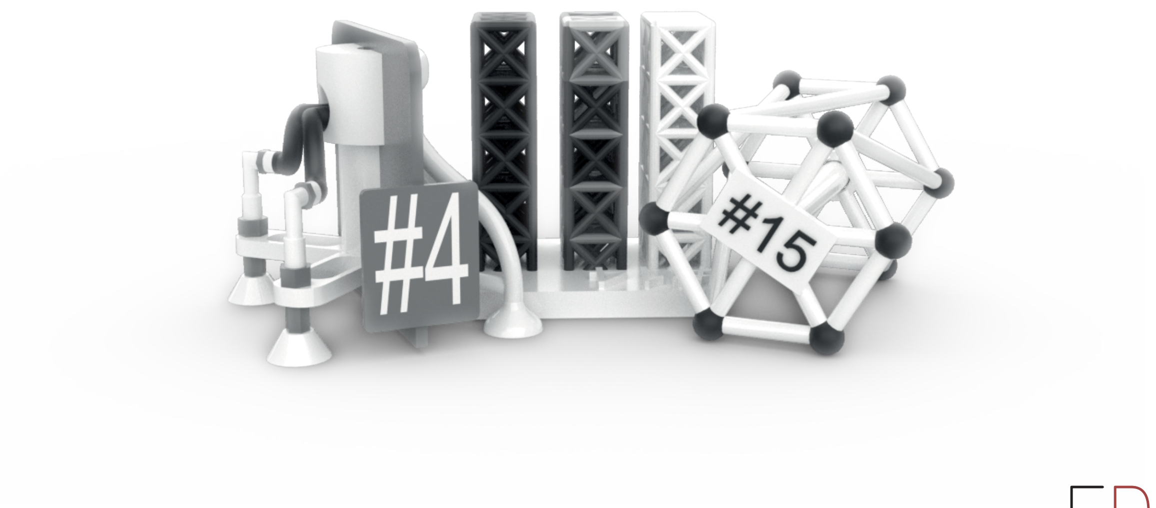
Design Heuristics for Additive Manufacturing



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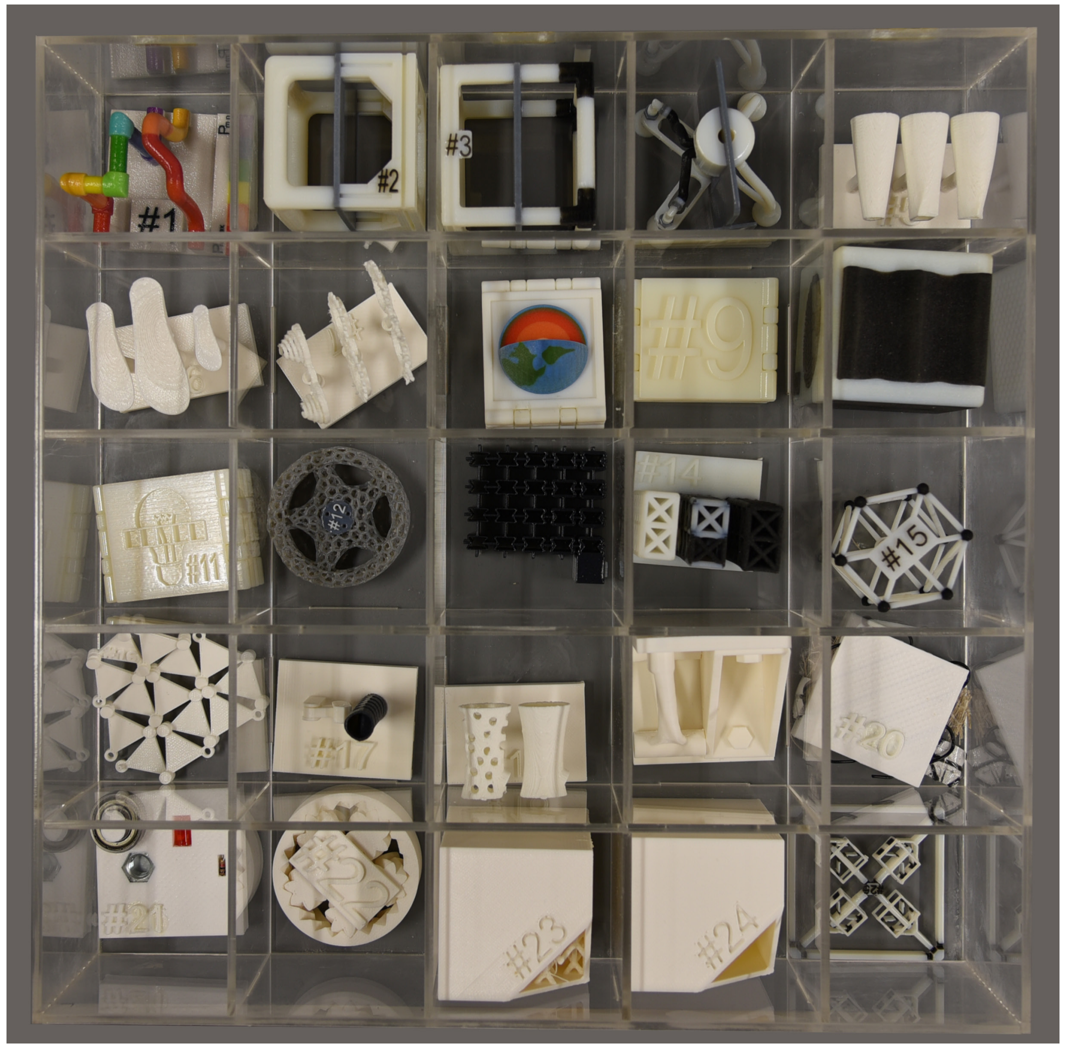
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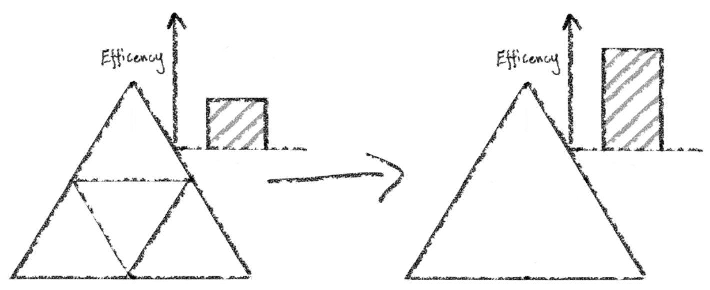
Consolidate parts for better functional performance

1

Part consolidation is possible with AM because of the geometric freedom it affords. Consolidating parts may allow the same function to be achieved with fewer energy and material losses, thus increasing the efficiency. Couplings and fittings can be eliminated and transitions between sections can be redesigned with more efficient geometry.



Part Consolidation

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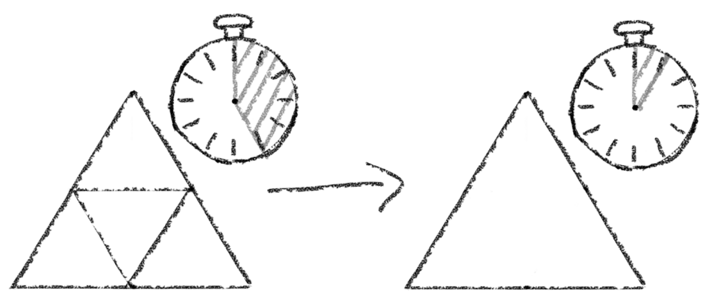
Consolidate parts to reduce assembly time

2

Part consolidation is possible with AM because of the geometric freedom it affords. Reducing the number of parts in an assembly will, in most cases, also reduce the assembly time. Fasteners between parts that are fixed with respect to each other can be eliminated in most cases.



Part Consolidation

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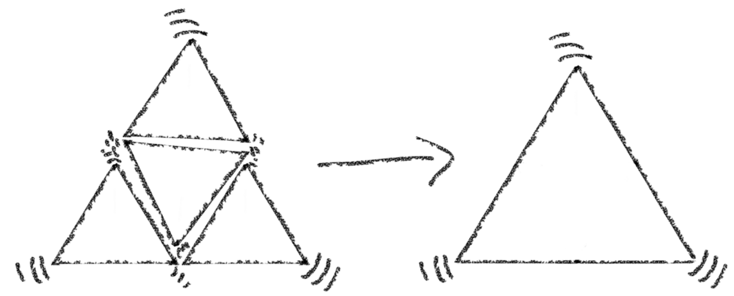
Consolidate parts to increase robustness

3

Part consolidation is possible with AM because of the geometric freedom it affords. When parts are consolidated, the design can be more resistant to fatigue and vibrational effects over time due to the elimination of fasteners and stress concentration zones.



Part Consolidation

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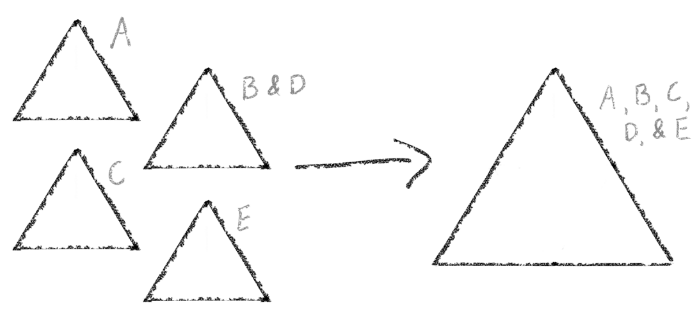
Consolidate parts to achieve multiple functions

4

Part consolidation is possible with AM because of the geometric freedom it affords. The construction of complex parts is possible without fear of significant additional costs due to complex geometries, and it is possible to construct artifacts that are not geometrically possible with traditional manufacturing methods. Thus, multiple functions can be condensed into one part.



Part Consolidation

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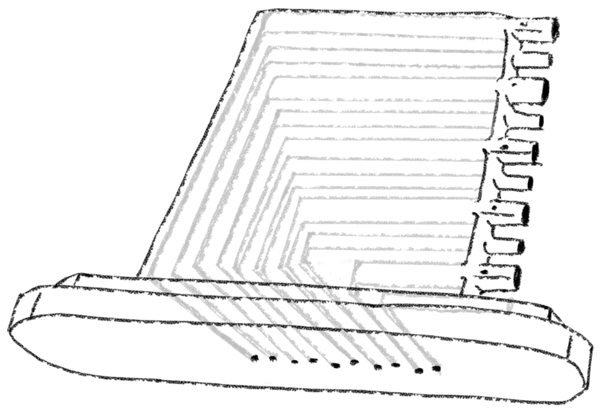
Consolidate parts to increase robustness 3

Collection of speed measurement probes for use inside jet engine is more robust against high temperatures and forces due to single print design.

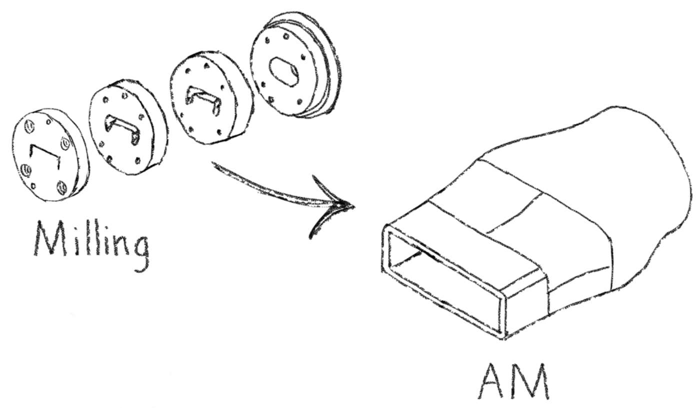
Vectorflow and EOS
[4]



Consolidate parts for better functional performance 1

Extrusion die manufactured with AM allows for smoother transions between sections than a milled and assembled die.

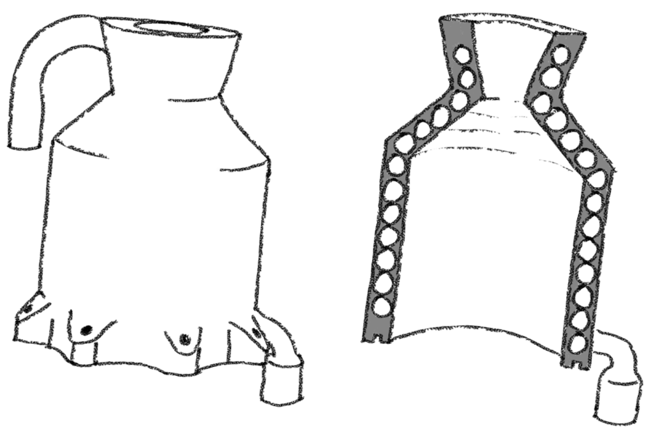
Zhang, Tarantino, and Lieber
New Jersey Institute of Technology
[2]



Consolidate parts to achieve multiple functions 4

AM liquid rocket fuel engine with integrated cooling channels makes engine function possible.

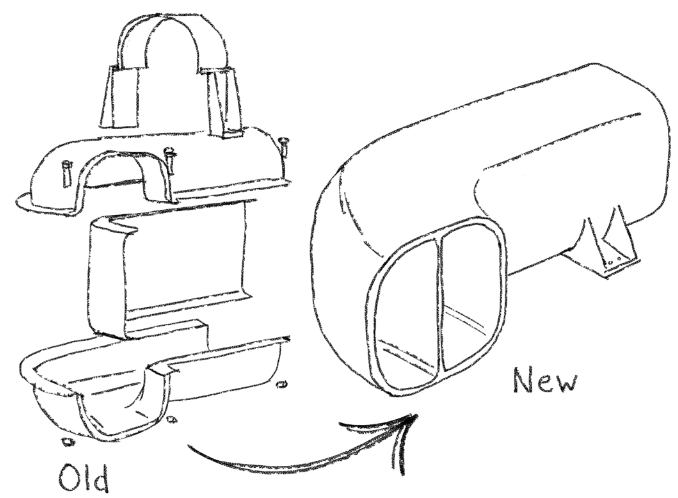
University of Minnesota and Protolabs
[5]



Consolidate parts to reduce assembly time 2

Aircraft duct part reduction from 16 to 1 parts, which now requires no assembly.

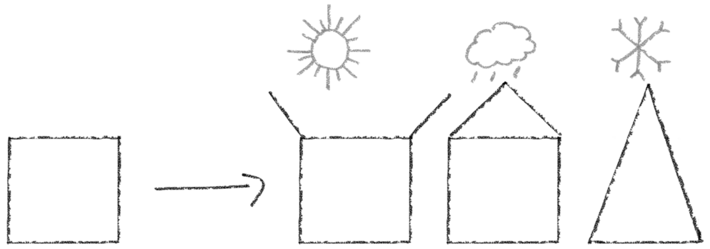
Gibson, Deakin University
Rosen, Georgia Institute of Technology
Stucker, University of Louisville
[3]



Customize geometry to use case

5

AM allows for customization at low or no additional cost, therefore changes to the geometry of the part can be tailored to the product requirements of each specific artifact.



Customize

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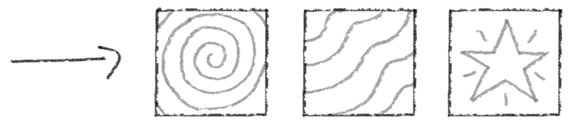
Customize artifact with decoration

7

AM allows for customization at low or no additional cost, therefore, the artifact can be easily customized to suit the aesthetic preferences of every user or different target groups.



Customize

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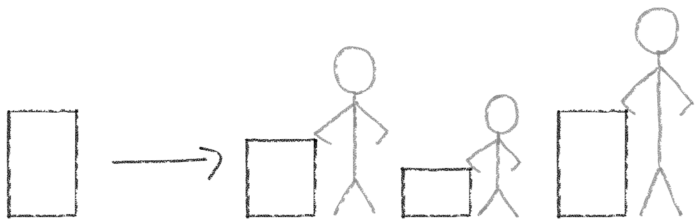
Customize user interface to use case

6

AM allows for customization at low or no additional cost, therefore, the user interface can be easily customized to suit the needs of every user or different target groups.



Customize

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Convey information with color

8

Some AM processes allow easy incorporation of multiple colors directly into the surface or body of a part in a freely-controllable distribution. This ability can be utilized to convey information such as text, instructions, guides, warnings, as well as simulate textures and shading.

Convey Information

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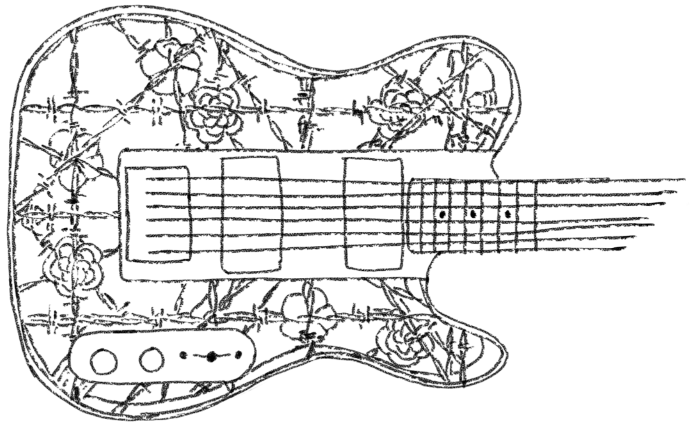
Customize artifact with decoration
7

Electric guitar body customized with decoration.

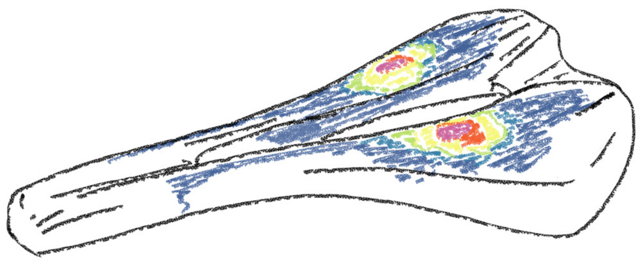
Olaf Diegel
[8]



Convey information with color
8

Pressure distribution of rider displayed on bicycle seat.

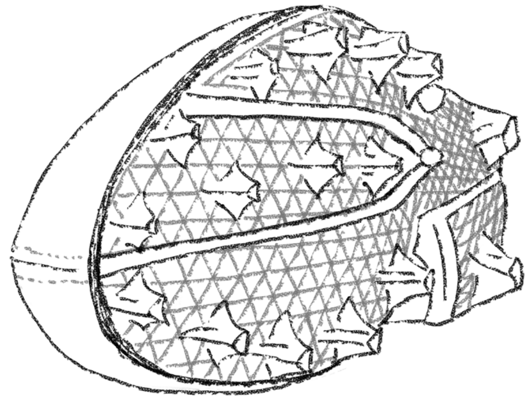
Trek and Stratasys
[9]



Customize geometry to use case
5

American football cleat designed to improve traction for specific field positions.

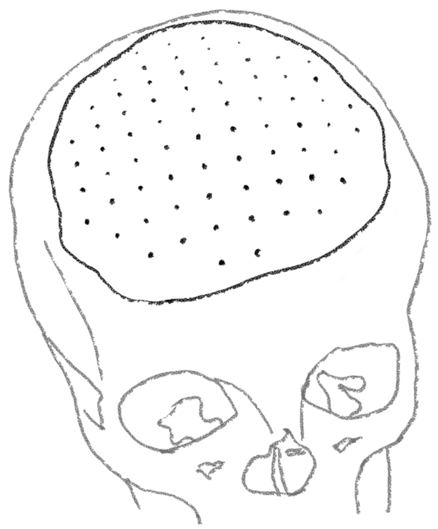
Nike
[6]



Customize user interface to use case
6

Patient specific cranial implants based on CT or MRI scan data.

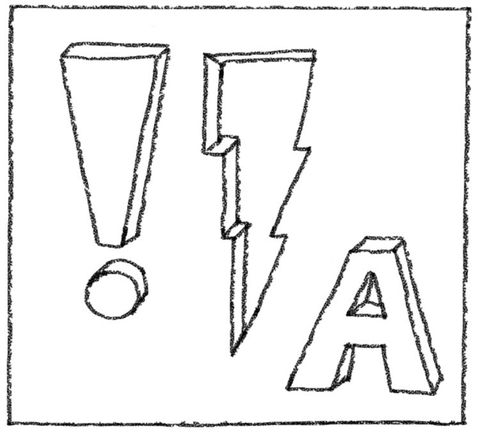
Oxford Performance Materials and EOS
[7]



Convey information with geometry

9

AM allows for geometric freedom at low or no additional cost. Sunken or raised indicators, areas or guides can be utilized to convey information such as text, instructions, motion guides, and warnings.

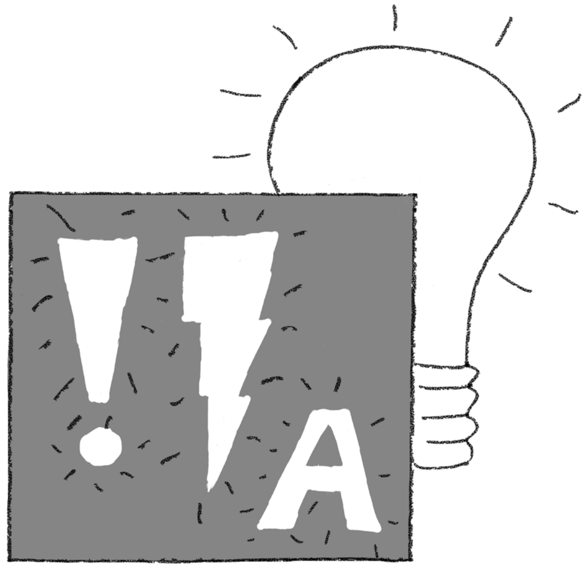


Convey Information

Convey information with light

11

AM allows for freely-controllable distribution of material, which can be used to transmit light to convey information.

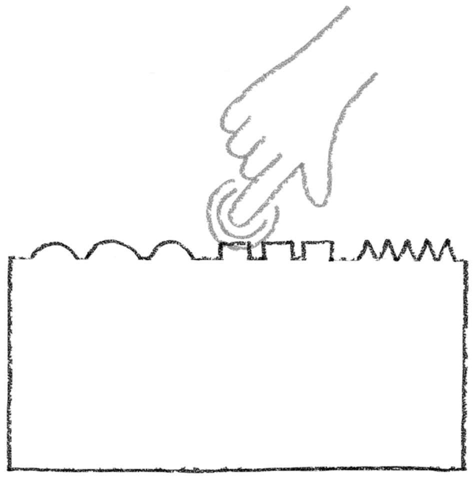


Convey Information

Convey information with haptics

10

Some AM processes allow easy incorporation of variable material properties and surface textures in a freely-controllable distribution. This ability can be utilized to convey information such as user handling instructions and different physical responses.

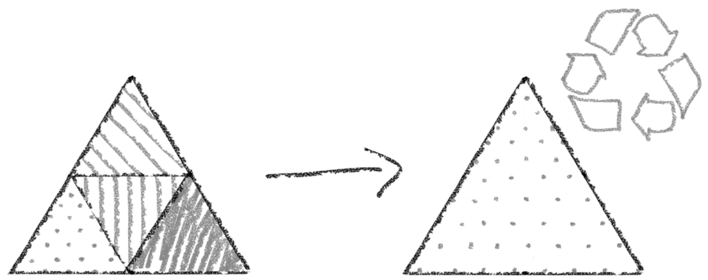


Convey Information

Use single material to achieve recyclability

12

Recycling at the end of the product lifecycle can often be a challenge because of the mix of materials present in artifacts. However, metamaterials and special material distributions allow the achievement of unique and variable material properties while only using a single construction material throughout the part, which eases end-of-life recycling.

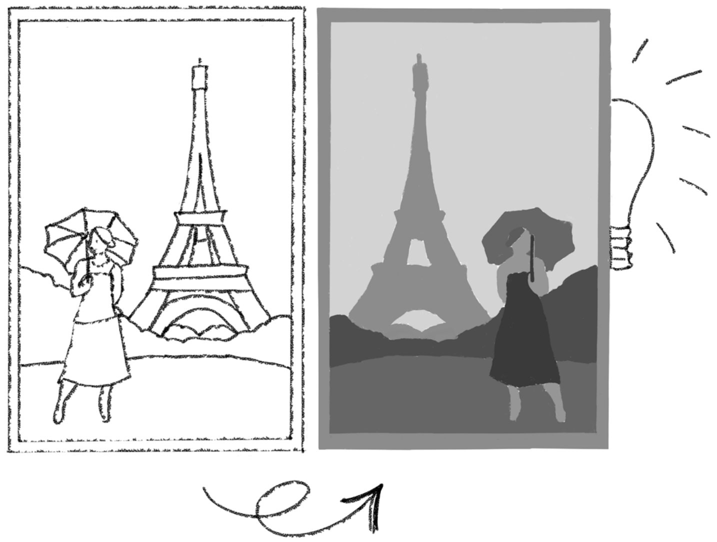


Material

Convey information with light 11

Postcard with various thicknesses of material reveals image when held up to light.

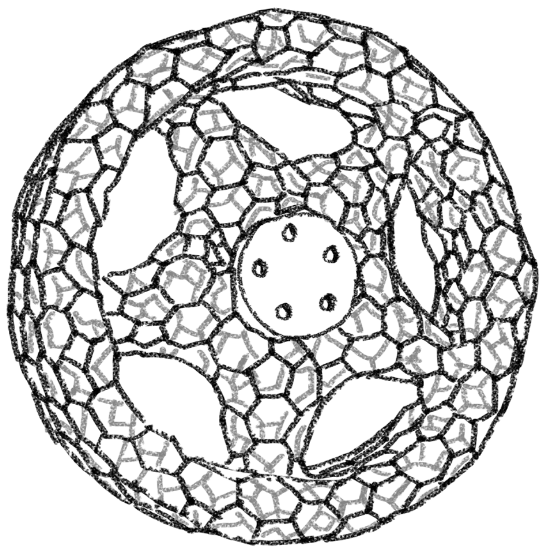
Vidimce, Wang, Ragan-Keley, and Matusik
MIT
[12]



Use single material to achieve recyclability 12

Single-material tire uses material distribution to achieve the desired properties.

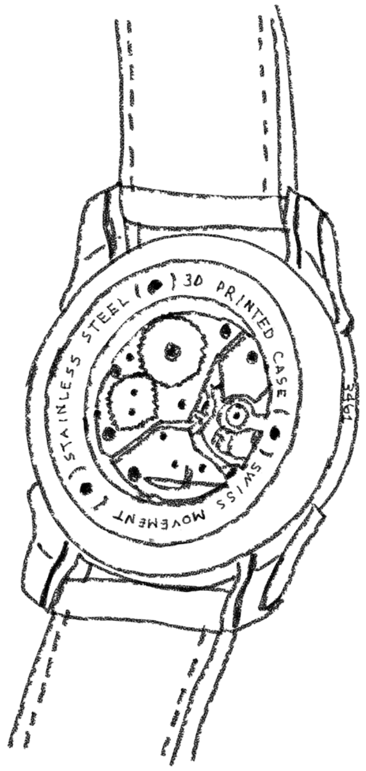
Nessi and Stankovic
ETH Zürich
[13]



Convey information with geometry 9

Watch case with raised text to indicate maker, serial number, and model information.

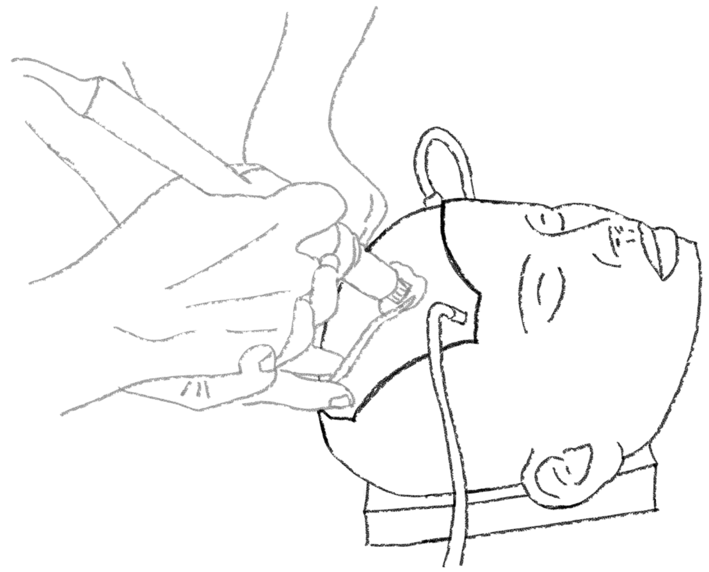
Holthinrichs Watches
[10]



Convey information with haptics 10

Surgical preparatory training model offers realistic tissue responses through use and layering of multiple materials.

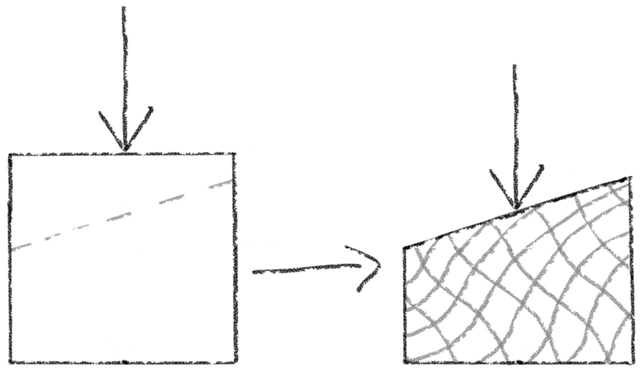
Leone and Stratasys
[11]



Use metamaterial to achieve unique and graded material properties

13

Metamaterials are synthetic composite materials with special structures, which exhibit material properties not found naturally, and many of these materials can only feasibly be constructed using AM. Metamaterials can be incorporated into the artifact to utilize or achieve unique single and combination material properties. Metamaterials can also be incorporated into the artifact to achieve unique and graded material properties.



Material

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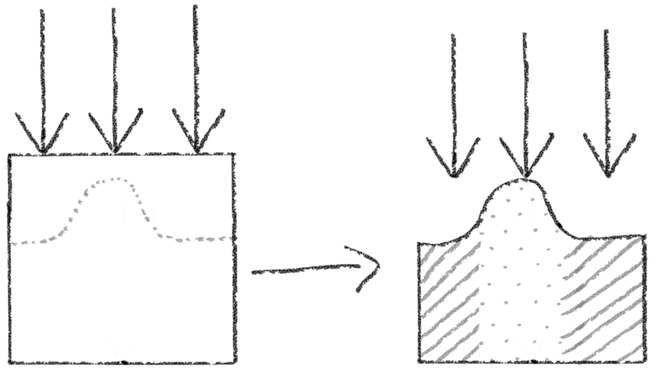
Use multiple materials to achieve graded material properties

14

Some AM processes allow the inclusion of multiple materials in a freely-controllable distribution. This can be utilized to achieve functionalities that are dependent on a difference in material properties and various materials can be locally incorporated into the artifact to achieve graded material properties within the artifact.



Material

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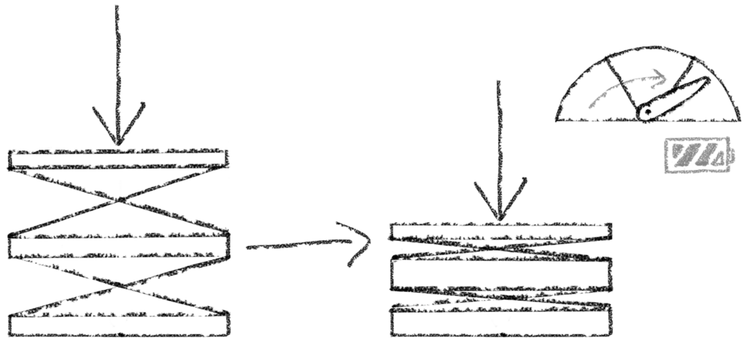
Absorb energy with small interconnected parts

15

Many AM processes are capable of producing complex structures of small, interconnected geometries, which can be utilized to absorb energy either through elastic or plastic deformation, movement, or controlled breakage.



Material Distribution

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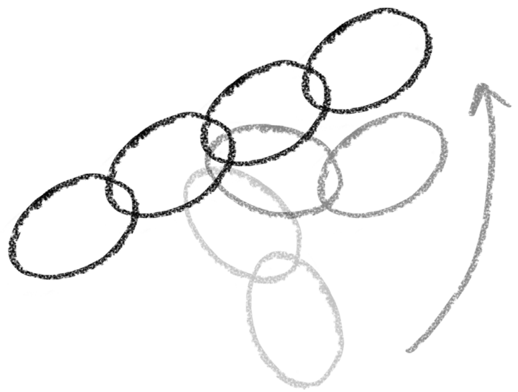
Allow movement with small interconnected parts

16

Many AM processes are capable of producing complex structures of small, interconnected geometries, which can be utilized to allow movement of the part without having to assemble parts or use materials that are flexible in bulk form.



Material Distribution

ETH zürich ED +C ENGINEERING DESIGN AND COMPUTING

Absorb energy with small interconnected parts

15

Scale-based armour is more resistant to knife attacks than a solid sheet of same thickness.

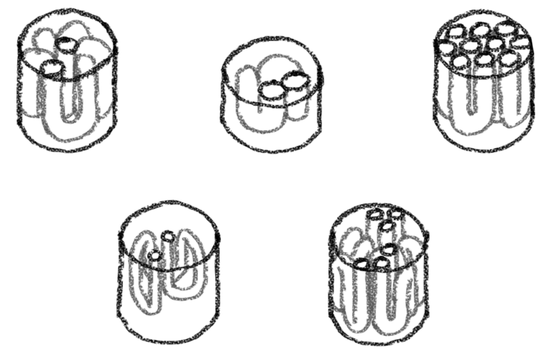
Johnson and Bingham, Loughborough University
Wimpenny, De Montfort University
[16]

Use metamaterial to achieve unique and graded material properties

13

Passive descructive interference acoustic absorbers tuned to absorb specific acoustic frequencies.

Setaki, Tenpierik, Turrin, and van Timmeren
Delft University of Technology
[14]

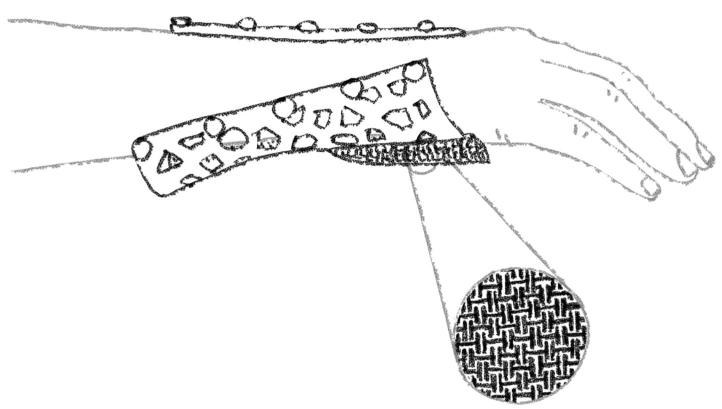


Allow movement with small interconnected parts

16

Fabric-like structure allows for hinge-like movement in arm brace so that it can be removed.

Paterson, University of Manchester
Bibb, Campbell, and Bingham, Loughborough University
[17]

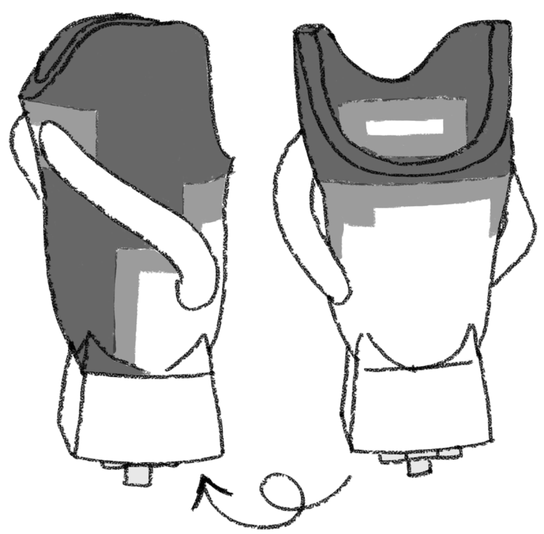


Use multiple materials to achieve graded material properties

14

Variable impedance prosthetic socket uses multiple materials to selectively provide support and comfort.

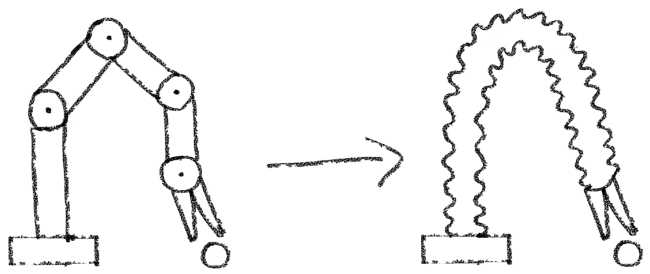
Sengeh and Herr
MIT
[15]



Use material distribution to achieve desired behavior

17

AM enables geometric freedom, which allows for the construction of artifacts with portions that exhibit specific physical behaviors without having to introduce traditionally manufactured parts into the system.



Material Distribution

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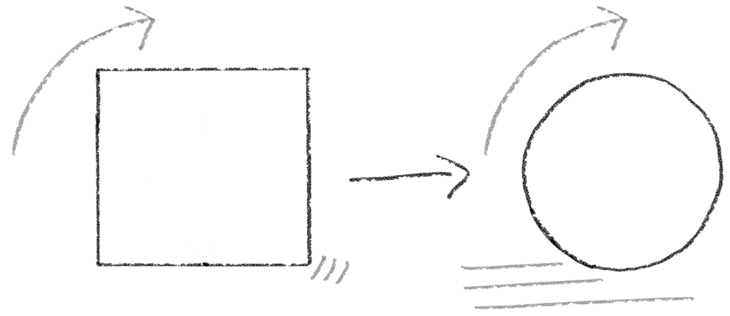
Optimize structural topology or geometry

19

Optimized structural topologies and geometries take full advantage of the geometric freedom allowed by AM. By using the optimized design, artifact mass can be reduced and/or performance can be increased.



Material Distribution

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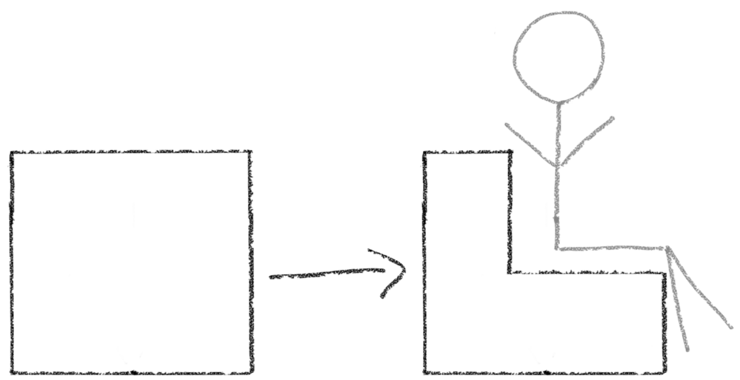
Remove material to provide function

18

AM enables geometric freedom, which assists in the exclusion of material from artifacts, which can create or improve function.



Material Distribution

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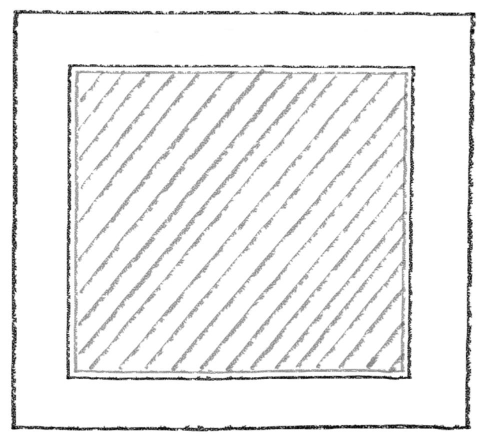
Embed functional material

20

Some AM processes allow for the inclusion of non-AM materials during the artifact production process. This opportunity can be utilized to embed functional materials within the artifact that can be used to achieve the artifact function.



Embed-Enclose

ETH zürich

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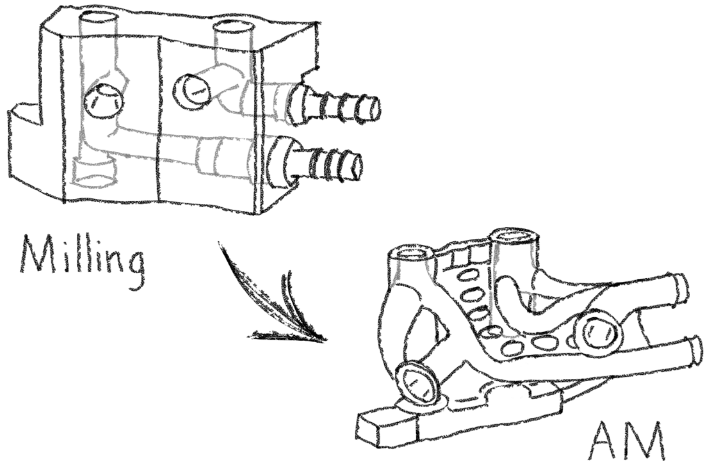
Optimize structural topology or geometry

19

Water manifold redesigned to reduce vibrations by factor of 10.

ASML
[20]

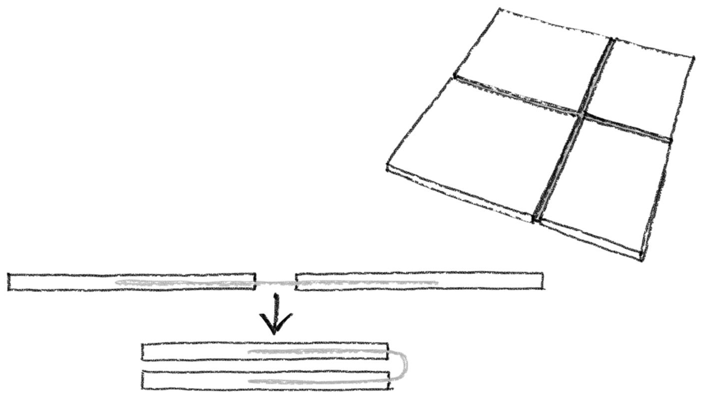


Embed functional material

20

Embedded shape memory alloy ribbons act as hinges when activated with heat.

Marcelo Dapino
Ohio State University
[21]

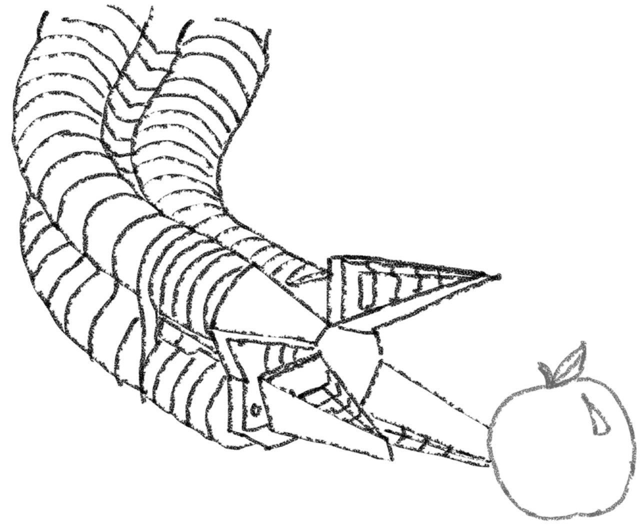


Use material distribution to achieve desired behavior

17

Flexible grippers and hose achieved through distribution of material.

Festo and EOS
[18]

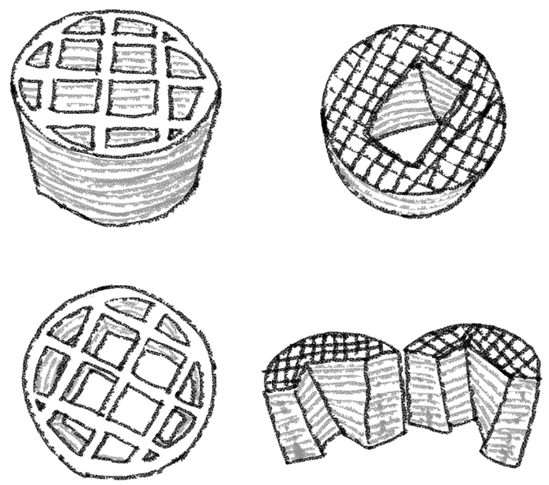


Remove material to provide function

18

Solid rocket fuel capsule with intentional free space to allow for better radial burning.

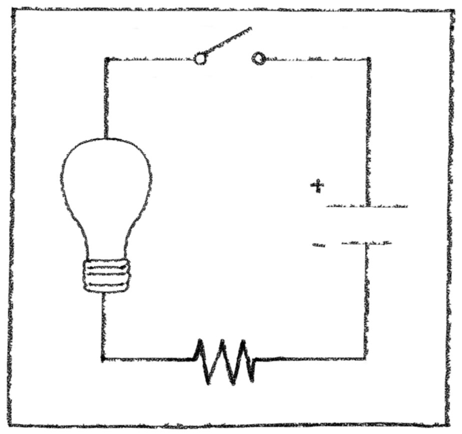
Chandru, Balasubramanian, Oommen, and Raghunandan
Indian Institute of Science
[19]



Embed functional component

21

Some AM processes allow for the inclusion of non-AM functional components during the artifact production process. This opportunity can be utilized to embed functional components within the artifact that can be used to achieve the artifact function.



Embed-Enclose

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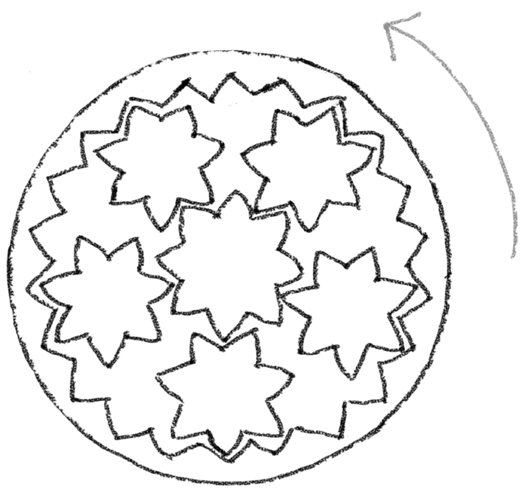
Use enclosed, functional parts

22

Some AM processes enable the possibility to manufacture free-moving parts that are either fully or partially enclosed within another part without assembly processes, which can be utilized to realize, e.g. hinges, sliding guides, bearings, joints, and valves.



Embed-Enclose

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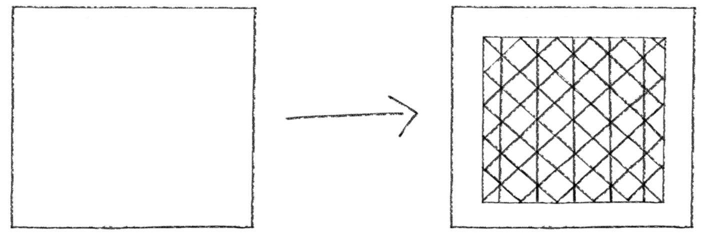
Replace internal structure with lightweight lattice structure

23

The geometric freedom allowed by AM enables non-solid fill of enclosed spaces, often realized as cellular or lattice structures, which give the benefit of reduced artifact mass without drastically compromising the structural strength of the artifact. This can be applied to the entire artifact or portions of it.



Lightweight

ETH zürich

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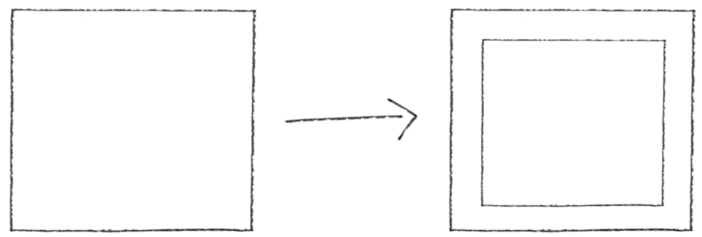
Hollow out artifact to reduce weight

24

Some AM processes allow for final artifacts that are wholly or partially hollow. Hollowing out all or part of an artifact, particularly a non-structurally significant portion, can reduce the overall mass of the system.



Lightweight

ETH zürich

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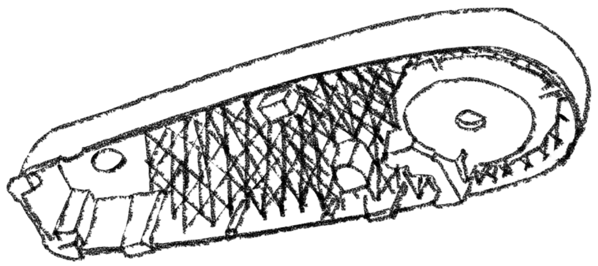
Replace internal structure with lightweight lattice structure

23

Robot apendege link filled with lattice structure to reduce weight and maintain strength.

Omron Adept Technologies
[3]



Hollow out artifact to reduce weight

24

Hollowed-out head of actuated octopus reduces weight of object.

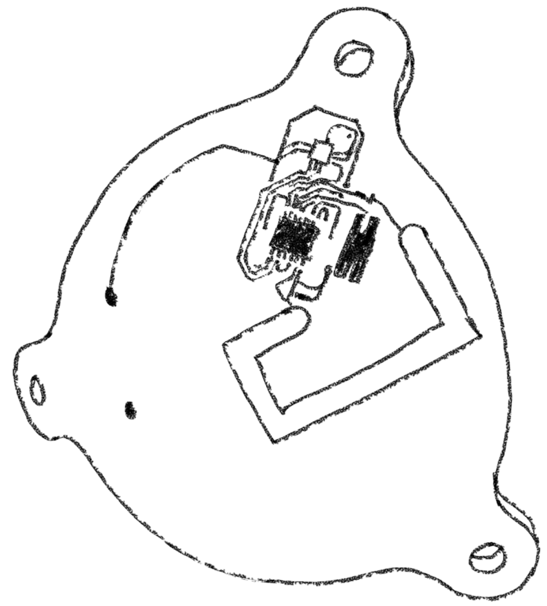
ViruZ3
Thingiverse
[24]

Embed functional component

21

Accelerometer and other circuitry embedded into helmet insert that measures the acceleration of the head.

Castillo, Muse, Medina, MacDonald, and Wicker
University of Texas at El Paso
[22]

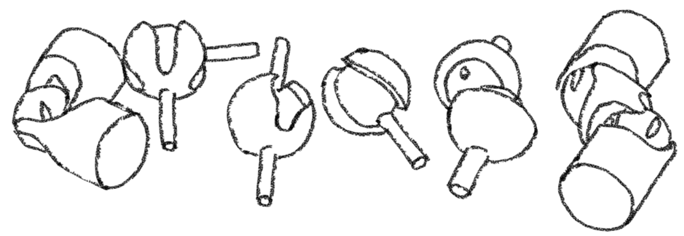


Use enclosed, functional parts

22

Ball and socket joints printed in single print.

Calì, Calian, Amati, Kleinberger, Steed, Kautz, and Weyrich
University College London
[23]



Create multi-functional artifact with reconfigurable structures

25

AM enables the production of reconfigurable structures, which utilize special materials and/or geometric distributions to reconfigure themselves into different functional structures based on the surrounding environment and/or control triggers.

Reconfiguration

ETH zürich

ED+C ENGINEERING DESIGN AND COMPUTING

R1

[1] Yilmaz, S., Daly, S., Christian, J., Seifert, C., and Gonzalez, R., 2012, "77 Cards: Design Heuristics for Inspiring Ideas."

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Design Heuristics for Additive Manufacturing

Design heuristics are design tips and strategies based on the knowledge of experienced designers that help both novices and experts generate better designs and explore more of the design space. These Design Heuristics for Additive Manufacturing are inspired by the general Design Heuristics of Yilmaz, Daly, Christian, Seifert, and Gonzalez [1] and are designed to help both students and professionals learn about and utilize the unique capabilities of Additive Manufacturing (AM) in their designs.

These heuristics are derived from the analysis of hundreds of AM artifacts from academic papers, industry, and hobbyists. They have been tested in user studies with both students and professionals and have been found to increase not only the number of AM-enabled concepts generated by users, but also the novelty and variety of the ideas generated.

These cards, alone or with the accompanying objects, can be used during concept generation to help inspire AM-enabled concepts. More information about the Design Heuristics for AM can be found on our website, along with copies of these cards and the objects to download: https://edac.ethz.ch/Research/current-research-projects/Design-Heuristics-AM.html

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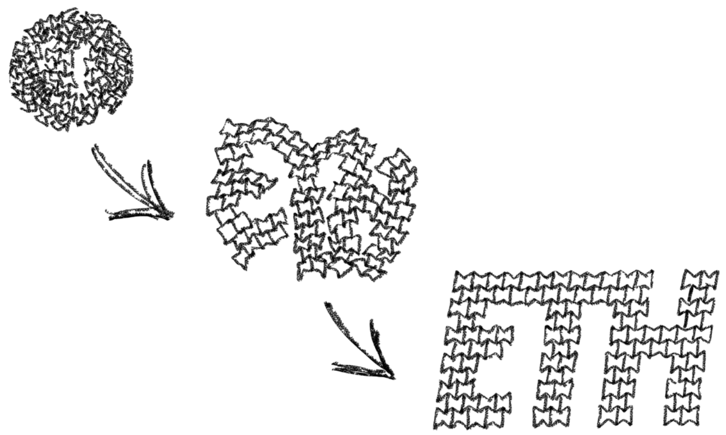
Create multi-functional artifact with reconfigurable structures

25

Programmed auxetic structures change shape when placed in hot water.



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Please visit our website for updates and further information:

https://edac.ethz.ch/Research/current-research-projects/Design-Heuristics-AM.html