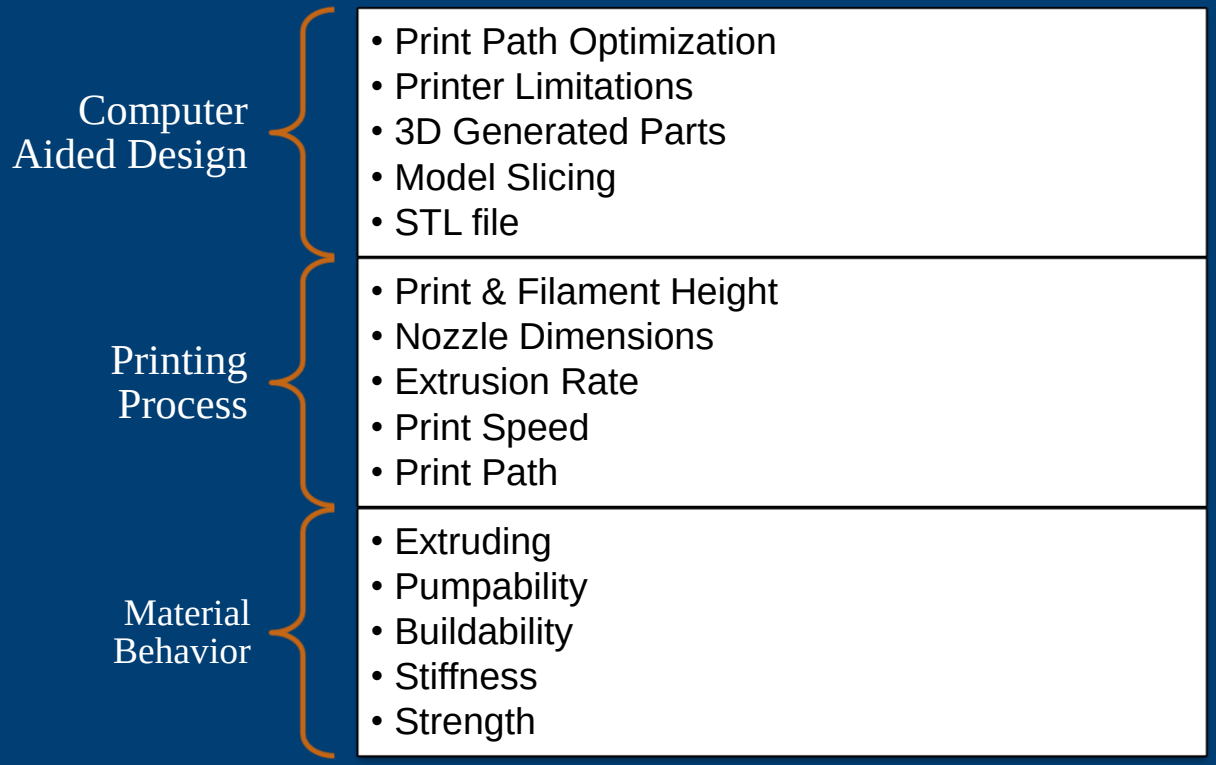
Challenges of 3DCP

1. Conservative Industry,
2. Low profit margin,
3. Expensive materials and equipment are used,
4. Regulatory obstacles,
5. At best only the cost and time of building the shell is impacted,
6. Major paradigm change requirement with respect to inspection,
7. Potential labor union opposition.
8. Post-processing (need for controlled environment)
9. Reinforcement in the 3D printed structure
10. Standard for concrete printing
11. Scalability

Main Components of 3DCP System

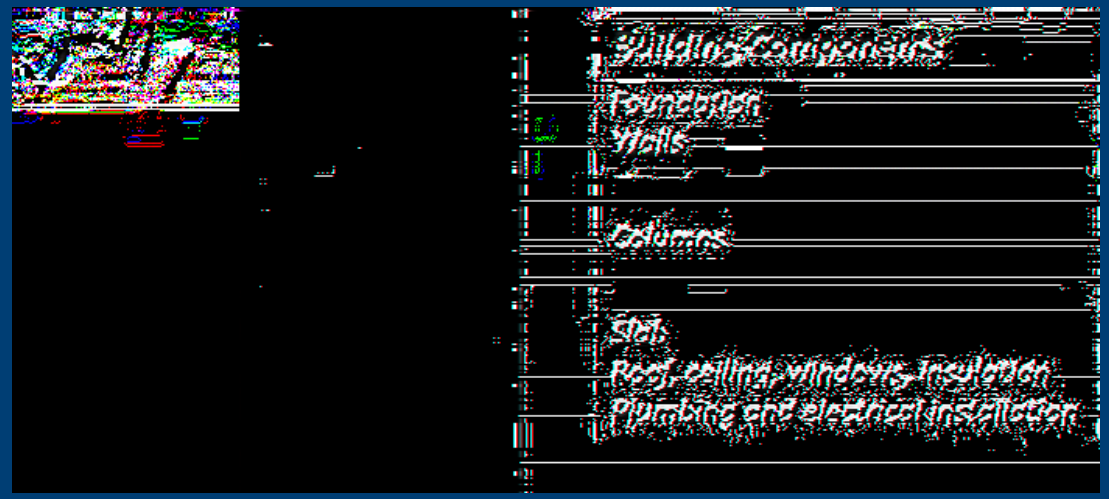
The multi-parameters interdependency of the main components of the 3DCP system.

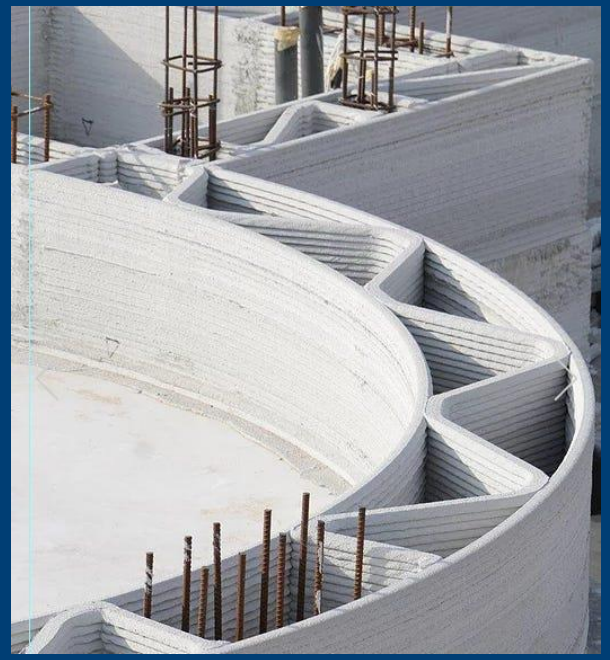
- Design (Print Geometry)
- Printing (3D Printer)
- Materials (Printable Concrete)



Main Components of 3DCP System

Printable Building Elements

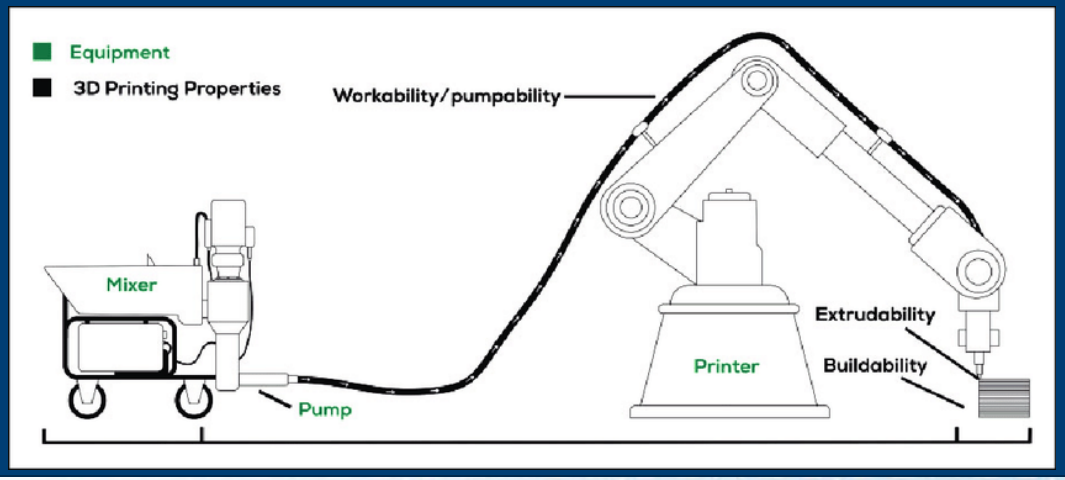




Benefits & Challenges of 3DCP

Challenges of 3DCP: Materials

- 3D printable materials (cementitious mortar or concrete)
  - ❖ Fresh properties: Flowability (pumpability), Extrudability, Buildability, Open time.
  - ❖ Hardened properties: Density, Compressive strength, Flexural strength, Tensile band strength, Shrinkage and Cracking.
- Structural integrity and anisotropic properties



Materials

3D printing mortar based on two principles:

1. Rheology based : easier to work with.
2. Setting Time based : easier to build with.

Mortars could use cements based on :

- Portland cement,
- Sulfur cements,
- Limestone cements,
- Calcium aluminate cements,
- Geo-polymer mixtures

Materials

Material Parameters:

- Flowability / Pumpability : the material need to be pumped through the delivery system to the nozzle. Setting time and workability must be checked. A prerequisite to extrudability.
- Extrudability/Printability: consistency of the material as it comes out of the nozzle. The material must be continuous and able to retain the shape of the nozzle .
- Buildability: the ability to add layers on top of each other. The material is expected to hold the weight of the fresh layers as they build up .
- Setting Time : Adhesion and bonding between printed layers. No formation of cold joints and material must fuse with neighbouring layers.

Materials

❖ Cementitious materials in their fresh state are **Bingham Plastic:**

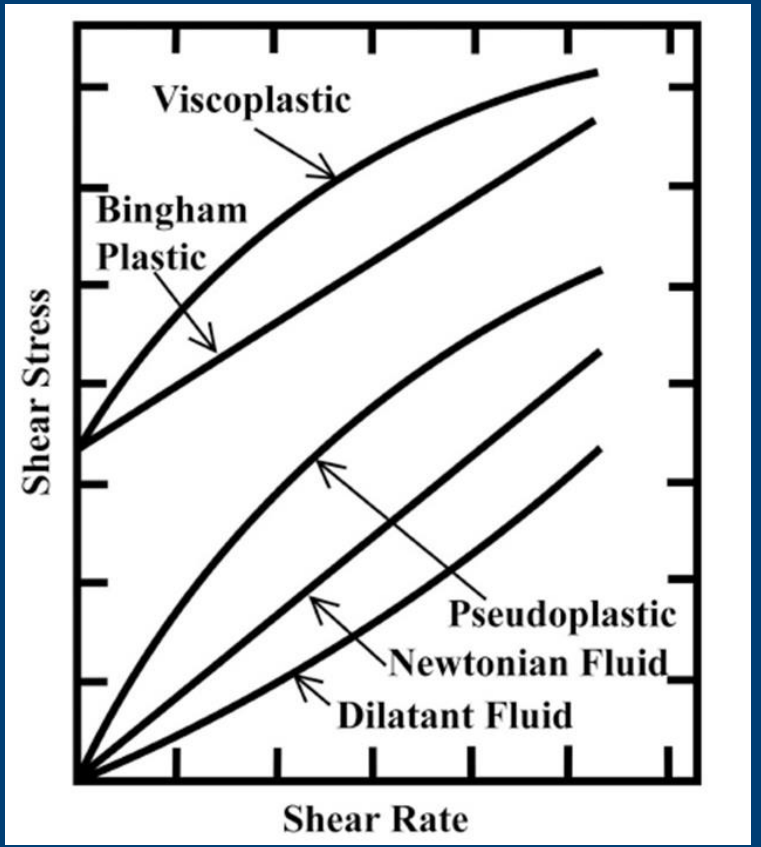
They need a specific shear force to flow,

The flow speed depends on the plastic viscosity.

❖ These are the fundamental rheological properties that must be controlled for 3D printing materials.

Realistically materials also have a time dependency: **thixotropy.**

After stress, yield-stress recovery rate or relaxation time is important for 3D printing.

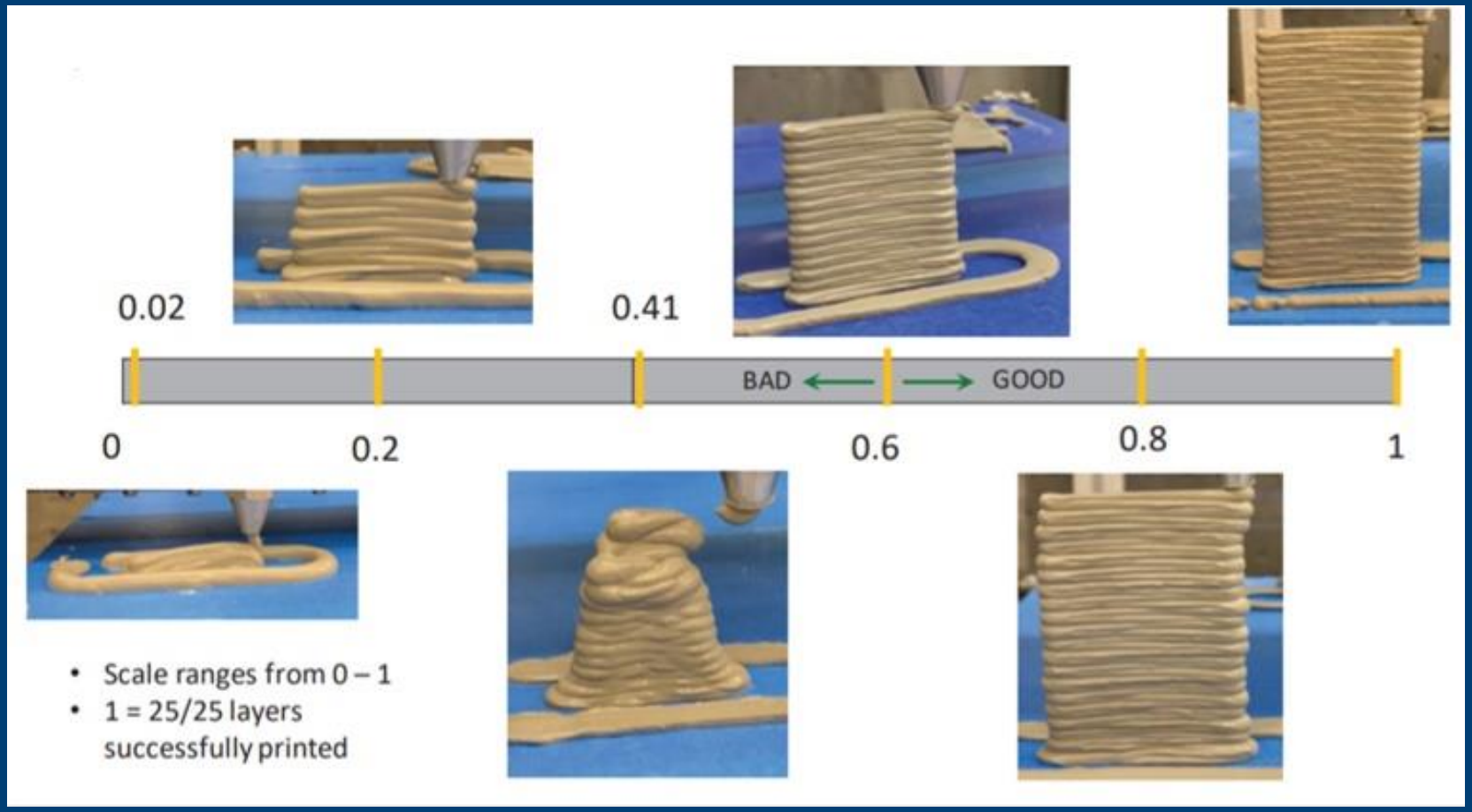


Materials

Concrete printing relies on depositing layers of material upon existing ones. This deposition process requires the material to behave as fluid during extrusion and as a pseudo-solid as soon as it is extruded.

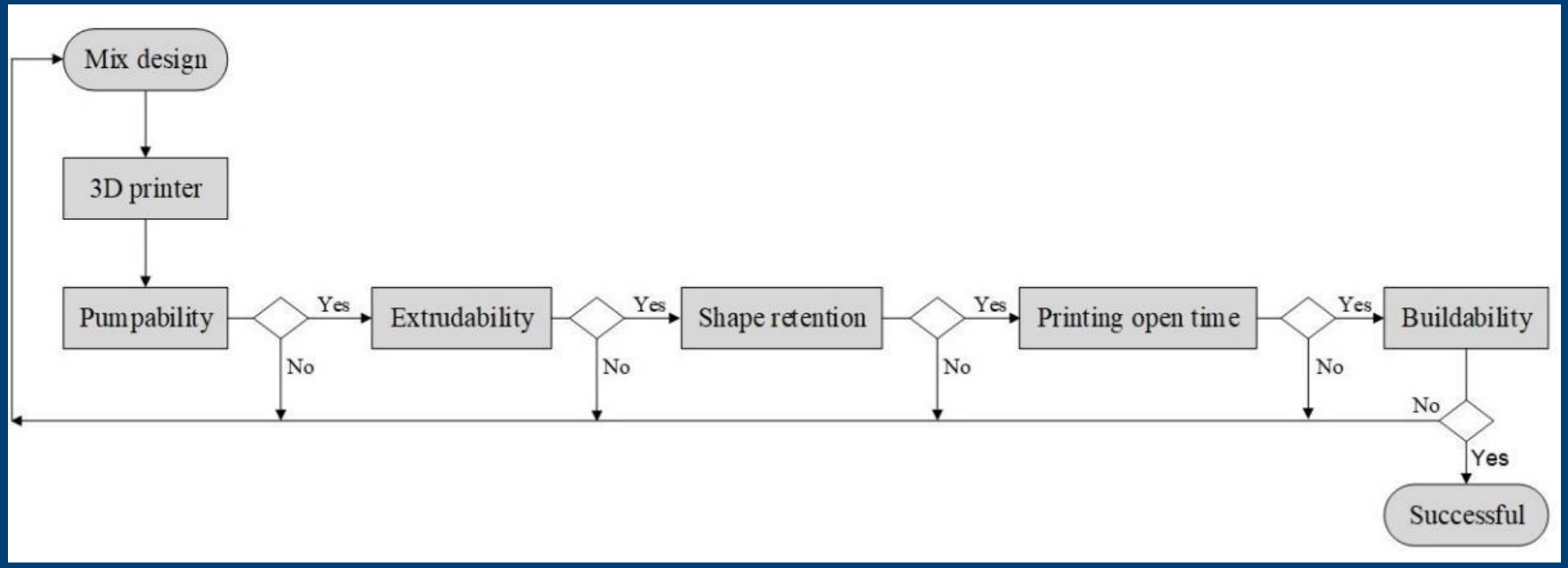
Materials

Printing Index



Materials

Process of preparing a printable concrete mix

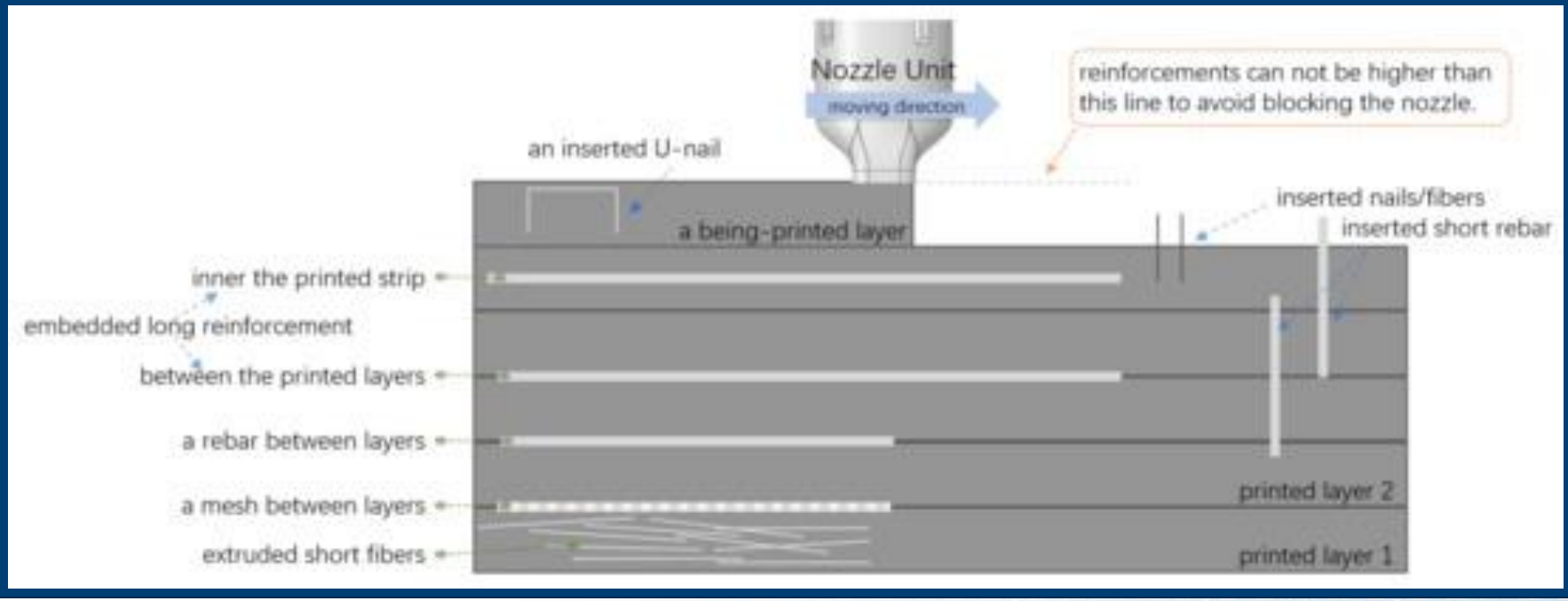


Materials

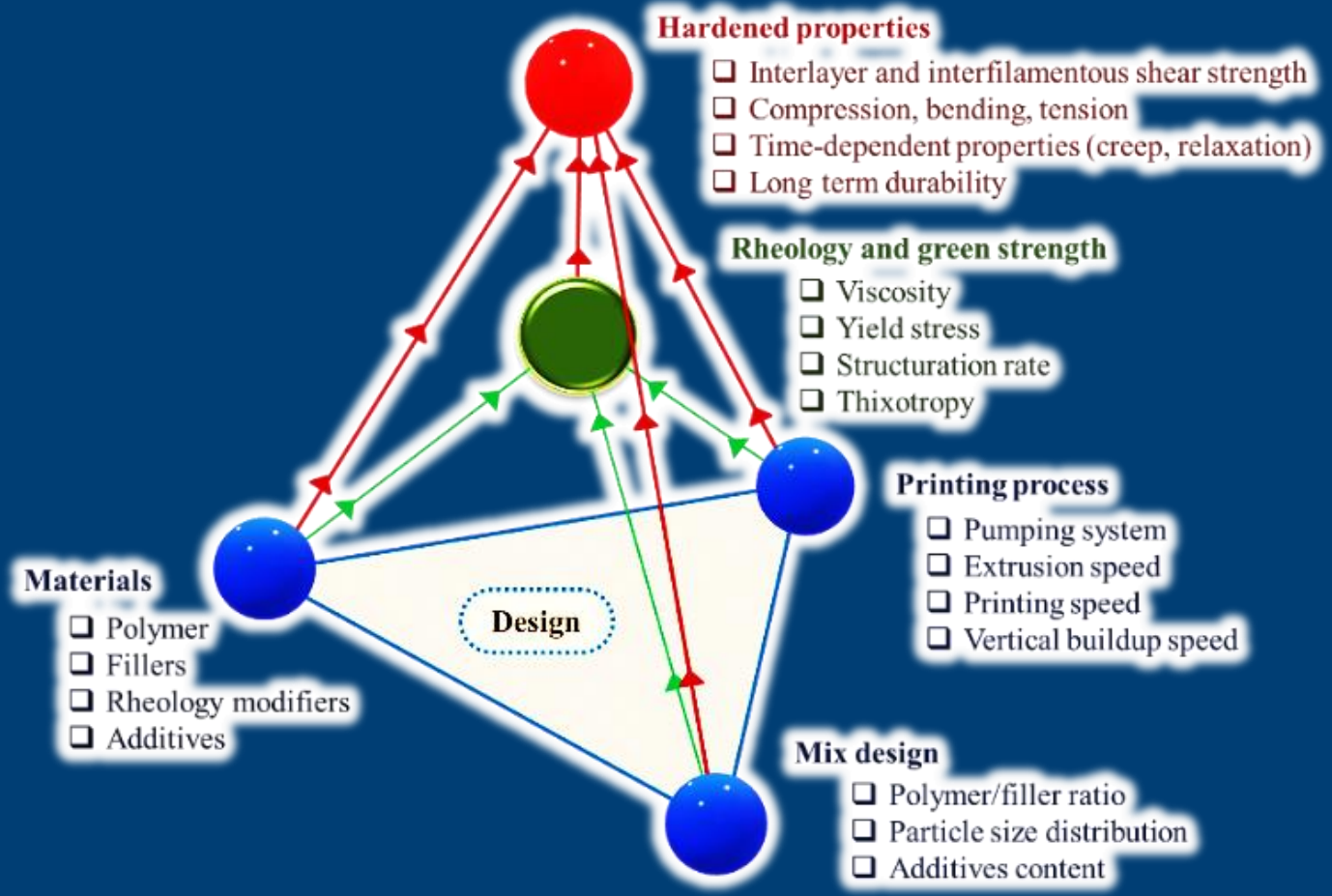
Challenges of 3DCP: Reinforcement

The current reinforcement techniques can be summarized as the following:

- ❑ Mixing (fibers): inner the filaments (Horizontal) ,
- ❑ Inserting: across the layers (Vertical) ,
- ❑ Placing: between the layers (Horizontal),
- ❑ Embedding: inner the filaments, between the layers (Horizontal).

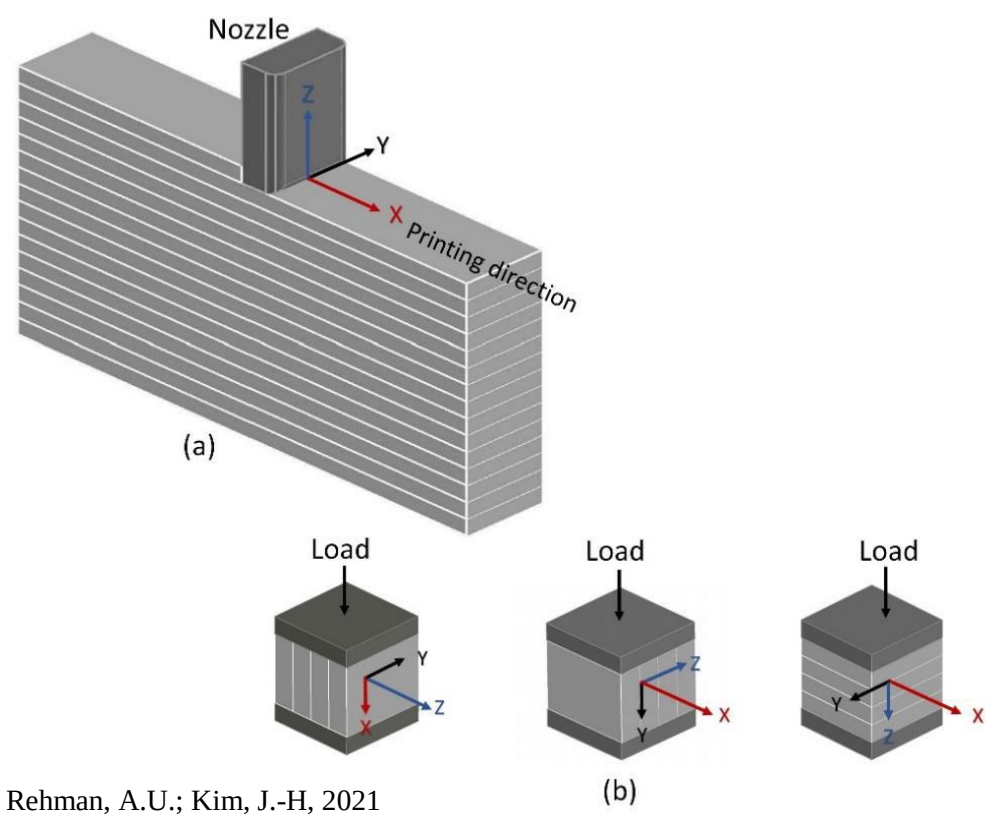


Materials


Hardened properties
❑ Interlayer and interfilamentous shear strength
❑ Compression, bending, tension
❑ Time-dependent properties (creep, relaxation)
❑ Long term durability
Rheology and green strength
❑ Viscosity
❑ Yield stress
❑ Structuration rate
❑ Thixotropy
Printing process
❑ Pumping system
❑ Extrusion speed
❑ Printing speed
❑ Vertical buildup speed
Materials
❑ Polymer
❑ Fillers
❑ Rheology modifiers
❑ Additives
Design
Mix design
❑ Polymer/filler ratio
❑ Particle size distribution
❑ Additives content

Materials

Anisotropy in Mechanical Properties of 3D-Printed Concrete



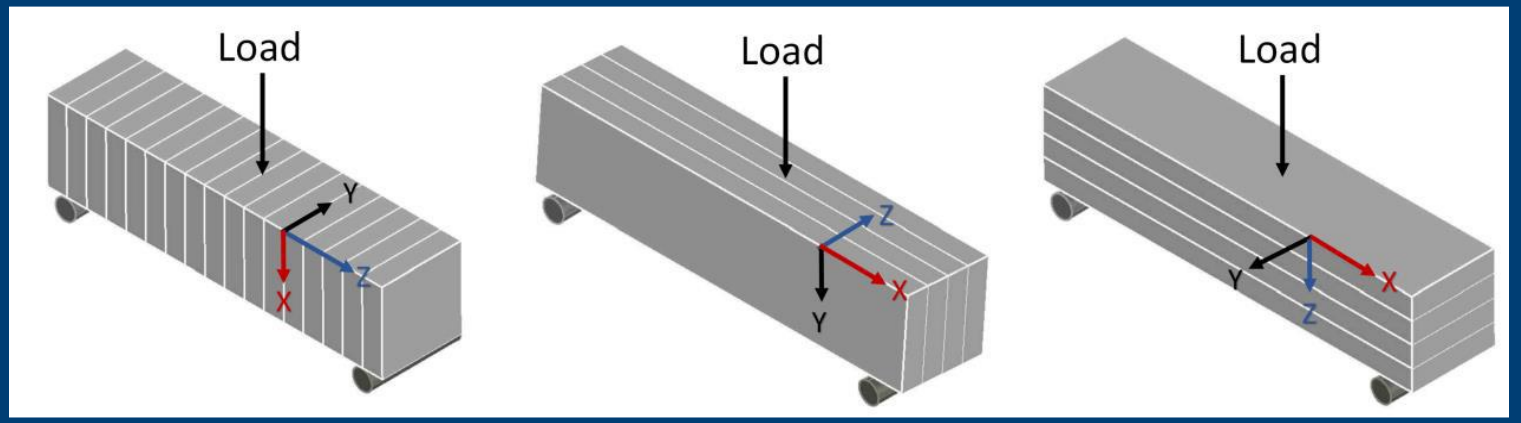
Rehman, A.U.; Kim, J.-H, 2021

(a) Designation of directions X, Y, and Z axes, to evaluate the anisotropic mechanical behavior;

(b) measurement of anisotropy in compressive strength

Materials

Anisotropy in Mechanical Properties of 3D-Printed Concrete



Designation of *X*, *Y*, and *Z* axes for the measurement of the anisotropy in flexural strength of printed concrete. Rehman, A.U.; Kim, J.-H, 2021

Thank you

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www.concrete.org