RESEARCH ON DESIGNING-SIMULATION AND 4D PRINTING OF A PRODUCT

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ABSTRACT: The aim of this research was to gain knowledge about a new product concept - 4D products. 4-dimensional printing uses the same techniques like 3D printing through computer-programmed deposition of material in successive layers to create a three-dimensional object. 4D printing is mainly based on 3D printing and become a branch of additive manufacturing; objects are no longer static and they can be transformed into complex structures. Compared with the static objects created by 3D printing, 4D printing allows a 3D printed structure to change its size, shape, property, and functionality with time in response to external stimuli such as temperature, light, water, etc., which makes 3D printing alive.

KEY WORDS: 4D, printing, stimuli, simulation

1. Introduction

4D printing has become an exciting new branch of 3D printing. Unlike 3D printing, 4D printing allows shape and function to change over time in response to changing external conditions such as temperature, humidity, pH, electricity, and light.[1] 4D printing is also known as active origami, 4D bioprinting or shape transformation system.[2]

The main objective behind 4D printing is the self-assembling property of 3D printed objects when exposed to certain stimuli.[1] This shape-changing phenomenon of 3D printed objects is based on the material's ability to transform over time in response to specific stimuli, and it does not require human intervention to aid the process.[4]

A four-dimensional product (4D product) regards a physical product as a living organism capable of altering the shape and physical attributes on its own over time when exposed to stimuli.[2]

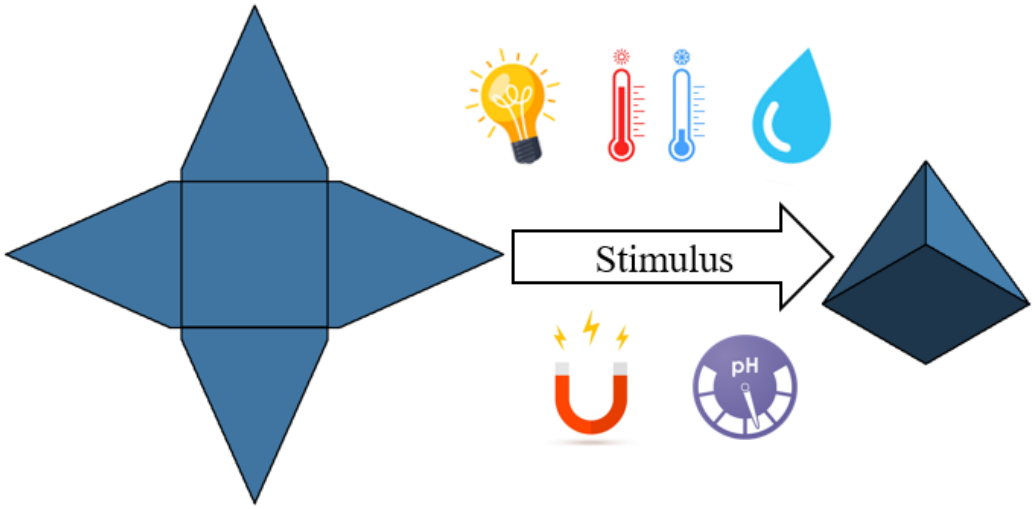

Fig 1.1 4D product

2. Current stage

4D printing marks a futuristic approach to printing technology with incredible potential. 4D printing offers the ability to design any transformable shape from a variety of materials that exhibit shape transformation characteristics under the influence of stimuli. [1]

The increasing need for flexible objects in various applications has fueled the emergence of 4D printing. Researchers are currently looking ahead of conventional 3D printing to develop a new structure by combining different materials that respond to stimuli and allowing the product to change its structure by bending, elongating and twisting along axes.[4]

The major differences between 3D printing and 4D printing are the use of materials to be printed and the printing facility.[4]

Four-dimensional (4D) printing stimulation method

The form and function of printed structures can be changed depending on one or more stimuli. There are several categories of stimuli: physical stimuli, biochemical stimuli and chemical stimuli. These stimuli are shown in the table 1.[3]

Table 1. Stimuli classification

Physical Stimuli	Biochemical stimuli	Chemical stimuli
Light	Glucose	pH
Temperature	DNA	Ion
Water/Humidity	Protein	Gas
Magnetic field	Enzyme	Redox
Electric field		

Material selection

The key to 4D printing is not so much the process, based on the familiar 3D printers, but the materials. As this is a fairly new technology, the materials available are not as varied as those used for standard 3D printing.

- SMP (shape memory polymers) – Polymers that remain rigid at room temperature and offer special properties when they reach the glass transition point. An example would be Convena's TPU SMP: a 4D filament with a composition based on TPU (thermoplastic polyurethane) that allows post-processing to modify the shape of 3D printed parts. Thanks to its special composition and Shape Memory Polymer technology, parts printed with this filament can be modified manually, allowing them to acquire another shape and maintain it over time.
- LCE (liquid crystal elastomers) – They contain liquid crystals that are sensitive to heat. By controlling their orientation, the desired shape can be programmed: under the effect of temperature, the material will relax and transform according to the dictated code.
- Hydrogels – Polymer chains consisting mainly of water, particularly used in light-curing processes. The latter is focused on the medical sector due to its biocompatibility.

In addition, some 4D printing processes can use various materials, mainly composites such as wood or carbon, which are added to SMP or hydrogels. This results in objects with rigid and movable areas.[5]

Application of 4D printing

Being a novel technology, most of the applications are currently in the research & development phase. Major end-use applications of 4D printing technology are expected to arise from healthcare, automotive, aerospace, and consumer industries. However, the potential of 4D printing is expected to impact other industries as well, such as electronics, construction, industrial, etc., in the near future.[4]

Medicine and surgery

In 2015, a medical team from the University of Michigan saved the lives of three babies with respiratory problems by inserting a 4D printed implant. This polycaprolactone device, designed to fit each patient, was designed to adapt its size to the child's growth and to dissolve itself when no longer necessary.

At present, the use of 4D printing in ultrasound scans allows, for example, to know more precisely the structural and functional development of the nervous system of the fetus.

In the future, vascular endoprosthesis (stents) or other 4D parts that react to body heat and expand to adapt to the patient, may be able to be printed.[6]

Clothing and footwear

4D printing allows the manufacture of clothing that adapts to the body's shape and movement. The U.S. military is testing, for example, uniforms that change color depending on the environment, or that regulate perspiration depending on the soldier's pulse or environment temperature.

4D printed shoes will also be able to adapt to movement, impact, temperature, and atmospheric pressure.[6]

Aeronautics and automotive

The NASA has developed an intelligent metallic fabric with 4D printing. This fabric, which is already used for astronaut suits due to its insulating nature, could also be used to protect spacecraft and antennas against the impact of meteorites. Meanwhile Airbus is testing materials that react to heat to cool its aircraft engines.

Thanks to 4D printing, intelligent airbags can be produced in the future that can anticipate any impact and reduce the risk of injury to the driver and passengers. [6]

3. Designing–simulation and 4D printing

To design a 4D product, it is necessary to consider the change of size and/or shape when the product is exposed to a stimulus. Thus, the product must be designed considering both the function for which it is designed and its future changes.

Designing and printing 4D products are done in a similar way to 3D. This is why the same software used for 3D products can be used. These programs are Autodesk Inventor, SolidWorks, Catia, and Cura, Z-Suite can be used to generate G-code.

Because it is a relatively new technology, 4D simulation software is not widely available and is in short supply. Because of this, it was decided to perform the simulation physically. The simulation was done using colored cardboard and a string as follows:

1. Draw the model of the product on the colored cardboard;
2. Cut out the cardboard and make the holes for the string;
3. Insert the string into the holes made;
4. Attach the ends of the string.

The modifications of the chosen models are shown in Figures 1.2-1.5. The simulation was done using simple models.

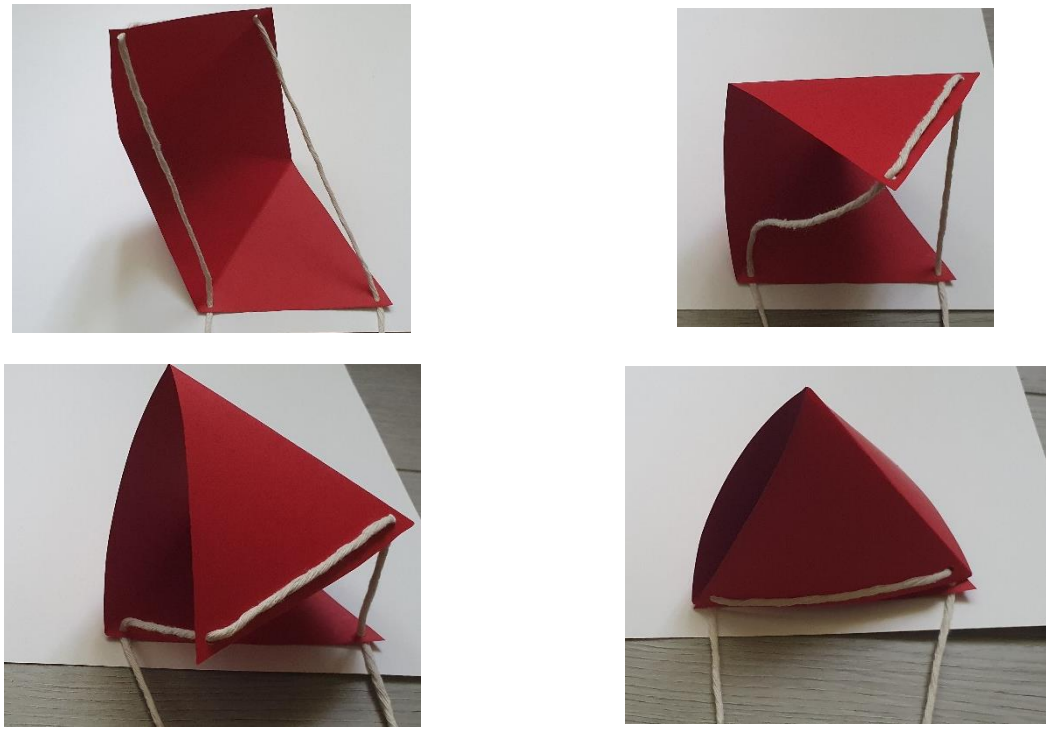

Fig1.2 Triangle based pyramid

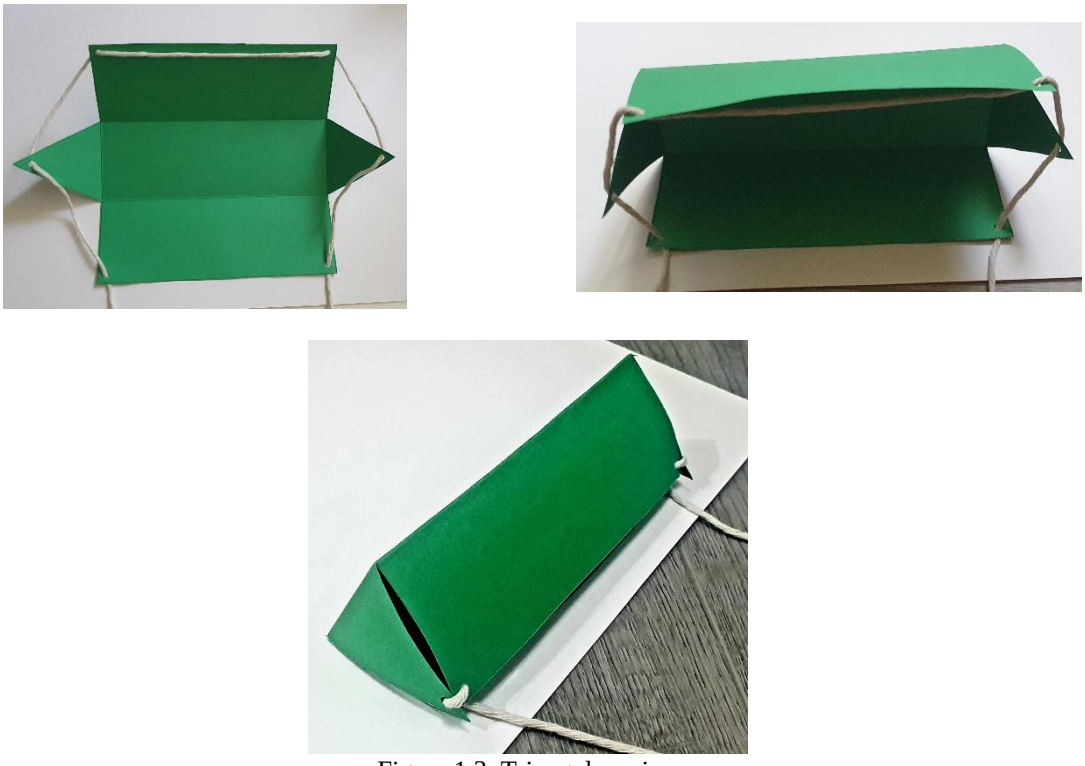

Figura 1.3 Triangular prism

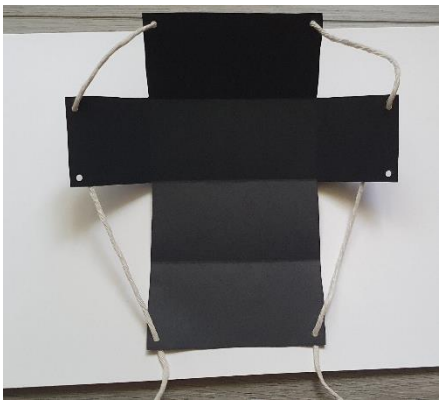
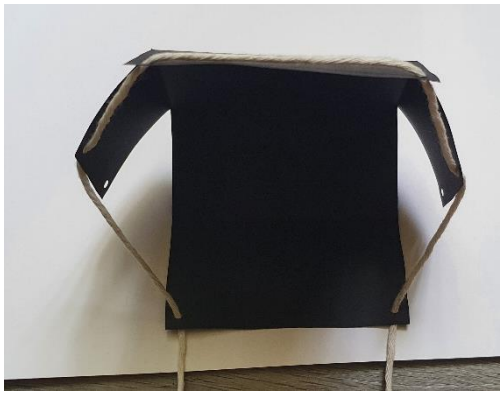


Figura 1.4 Cuboid

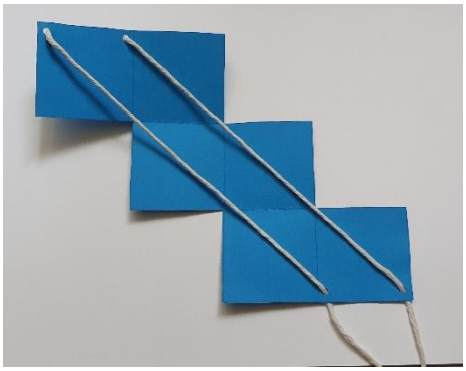
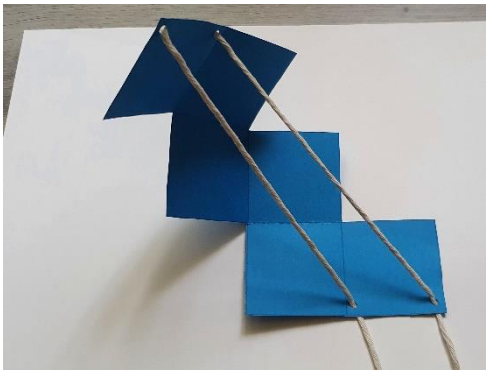
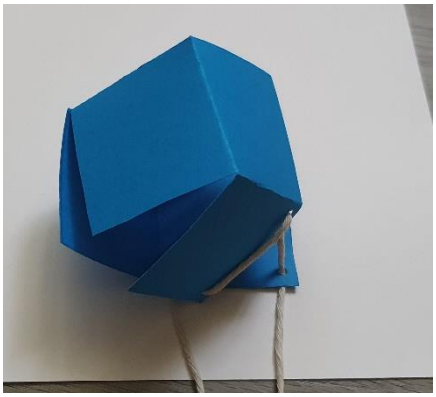
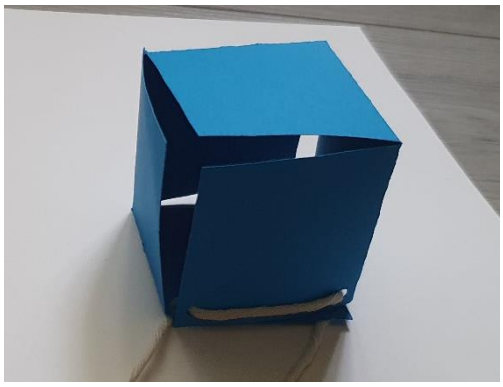

Figura 1.5 Cube

4. Conclusions

Even though it is a new technology, the potential opportunities for using 4D printing are vast. That's why there will be more research and development projects in industries such as healthcare, electronics, automotive, aerospace and defense, fashion and consumer durables, textiles, construction, and industrial machinery.

4D printing is a promising technology because of its self-assembly property.

The advantages of 4D printing are change of size, shape, property, and functionality according to current needs, the realization of complex structures, innovative design, environmentally friendly, and biocompatible.

Disadvantages of 4D printing are lack of control over intermediate deformation states, slow response of material when exposed to stimuli, lack of low-cost smart printers and materials, limited long-term reliability.

4D printing uses the same techniques as 3D printing. Because the materials used to respond to certain stimuli such as temperature, humidity, etc., it makes 3D printing come alive.

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