4D Printing and Its Applications

Kaushik Seshadri[1], Robert Cormia[2]
[1]Palo Alto High School, [2]Foothill College

INTRODUCTION:

4D printing is a technology where certain materials are 3D printed into different shapes using a few specialized machines. These objects can change shape in specific ways based on environmental controls (i.e., changing the object's immediate surroundings, such as temperature, humidity, placing the object underwater, and more). While 4D printing is an emerging technology, there has been a whole slew of research into this new field. At the forefront is Skylar Tibbits, who is working with his MIT laboratory research group in conjunction with a company called Stratasys. So far, they have been able to induce folding of sheets into cubes when placed underwater, as well as long tubelike structures that can contort to form words. With regard to space, this precise control over different materials could be very useful. For example, carrying up a small block that folds out into a satellite in space would be cheaper and logistically simpler than launching a conventional satellite. However, it can be difficult to utilize these principles in space, as an object's surroundings in space cannot be readily altered due to lack of available resources. Therefore, to figure out how different materials would respond to different environments, and to choose the optimal material, knowledge of smart and programmable materials is key. 4D printing has extensive implications in biotechnology as well, to model nano-scale biological structures and their movements. However, as of now, 4D printing can only be done using expensive printers with multi-material printing capabilities (i.e., the ability to 3D print using different materials at once).

The goal of this project is to model the folding effects of 4D printing without an actual 4D printer. Also, I will look into different modeling methods to fold different shapes.

RESEARCH METHODOLOGIES:

As mentioned above, there has not been any research into the intersection between these three fields. However, a lot of prior work has been done on each field separately. Additionally, I did not have access to laboratory space needed to build and test models through any form of experimental research. Because of this, my data collection consisted mainly of reading through previous research on each individual field and drawing conclusions about how this work could be combined to utilize concepts from multiple categories. Figure 1 shows an illustration of 3D vs. 4D printing.

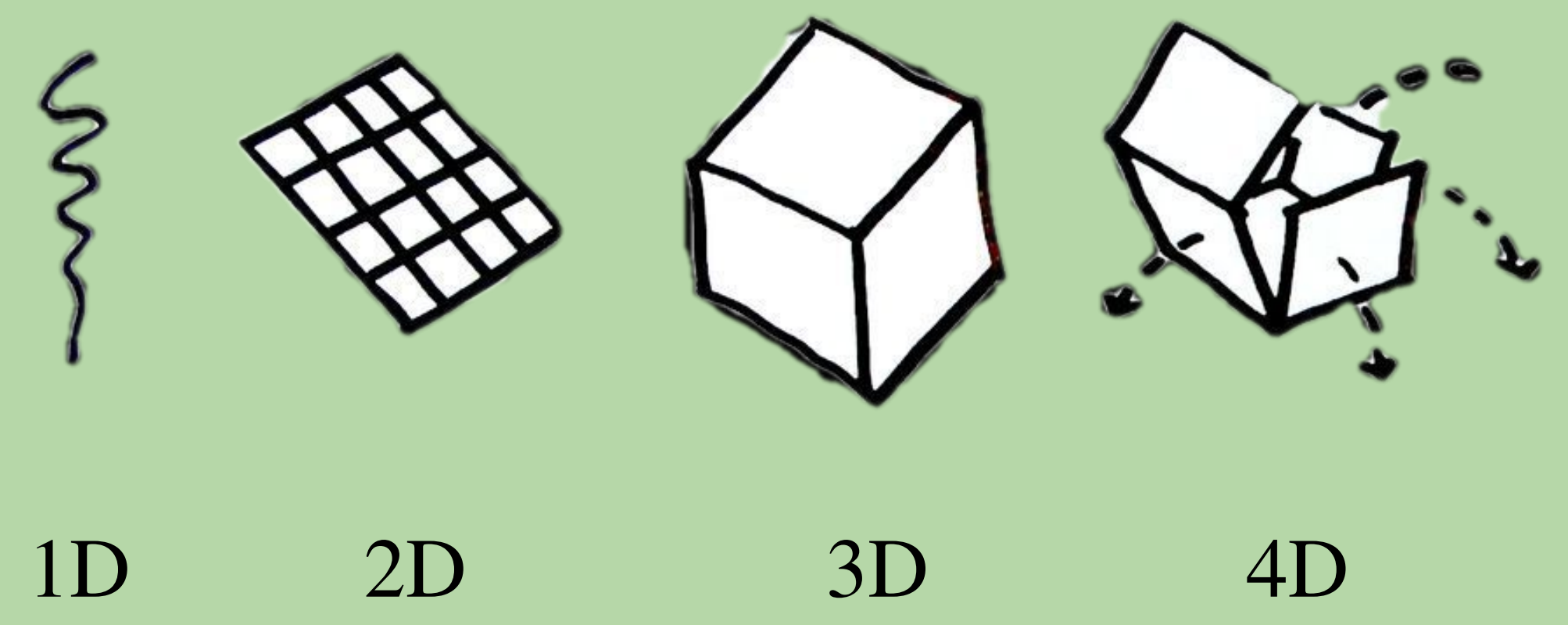

Figure 1

This approach likely falls under the umbrella of "descriptive research." I contacted Dr. Jessica Snyder, a NASA scientist looking at 4D printing, and talked with her about the current state of the technology and possible applications in space. I further gathered qualitative data by looking through articles from databases such as Science Direct. Additionally, I made my own models of 4D-printed objects that move in similar ways when stimulated. I worked with my mentor, Mr. Cormia, to create these models. From here, I made inferences about how these technologies could be used in space and biotechnology to answer my research question. This means there was a mix of observation and experimentation techniques in this project. Finally, to sort through and analyze the data collected, I used the "summarizing" technique. I got a sense of how the technologies I'm researching are evolving, and thus, I was able to discuss possible applications of these technologies in space.

DATA AND FINDINGS:

TYPE OF MATERIAL	STIMULUS TYPE	RESPONSE TYPE
Pyroelectric materials	Temperature change	Electric signal (voltage change)
Polymers (cellulose/ceramic based materials)	Humidity change	Capacitance or resistance change
Self healing materials	Outside force	Reactionary force
Smart metal alloys	Temperature	Shape
Bimetallic Strips	Temperature	Shape (change in curvature)

Table 1: types of materials that can be used with 4D printing and the types of stimulus and responses that occur as a result

In 4D printing, a 2D surface is printed that folds up into a 3D shape. Dürer nets map out every point on the 3D structure onto a 2D surface, allowing one to see where the specific positions of creases and edges should be when printed. For more complex structures, many Dürer nets exist. For example, a dodecahedron has 43,480 possible nets. One is shown below in Figure 2. Using Autodesk Fusion 360, I modeled and 3D printed a dodecahedron, then placed magnets in certain areas to mimic the idea of self-assembly when the pieces are shaken.

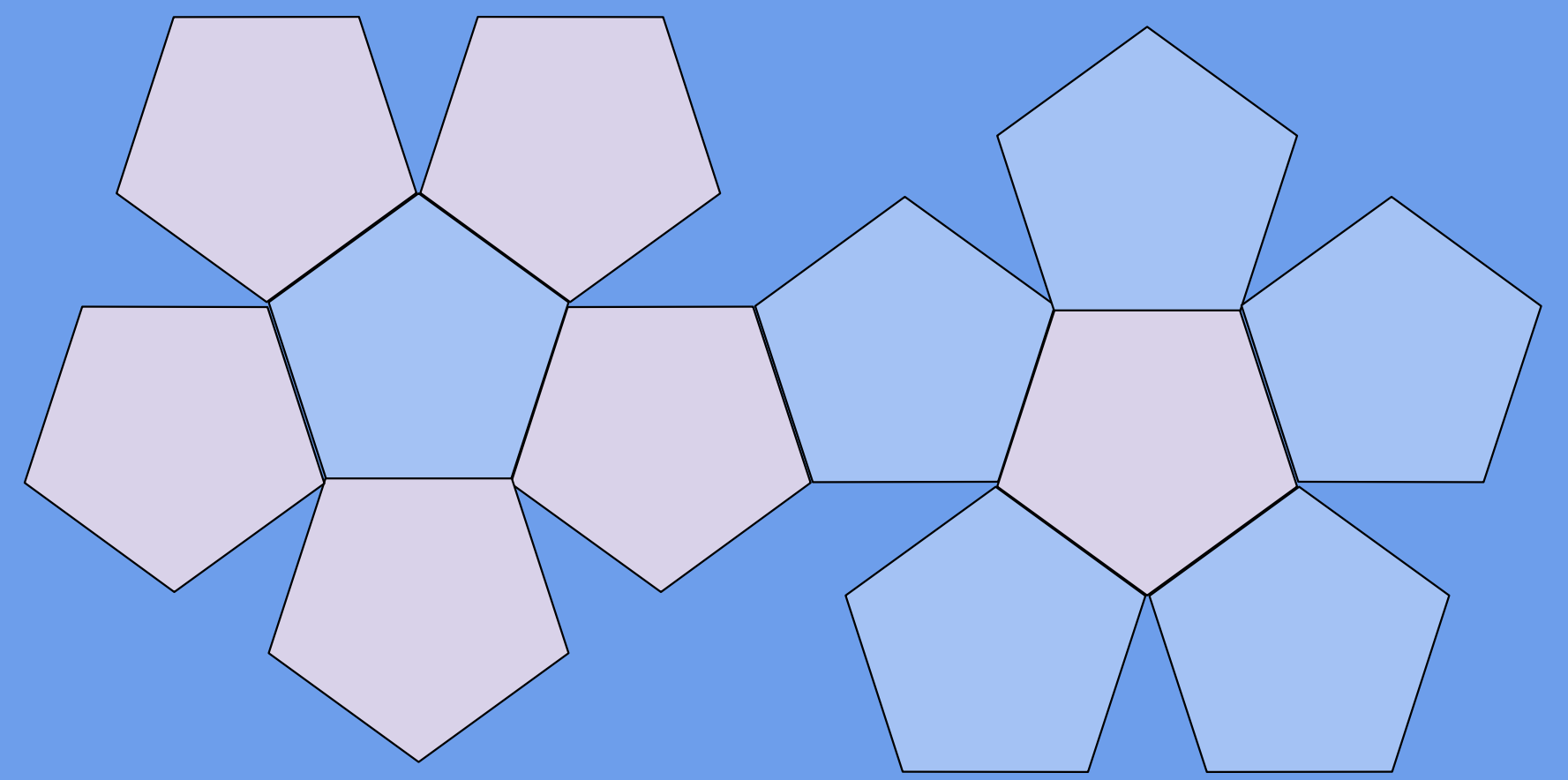

Figure 2

I also modeled a self-folding cube lattice out of a shape memory alloy known as nitinol, an alloy of nickel and titanium (see Figure 4). After being deformed, nitinol can return to its original shape when heated. This is due to phase change of its crystal structure when temperatures change.

Figure 3

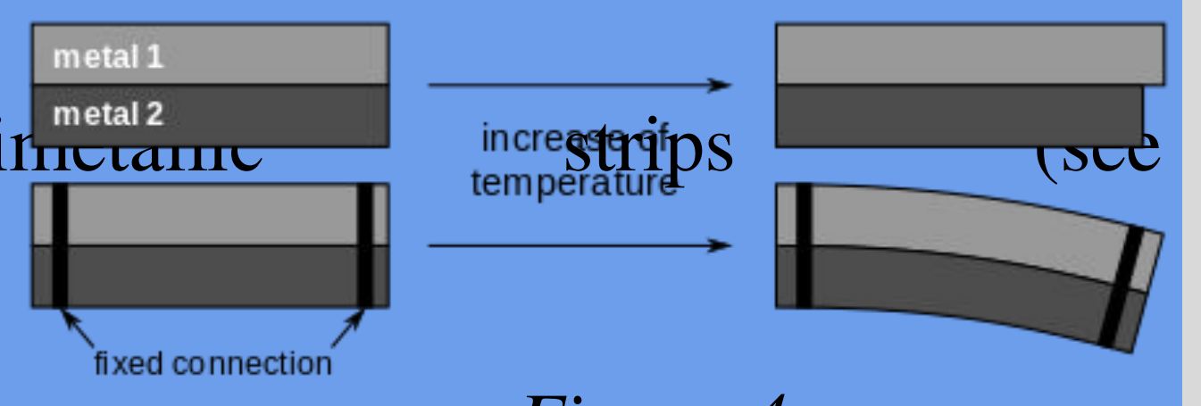

Figure 4

A third method of producing self-curving materials is through bimetallic strips (see Fig. 4). The exact curvature of a bimetallic strip can be calculated by:

$$\kappa = \frac{6E_1E_2(h_1+h_2)h_1h_2\epsilon}{E_1^2h_1^4 + 4E_1E_2h_1^3h_2 + 6E_1E_2h_1^2h_2^2 + 4E_1E_2h_2^3h_1 + E_2^2h_2^4}$$

Where E is Young's Modulus, h is height, and ϵ is misfit strain of the metal. ϵ is calculated by:

$$\epsilon = (\alpha_1 - \alpha_2)\Delta T$$

Where α_1 and α_2 are the thermal coefficients of expansion of metals 1 and 2.

IMPLICATIONS AND NEXT STEPS:

The techniques used in 4D printing can be extended to many different types of materials, each with different stimuli (temperature change or electrical impulses, for example). 4D printing technology has many uses in space and could become important in massively reducing the cost of space missions, increasing the efficiency of these missions, and possibly improving safety for astronauts and workers conducting maintenance on spacecraft during missions. For example, objects could be packed as flat pieces of plastic or metal that would subsequently fold out to assume their final form through stimulation once in outer space. This could be applicable to anything from objects as simple as a cup or bowl to complex machines such as solar panels and satellites. Foldable satellites would be an extremely important advancement, as they would allow for the development of more advanced multipurpose satellites and larger telescopes. Already, techniques such as origami are being used with regard to space-saving machines (see Figure 5), and 4D printing could be the solution to quickly and cheaply mass-produce foldable satellites.

Figure 5

It's important to note that this project was more of an exploration into 4D printing technology, with some inferences made regarding possible applications in space. That being said, the work done is important because it consolidates existing knowledge about 4D printing, which can be scattered, and comes up with possible applications of this technology that have not been explored in depth at this time.

In the future, this research can be extended to try and figure out exactly which materials/stimuli would be the most optimal for use in space missions, based on parameters such as their chemical and physical properties. Additionally, more collaboration with entities such as NASA would be very helpful to continue testing various materials, their effects, and determine exactly how they could be used in different aspects of a space mission.

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