4D-printed motion mechanisms inspired by Dioscorea bulbifera

Tiffany Cheng
Material Programming, Institute for Computational Design and Construction (ICD), University of Stuttgart

2021 June 22 | MéPhy Seminar: From Computational Fabrication to Material Design
4D-printed motion mechanisms inspired by Dioscorea bulbifera
4DmultiMATS:

Personalised 3D- and 4D-Printing of programmable, self-adjusting and multifunctional Material Systems for Sports and Medical Applications

Collaborators:

Institute of Macro Molecular Chemistry (Prof. R. Mülhaupt)

Plant Biomechanics Group Freiburg (Prof. T. Speck)

Oral Biotechnology, University Hospital Freiburg (Prof. T. Steinberg)

BIOLOGICAL INSPIRATION: FORCE GENERATION OF DIOSCOREA BULBIFERA

BIOLOGICAL INSPIRATION: FUNCTIONAL PRINCIPLE AND ABSTRACTION

Functional principle

Abstraction & technical interpretation
COMPUTATIONAL DESIGN: GEOMETRIC TOPOLOGICAL MODELING

Geometric Modelling

Shape prediction

Fabrication data

HYGROSCOPIC SHAPE CHANGE: TESTING AND EVALUATION

STwist_10h60_45deg_2layers_x_grid_03 (3D printing name)_8.0 mm (layer size)_0.8 mm (layer size)_0.6 mm (height size)

Diagram
Perspective Humid
Front Humid
Side Humid
Top Humid
Perspective Dry
Front Dry
Side Dry
Top Dry

PRINTING SETUP

<table>
<thead>
<tr>
<th>Printer Model</th>
<th>Filament Type</th>
<th>Tower</th>
<th>塔数</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full 3.0</td>
<td>PLA 1.75</td>
<td>1/2</td>
<td>2</td>
</tr>
</tbody>
</table>

LOW RH MEASUREMENTS (Average)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Measurement</th>
<th>Width (mm)</th>
<th>Length (mm)</th>
<th>Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>Average</td>
<td>12.885</td>
<td>58.98</td>
<td>0.71</td>
</tr>
<tr>
<td>Sample 2</td>
<td>Average</td>
<td>0.316</td>
<td>57.79</td>
<td>0.78</td>
</tr>
</tbody>
</table>

ACTUATION CONDITIONS

| Humidity (%) | 25 | 50 | 75 | 2 | 4 |

SPECIMEN INFO

<table>
<thead>
<tr>
<th>Material</th>
<th>Arrow</th>
<th>Line</th>
<th>45°</th>
<th>60°</th>
<th>60°</th>
<th>0.6mm</th>
<th>1 layer</th>
<th>2 layer</th>
</tr>
</thead>
</table>

SAMPLE 1

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Weight (g)</th>
<th>Width (mm)</th>
<th>Length (mm)</th>
<th>Height (mm)</th>
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</thead>
<tbody>
<tr>
<td>20210301</td>
<td>08:00</td>
<td>25°C</td>
<td>27%</td>
<td>0.4305</td>
<td>58.98</td>
<td>0.71</td>
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HIGH RH MEASUREMENTS

<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>Width (mm)</th>
<th>Length (mm)</th>
<th>Height (mm)</th>
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<tr>
<td>0.316</td>
<td>57.79</td>
<td>0.78</td>
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SAMPLE 2

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Temperature</th>
<th>Humidity</th>
<th>Weight (g)</th>
<th>Width (mm)</th>
<th>Length (mm)</th>
<th>Height (mm)</th>
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</thead>
<tbody>
<tr>
<td>20210302</td>
<td>08:00</td>
<td>27°C</td>
<td>25%</td>
<td>0.489</td>
<td>55.37</td>
<td>53.24</td>
<td>0.83</td>
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</tbody>
</table>
MATERIAL PROGRAMMING OF 4D-PRINTED MOTION MECHANISMS

- Angle
- Offset
- Height

Material programming | Shape change | 4D-printed self-shaping

---

**a**

<table>
<thead>
<tr>
<th>Bending direction</th>
<th>Actuating material</th>
<th>Restricting material</th>
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**b**

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**c**

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**d**

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MATERIAL PROGRAMMING OF 4D-PRINTED MOTION MECHANISMS

Combining Stacking

- **Material programming**
- **Shape change**
- **4D-printed self-shaping**

<table>
<thead>
<tr>
<th></th>
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<th>Shape change</th>
<th>4D-printed self-shaping</th>
</tr>
</thead>
<tbody>
<tr>
<td>e</td>
<td><img src="image_e" alt="Image of material programming" /></td>
<td><img src="image_e" alt="Image of shape change" /></td>
<td><img src="image_e" alt="Image of 4D-printed self-shaping" /></td>
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<tr>
<td>f</td>
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<tr>
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</table>

- **Bending direction**
- **Actuating material**
- **Restricting material**
MATERIAL PROGRAMMING OF 4D-PRINTED MOTION MECHANISMS

Bending angle:
0° - 60°
MATERIAL PROGRAMMING OF 4D-PRINTED MOTION MECHANISMS

Bending radius: 15mm – 60mm
MATERIAL PROGRAMMING: HELIX MECHANISM

curvature: 45° (constant)
active layers: 3 (constant)
width: 15:150
MATERIAL PROGRAMMING: HELIX MECHANISM

curvature: 45° (constant)
active layers: 2 / 3 / 4 / 5
width: 15:150
The base helix first actuates, then the flap slowly follows.
SQUEEZING FORCES OF THE 4D-PRINTED TENSIONING MECHANISM

- More pocket mechanisms (110mm spacing) & delayed actuation
- More pocket mechanisms (110mm spacing)
- Fewer pocket mechanisms (220mm spacing)
- No pocket mechanisms (pure helix)

Graph showing the squeezing forces over time. The forces are as follows:
- 1.24 N
- 1.01 N
- 0.72 N
- 0.22 N
Customization to unique body parts

Adaptation to changes over time
BIOMIMETIC PROCESS: BIOLOGY-PUSH APPROACH

**A** BIOLOGY

Helix mechanism
- direction: 45°
- magnitude: 2.5
- orientation: concave

Pocket mechanism
- direction: 20°
- flap magnitude: 4
- flap orientation: concave
- base magnitude: 3
- base orientation: convex

Meso-scale structuring

**B** TECHNICAL TRANSFER

**C** APPLICATION

Tiffany Cheng | MéPhy Seminar 2021
4D-PRINTING ACROSS SCALES AND MECHANISMS

- Bending
- Folding
- Stacking
- Openings
TOWARDS SELF-TIGHTENING LARGE-SCALE STRUCTURES?

Time = 0 hours

80 cm

T = 0 hr

T = 6 hr

T = 18 hr

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