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Ondulé | Designing and Controlling 3D Printable Springs





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How can we embed springs in 3D-printable objects?





Making a spring man using our design tool...

Convert to spring	Change spring
Generated Ondule Units:	
Ondule Spring Customization	'n
Basic stiffness control	dvanced spring contro
Least stiff	
Wire Thinckness 1.6mm 1.6	
Tum Gap: 0.4mm 0.4	
Ondule Joint Constraints	
Individual Behavior	
C Linear Only	
O Twist Only	
O Bend Only	
Compound Behaviors	
C Linear + Twist	
Bend + Twist	
Include decorative spring	g layer
	Convert to spring Generated Ondule Units: Ondule Spring Customization



But let's take a step back... How can we add deformation to 3D printed objects?







Iwafune et al. SIGGRAPH ASIA'18





A Constant of the second secon







Telescoping Yu et al. SIGGRAPH'17

Here is a 3D printed version of the same telescope.



Joint Bacher et al. SIGGRAPH'12



Side View





Top View



C Disnep





But one of the most common deformable structures in manufacturing that has not been extensively studied is

Here is a 3D printed version of the same telescope





Fabrication



Heical Spring



Benefits of Helical Spring



compress extend

twist



bend





energy



Key Challenges

The mechanical performance of 3D-printed helical springs are not known Design, customize, and control spring deformation behaviors can be difficult

Research Questions

Do 3D printable springs follow mechanical theory?

How can we isolate the deformation behaviors in a spring?

How to lower the barrier to create and control springs in CAD design tools?

RQ1: Do 3D printable springs follow mechanical theory? Mechanical Experiments

Material Properties

Young's modulus (E) Shear modulus (G)

Spring Parameters

spring diameter (D) wire thickness (d) number of coil turns (N)





3D-Printed Spring Tensile Tests

Condition	Wire Thickness (mm)	Diameter (mm)	Length (mm)	Turn Number
Wire Thickness (<i>d</i>)	2, 3.4, 4.8, 6.2, 7.6	32	50	
Diameter (<i>D</i>)	4	25, 30, 50, 60	50	
Spring Length (<i>L</i>)	4	32	25, 45, 65, 85	
Turn Number (<i>N</i>)	4	32	50	4, 6, 8, 10



100% infill lines infill pattern 90° printing angle

17 3D-printed springs



- Experiment Results
- Theoretical Predictions

3D-Printed Spring Tensile & Torsion Test Results

Tensile Test Result

Torsion Test Result



The tensile and torsion behaviors of 3D-printed helical springs closely mirror theoretical predictions



RQ2: How can we isolate the deformation behaviors? Deformation Techniques

Ondulé Deformation Techniques

Individual Behavior



Prismatic Joint

Compound Behavior



Cylindrical Joint





Bend Only Chained Knuckle Joint



Bend + Twist Chained Ball Joint





Ondulé Deformation Techniques Compress + Extend Only: Prismatic Joint





Ondulé Deformation Techniques Twist Only: Revolute Joint





Ondulé Deformation Techniques Bend Only: Chained Knuckle Joint





Ondulé Deformation Techniques Linear + Twist: Cylindrical Joint





Ondulé Deformation Techniques Bend + Twist: Chained Ball Joint





Ondulé Decorative Spring



Original Model

Deformation Spring

Deformation + Decorative Springs

RQ3: How to lower the barrie in CAD design tools? Ondulé Design Tool

allows novice designers to add deformation behaviors to static 3Dprinted objects using embedded springs and joints.

RQ3: How to lower the barrier to create and control springs

Ondulé Design Tool



Convert to spring Generated Ondule Units: Ondule Spring Custo	Change sponted and a second	pring length	Spring Generation Panel
Wire Thinckness 3.0 Tum Gap: 4.0	1.6 3.2	Most stiff 7.6 30.4	Spring Stiffn Control Pane
 Ondule Joint Cons Individual Behavior Linear Only Twist Only Bend Only Compound Behaviors Linear + Twist Bend + Twist 	straints) mm (70.4%) n (31.3%)	Spring Beha Design Pane





Ondulé Design Tool Spring Generation

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Calculate the size		





Ondulé Design Tool Spring Generation

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spiral deformation spring





Ondulé Design Tool Spring Generation

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Sultuite the SIZE		



a spiral deformation spring



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Most stiff
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Ondulé Design Tool Spring Stiffness Control

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Basic stiffness control	0	Advanc	ed spring	g contro	d
Least stiff					Most
Wire Thinckness 3.0	1.6				7.6
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Ondule Joint Cor					
 ndividual Behavior Linear Only Twist Only Bend Only Compound Behaviors Linear + Twist Bend + Twist 	Max co Max ex Max los	ompress tension ad: 0.3	ion: 17 : 14.9 n 3 N	.0 mm (nm (31.3	70.4%) 3%)

ude decorative spring lay

lost stiff

1. Default Stiffness



2. Stiffness Adjustment Least stiff Most stiff Wire Thinckness 5.8 mm 1.6 7.6



control the spring stiffness

30.4

Least stiff Wire Thinck Sst 1.6 mm 1.6 Tum Gap: 2.8 mm 2. Ondule Joint Const Individual Behavio Linear Only Twist Only Bend Only Compound Behavior Linear + Twist Bend + Twist Include decorative spring layer





	Most stiff
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Ondulé Design Tool Spring Deformation Behavior Design

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	Basic stiffness
	Least stiff
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	Compound Behav
	O Linear + Twis
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	✓ Include de

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O Bend Only	Мах со	mpression: 17.0 m	m (70	
Compound Behaviors	Max ex	tension: 14.9 mm (31.3%	
O Linear + Twist	Max loa	ad: 0.3 N sk		

nclude decorative spring layer

Joint Generation



1. Default Joint Design





2. Behavior Design

Max compression: 17.0 mm (70.4%) Max extension: 14.9 mm (31.3%) Max load: 0.3 N Lock



Ondulé Design Tool Spring Deformation Behavior Design

Ondule Joint Constraints				
Individual Behavior				
Linear Only				
O Twist Only				
O Bend Only	Max compression: 13.7 mm (51.3%)			
Compound Behaviors	Max extension: 25.1 mm (47.5%)			
O Linear + Twist	Max load: 0.1 N			
Bend + Twist	Lock			

Linear Only



✓ Ondule Joint Constraints			
la dividual Dahavian			
Individual benavior			
C Linear Only	(@),)		
O Twist Only			
Bend Only	Bending direct		
Compound Behaviors	Bending angle		
O Linear + Twist	17°		
O Bend + Twist			

Bend Only



Ondule Joint Constraints Individual Behavior Linear Only Twist Only Bend Only Max compression: 8.3 mm (31.3%) Max extension: 13.9 mm (26.3%) Max Load: 0.1N Compound Behaviors Linear + Twist Twisting Angle is 0° to 90°

O Bend + Twist

Linear + Twist

Force to max twisting: 0.1 N

Ondule Joint Constraints Individual Behavior Linear Only Twist Only Bend Only Compound Behaviors Linear + Twist Twisting angle is 0° to 90° Force to max twisting: 0.1 N

Bend + Twist







4Х

Convert to spring	3	Change
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Tum Gap: 6.8	2.4	•
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O Bend Only	Max co	mpression: 0.6
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O Linear + Twist	Max loa	d: U.4 N k
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Include decorat	ive sprin	g layer





Ondulé Applications

Jack-in-the-box

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Freeform –

Twist+Linear













Tangible Prop for Storytelling

Storytelling Authoring Interface



Circuitry

3D-Printed Prop





Future Work



Geometry Constraints





Spring Robustness

Simulation

Summary

A new approach to allow novices to convert a static 3D shape into a deformable object with embedded 3D-printed springs and joints.

Conducted mechanical experiments Proposed a set of deformation techniques using springs and joints Developed a design tool Built a set of example applications supported by Ondulé

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Ondulé: Designing and Controlling 3D Printable Springs



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Thank you! Questions?