

# Mattrbot

Robotic Soft Material

EXP  
An Endeavour to Invent Soft Materials  
for Robotic Applications  
by Utilizing Machine Learning

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## Executive Summary

*“Imagine a future where a material itself is a robot that can sense, actuate, compute and communicate!”*

Mattrbot is an endeavour to invent such materials through machine learning. The custom designed robotic material will not only revolutionize today's robots like humanoids and exosuits which have limitations due to silicone, but also bring new and exciting ones into existence like energy harvesting robots.

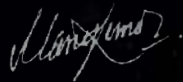
As of today silicone remains as the limited material choice for emerging robotics applications from exosuits to humanoids. This limitation is leading to limited forms, behaviour, scope of intelligence and ultimately limited applications of robots. Moreover, silicone scores poorly in environmental aspects as it is difficult to recycle, non-biodegradable, considered as a pollutant and an unwelcome material for the other forms of life. I believe that a way forward is not only inventing a robotic material, but also writing new rules based on the philosophy of harmonious making, using and unmaking of it without exploiting the world and without limiting the human creativity. Obviously these new rules must also include the values of atom economy, minimum energy, renewable resources, least processing waste, and eco-friendly degradation. What could be a better approach than Machine Learning to value these values. Using state of the art material libraries and machine learning, it has become possible to invent such a material that can become a robot in coming time. This unique ability of the material will open the doors of human exploration in unknown territories, in situations that are beyond the limits of human imagination.

Mattrbot has three important characteristics. First, “Plug-n-play” which enables it to acquire properties like self-healing, shape memory, light emitting, piezoelectric, ferroelectric, conductive, you name it. Second, it is “3D Printable” and third, it has “Triggered Degradation”, meaning that it can degrade whenever and wherever required. Mattrbot comes with Box and Bin. Box is nothing but a system that makes Mattrbot through a unique process and Bin is the place where Mattrbot goes after the end of life where triggered degradation takes place. Apart from revolutionizing the existing robots, the custom designed robotic material can create energy harvesting robots. Such robots with adaptive shape shifting structures can harvest multiple forms of renewable energy in one go. Energies around us are always in the combination of different forms, why we just focus on harvesting only one at a time. What if we can harvest multiple forms of renewable energy with Mattrbot that can float on our ocean with optimal shape shifting structure, material composition and ability to give desired response even in unknown external conditions. As our energy demand rises, we must look beyond the 20th century ideas of solar panels and windmills.



## Statement of Originality

Except where indicated in the text, all work in this report are my own original work. All materials in this report have not previously been submitted for a degree at any university.



Manoj Sahi Kumar  
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London, UK

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HARVARD  
UNIVERSITY

SIGMA-ALDRICH

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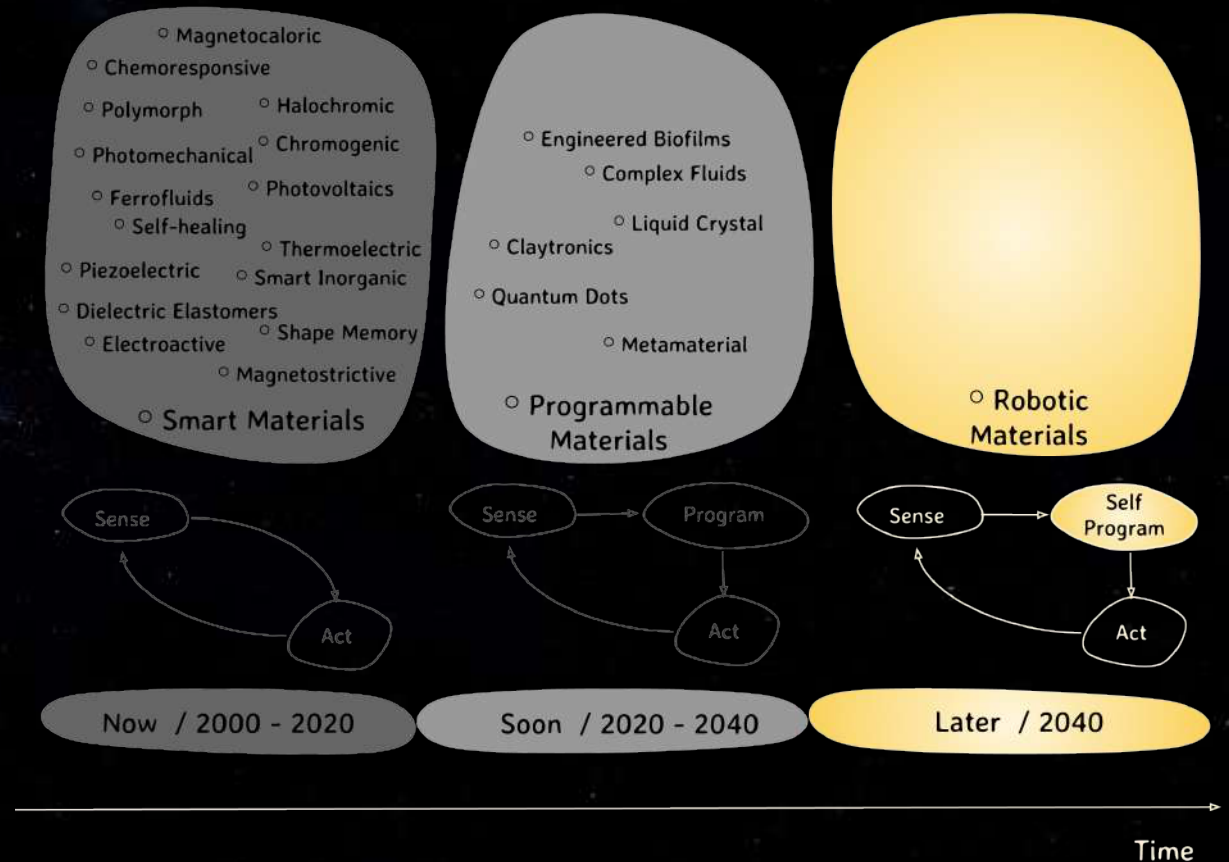
# 1. Future

## 1.1. Robotic Materials in Future

Let's start with the developments happening in the material world since the year 2000. It appears that the current and the past decade belong to smart materials. Smart materials are intelligent or responsive materials that have one or more properties which can be significantly changed in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields, light, or chemical compounds.<sup>1</sup> Many applications including new types of sensors and actuators such as artificial muscles uses these materials.<sup>2</sup>

While smart materials are proving effective for a range of applications, I believe that the next two decades will belong to programmable materials. Initially coined in 1991 as "Programmable matter" by Toffoli and Margolus, these materials have unique inner structure which is an ensemble of fine-grained computing elements arranged in space.<sup>3</sup> The geometry of the structure allows the properties of the material to be specifically influenced or in other words quasi programmed which is possible by using new ways of material manufacturing such as 3D nano-printing.<sup>4</sup>

However, I want to see further beyond 2040, which will mark the era of robotics materials in our lives. These materials will combine the capabilities of sensing, actuation, computation and communication and due to which these are also referenced as computational metamaterials<sup>5</sup> or in other words robotic materials.



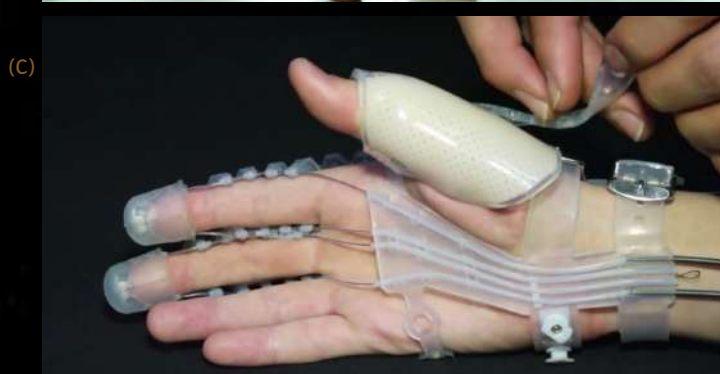
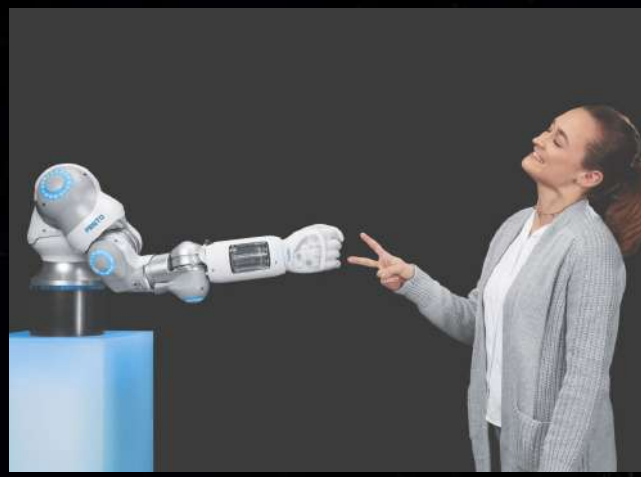
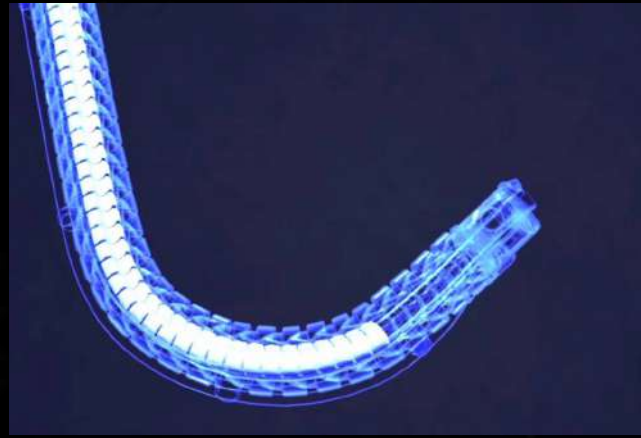
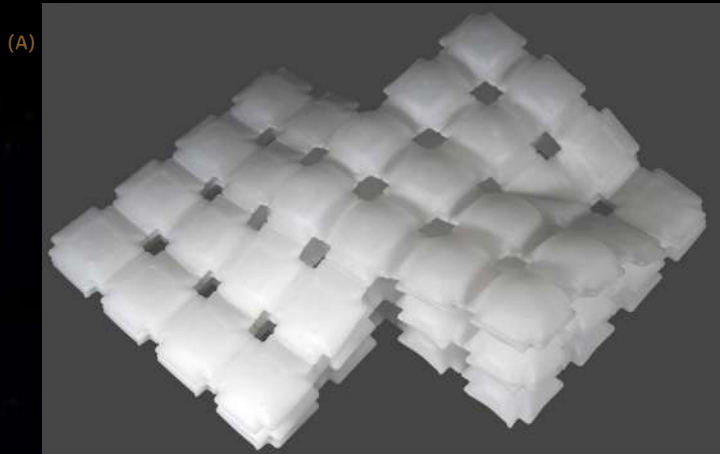
<sup>1</sup> Mohsen Shahinpoor, *Intelligent Materials*(Cambridge; UK: The Royal Society of Chemistry, 2008), p. 5

<sup>2</sup> Mohsen Shahinpoor, *Intelligent Materials*(Cambridge; UK: The Royal Society of Chemistry, 2008), p. 17

<sup>3</sup> Tommaso Toffoli; Norman Margolus, 'Programmable matter: concepts and realization', *Physica D: Nonlinear Phenomena*, vol 47, issue 1-2(1991):263

<sup>4</sup> <https://www.fraunhofer.de/en/research/key-strategic-initiatives/programmable-materials.html> (accessed on 16 May 2019)

<sup>5</sup> M. A. McEvoy, 'Materials that couple sensing, actuation, computation, and communication', *Science*, vol. 347, issue 6228: 1328



## 2. Present

### 2.1. Emerging Robotic Applications

Let's come to the present context of emerging robotic applications. An autonomous or driverless car which is capable of sensing its external environment also needs sensing capabilities inside it. The interiors of such vehicles (photo A) require intelligent soft materials.

The next generation of soft wearable robots or exosuits (photo B) that augment the human capabilities need innovative soft materials to give a more unobtrusive and human body compliant interface. Similarly, the robotic gloves (photo C) which is a soft wearable robot for the hand and enables the people such as elderly who have lost their hand function to grasp various objects again require intelligent hand compliant materials.

The novel surgical procedures that uses a robotic endoscope (photo D) to move inside the human body requires soft materials which are easy to manipulate. The collaborative robots (photo E) can physically interact with humans in a common or shared workspace. Such robots must also have soft, sensing and safe materials which doesn't hurt or harm humans upon physical contact.

The products for intimacy (photo F) are taking humanoid form to represent a human or human-like being in its appearance, behaviours and movements. These properties need soft and intelligent materials to appear natural with rich details.

The properties or features for materials may vary from one application to another application but eventually these are soft. Today, we find many of the emerging robots or autonomous products having soft material, fully or partially.

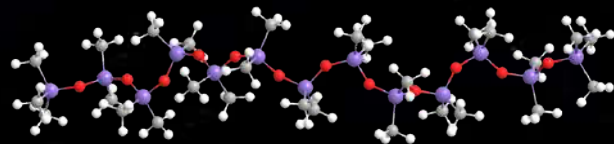
A Liquid Printed Pneumatics for Car Interiors (credit: BMW and MIT)  
B Soft Exosuits (credit: Wyss Institute and ReWalk Robotics)  
C Exo Glove (credit: Seoul National University)

D Endoscopic Robot (credit: Auris Health)  
E Collaborative Robot (credit: Festo)  
F Robot for Intimacy (credit: Daniel Holmes and Zou Chengxi/Sixth Tone)

## 2.2. Deep Obsession with silicone

However, have you noticed anything common among the emerging robotic applications? Almost all of them are based on silicone. In fact there is deep obsession for silicone even among the robotics researchers. Taking a good look at the soft robotics research happened since 2014 until 2018, it becomes quite evident that almost all robots are based on silicones, and one more interesting finding is that the silicone comes from a same supplier. A big question arises, why so? Is silicone the only best possible option?

Why there is only one material? The limitation of material leads to limited form. A limited form means limited possibility of behaviour. Limitation of behaviour limits the scope of intelligence and that results to limited application. Is it a disorder? I believe it is. I believe it is a disorder resulting from limited choice of material in emerging robotic applications.



Credit: American Chemical Society



○ Autonomous Fish / 2013



○ Octobot / 2018

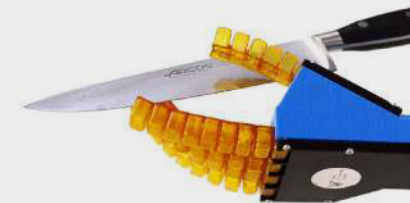


○ STIFF-FLOP / 2014



Material:  
Silicone Rubber

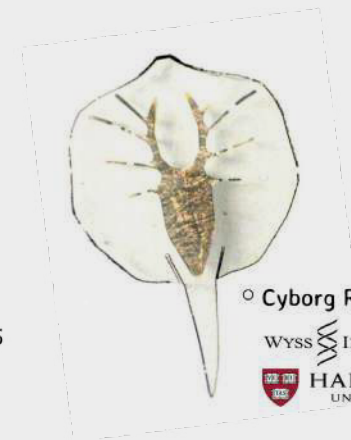
Supplier:  
Smooth On



○ Soft Pneumatic / 2017



○ RBO Hand / 2015



○ Cyborg Ray / 2016



## 2.3. Material Better than silicone

### *The Minimum Viable Proposition*

Silicones are problematic simply because of many reasons. Silicones are non-biodegradable. The recycling of silicone is limited process and in most of the case it is proprietary. Silicone may have attractive properties like viscoelastic, which means that at high temperature it acts similar to honey and at low temperature it acts like rubber, but this property can not be manipulated easily. Silicone may have low chemical reactivity, and translucency. However, it gathers dust on its surface and remains sticky to a large extent. Silicone compounds are pervasive in the environment. Particular silicone compounds, cyclic siloxanes D4 and D5, are air and water pollutants and have negative health effects on test animals.<sup>1</sup> The European Chemicals Agency found that "D4 is a persistent, bioaccumulative and toxic (PBT) substance and D5 is a very persistent, very bioaccumulative (vPvB) substance".<sup>2 3</sup>

Apart from above, 3D printing silicone is complicated and expensive. Also, silicone doesn't give good scope for plug-n-play features. By plug-n-play I mean that it has limitations while incorporating additional features such as self-healing, shape memory, conductive, light emitting, piezoelectric, magnetic, optoelectronic, photorefractive and so on, which are basic essential requirement for robotic soft materials.

So, making a material better than silicone that can eventually act as the founding block for robotic soft material is my MVP. This new material should open up the doors of new possibilities for robotics of today which is getting constrained by limitation of choice. I call this new material as Mattrbot.



1 <https://www.scientificamerican.com/article/chemicals-from-personal-care-products-pervasive-in-chicago-air/?redirect=1> (accessed 16 May 2019)

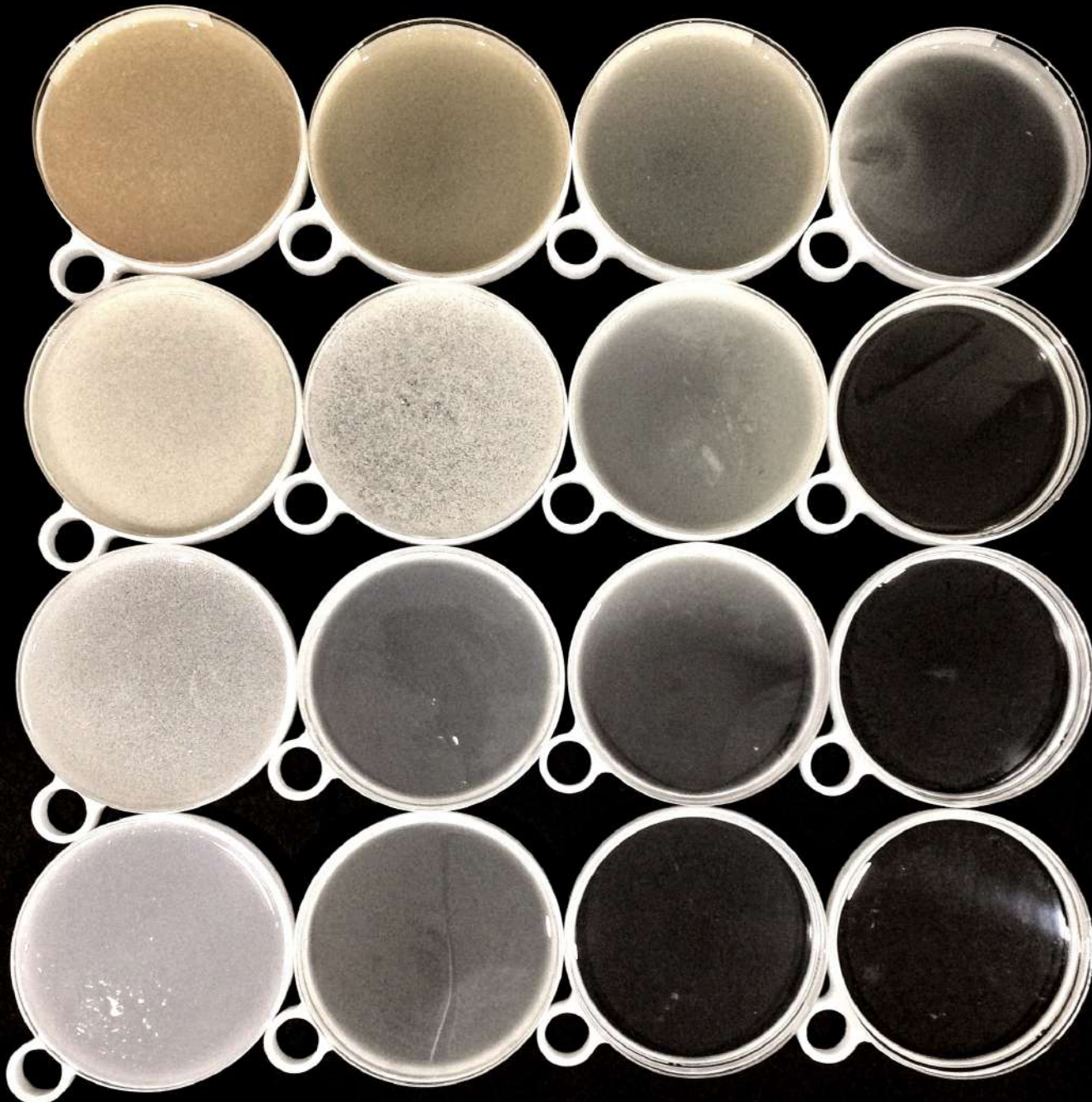
2 <https://echa.europa.eu/-/committee-for-risk-assessment-concludes-on-restricting-d4-and-d5> (accessed 16 May 2019)

3 <https://www.foodpackagingforum.org/news/echa-classifies-cyclic-siloxanes-as-svhcs> (accessed 16 May 2019)

## Eureka!!! Not Yet

After correcting the mistakes related with process of mixing and combinational ratios, I started getting success with my experiments. But the results were completely different. In fact I got strange looking materials. These were not what I was expecting as a material better than silicone. As it was important to stay focused on my objective, I decided to park these aside and moved on.





### *Over 100 Experiments and Then Finally!*

Next, I conducted over 100 experiments to get good results. These experiments were based on various combinational ratios and timing of mixing of the ingredients. These values were derived through Machine Learning. Finally, I started getting positive results and the materials that has the potential to be better than silicone. Further refinement of those materials improved the results considerably.



