

Technische Universität München

TUM School of Life Sciences Weihenstephan

Lehrstuhl für Brau- und Getränketechnologie

Univ.-Prof. Dr.-Ing. Thomas Becker

150 Jahre  
culture of  
excellence



# Digital food design: 3D printing of customized cereal-based food

8. Frühjahrstagung



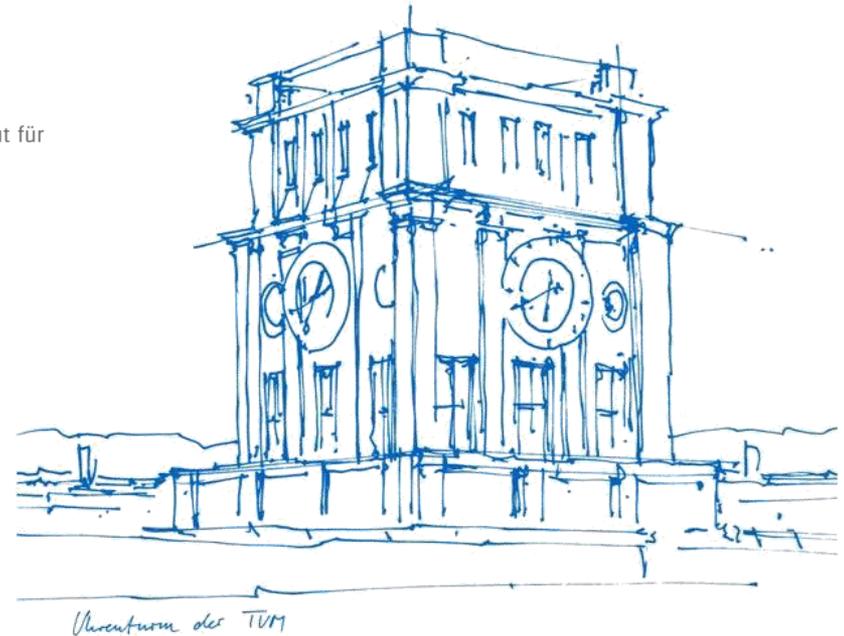
Weihenstephaner Institut für  
Getreideforschung

Fahmy, A.

Jekle, M.

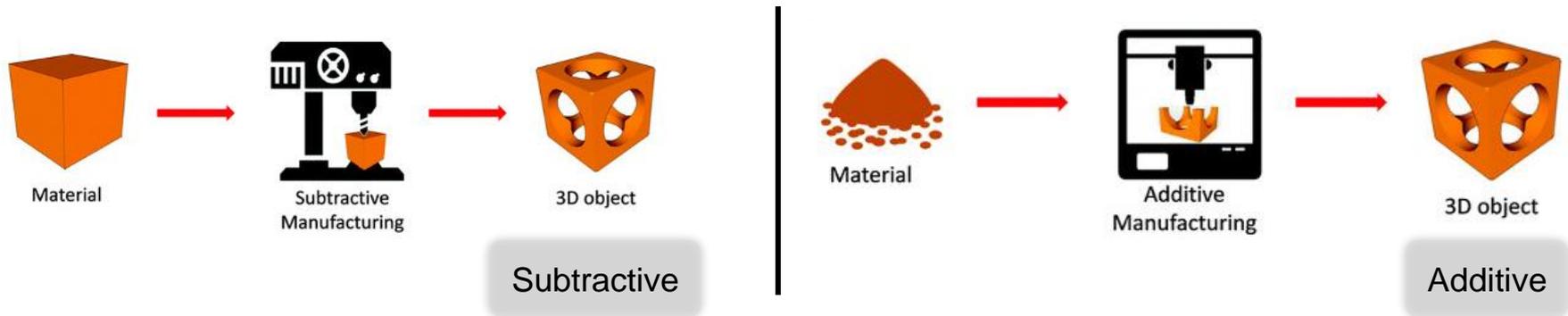
Becker, T.

Freising, 27.03.2019



## 3D printing technology:

- A rapid prototyping technique „using 3D computer aided design models“
- It belongs to the additive manufacturing process group „layer-based“



## Materials:

Plastics



Metals



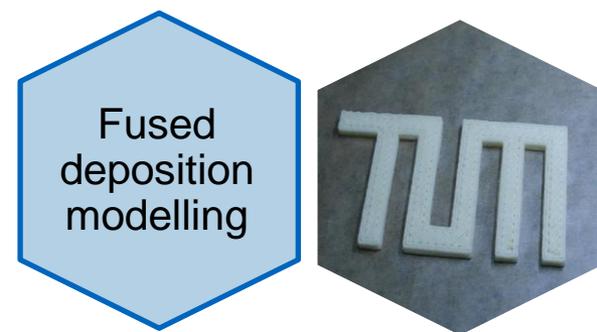
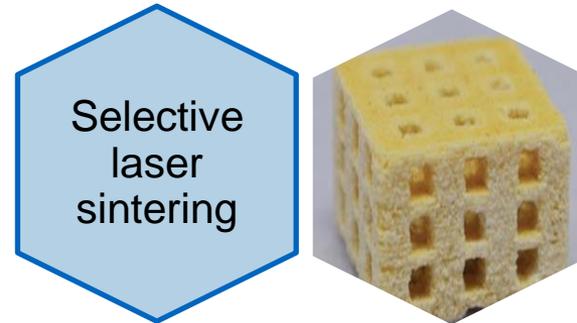
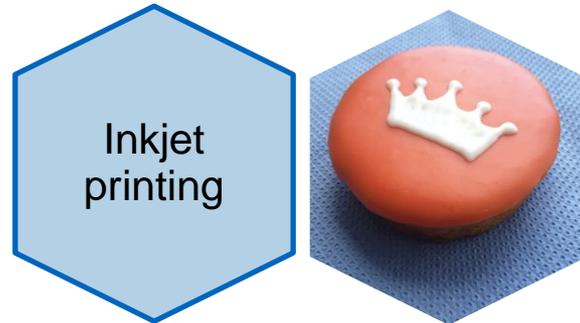
Food



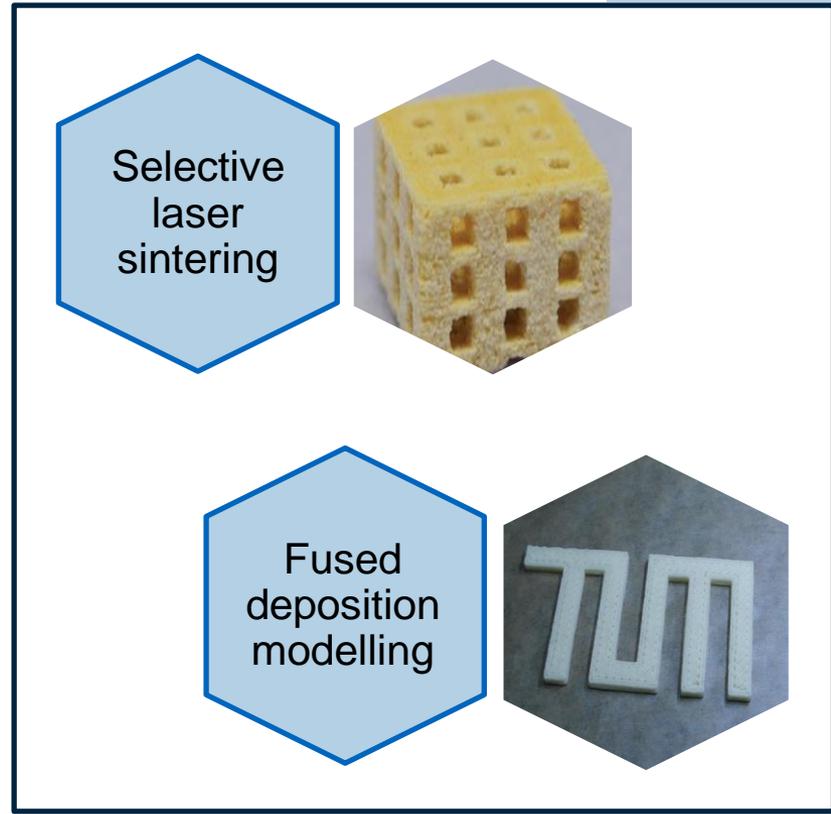
Subtractive vs. additive manufacturing (Ambrosi A. and Pumera M., 2016).

# State of the art

## Available technologies in the food industry:



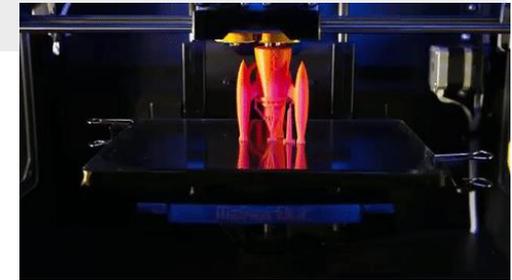
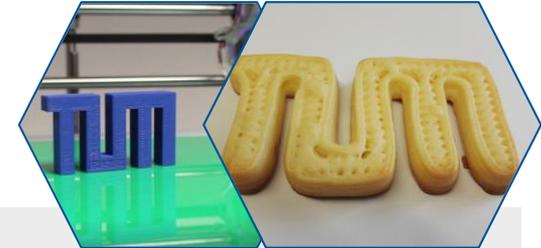
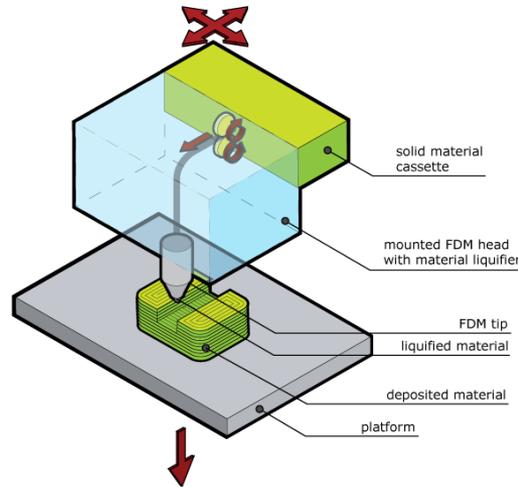
Cereals



# FDM: Extrusion-based technology

Working principle:

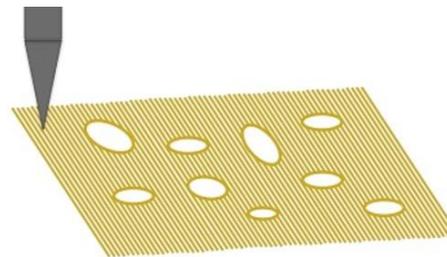
Fused  
deposition  
modelling



Advantages for cereal-based food:

By obtaining control over layer-based properties:

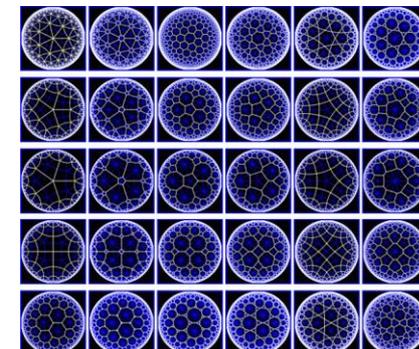
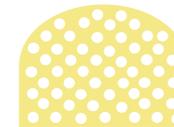
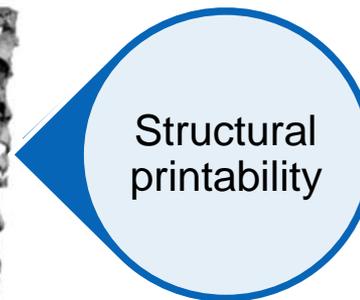
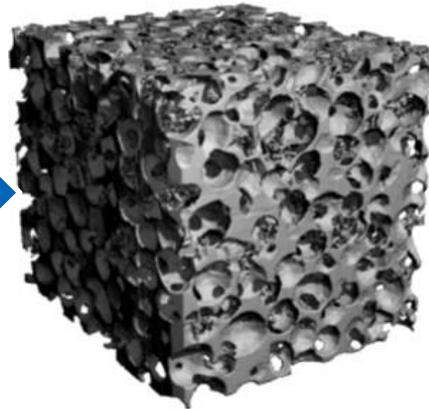
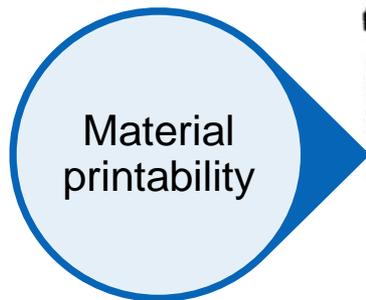
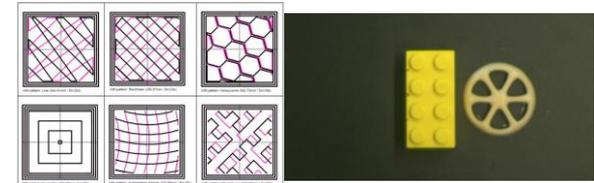
- Elimination of multiple processes
- Texture control
- Flavor manipulation



FDM schematic and operation (creax FDM 300).

## Printability:

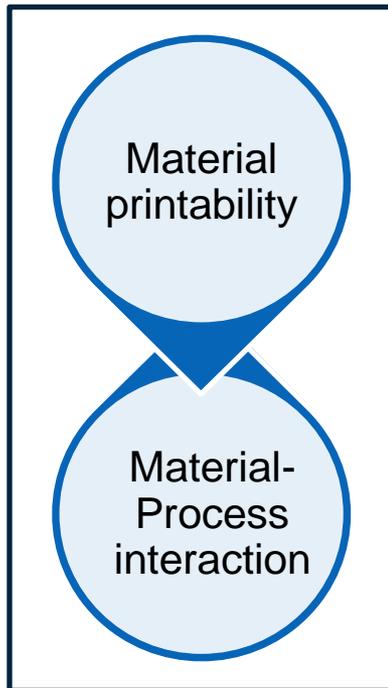
- Original definition: „the ability of paper to take in ink“ which from a scientific perspective discusses the ability not just in terms of material but process and conditions as well



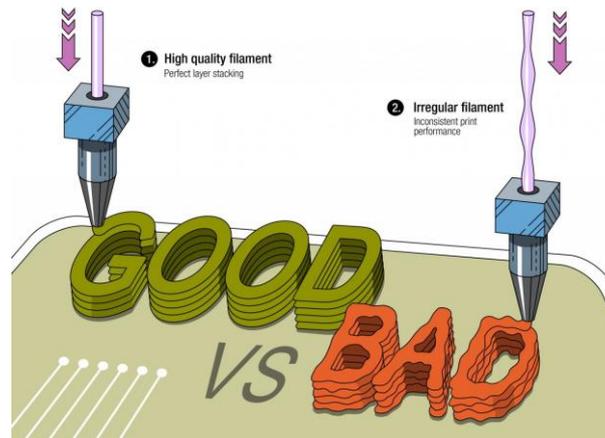
# Process compatibility: materials and structures

## Printability:

- Is cereal-based materials printable using such process and conditions?
  - Understanding the material-process interaction



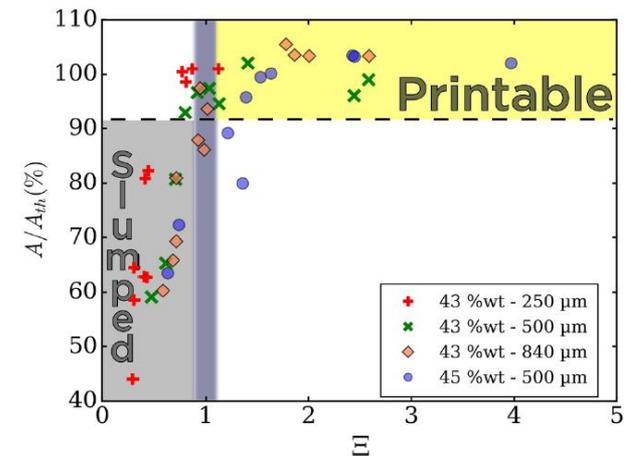
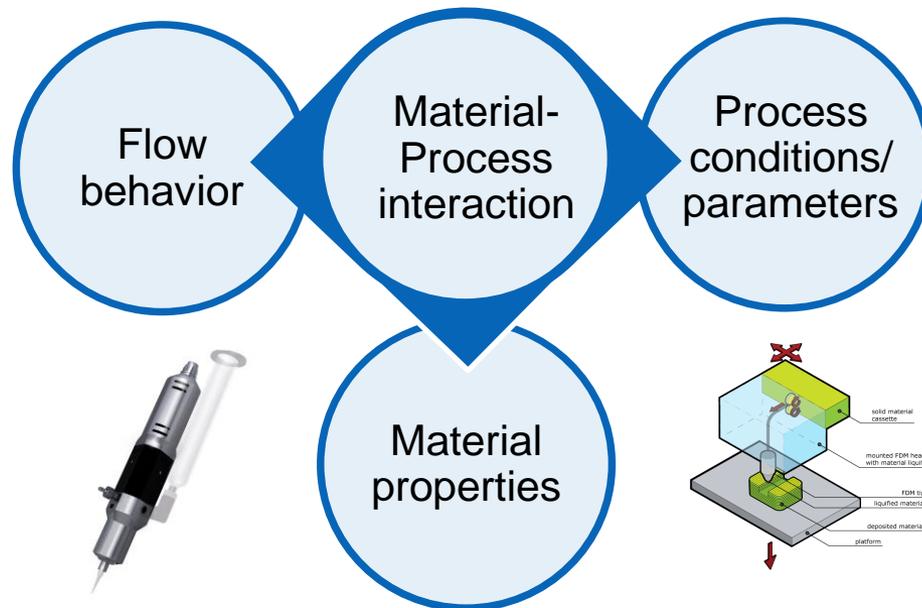
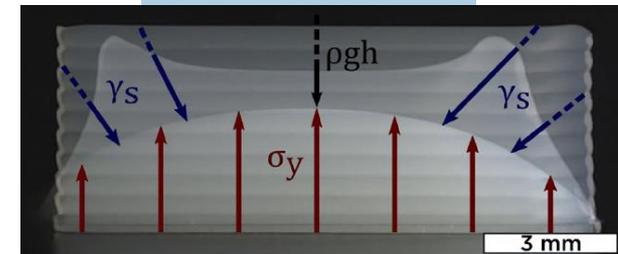
How extrusion affects the material?  
How the material behavior affects the 3D printing process?



## Printability:

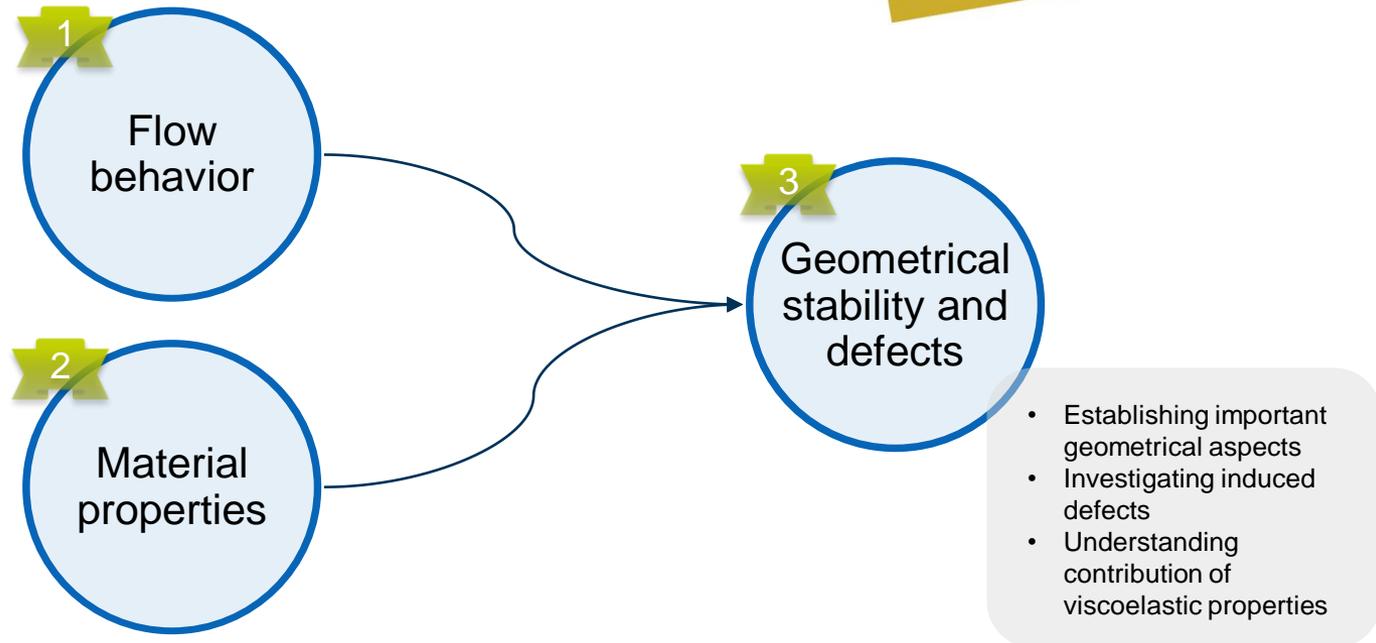
- Is cereal-based materials printable using such process and conditions?
  - Understanding the material-process interaction
  - Establishing an evaluation method
  - Establishing a criteria or a standard

Forces acting on the system



# Process compatibility: materials and structures

## Scientific approach:



## Materials:

- Simulating a high range of material properties and their interaction with the printing process, thus affecting the geometrical stability and stack-ability of the printed structures

Wheat flour doughs with varying water contents

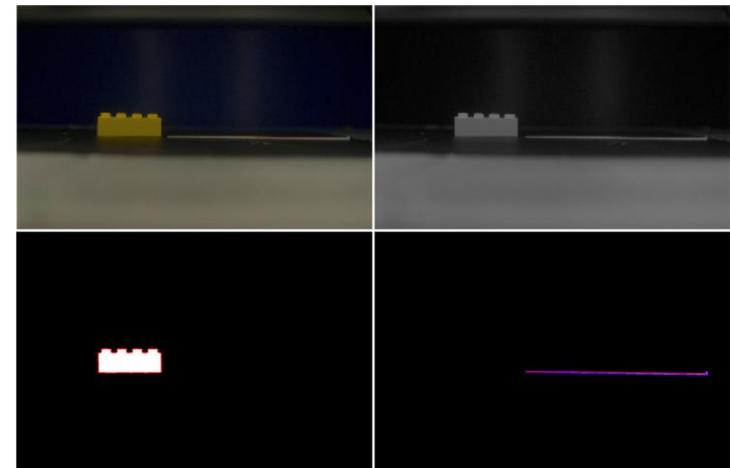
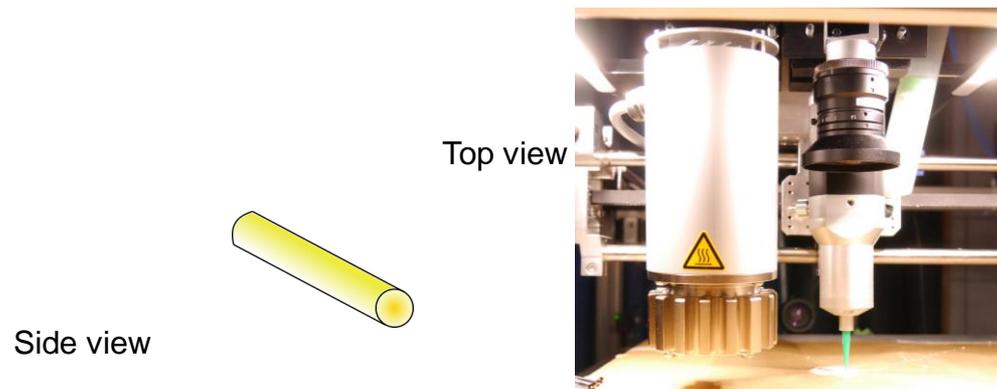
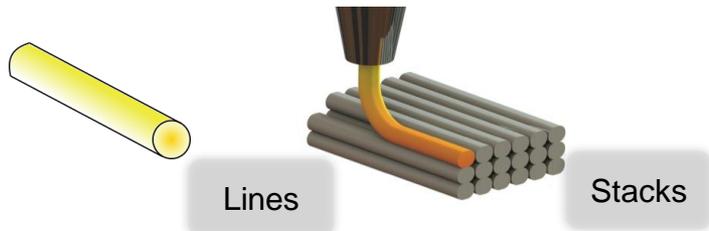
Wheat starch-egg white protein blends with varying water contents

# Quality analysis using an imaging morphological method

## Scientific approach:

- Printing of lines and stacks up to 5 layers
- On-board top and side view cameras
- Using image analysis algorithm to determine geometrical aspects

Geometrical stability and defects

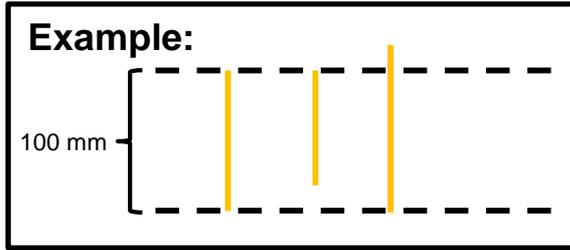


Process flow: from image to features extraction

# Quality analysis using an imaging morphological method

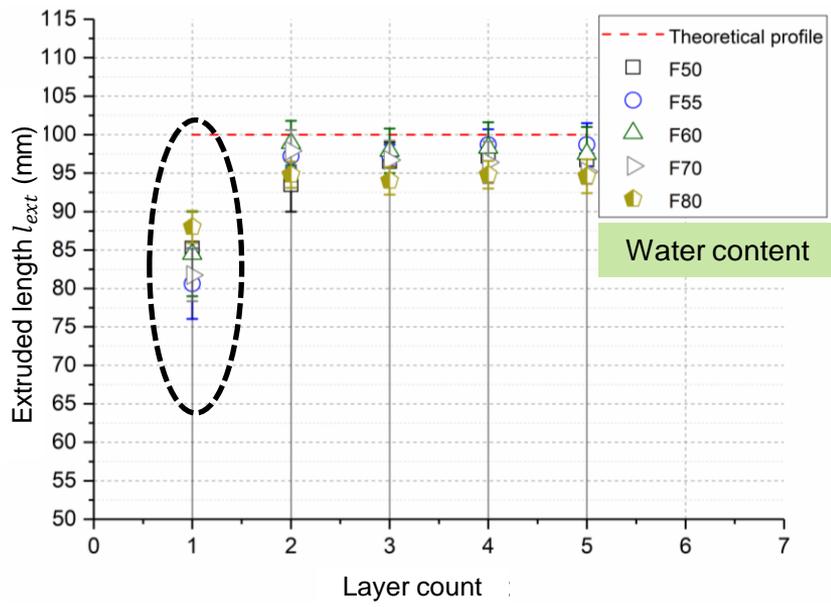
## Results overview:

**Abbreviations:**  
F50 abbreviation corresponds to the wheat flour mixture with water content 50 g/100g of dry material

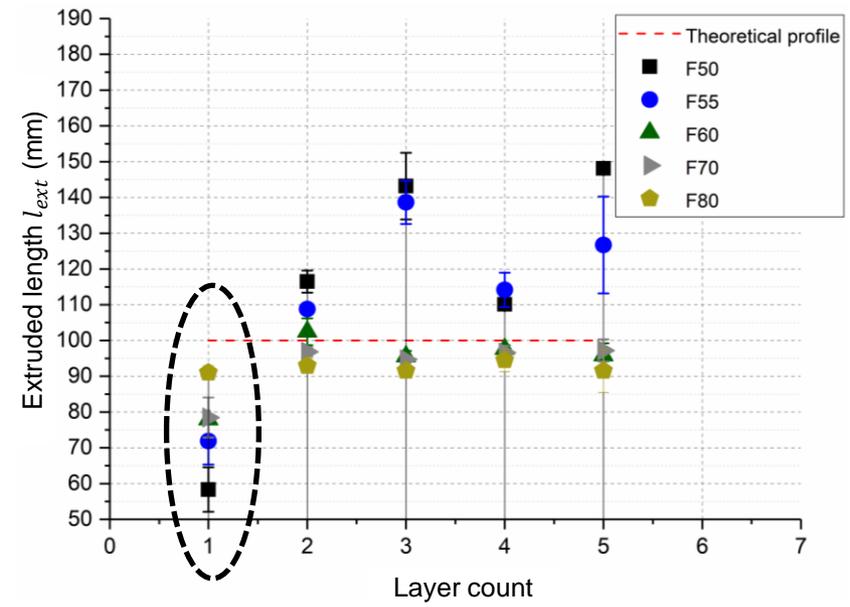


Extruded length

Wheat starch-egg white protein blends



Wheat flour doughs

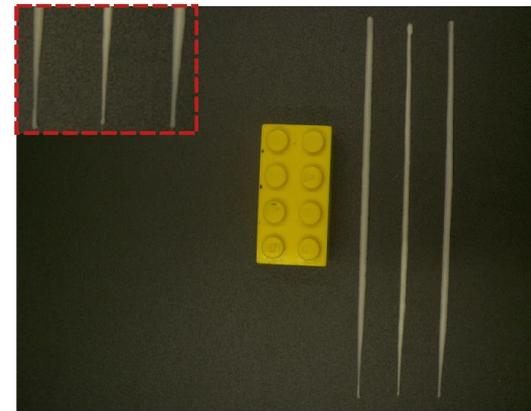


# Quality analysis using an imaging morphological method

## Results overview:

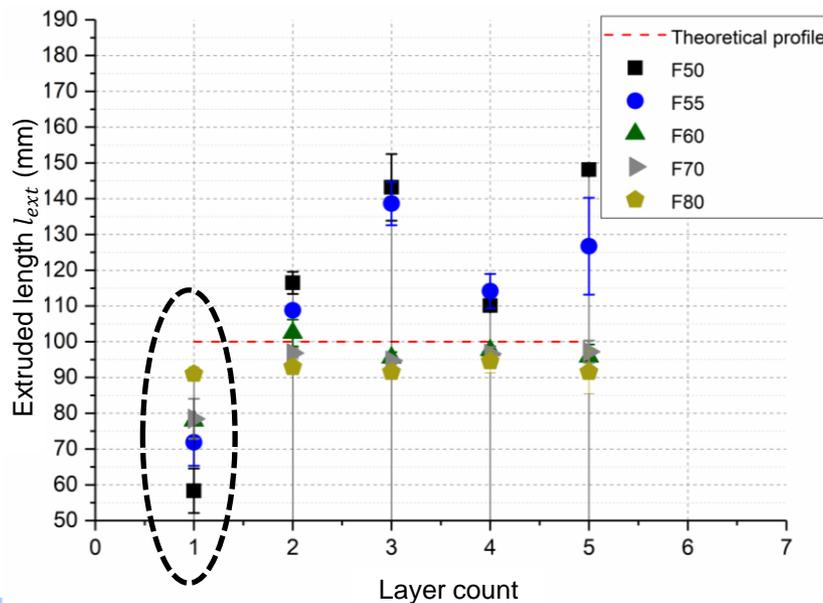
Induced delay caused by pressure gradient requirement to reach material yield strength

- During initiation of extrusion
- Corrected for increasing number of layers

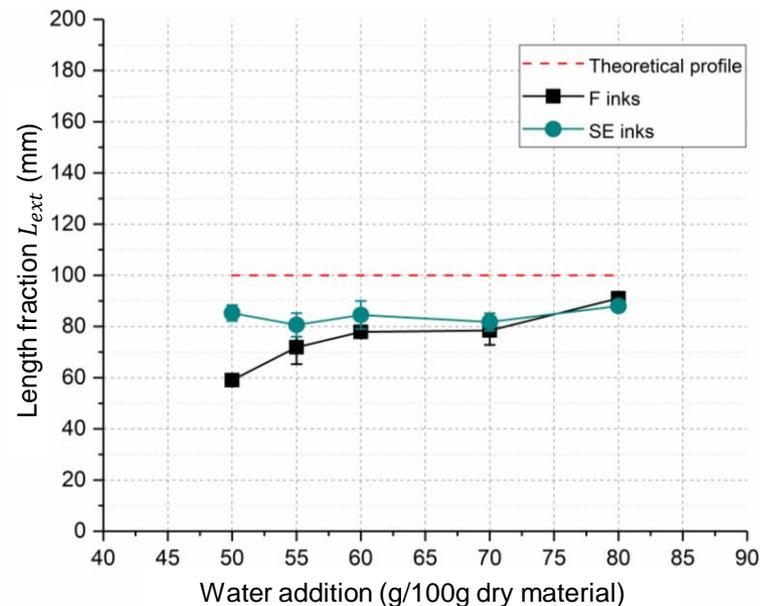


Under-extrusion

Wheat flour doughs



Initial delay in extrusion

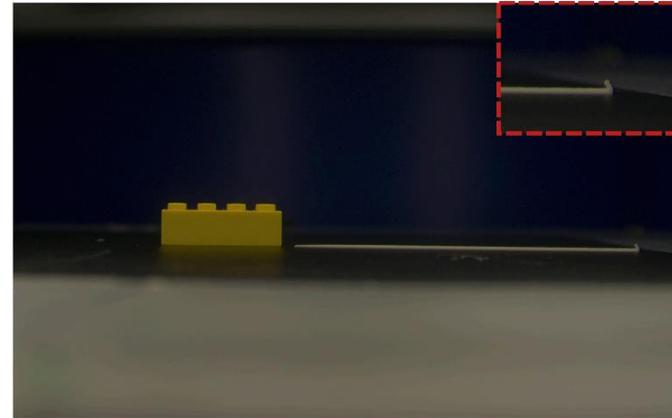


# Quality analysis using an imaging morphological method

## Results overview:

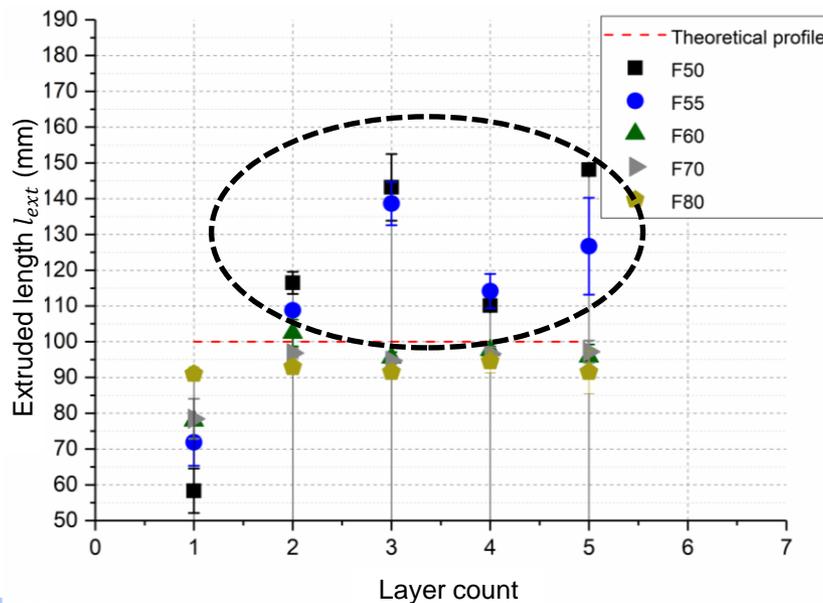
Pressure gradient increases due to yield strength hysteresis causing ooze behavior at the termination of extrusion

- Drag behavior occurs due to the network formation ability of gluten

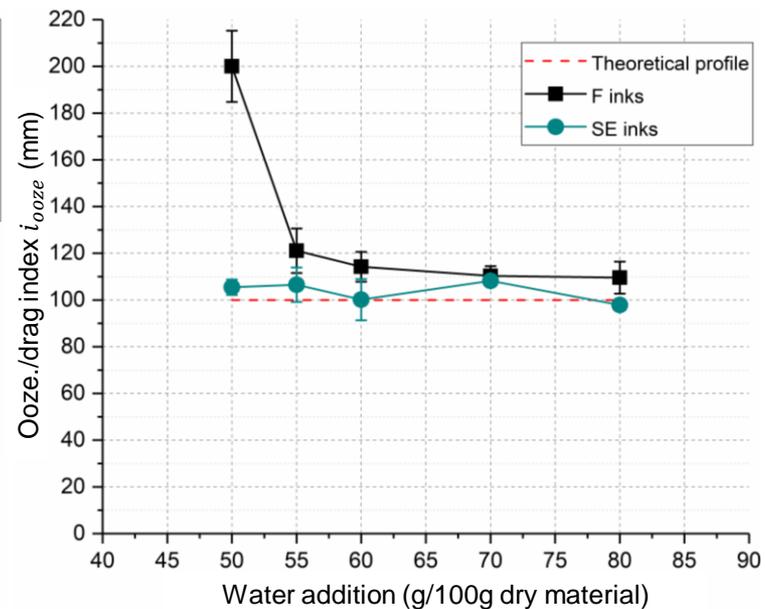


Over-extrusion

Wheat flour doughs



Final delay in termination

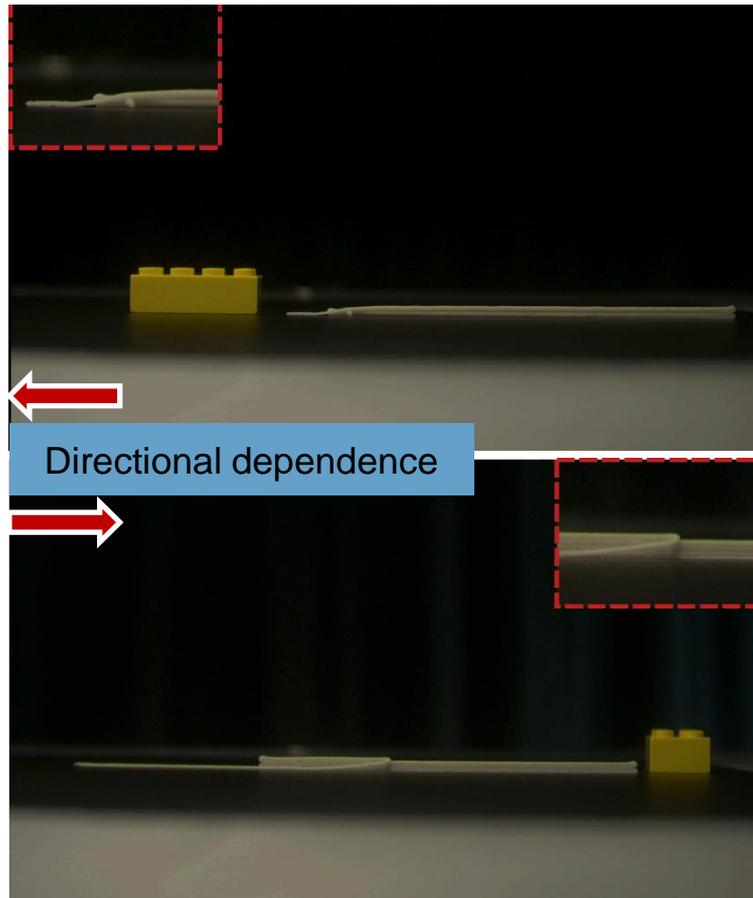


# Quality analysis using an imaging morphological method

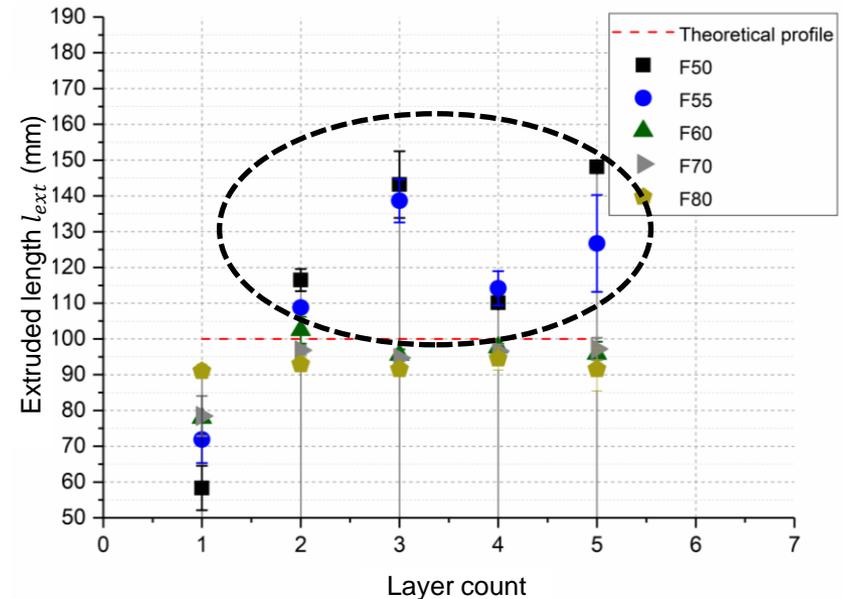
## Results overview:

Drag behavior causes elongation in the longitudinal direction while compression in the transversal direction which is directional dependent due to adhesion discrepancy

Stretch/drag behavior



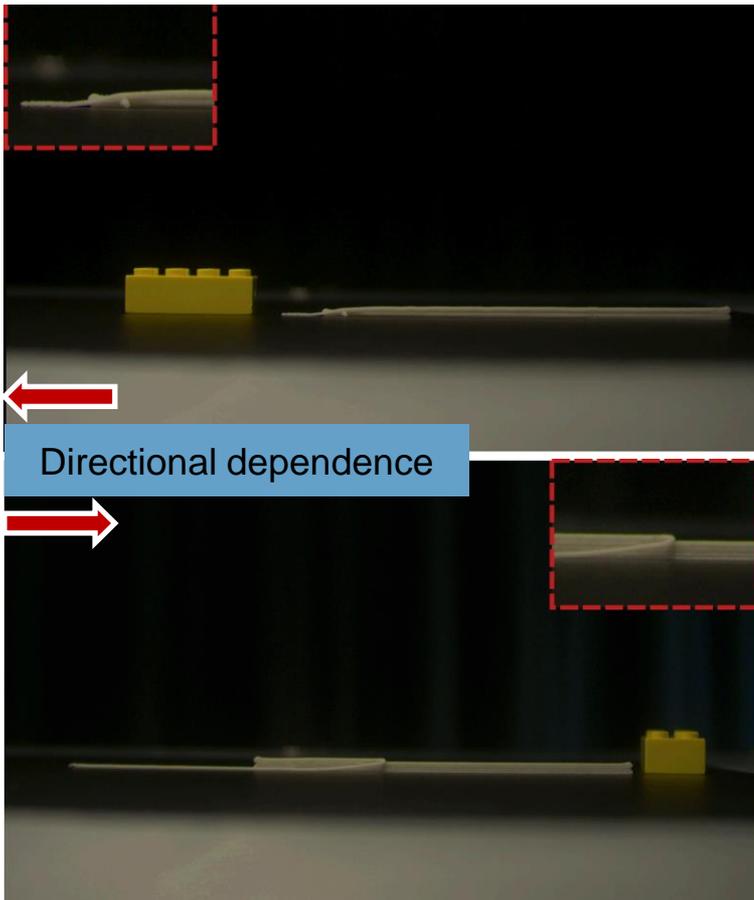
Wheat flour doughs



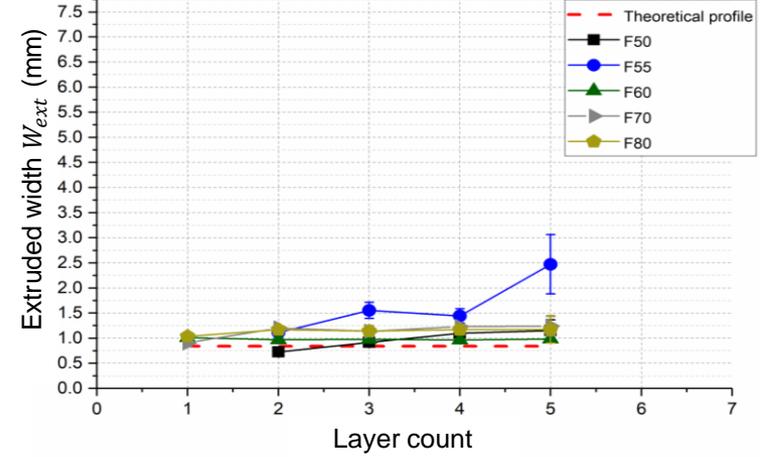
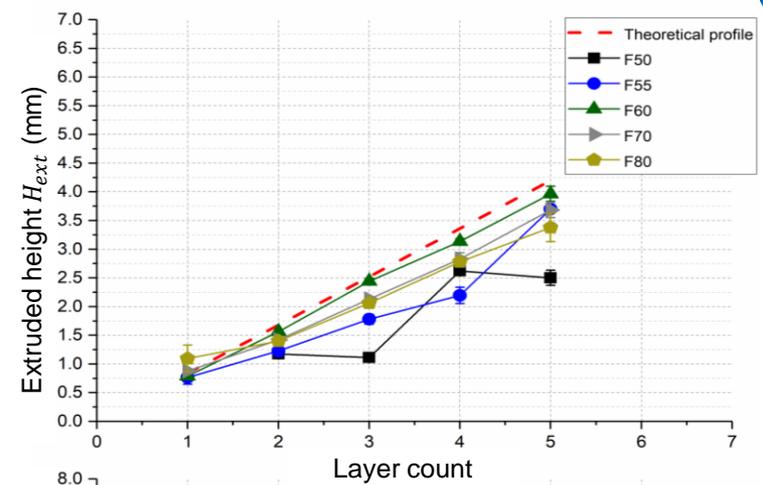
# Quality analysis using an imaging morphological method

Results overview:

Stacking-ability



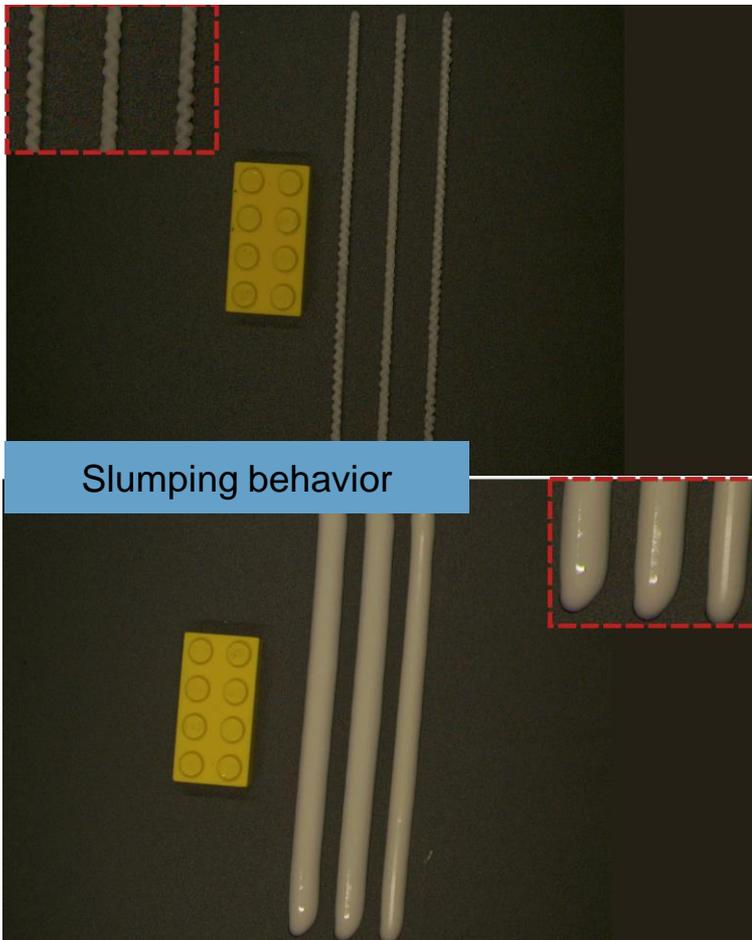
Wheat flour doughs



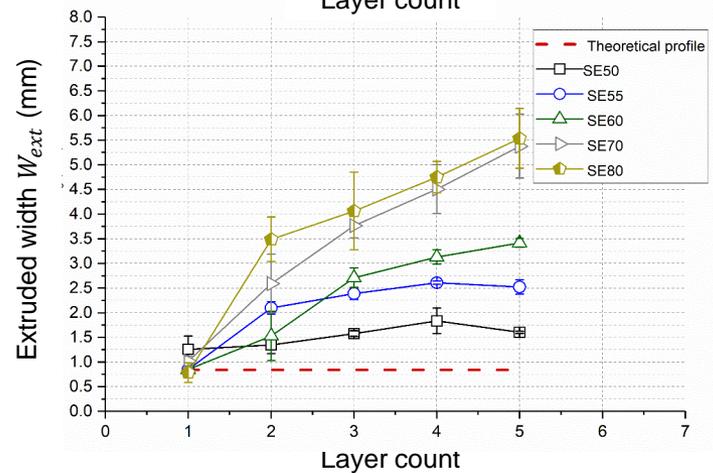
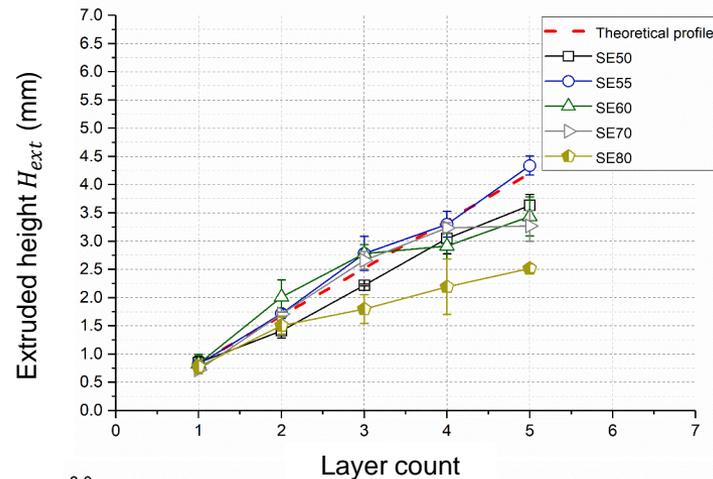
# Quality analysis using an imaging morphological method

Results overview:

Stacking-ability



Wheat starch-egg white protein blends



# Quality analysis using an imaging morphological method

## Material selection:

Wheat starch-egg white protein blends

### Pros and cons:

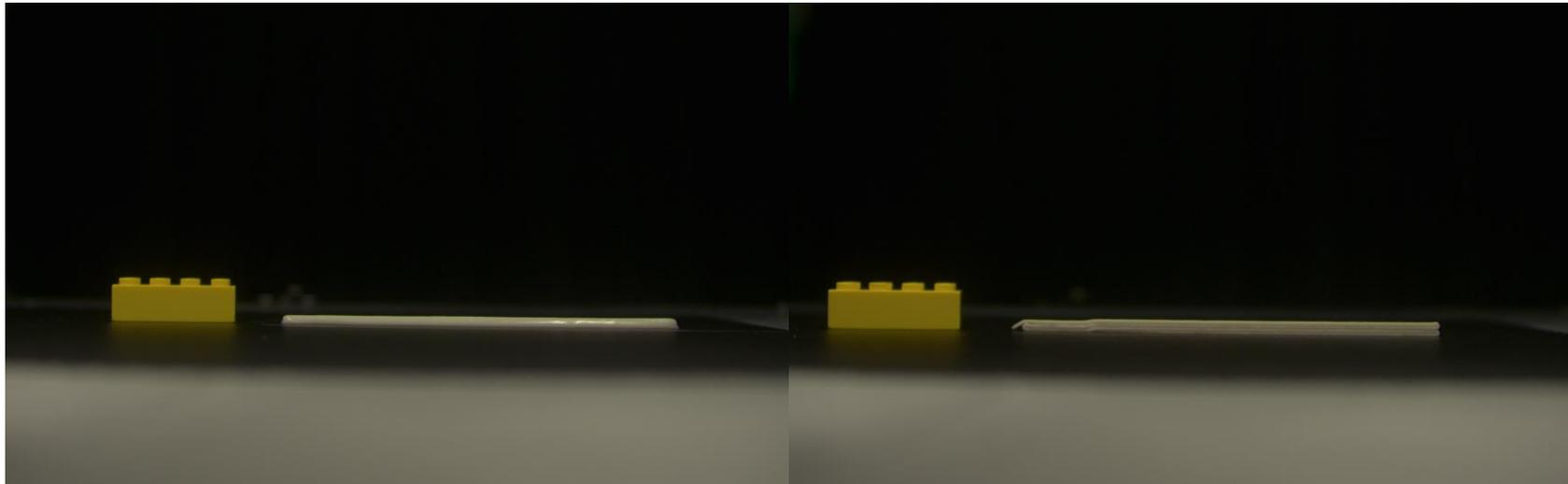
- Better dimensional accuracy
- Reduced overall defects
- Inferior structural stability even at lower water contents

Wheat flour doughs

### Pros and cons:

- Worse dimensional accuracy
- Higher overall defects at lower water contents
- Superior structural stability

Summary

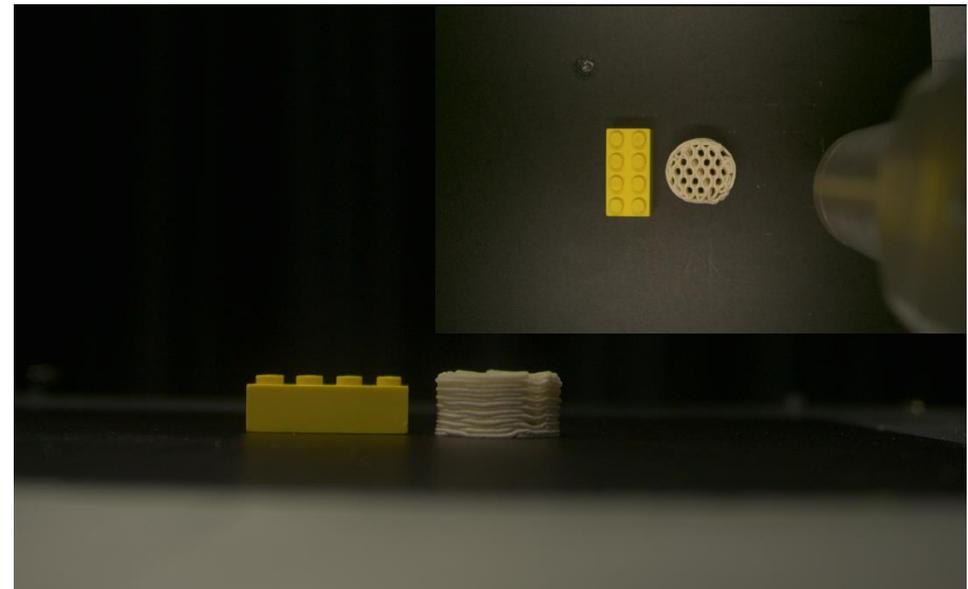


## Practical applications:

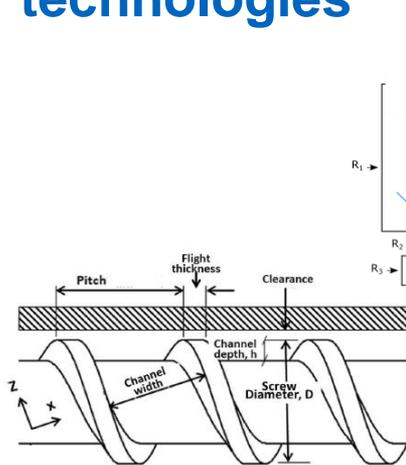
- Dual extrusion with local IR heating
  - Printing of composite materials
  - Addition of bread flavor or odor recombinants
  - Creation of local concentration gradients of flavors
  - Manipulation of textures

Sensory  
perception

## Design and execution:

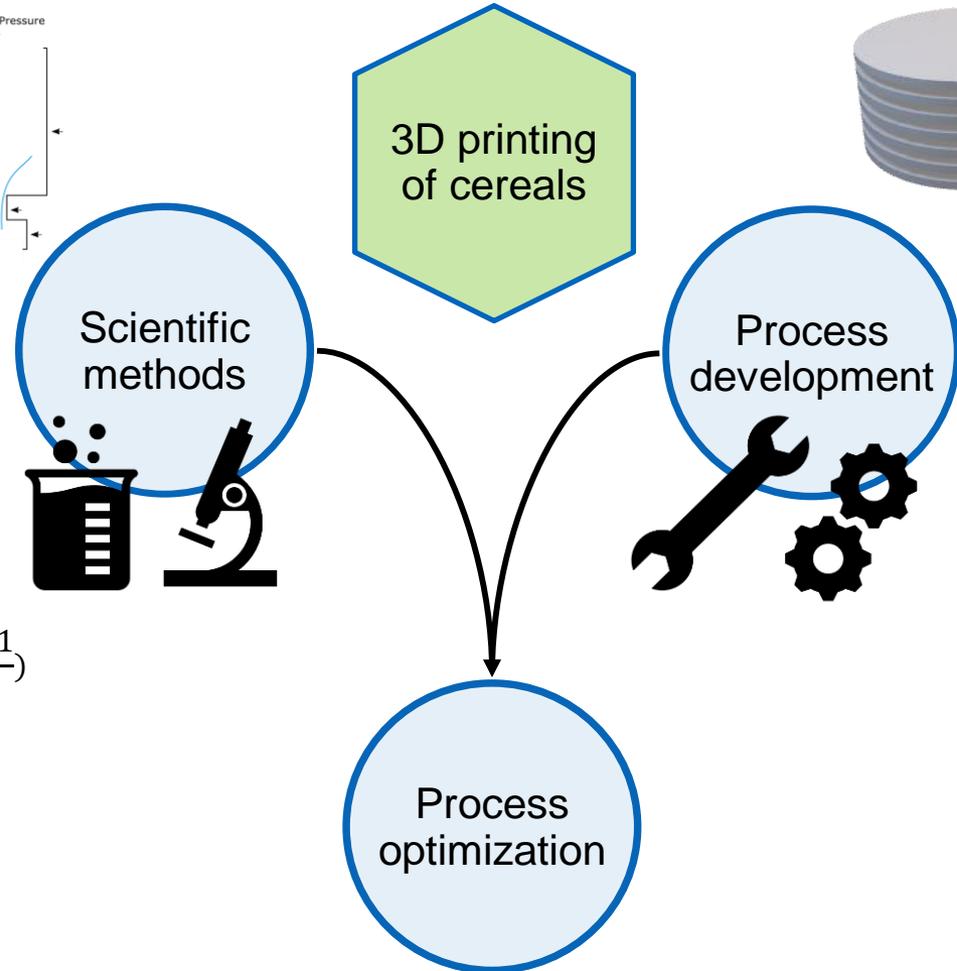


# Digital design of cereals and new production technologies



$$\dot{\gamma}_s = \frac{2Q}{\pi D \sin \varphi \cos \varphi H^2}$$

$$\dot{\gamma}_N = \frac{4Q}{\pi R^3} \left( \frac{3n+1}{4n} \right)$$

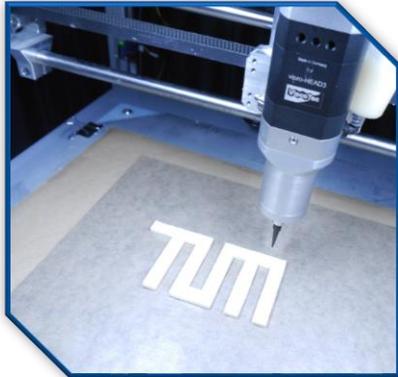


Thank you ...

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*... for your attention*



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Forschungsgemeinschaft  
German Research Foundation

Students acknowledgments:

- Marlene Reiser
- Deborah Kracheletz

Technische Universität München  
Lehrstuhl für Brau- und Getränketechnologie  
Weihenstephaner Steig 20  
D-85354 Freising

Tel: +49 8161 71 3404  
Fax: +49 8161 71 3883  
E-Mail: [ahmed.fahmy@tum.de](mailto:ahmed.fahmy@tum.de)  
[lbgt.wzw.tum.de](http://lbgt.wzw.tum.de)



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