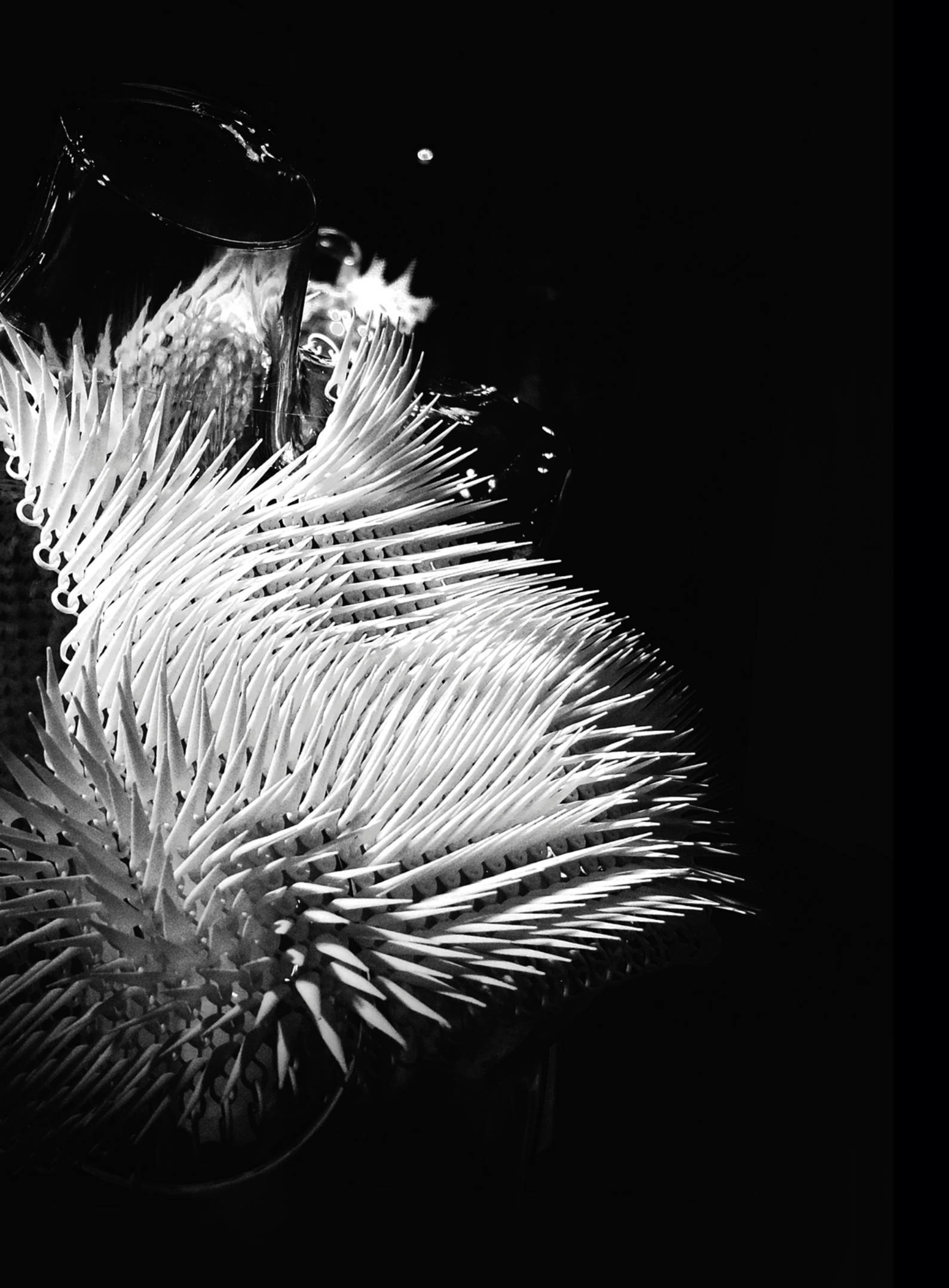


Guest-edited by
NEIL LEACH and
BEHNAZ FARAHI

06 | Vol 87 | 2017

3D-Printed Body Architecture





**ARCHITECTURAL
DESIGN**

November/December 2017
Profile No 250

3D-Printed Body Architecture

Guest-edited by
NEIL LEACH and
BEHNAZ FARAHİ

About the Guest-Editors

Neil Leach and Behnaz Farahi

05

Introduction

What is 3D-Printed Body Architecture?

Neil Leach

06

Dermi-Domus

A Grown Wardrobe for Bodies and Buildings

Neri Oxman

16

Curating the Digital

An Interview with MoMA's Paola Antonelli

Neil Leach

26

Neri Oxman and members of the Mediated Matter Group in collaboration with Stratasys, *Rottlace*, 2016

Interactions

Dialogues on Body, Protections and Derivatives

Niccolò Casas

34

Digitally Crafted Couture

Julia Koerner

40

Dress/Code

Democratising Design Through Computation and Digital Fabrication

Jessica Rosenkrantz and Jesse Louis-Rosenberg

48

Mass Customisation

Designed in China, Produced Globally

Steven Ma

58

Nervous System, Kinematics Petals Dress #1, Museum of Fine Arts, Boston, 2016

Micromechanical Assemblies and the Human Body

Francis Bitonti

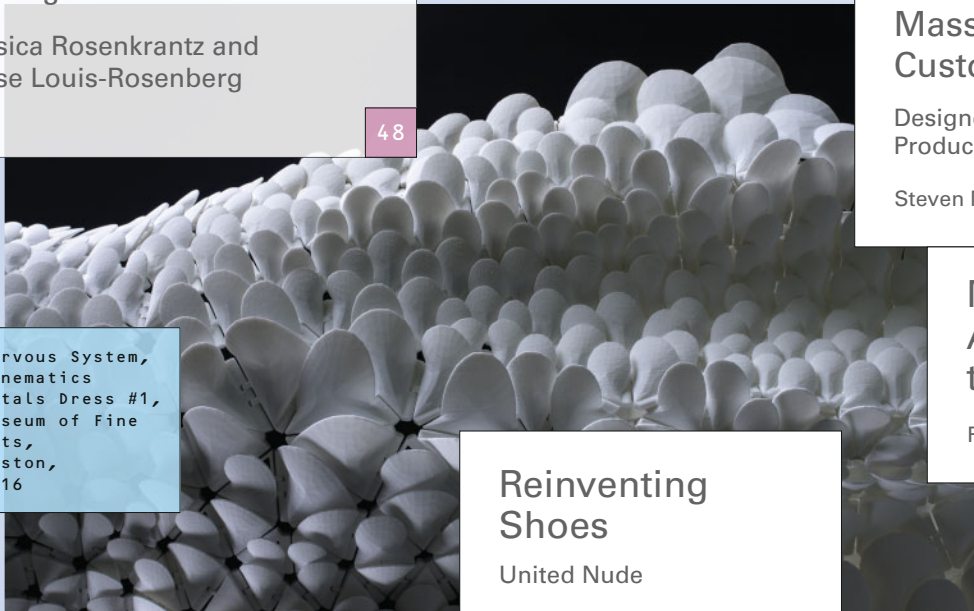
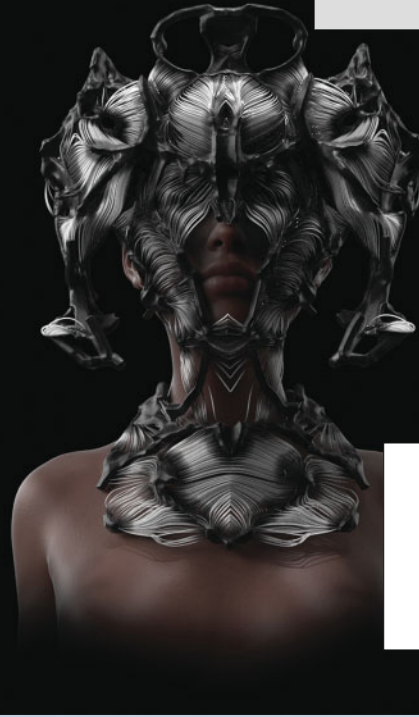
64

Reinventing Shoes

United Nude

Rem D Koolhaas

70



Size Matters

Why Architecture is the Future of 3D Printing

Neil Leach

76

Mamou-Mani Architects, *Overcast*, Victoria and Albert Museum, London, 2012

Material Behaviours in 3D-Printed Fashion Items

Behnaz Farahi

84

Clay Bodies

Crafting the Future with 3D Printing

Ronald Rael and Virginia San Fratello

92

Crystalline Tectonics

An Architect's Guide to 3D-Printing Sugar or Anything Else

Kyle von Hasseln

98

Madeline Gannon/ ATONATON, *Tactum*, 2014

Tectonism in Architecture, Design and Fashion

Innovations in Digital Fabrication as Stylistic Drivers

Patrik Schumacher

106

The Shape of Touch

On-Body Interfaces for Digital Design and Fabrication

Madeline Gannon

114

The Sonic Spectacle of the Enhanced Body

Eric Goldemberg

120

Counterpoint Teapots, Dresses and Chairs

Gilles Retsin

126

Contributors

134

Editorial Offices

John Wiley & Sons
9600 Garsington Road
Oxford
OX4 2DQ

T +44 (0)1865 776868

Consultant Editor

Helen Castle

Managing Editor

Caroline Ellerby
Caroline Ellerby Publishing

Freelance Contributing Editor

Abigail Grater

Publisher

Paul Sayer

Art Direction + Design

CHK Design:
Christian Küsters

Production Editor

Elizabeth Gongde

Prepress

Artmedia, London

Printed in Italy by Printer

Trento Srl

Will Alsop
Denise Bratton
Paul Brislin
Mark Burry
André Chaszar
Nigel Coates
Peter Cook
Teddy Cruz
Max Fordham
Massimiliano Fuksas
Kate Goodwin
Edwin Heathcote
Anthony Hunt
Charles Jencks
Bob Maxwell
Brian McGrath
Jayne Merkel
Peter Murray
Kester Rattenbury
Mark Robbins
Deborah Saunt
Patrik Schumacher
Coren Sharples
Neil Spiller
Leon van Schaik
Claire Weisz
Ken Yeang
Alejandro Zaera-Polo

EDITORIAL BOARD

Journal Customer Services

For ordering information, claims and any enquiry concerning your journal subscription please go to www.wileycustomerhelp.com/ask or contact your nearest office.

Americas

E: cs-journals@wiley.com
T: +1 781 388 8598 or
+1 800 835 6770 (toll free
in the USA & Canada)

Europe, Middle East and Africa

E: cs-journals@wiley.com
T: +44 (0)1865 778315

Asia Pacific

E: cs-journals@wiley.com
T: +65 6511 8000

Japan (for Japanese- speaking support)

E: cs-japan@wiley.com
T: +65 6511 8010 or 005 316
50 480 (toll-free)

Visit our Online Customer
Help available in 7 languages
at www.wileycustomerhelp.com/ask

Print ISSN: 0003-8504

Online ISSN: 1554-2769

Prices are for six issues
and include postage and
handling charges. Individual-
rate subscriptions must be
paid by personal cheque or
credit card. Individual-rate
subscriptions may not be
resold or used as library
copies.

All prices are subject to
change without notice.

Identification Statement

Periodicals Postage paid
at Rahway, NJ 07065.
Air freight and mailing in
the USA by Mercury Media
Processing, 1850 Elizabeth
Avenue, Suite C, Rahway,
NJ 07065, USA.

USA Postmaster

Please send address changes
to *Architectural Design*,
John Wiley & Sons Inc.,
c/o The Sheridan Press,
PO Box 465, Hanover,
PA 17331, USA

Rights and Permissions

Requests to the Publisher
should be addressed to:
Permissions Department
John Wiley & Sons Ltd
The Atrium
Southern Gate
Chichester
West Sussex PO19 8SQ
UK

F: +44 (0)1243 770 620
E: Permissions@wiley.com

All Rights Reserved. No
part of this publication
may be reproduced, stored
in a retrieval system or
transmitted in any form or
by any means, electronic,
mechanical, photocopying,
recording, scanning or
otherwise, except under
the terms of the Copyright,
Designs and Patents Act
1988 or under the terms
of a licence issued by the
Copyright Licensing Agency
Ltd, Barnard's Inn, 86 Fetter
Lane, London EC4A 1EN, UK,
without the permission in
writing of the Publisher.

Subscribe to Δ

Δ is published bimonthly
and is available to purchase
on both a subscription basis
and as individual volumes
at the following prices.

Prices

Individual copies:
£24.99 / US\$39.95
Individual issues on
 Δ App for iPad:
£9.99 / US\$13.99
Mailing fees for print
may apply

Annual Subscription Rates

Student: £84 / US\$129
print only
Personal: £128 / US\$201
print and iPad access
Institutional: £275 / US\$516
print or online
Institutional: £330 / US\$620
combined print and online
6-issue subscription on
 Δ App for iPad: £44.99 /
US\$64.99

Front cover: Behnaz
Farahi, *Caress of the
Gaze*, San Francisco,
2015. © Elena Kulikova
Photography [www.
elenakulikova.com](http://www.elenakulikova.com)

Back cover and inside
front cover: Changhao
Xin, Bingmo Zhang and
Lingyu Wang, 3D-printed
wearable, College
of Architecture and
Urban Planning, Tongji
University, Shanghai,
2016. © Behnaz Farahi

06 / 2017



ARCHITECTURAL DESIGN

November/December

2017

Profile No.

250

Disclaimer

The Publisher and Editors cannot be held responsible for errors or any consequences arising from the use of information contained in this journal; the views and opinions expressed do not necessarily reflect those of the Publisher and Editors, neither does the publication of advertisements constitute any endorsement by the Publisher and Editors of the products advertised.



ABOUT THE
GUEST-EDITORS

NEIL LEACH AND BEHNAZ FARAHİ



Guest-Editors Neil Leach and Behnaz Farahi have been collaborating since meeting at the University of Southern California (USC) where from 2011 to 2013 they worked on a research project to develop a robotic fabrication technology for 3D-printing structures on the Moon and Mars, funded by two NASA Innovative Advanced Concepts grants. Leach is an academic and theorist. Farahi is a creative designer and technologist. Both are trained as architects. This issue of *Δ* illustrates their complementary perspectives on the new possibilities opening up for architectural designers within the emerging field of 3D-printed body architecture.

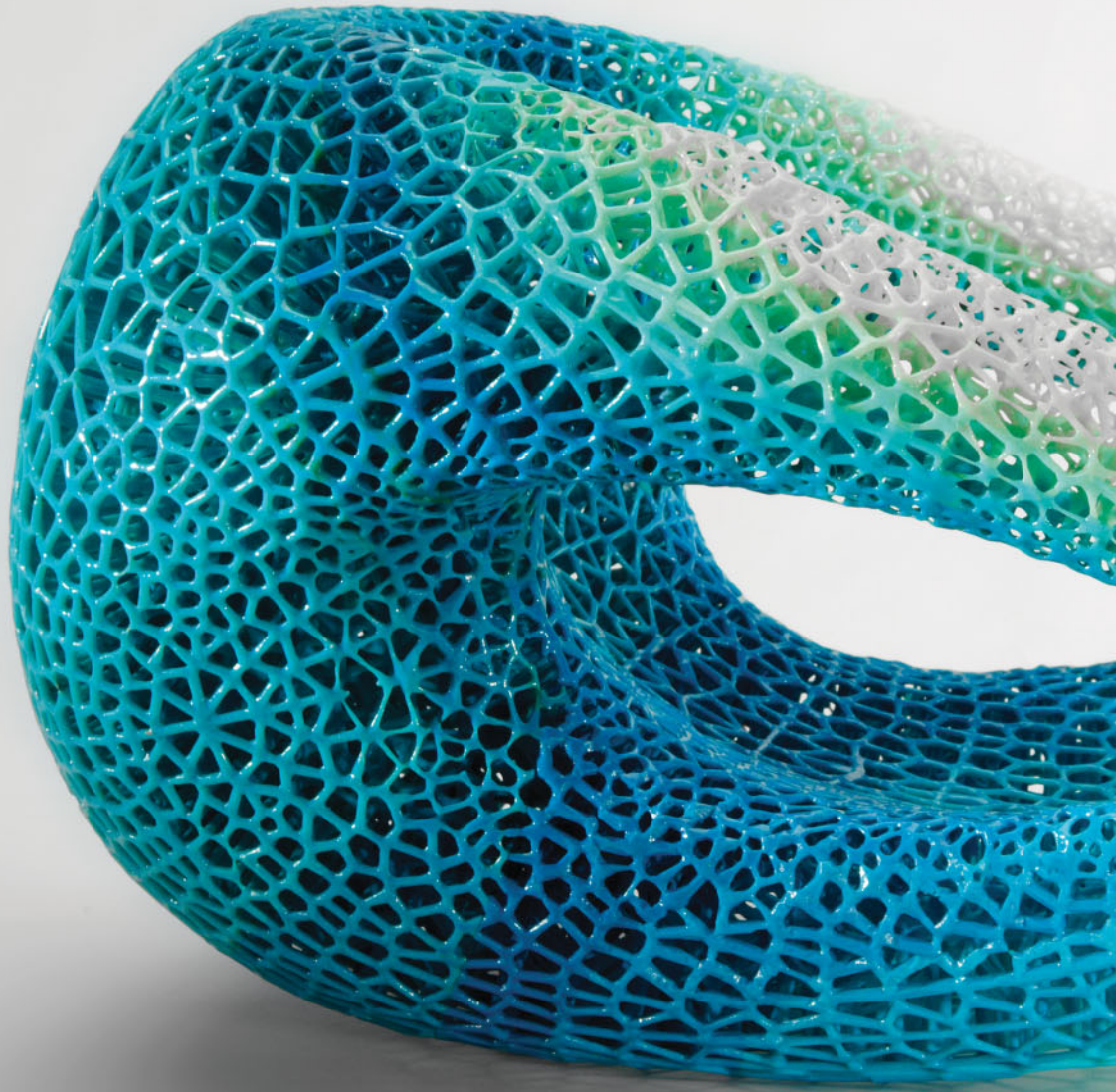
Neil Leach teaches at Florida International University, at Tongji University in China, and at the European Graduate School in Switzerland. He has also taught at many of the leading schools of architecture, including the Architectural Association (AA) in London, Harvard Graduate School of Design (GSD), Columbia Graduate School of Architecture, Planning and Preservation (GSAPP), Cornell University and the Southern California Institute of Architecture (SCI-Arc). He studied architecture at the University of Cambridge, and holds a PhD from the University of Nottingham. He is a licensed architect in the UK, and one of only three architects to be elected to the Academia Europaea. He has published over 30 books, and has guest-edited two previous issues of *Δ*: *Digital Cities* (2009) and *Space Architecture: The New Frontier for Design Research* (2014). His publications on architectural theory include *Rethinking Architecture* (Routledge, 1997), *The Anaesthetics of Architecture* (MIT Press, 1999), *Millennium Culture* (Ellipsis, 1999) and *Camouflage* (MIT Press, 2006). His publications on computational design include *Designing for a Digital World* (Wiley, 2002), *Digital Tectonics* (Wiley, 2004), *Machinic Processes* (China Architecture and Building Press, 2010), *Fabricating the Future* (Tongji University Press, 2012), *Scripting the Future* (Tongji University Press, 2012), *Robotic Futures* (Tongji University Press, 2013) and *Swarm Intelligence: Architectures of Multi Agent Systems* (Tongji University Press, 2017). He is also the translator of Leon Battista Alberti, *On the Art of Building in Ten Books* (MIT Press, 1988).



Behnaz Farahi is a creative designer and technologist working at the intersection of fashion, architecture and interaction design. She holds a Bachelor's and two Master's degrees in architecture, and is currently an Annenberg Fellow and PhD candidate in Interdisciplinary Media Arts and Practice at the USC School of Cinematic Arts. She is interested in exploring the potential of interactive environments and their relationship to the human body through the implementation of emerging technologies in contemporary art/architecture practice. Her goal is to enhance the relationship between human beings and the built environment by following design/motion principles inspired by natural systems. Application areas include architecture, fashion and interaction design. She also specialises in physical computing, sensor technologies, additive manufacturing and robotic technologies. Her work has been exhibited internationally at Ars Electronica in Linz, Austria; Context Art, Miami; the 3D Printed Fashion Show/Exhibition for Lexus x Voxelworld Show, Düsseldorf; and the Wearable Fashiontech Festival, La Gaîté Lyrique, Paris. It has also been featured in several magazines and online websites including *Wired*, *Frame*, the *Guardian*, BBC and CNN. Awards include the 2016 Innovation by Design Linda Tischler Award and the 2016 World Technology Award (WTN), and she is the recipient of a Madworkshop grant and the Rock Hudson Fellowship. She has also been an Artist in Residence at Autodesk Pier 9 in San Francisco. ▾

INTRODUCTION

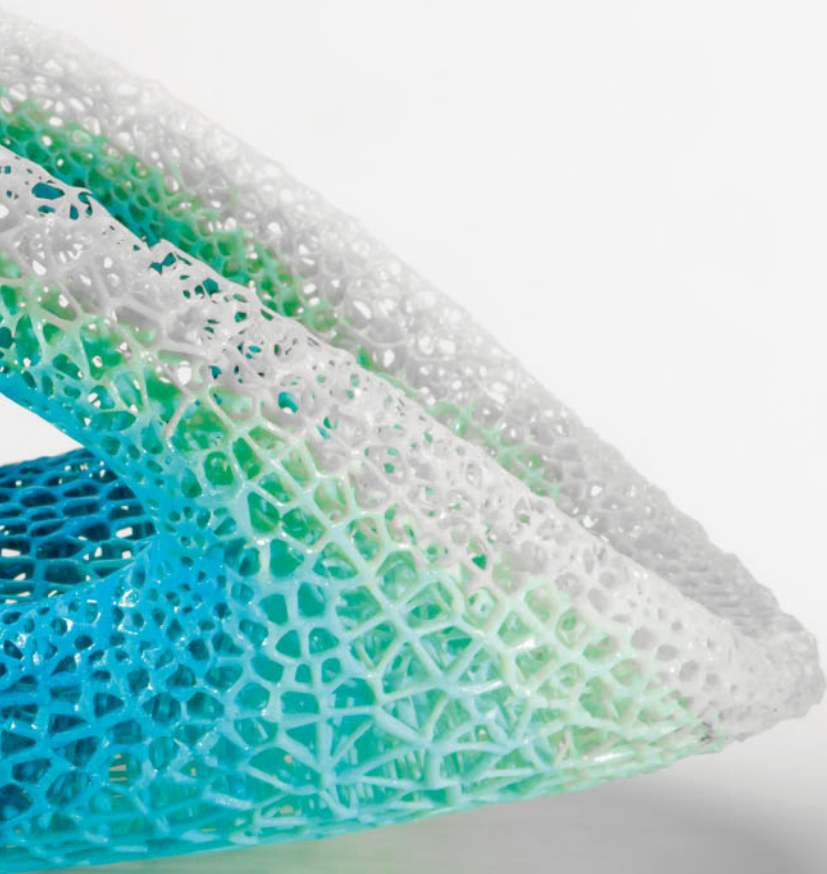
NEIL LEACH



Synthesis Design + Architecture,
Durotaxis Chair,
2014

Multi-material 3D-printed chair inspired by
the biological process of the same name,
which refers to the migration of cells guided
by gradients in substrate rigidity.

WHAT IS 3D-PRINTED BODY ARCHITECTURE?



Let us start with a brief definition: '3D-printed body architecture' could be defined as 3D-printed designs by architects for clothing, shoes, food, chairs and other items either for the human body, or at the scale of the human body.¹ While the term itself is new, it nonetheless builds upon a number of existing traditions – the relatively recent history of 3D printing, and the longer-standing history of exploring the relationship between the human body and architecture.

Body architecture introduces a new genre of design practice to the rapidly expanding field of 3D printing, or 'additive manufacturing' as it is also called. The use of 3D printing for the fabrication of models has become widespread even within architectural education, to the point that Florida International University has invested in the provision of over 30 MakerBot 3D printers so that every student in its Innovation Lab is provided with their own personal machine.² Meanwhile, certain architectural practices, such as Foster + Partners, have been involved in exploring the potential use of 3D printing in building construction for both terrestrial and extraterrestrial environments.³ Likewise, certain schools of architecture, such as the Institute for Advanced Architecture of Catalonia (IAAC), have also been conducting research into the potential of large-scale 3D printing.⁴ 3D-printed body architecture is now opening up and expanding this tradition into a new design arena that shifts the focus from actual buildings to the household items to be found in them.

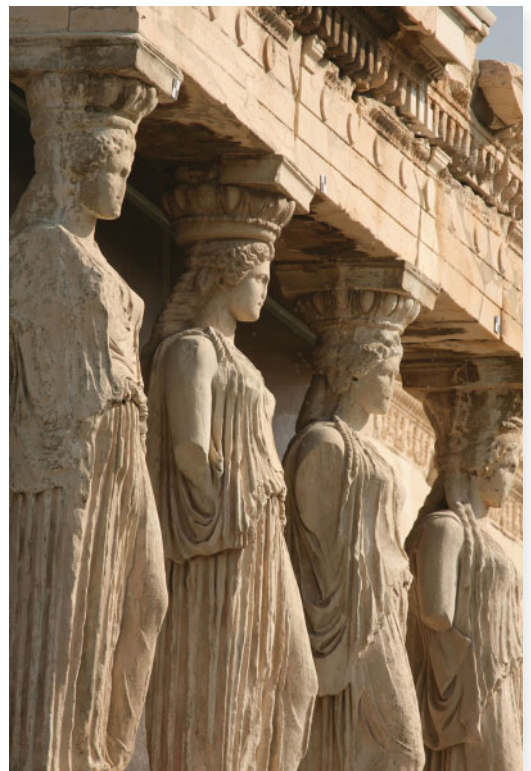
Behnaz Farahi,
Bodyscape,
2016

This 3D-printed outfit was designed according to a spiral logic based on the Langer lines of skin tension in order to allow it to flex with the body.

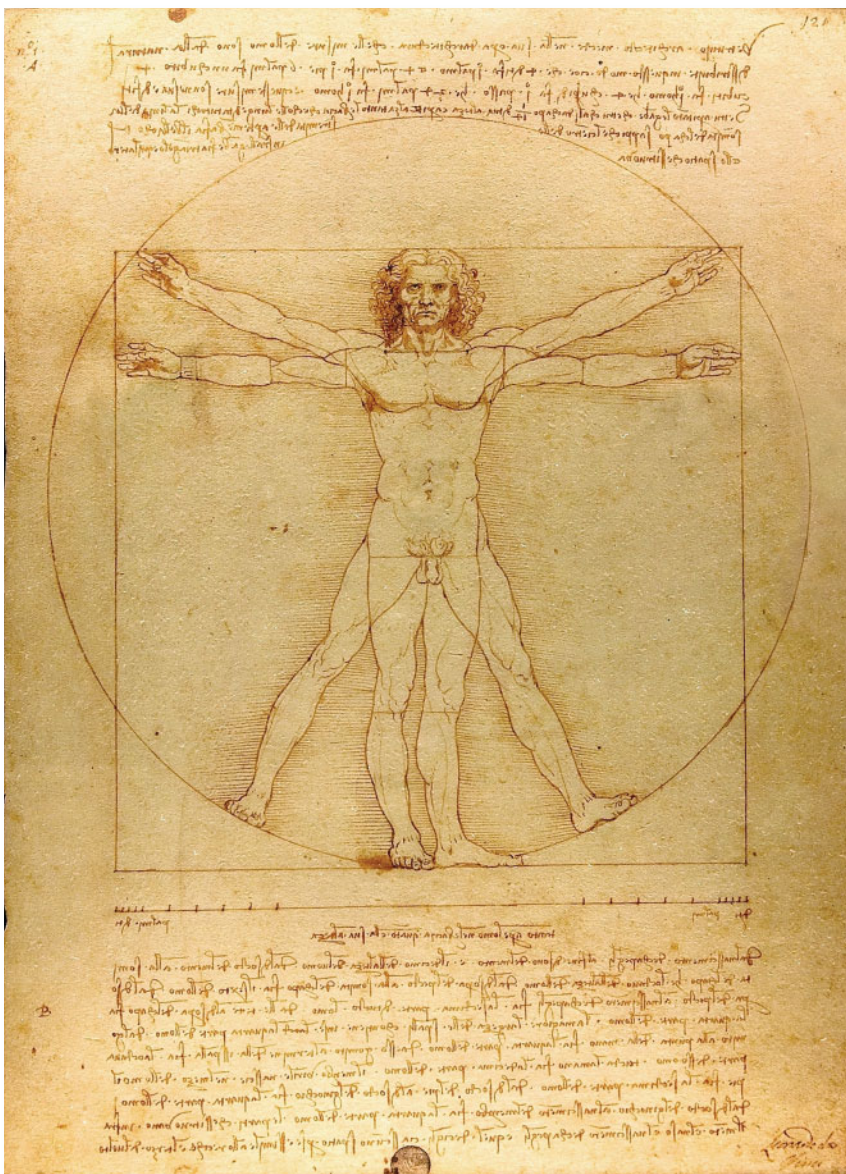


Caryatid
statues,
Acropolis,
Athens,
2008

According to Vitruvius, the Caryatids represent the women of Caryae, who were punished for betraying Athens and siding with the Persians in 480 BC.



This famous drawing is based on Vitruvius's description of the ideal proportions of the human body that were to become replicated in the design of buildings throughout the world.



Body architecture also introduces a new perspective on the history of the relationship between the body and architecture. From Vitruvius's discussion of proportions in his treatise *De architectura* (c 30–15 BC),⁵ made famous by Leonardo da Vinci's drawing *Vitruvian Man* (c 1490), through to Le Corbusier's stylised universal human figure the *Modulor Man* (1943), there have been attempts to relate buildings to the proportions and physiognomy of the human body. In the case of the Caryatids, where human figures serve as columns to support the entablature of the Erechtheion on the north side of the Acropolis in Athens, architecture literally takes the form of the human body. More recently, the connection between architecture and the body has led architects to develop an interest in the fashion industry, as in the 2007 'Skin + Bones' exhibition at the Museum of Contemporary Art (MOCA), Los Angeles, and the accompanying publication,⁶ which drew extensively on architects designing fashion items. Body architecture draws from this in new and exciting ways to include not just fashion items, but also other design products for the human body.

So what are we to make of the emergence of 3D-printed body architecture? Does it constitute a passing fad where architects are merely experimenting with a new technology? Or could it perhaps be described as a form of 'proto-architecture' – like furniture, espresso makers and pavilions in the past – where architects explore at a smaller scale design strategies that will eventually feed into full-scale buildings? Or does it actually constitute a radical new genre of architectural design that not only expands the range of potential commissions for architects, but also forces them to rethink the very nature of architectural education and practice?

However we might appraise the work, one thing is abundantly clear: the contributors to this Δ have all experienced some form of architectural education. In other words, the work is connected fundamentally to the discourse of architecture. The issue seeks to chart and analyse 3D-printed body architecture, and expose it as one of the most exciting developments in the discipline in recent years.

OTHER ARCHITECTURES

In few other disciplines are students taught to design, think three-dimensionally and understand material behaviour quite as well as in architecture. The skills taught in architectural education are readily transferrable to other arenas, and there has been a long tradition of architects migrating to other disciplines. Constance Adams, for example, studied architecture at Yale University, but moved into the space industry to become one of the designers of the International Space Station.⁷ Joseph Kosinski, who studied architecture at Columbia University's Graduate School of Architecture, Planning and Preservation (GSAPP), moved into the film industry to become the director of movies such as *Tron: Legacy* (2010) and *Oblivion* (2013).⁸

Architectural education now places a heavy emphasis on digital skills. Moreover, with the introduction of digital technologies, as Mark Burry has noted, the differences between architecture and other disciplines are being effaced.⁹ With these new opportunities has come an increase in the number of architects shifting to other design fields, especially 3D printing. For example, many have used their digital skills to work for fashion designers, such as Iris van Herpen, even though – or perhaps because – Van Herpen herself does not possess those same digital skills. In this issue of *Δ* alone, contributors Niccolò Casas (pp 34–9), Neri Oxman (pp 16–25) and Julia Koerner (pp 40–47) have all worked for Van Herpen, whether or not their names appear on the list of credits. Other contributors designing 3D-printed fashion items include Francis Bitonti (pp 64–9), Jessica Rosenkrantz and Jesse Louis-Rosenberg, cofounders of design studio Nervous System (pp 48–57) and Guest-Editor Behnaz Farahi (pp 84–91).

Often these designers engage with other computational systems. Farahi combines her interest in 3D printing with interactive systems. Similarly, Eric Goldemberg's MONAD Studio has collaborated with interactive designer Anouk Wipprecht on the design of a series of interactive 3D-printed musical instruments and a prosthesis for bionic pop artist Viktoria Modesta (pp 120–25). Meanwhile, Madeline Gannon explores how digital technologies can scan the topography of the body so that jewellery can be customised for the user (pp 114–19).

MATERIALITY

It could be argued that whenever architects find themselves working in other design fields, they always bring with them deep-seated architectural concerns, such as an interest in materiality and material behaviours. This is reflected in many of the contributions to this issue. Neri Oxman has been a leading figure in exploring the limits of 3D printing, and her contribution includes designs for 3D-printed glass (see pp 31–33). What distinguishes Oxman's work in particular is her capacity to marry technical expertise with design ability. Not only are the 3D-printed glass designs she has produced with her Mediated Matter Group at the MIT Media Lab technically innovative in their production methods, but the results are also ravishingly beautiful.

Farahi is likewise interested in 3D-printing materials, but for different reasons. Her article (pp 84–91) explores how design and geometry can be used to produce flexible items out of rigid materials, where printers using soft, flexible materials are not available or too expensive. Bitonti addresses similar concerns in his article (pp 64–9).

Emerging
Objects,
Twisting
Tower,
2017

This container
is 3D-printed in
salt from the San
Francisco Bay.





3D Systems
Culinary Lab,
Banana,
2016

This exploration
in 3D printing with
sugar takes the
form of bananas.

One of the key constraints with 3D printing is the cost of materials. Ronald Rael and Virginia San Fratello have been researching alternative low-cost materials, such as salt and clay.

One of the key constraints with 3D printing is the cost of materials. For some time now, Ronald Rael and Virginia San Fratello have been researching alternative low-cost materials, such as salt and clay. Their article (pp 92–7) explores the potential use of clay – one of the most ancient building materials – in one of the most contemporary modes of fabrication: 3D printing.

As a student of architecture at the Southern California Institute of Architecture (SCI-Arc), Kyle von Hasseln experimented with 3D-printing food. Together with his partner, Liz von Hasseln, he went on to establish a company for 3D printing with sugar, the Sugar Lab, which was subsequently acquired by 3D Systems. With a background in the sciences prior to his architectural education, for him the crucial challenge here is to understand the crystalline tectonics of sugar itself (pp 98–105).

The question of tectonics is also touched upon by Patrik Schumacher, Director of Zaha Hadid Architects (ZHA), which has produced a range of 3D-printed items, from jewellery through to relatively large-scale structures (pp 106–13). Schumacher sees his notion of ‘tectonism’ as a subset of the new global style that he has coined ‘parametricism’. The extent to which tectonic principles can be understood within a framework of ‘style’ will no doubt generate considerable debate.

ECONOMIC MODELS

What is remarkable about the contributors to the issue is that, rather than working for others, many of them have seized the chance to set up their own 3D-printing design companies. As such, 3D printing presents a new field of potential entrepreneurship for architects.

Bitonti, and Rosenkrantz and Louis-Rosenberg have respectively established highly successful design practices, Studio Bitonti and Nervous System, focusing exclusively on 3D-printed wearables. Ronald Rael and Virginia San Fratello are the cofounders of 3D-printing ‘make-tank’ Emerging Objects. Likewise, Rem D Koolhaas, nephew of the famous architect with the same name from the Netherlands, has established his own shoe brand, United Nude, and collaborated with a series of architects in developing 3D-printed footwear (see pp 70–75). Julia Koerner has established JK Design, where she designs 3D-printed fashion items alongside buildings and products (pp 40–47).

Perhaps the biggest entrepreneurial success story, however, has been that of Steven Ma (pp 58–63), who trained as an architect at SCI-Arc, and has established a thriving 3D-printing practice, Xuberance, in Shanghai, where he designs everything from jewellery to architectural facades. Ma has been valued at \$40 million by his investors, and has opened up a 3D-printing museum and three 3D-printing cafes in Shanghai.

FabUnion,
3D Printed
Chair,
2017

The chair is fabricated by robotic 3D printing with the colour change achieved by varying the mixing rate of the two different materials during the printing process.



WHAT IS ARCHITECTURE?

If architects are so successful in the domain of 3D-printed body architecture, as a result of their background training and skill set, then the question arises as to whether we should be reconsidering the very definition of architecture. For what begins to emerge is a portrait of architects as being defined less by their traditional roles within the construction industry, and more by a certain creative outlook and design sensibility that could be deployed in other industries.

‘Are shoes architecture?’ asks Koolhaas. Zaha Hadid, who collaborated with him in developing a pair of 3D-printed shoes, could certainly see the connection: ‘Fashion and architecture can be considered as components within a single system of design. The immersive experience of a building can be likened to the tactile sensations of wearing a garment or an accessory. Just as clothing is based on the proportions of the human body, architecture must also be structured in relation to the human scale’ (p 75).

As the Senior Curator of the Department of Architecture and Design at the Museum of Modern Art (MoMA) in New York, Paola Antonelli, herself trained as an architect, is in a unique position to offer an overview on these developments. Importantly, for Antonelli, design is everywhere, and architecture itself is an aspect of design. As she notes in my interview with her on pp 26–33 of this issue: ‘It doesn’t make sense any more to distinguish design disciplines because of the materials that they use, the dimensional scale that they tackle, or other old-school kinds of criteria.’ As such, both architecture and 3D-printed body architecture fall under the category of design, and should not be distinguished in terms of scale.

Architecture and 3D-printed body architecture fall under the category of design, and should not be distinguished in terms of scale.



Arpi Mangasaryan,
3D-printed
jewellery,
Dessau Institute
of Architecture,
Anhalt University
of Applied
Sciences,
Dessau,
Germany,
2016

The jewellery was
produced by
Master's student
Arpy Mangasaryan in
a Body Architecture
workshop tutored
by Behnaz Farahi
and Karim Soliman.