Design Heuristics for Additive Manufacturing Cards

Other Research Data

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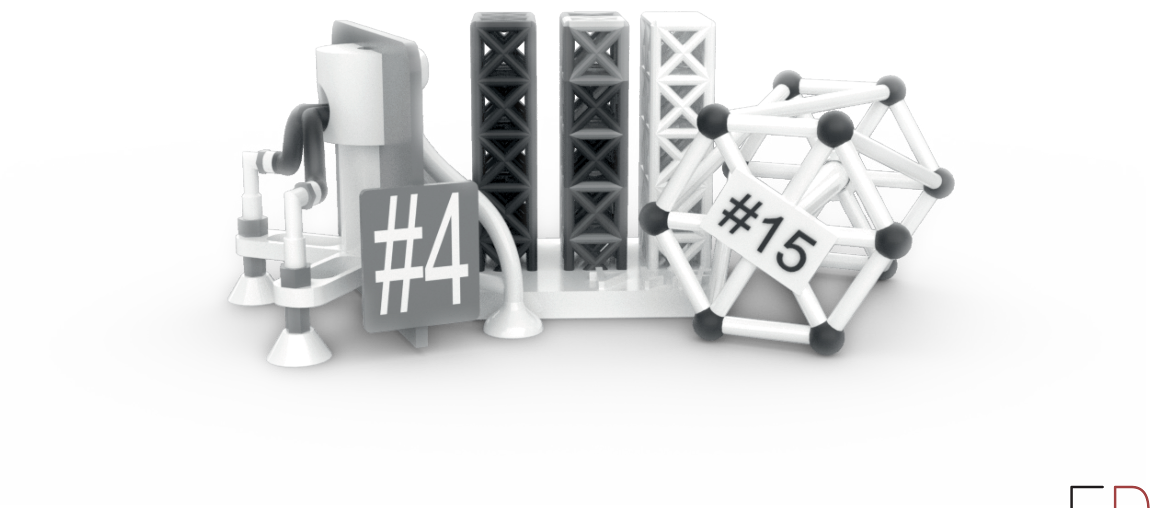
Publication date:
2019

Permanent link:
https://doi.org/10.3929/ethz-b-000537327

Design Heuristics for Additive Manufacturing



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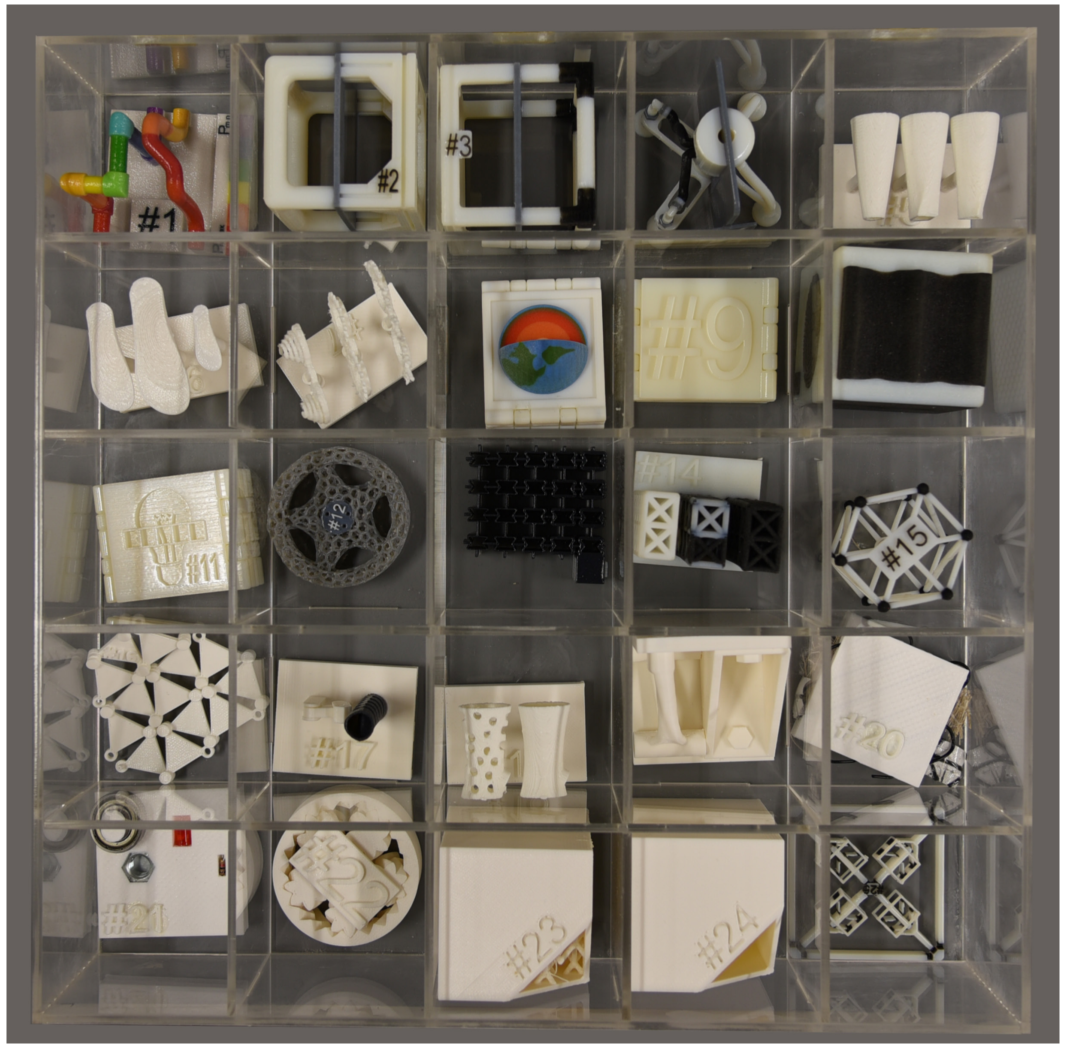

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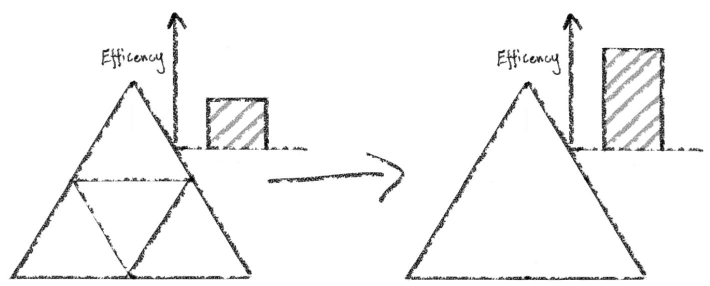
Consolidate parts for better functional performance

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.



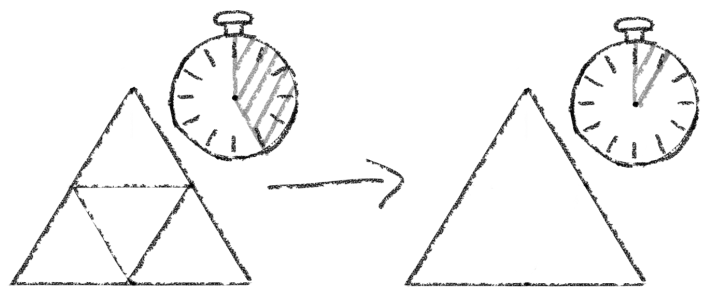
Part Consolidation

ENGINEERING DESIGN AND COMPUTING

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.



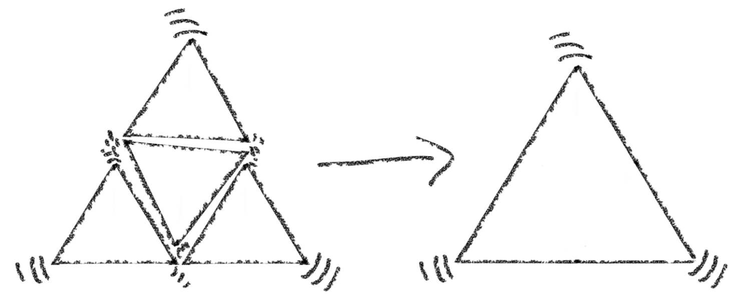
Part Consolidation

ENGINEERING DESIGN AND COMPUTING

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.



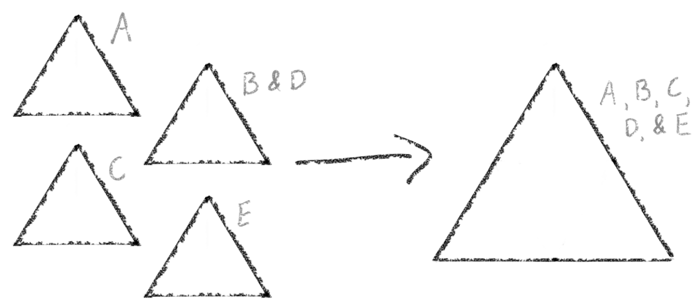
Part Consolidation

ENGINEERING DESIGN AND COMPUTING

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.



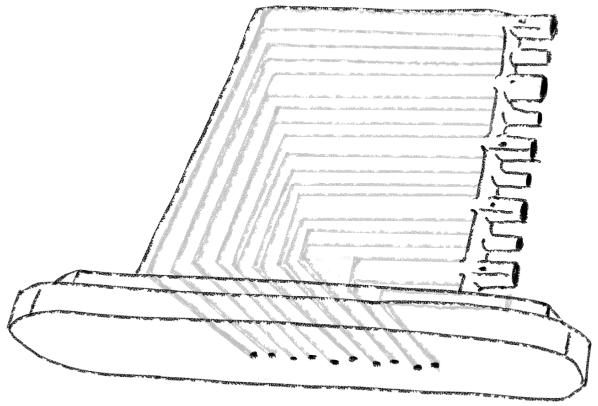
Part Consolidation

ENGINEERING DESIGN AND COMPUTING

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.

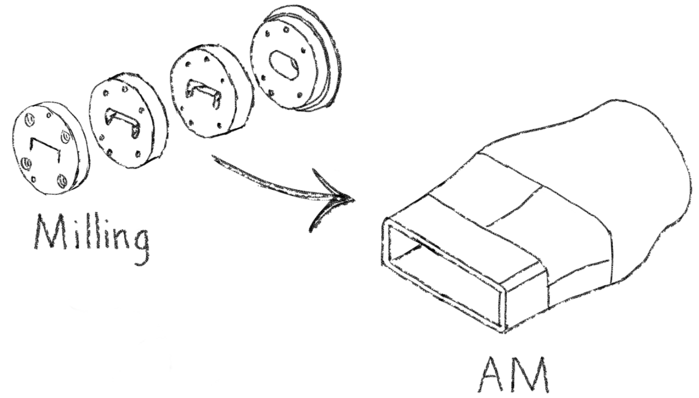
Vectorflow and EOS
[4]



Consolidate parts for better functional performance 1

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

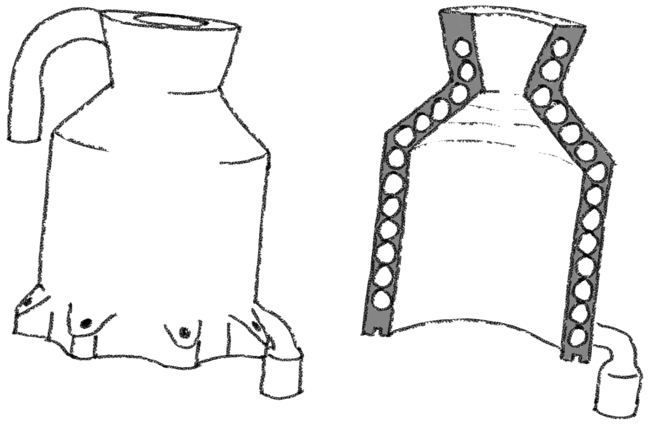
Zhang, Tarantino, and Lieber
New Jersey Institute of Technology
[2]



Consolidate parts to achieve multiple functions 4

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

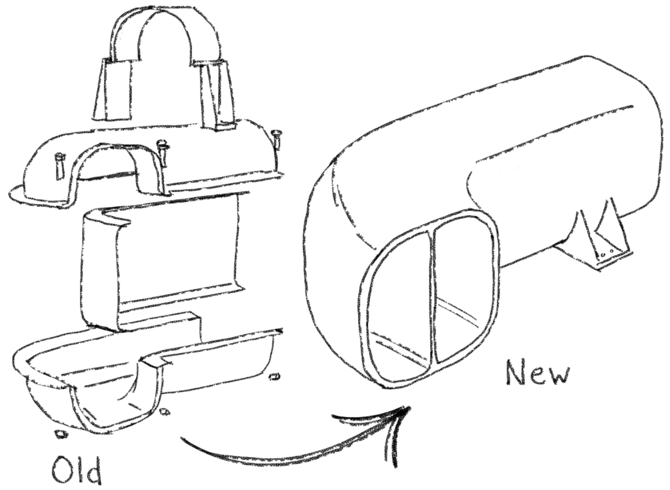
University of Minnesota and Protolabs
[5]



Consolidate parts to reduce assembly time 2

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

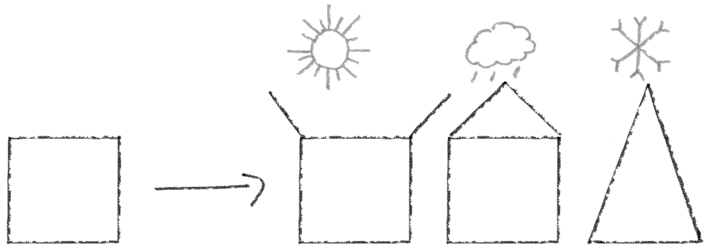
Gibson, Deakin University
Rosen, Georgia Institute of Technology
Stucker, University of Louisville
[3]



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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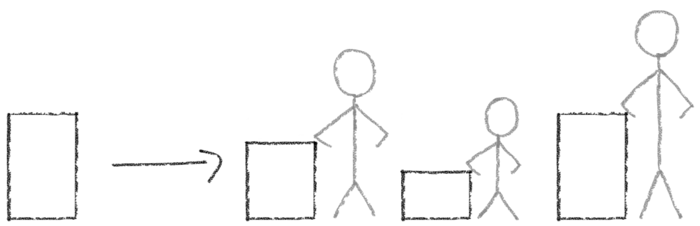
ENGINEERING DESIGN AND COMPUTING

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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ENGINEERING DESIGN AND COMPUTING

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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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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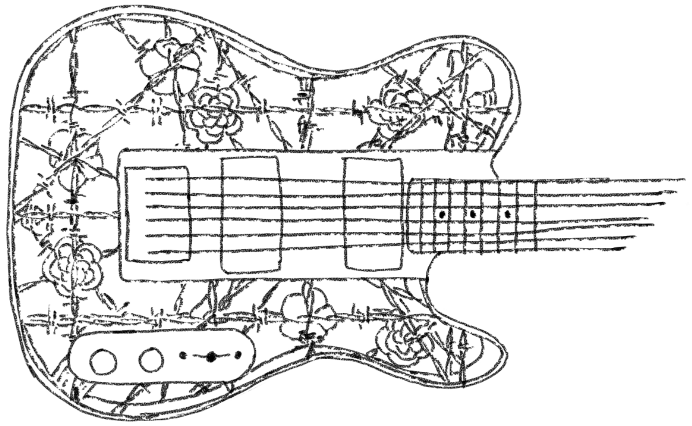
ENGINEERING DESIGN AND COMPUTING

Customize artifact with decoration

7

Electric guitar body customized with decoration.

Olaf Diegel
[8]

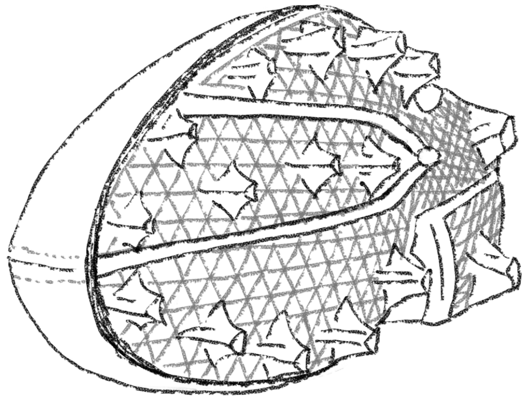


Customize geometry to use case

5

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

Nike
[6]

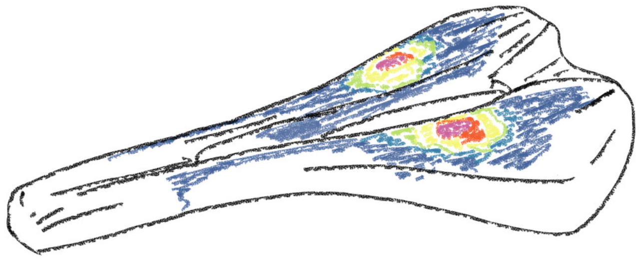


Convey information with color

8

Pressure distribution of rider displayed on bicycle seat.

Trek and Stratasys
[9]

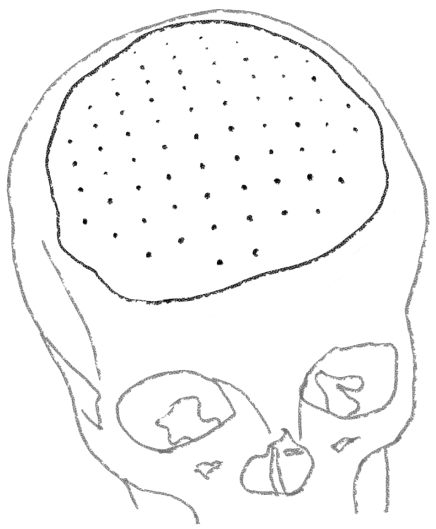


Customize user interface to use case

6

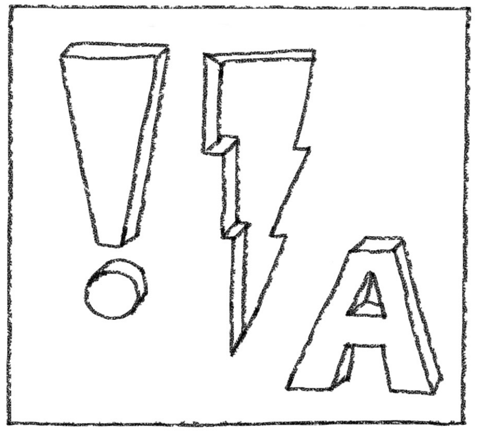
Patient specific cranial implants based on CT or MRI scan data.

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

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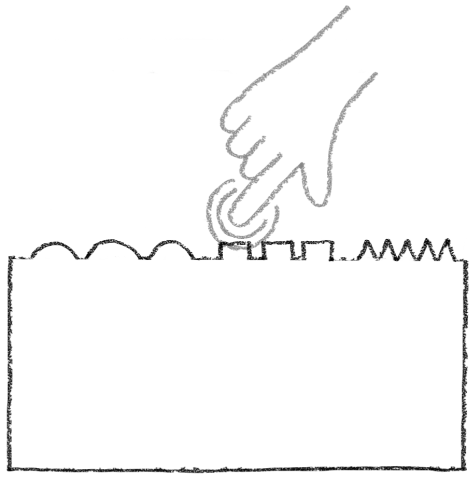
Convey information with haptics 10

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

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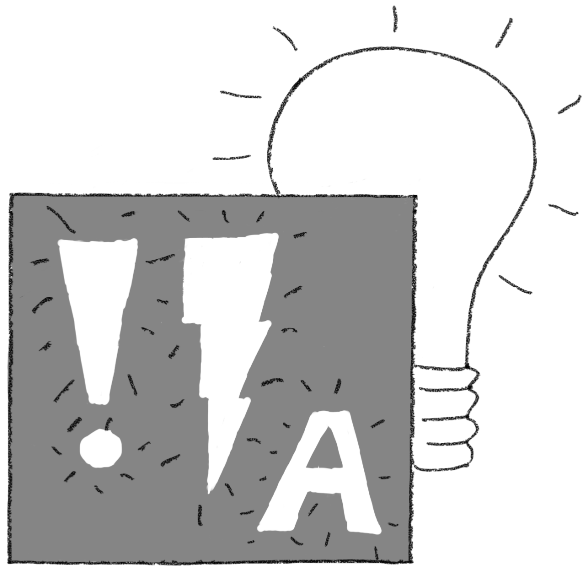
Convey information with light 11

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



Convey Information

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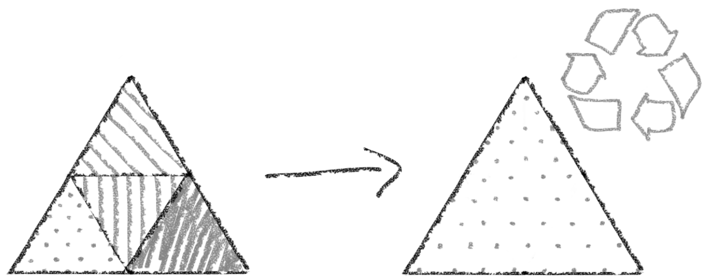
Use single material to achieve recyclability 12

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

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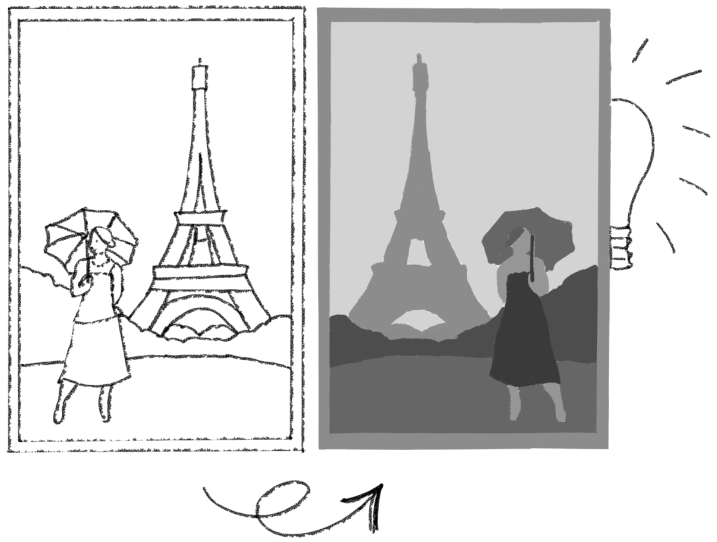
Convey information with light

11

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

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

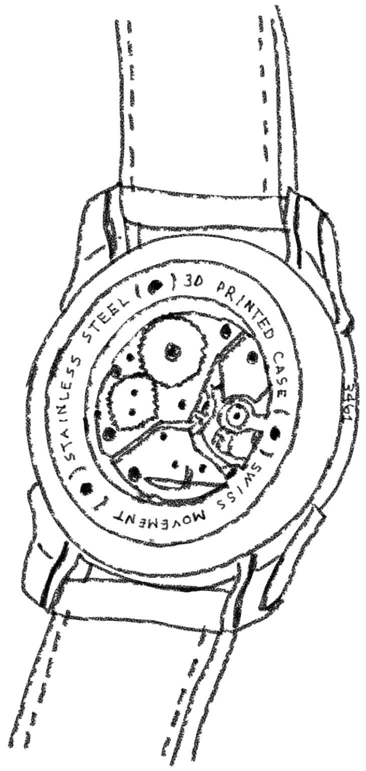


Convey information with geometry

9

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

Holthinrichs Watches
[10]

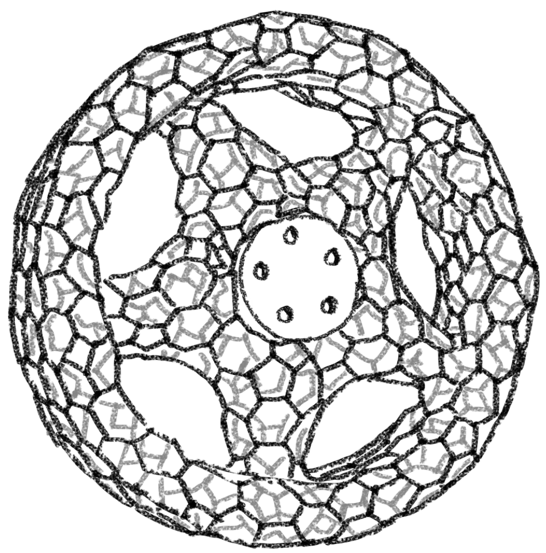


Use single material to achieve recyclability

12

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

Nessi and Stankovic
ETH Zürich
[13]

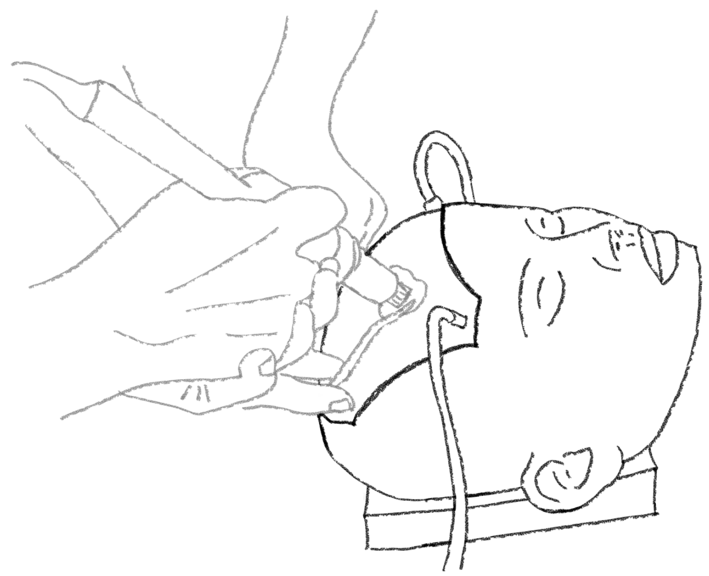


Convey information with haptics

10

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

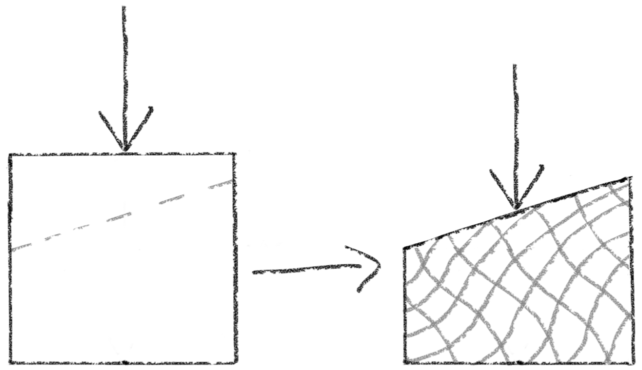
Leone and Stratasys
[11]



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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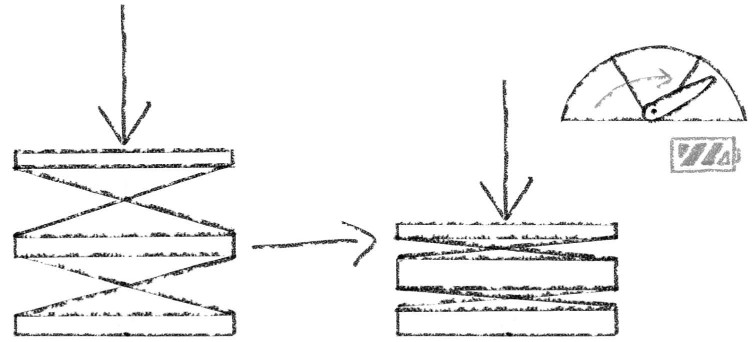
Absorb energy with small interconnected parts

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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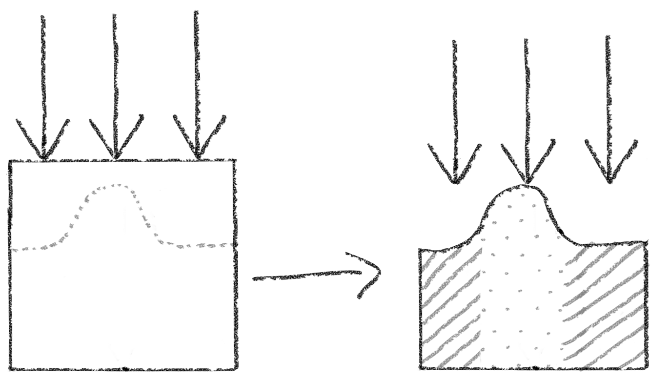
Use multiple materials to achieve graded material properties

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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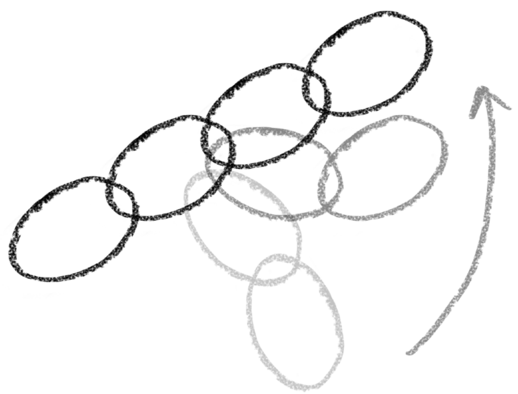
Allow movement with small interconnected parts

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

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ED+C ENGINEERING DESIGN AND COMPUTING

Absorb energy with small interconnected parts

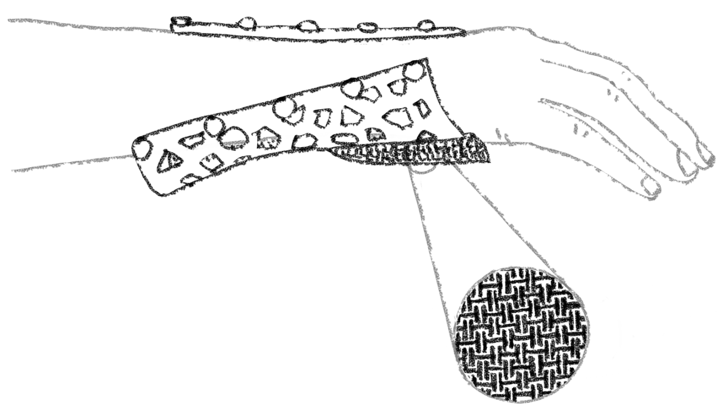
15

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]

Allow movement with small interconnected parts

16

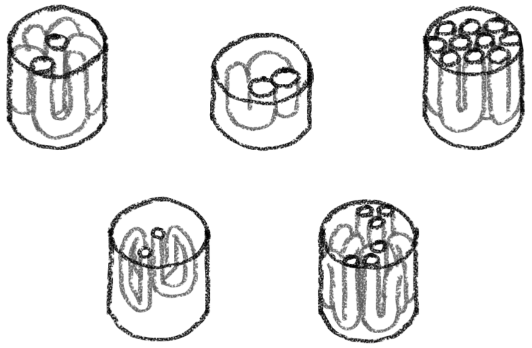


Fabric-like structure allows for hinge-like movement in arm brace so that it can be removed.

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

Use metamaterial to achieve unique and graded material properties

13

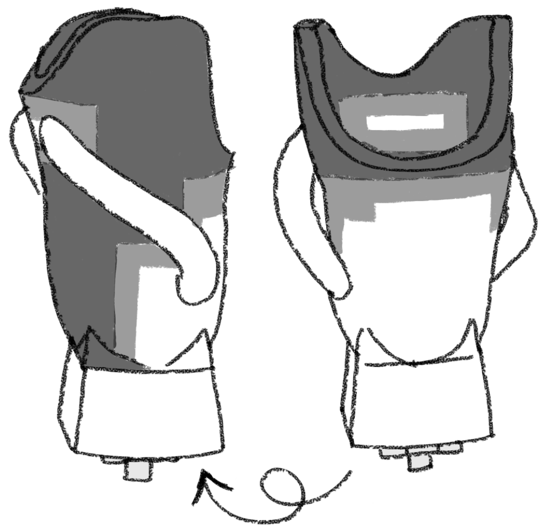


Passive descructive interference acoustic absorbers tuned to absorb specific acoustic frequencies.

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

Use multiple materials to achieve graded material properties

14



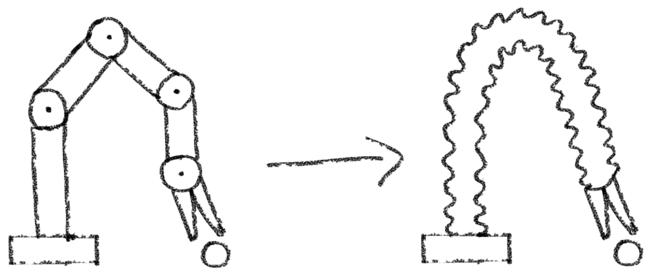
Variable impedance prosthetic socket uses multiple materials to selectively provide support and comfort.

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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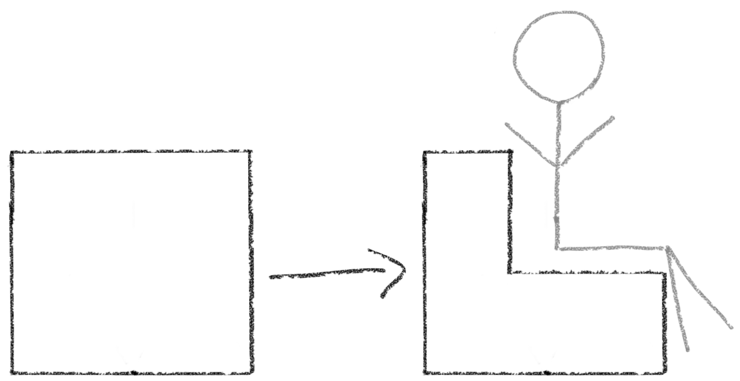
Remove material to provide function

18

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



Material Distribution

ETH zürich

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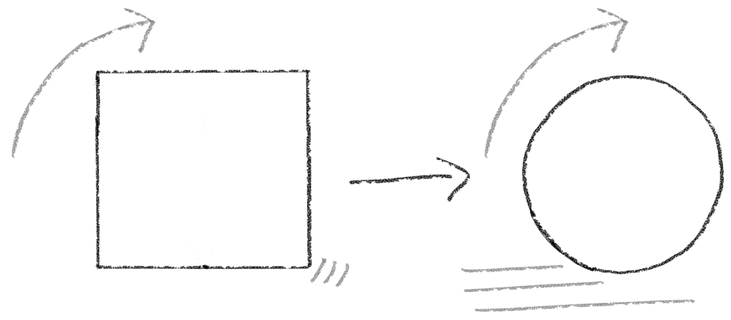
Optimize structural topology or geometry

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

ETH zürich

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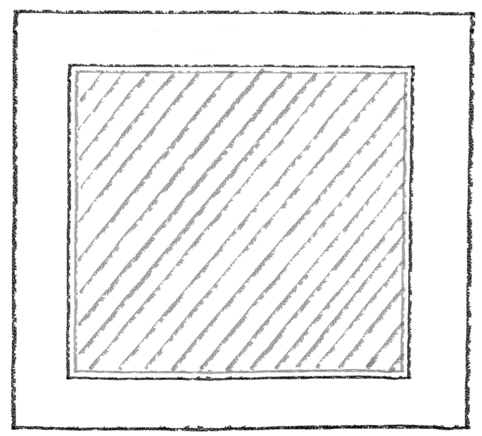
Embed functional material

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

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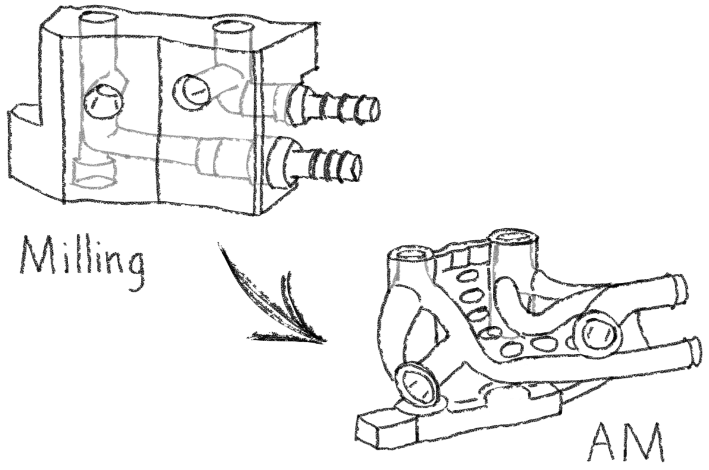
Optimize structural topology or geometry

19

Water manifold redesigned to reduce vibrations by factor of 10.

ASML
[20]

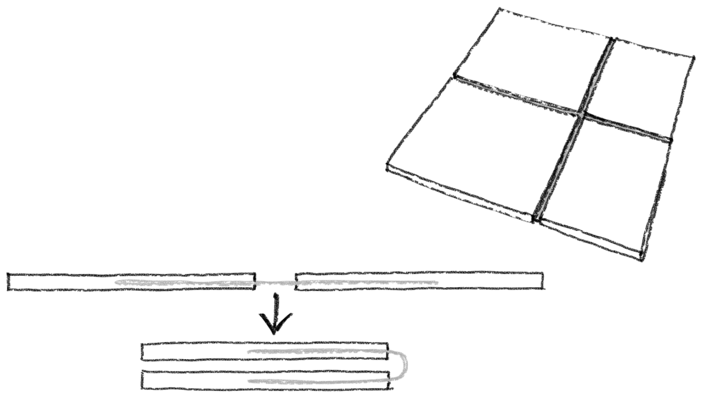


Embed functional material

20

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

Marcelo Dapino
Ohio State University
[21]

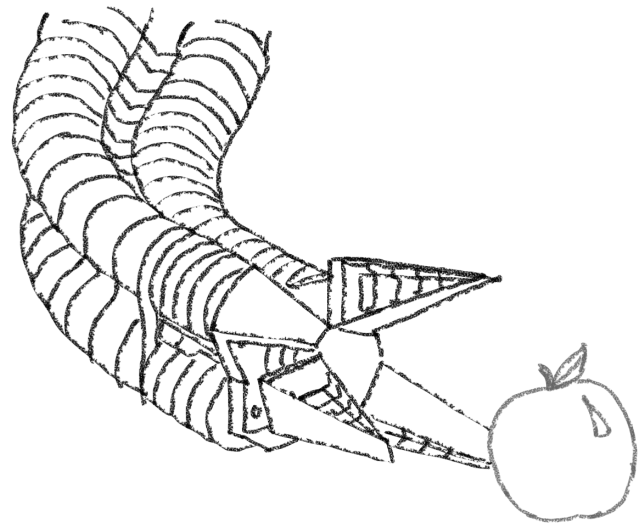


Use material distribution to achieve desired behavior

17

Flexible grippers and hose achieved through distribution of material.

Festo and EOS
[18]

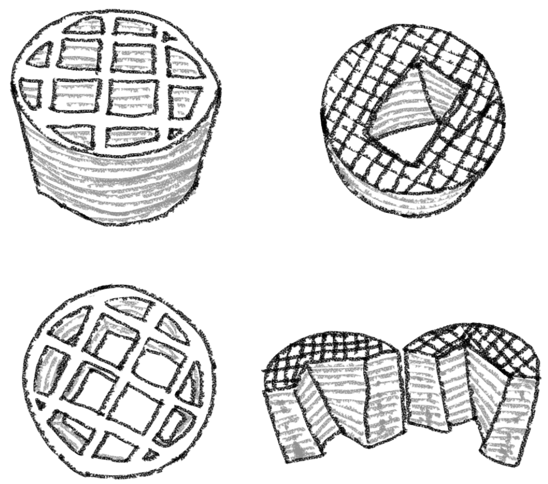


Remove material to provide function

18

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

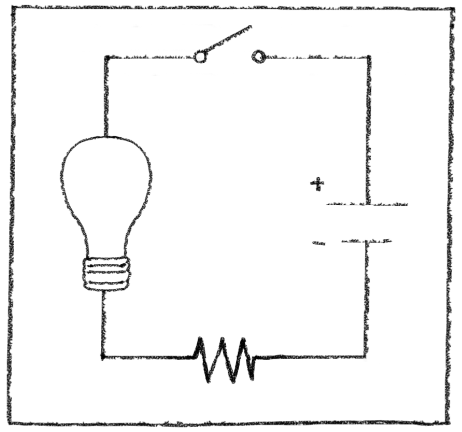
Chandru, Balasubramanian, Oommen, and Raghunandan
Indian Institute of Science
[19]



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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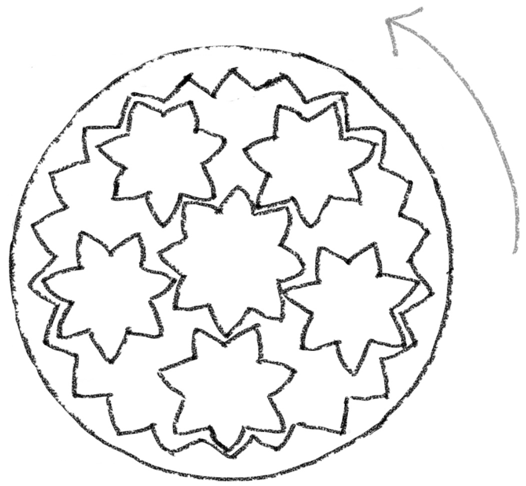
Use enclosed, functional parts

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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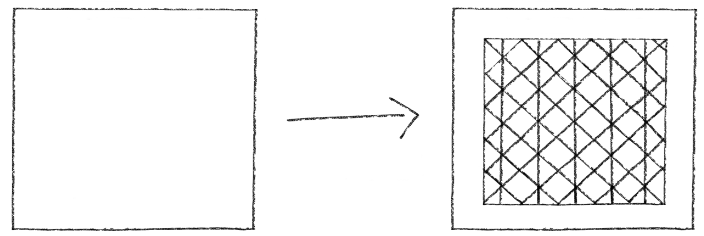
Replace internal structure with lightweight lattice structure

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.



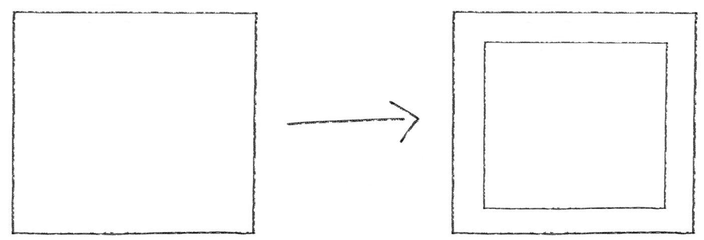
Lightweight

ETH zürich ED+C ENGINEERING DESIGN AND COMPUTING

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

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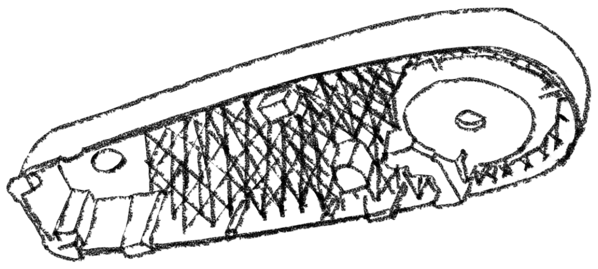
Replace internal structure with lightweight lattice structure

23

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

Omron Adept Technologies
[3]

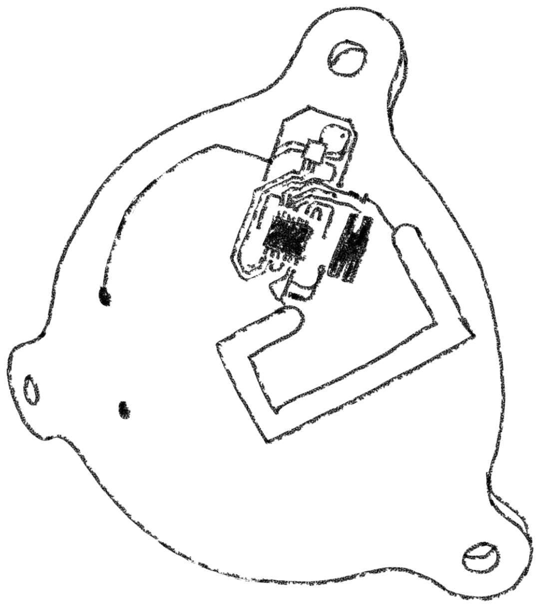


Embed functional component

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]



Hollow out artifact to reduce weight

24

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

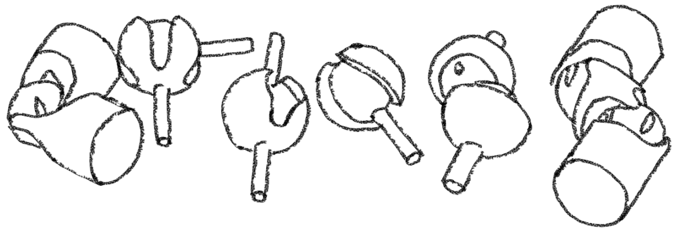
ViruZ3
Thingiverse
[24]

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

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R1

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

[2] Zhang, B., Tarantino, B., and Lieber, S. C., 2017, "Effect of Metal Additive Manufacturing on the Engineering Design of Manufacturing Tooling: A Case Study on Dies for Plastic Extruded Products," International Mechanical Engineering Congress and Exposition (IMECE2017), Tampa, Florida, USA. DOI: 10.1115/IMECE2017-71534

[3] Gibson, I., Rosen, D., and Stucker, B., 2015, Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing, Springer. DOI: 10.1007/978-1-4939-2113-3

[4] EOS, 2015, "Aerospace: Vectorflow - Additive Manufacturing of probes for measuring speed and temperature in turbo engines," https://www.eos.info/aerospace-vectoflow-additive-manufacturing-of-probes-for-measuring-speed-and-temperature-in-turbo-engines-ea0691d8a20ee1eb.

[5] Protolabs, 2017, "Ready for Take Off: Engineering students prepare 3D-printed rocket engine for launch," https://www.protolabs.com/resources/case-studies/university-of-minnesota-rocketry-group/.

[6] Chalcraft, E., 2013, "Nike Vaport Laser Talon 3D printed football boot studs," https://www.dezeen.com/2013/03/04/nike-vapor-laser-talon-3d-printed-football-boot-studs-by-nike/.

References

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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/Design-Heuristics-AM.html

R3

[13] Nessi, A., and Stankovic, T., 2018, "Topology, Shape, and Size Optimization of Additively Manufactured Lattice Structures Based on the Superformula," Proceedings of the ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC/CIE 2018)), Québec City, Québec, Canada, 26-29 August 2018, ASME. DOI: 10.1115/DETC2018-86191

[14] Setaki, F., Tenpierik, M., Turrin, M., and van Timmeren, A., 2014, "Acoustic absorbers by additive manufacturing," Building and Environment, 72, pp. 188-200. DOI: 10.1016/j.buildenv.2013.10.010

[15] Sengeh, D. M., and Herr, H., 2013, "A Variable-Impedance Prosthetic Socket for a Transtibial Amputee Designed from Magnetic Resonance Imaging Data," Journal of Prosthetics and Orthotics, 25(3), pp. 129-137. DOI: 10.1097/JPO.0b013e31829be19c

[16] Johnson, A., Bingham, G. A., and Wimpenny, D. I., 2013, "Additive manufactured textiles for high-performance stab resistant applications," Rapid Prototyping Journal, 19(3), pp. 199-207. DOI: 10.1108/13552541311312193

[17] Paterson, A. M., Bibb, R., Campbell, R. I., and Bingham, G., 2015, "Comparing additive manufacturing technologies for customised wrist splints," Rapid Prototyping Journal, 21(3), pp. 230-243. DOI: 10.1108/rpj-10-2013-0099

[18] EOS, 2012, "EOS Technology Enables Automation Specialist Festo to Design its Bionic Assistance System," https://cdn3.scrvt.com/eos/public/c7b56556f8794c2c/af62457d0a2ded1890c4b84c4d418a29/download_reference.pdf.

References

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R2

[7] EOS, 2014, "US Regulator FDA Awards First Approval for Customized 3D-Printed Polymeric Cranial Implants," https://cdno.scrvt.com/eos/public/d094c85b87e2919d/0304aa3d88631c96108abcef0794283d/Case_Study_EOS_OPM_Schaedelimplantat.pdf.

[8] Diegel, O., 2011, "Odd Guitars," http://www.oddguitars.com/.

[9] Stratasys, 2016, "Chasing Perfection: Cutting-Edge Prototypes Push a Passion for Cycling," http://global72.stratasys.com/~/media/Case-Studies/Consumer-Goods/CS_PJ_CN_TrekConnex3.pdf?la=en.

[10] Holthinrichs Watches, 2017, "Ornament 1 Delft Blue," https://holthinrichswatches.com/watches/ornament-1-delft-blue/.

[11] Stratasys, 2013, "Leone Develops Innovative Inverse Approach for Implantology Surgical Guides," http://www.stratasys.com/resources/case-studies/dental/leone.

[12] Vidimce, K., Wang, S.-P., Ragan-Kelley, J., and Matusik, W., 2013, "OpenFab: A Programmable Pipeline for Multi-Material Fabrication," ACM Transactions on Graphics, 32(4), p. 136. DOI: 10.1145/2461912.2461993

References

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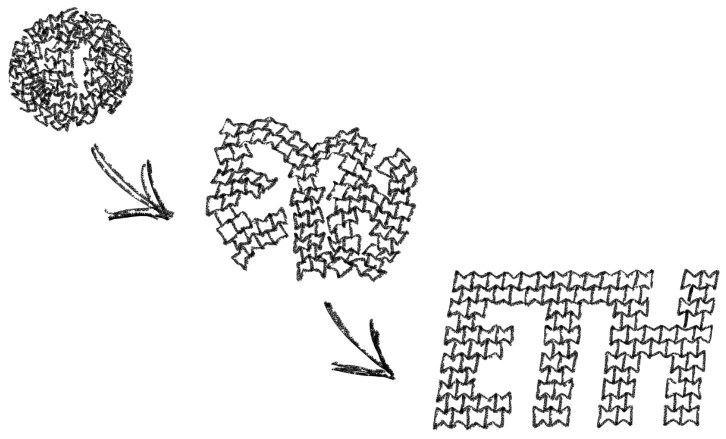
Create multi-functional artifact with reconfigurable structures

25

Programmed auxetic structures change shape when placed in hot water.

Wagner, Chen, and Shea
ETH Zürich
[25]



R4

[19] Chandru, R. A., Balasubramanian, N., Oommen, C., and Raghunandan, B. N., 2018, "Additive Manufacturing of Solid Rocket Propellant Grains," Journal of Propulsion and Power, pp. 1-4. DOI: 10.2514/1.B36734

[20] Loncke, D., 2014, "Following Moore's Law," Mikroniek, 54(6), pp. 17-22.

[21] Dapino, M., 2014, "Additive manufacturing of smart metallic structures," http://spie.org/newsroom/5322-additive-manufacturing-of-smart-metallic-structures?SSO=1.

[22] Castillo, S., Muse, D., Medina, F., MacDonald, E., and Wicker, R., 2009, "Electronics Integration in Conformal Substrates Fabricated with Additive Layered Manufacturing," Solid Freeform Fabrication Symposium 2009, Austin, TX, USA, 3-5 August 2009, pp. 730-737.

[23] Calì, J., Calian, D. A., Amati, C., Kleinberger, R., Steed, A., Kautz, J., and Weyrich, T., 2012, "3D-printing of non-assembly, articulated models," ACM Transactions on Graphics, 31(6), p. 130. DOI: 10.1145/2366145.2366149

[24] ViruZ3, 2016, "Realistic Octopus rounded and boxed."

[25] Wagner, M., Chen, T., and Shea, K., 2017, "Large Shape Transforming 4D Auxetic Structures," 3D Printing and Additive Manufacturing, 4(3), pp. 133-142. DOI: 10.1089/3dp.2017.0027

References

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ED +C ENGINEERING DESIGN AND COMPUTING

Design Heuristics for Additive Manufacturing Publications

[1] Blösch-Paidosh, A., and Shea, K., 2017, "Design Heuristics for Additive Manufacturing," Proc. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 5: Design for X, Design to X, Vancouver, Canada, 21-25 August 2017.

[2] Blösch-Paidosh, A., and Shea, K., 2018, "Preliminary User Study on Design Heuristics for Additive Manufacturing," Proceedings of the ASME 2018 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC/CIE 2018), Québec City, Québec, Canada, 26-29 August 2018, ASME. DOI: 10.1115/DETC2018-85908

[3] Blösch-Paidosh, A., and Shea, K., 2019, "Design Heuristics for Additive Manufacturing Validated Through a User Study," Journal of Mechanical Design, 141(4). DOI: 10.1115/1.4041051

[4] Blösch-Paidosh, A., Ahmed-Kristensen, S., and Shea, K., 2019, "Evaluating the Potential of Design for Additive Manufacturing Heuristic Cards to Simulate Novel Product Redesigns," Proceedings of the ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC/CIE 2019), Anaheim, CA, USA, 18-21 August 2019, ASME. DOI: 10.1115/DETC2019-97865

Please visit our website for updates and further information:

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