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4D Printing As A Solution For Saving Building Energy

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Abstract

In view of the energy crisis all over the world, in all types of energy such as the gas and electricity crisis, the call for the use of renewable energy appeared on the basis that it was the best solution to this crisis. However, the energy was stored in containers according to the nature of the stored energy, such as batteries for electricity, which exposes part of it to loss in the process of charging and discharging it.

However, the tendency to store this energy within the material itself began to emerge and apply, instead of storing energy in containers and then retrieval. The research tends to use the energy stored in the material as a solution to prevent wasting part of the energy in charging and discharging it, such as heat loss in charging and discharging electricity.

So the aim of the research is using 4D printing to store and discharge energy to directly interact with the architectural problem through environmental stimuli, using heat and light stimulus to reach the desired formation or movement to solve a problem in the building

Keywords: 4d printing, Energy, adaptive facade issues, stimulus materials**.**

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1. Introduction

In light of preserving the environment inside the building to achieve the convenience of users and externally, to preserve its resources. the architects turned to buildings interacting with the environment, whether by electrically interacting systems or environmental architectural elements inspired by architectural legacies. And because modern materials are available compared to the scarcity of natural materials used in buildings, so the inherited solution is not feasible except in special cases, and many of those who call for mechanically and electrically interacting buildings developed by changing the method of electrical feeding, until reaching photovoltaic cells. However, interactive systems based on interaction with the environment mechanically, that hindered by some problems, so it was necessary to reach solution that achieves interacting without these issues.

2. Issues of mechanical electrical interactive systems

These systems are of great benefit in achieving the desired goals in interaction and adaptation, but they have several problems. The first is electrical energy, not only in use, but also in losses throw Connectors, charging and discharging, even if it is from solar energy or wind energy, so it needs to devices with a greater capacity to avoid losses, The loss itself is emitted heat affecting the environment. The second problem is the periodic and urgent maintenance costs of these systems, The third problem is the loads on the building and the fourth is the lifespan of these systems in addition to the slow reactions, with adds to the above the programming complexity and complex calculations to reach the required adaptation.

2.1. The electricity losses issue

The loss of electricity to heat was recorded in different countries between 3-9% of the electrical energy, representing a total of 24-34% globally [1] fig. 1. All this loss of electrical energy other than the energy itself used in the required mechanical process

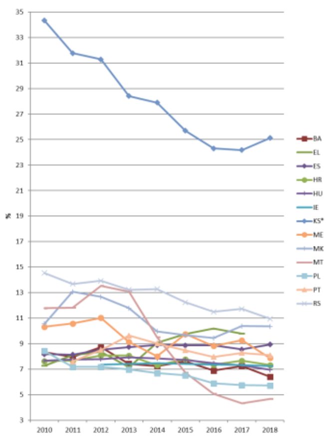


Fig. 1. Total losses of injected energy as %, [1]

For using electricity in the interacting buildings, the Kiefer Showroom had current annual usage cost / square meter is $24.8/m2/year and 342 kWh/m2/year [2], and in Al Bahr towers in Abu Dhabi is 400watts/meter [3]. One mashrabiya in Al Bahr towers needs 14.71 k.N. to move it [4].

(a) (b)

Fig. 2 (a) Kiefer Showroom, (b) Al Bahr towers

2.2. The issue of periodic and emergency maintenance

Operating systems and facade materials are classified as expensive alternatives, in addition to operating costs and costs of any possible modification [5].

In Institut du Monde Arabe in France, which was designed by Jean Nouvel, after only three years functional problems began to appear in the facade system, and within a few years the system completely stopped. In addition to the above 3 façade units in Al Bahr towers were ruined [6].

(a) (b)

Fig. 3 (a) Institut du Monde Arabe, (b) Al Bahr towers

2.3. Weights on the buildings

The unit on the facade of Al Bahr towers weighs 1.5 tons, and one tower contains 1,049 units [7], that mean the weight of façade in each tower is 1,573.5 tons! And the number of aluminum members in Institut du Monde Arabe is 30,000 in facades! The Kiefer Showroom's facade consists of 112 folding units that controlled by 56 motors! [3].

2.4. The lifespan issue

The lifetime of the mashrabiya is 20 years with all its components, while the motors have 15 years [7]. As for Institut du Monde Arabe in France, which did not complete the sixth year, was ruined [6].

2.5. Slow adaptation and reaction

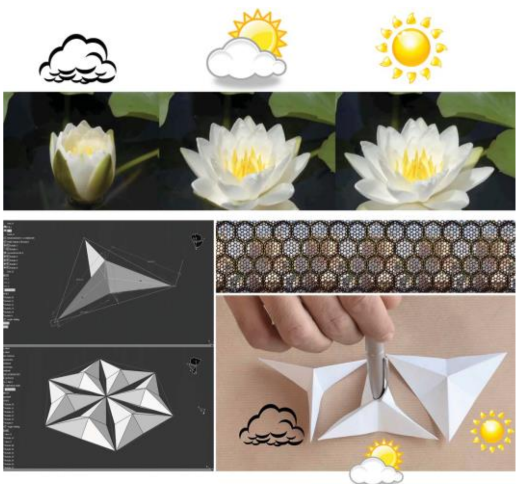
Response time refers to the required time for facade units system to adapt, that ranges from seconds to hours. The buildings, Al Bahr Towers and Kiefer Showroom, were classified as relatively slow facades in terms of response speed [8]. While Al Bahr Towers Facade take 15 min to interact [7].

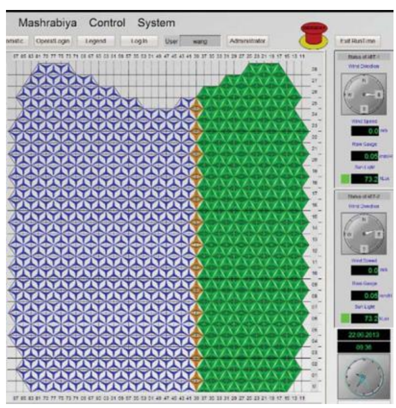
2.6. Programmatic and computational complexity to reach the required adaptation

Although the many benefits of Al Bahr Tower’s facades, but they are considered as high cost and complexly design.

The system of adaptive facades is complex in its various stages, starting from the design stage and choosing the movement recorded by the units on the facades to achieve the required adaptation, passing through the electrical circuits and sensors for environmental phenomena, up to simulating that and evaluating the performance of the system for the internal and external environment.

In the stages of the design Al Bahr towers, the following conditions are designed. In the stages of opening the units: If the angle of the sun on the units is between 00 and 79 degrees; unfolded configuration, if the sun angle on the units is between 80 and 83 degrees; Partially folded configuration if the angle of inclination of the sun's rays on the units is greater than 83°, fully folded configuration [9].

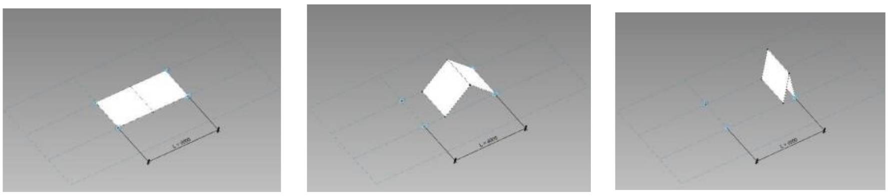




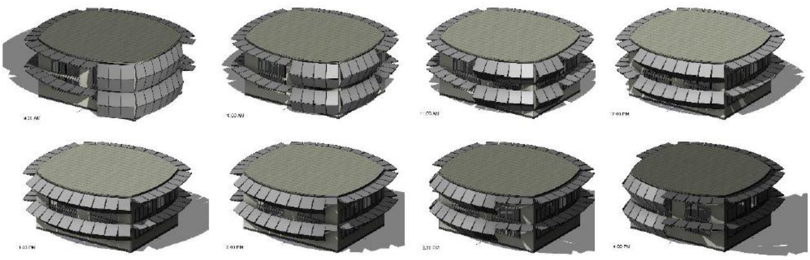
(a) (b)

Fig. 4 (a) Cases and concept of movement (b)The software used for the dynamic facade

As for the Kiefer Showroom, the design has evolved into a kinetic Photovoltaic façade (KPVF), but still complicated in the stages of adaptation, how to move, solar projection, and the positions of the units at all times, and how each stage of the angles of the rays has become a special case that includes Entering a measure of radiation and generating another measure of energy. Also, setting the coordinates on the virtual cities in the programs did not meet the desires, so the researchers had to manually make the settings for specific days in the year, during the sunshine hours. The complexity of the design appears in the programming of the units and linking them together to share the movement or sequently according to the required adaptation method [2].



(a) (b) (c)



(d)

Fig. 5 (a) Angle = 0, (b) Angle = 45, (c) Angle = 85, (d) units positions as example from 9 AM to 4 PM, December 21

3. Four-dimensional printing (4DP)

These issues had a significant impact on the recycling of the electrical system and its components, so there was a need to seek solutions that ensure that not wasted energy and tend to be reused, using a system that has no maintenance, low loads on the building, with a relatively long lifespan, sensitivity and high reaction to stimuli. The architects' utmost ambition is remained to change materials and efficiencies of the same electro-mechanical system, until 4DP appeared. The trend towards 4DP was a solution to all these problems, and we will see the impact of this in some attempts and experiments that seek to apply 4DP in building, and 4DP is the ideal solution that solves all issues of mechanical and electrical facades.

The main idea of 4D printing is creating complex 3D units that respond to stimuli and transform into different shapes when exposed to outside stimuli [10].

3.1. 4DP axes

4DP has four axes forming its system, these axes are Stimuli, Active material, Behavior and techniques.

3.1.1. Stimuli

stimuli are used to change the shape and function of printed materials according number and type of stimuli. The stimuli are classified to physical, chemical and biological. biological stimuli such as glucose and enzymes. Physical stimuli such as light, humidity, magnetic and electrical energy, temperature, ultraviolet light and others. and chemical stimuli such as, PH level and use of oxidant and reducer [11].

3.1.2. Active material

An active material is a system that considered as internal sensors, which are capable of sensing, responding to an external stimulus in a predetermined duration, and returning to original state once removing stimulus [12].

3.1.3. Behavior

Behavior has many types, including: rotation, deformation, folding, sliding, and hybrid [8].

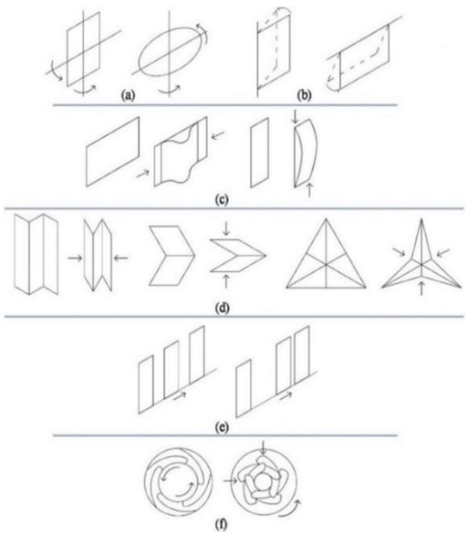


Fig. 6 (a) , (b) rotation types , (c) deforming, (d) folding, (e) sliding, (f) hybrid. [8].

3.1.4. Techniques

There are many techniques used such as Fusion Deposition Modeling (FDM) [13], Stereolithography (SLA) [14], Selective Laser Sintering (SLS) [15], Direct Ink Writing (DIW) [16], Material jetting inkjet, Fused Filament Fabrication (FFF) and many other techniques [17],[18], [19].

3.2. Adaptive building using 4DP

4DP was used in buildings in many parts, such as facades, openings, partitions, and many others. Among the projects which used 4DP are Hygroskin Meteorosensitive Pavilion, Bloom pavilion, Homostatic Building Façade.

3.2.1. Hygroskin Meteorosensitive Pavilion

The Hygroskin Meteorosensitive Pavilion achieved biomimicry of a pine cone plant, and the responsive openings were designed from porous wood that responsive to changes in relative humidity. The outer envelope of the pavilion is at the same time a load-bearing structure and a sensitive skin of the building all within the same material units [20].

Fig. 7 Hygroskin Meteorosensitive Pavilion [20]

3.2.2. Bloom pavilion

The main idea of Bloom pavilion is an active, zero-energy interface that is self-responsive to the sun's heat. The team used two layers of metal that react differently with heat and cover created with 414 units, that containing bimetallic sheets, which wrapped and provide shading when exposed to sunlight [21].

Fig. 8 Bloom pavilion [21].

3.2.3. Homostatic Building Façade.

In Homostatic Building Façade, the façade was designed with a double-skinned glazing system where the units opened and closed by themselves in response to the internal temperature of the building. smart materials regulate a building's climate as many organisms maintain their own temperatures through homeostasis, that called aero symmetric system [22], [23].

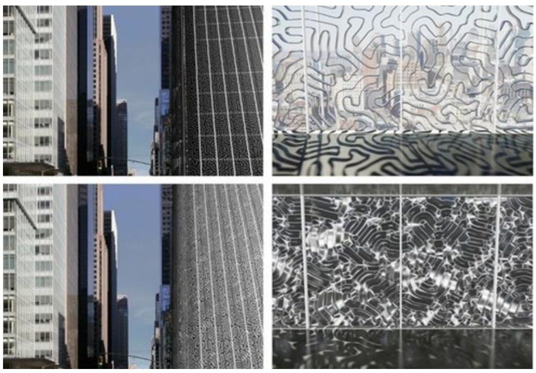
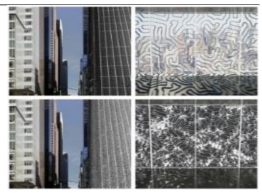


Fig. 9 Bloom pavilion [21].

4. Discussion

Hygroskin Meteorosensitive Pavilion, Bloom pavilion and Homostatic Building Façade have varied in the materials used, the stimuli, and the applied techniques, but they have main common factor that avoided all the issues discussed in electromechanical systems. In addition to achieving all the desired adaptations. The following table shows how to achieve the axes of 4DP for each project, and to avoid all issues that appeared in the electromechanical system.

Table 1. 4DP axes and Electromechanical issues criterion.

project name	Hygroskin Meteorosensitive Pavilion	Bloom pavilion	Homostatic Building Façade
Project picture			
The type of biological phenomenon	Sensing and responding	Sensing and responding	self-regulation
Biomimicry	Conical pine plant 	Silver thistle plant 	body muscles 
Architectural Element	windows	architectural envelope	facade
4DP Materials used	wood polymer composite, Acrylonitrile Butadiene Styrene, Thermoplastic polyurethane and Active polyester	Thermal bimetals	Strips of synthetic rubber and flexible polymer responsive to electrical charges.
stimuli	Humidity	Heat	Light and Electric field
Adaptation type	Folding	Folding	Contraction and expansion
Techniques	Fused Filament Fabrication (FFF)	Selective Laser Sintering (SLS),	Direct Ink Writing (DIW)
Electricity losses	No losses, but Generator source	No losses, but Generator source	No losses, but Generator source
Maintenance	No Maintenance	No Maintenance	No Maintenance
Weights	Extremely light	Extremely light	Extremely light
The lifespan	endless	endless	endless
Adaptation and reaction	Fast reaction	Fast reaction	Fast reaction
Programmatic and computational	Not complexity	Not complexity	Not complexity

And just as 4DP avoids all the problems of electromechanical systems, and this is a great benefit in itself, it can also generate electricity in both adaptive movements or return to its origin, as shown in Fig. 10.

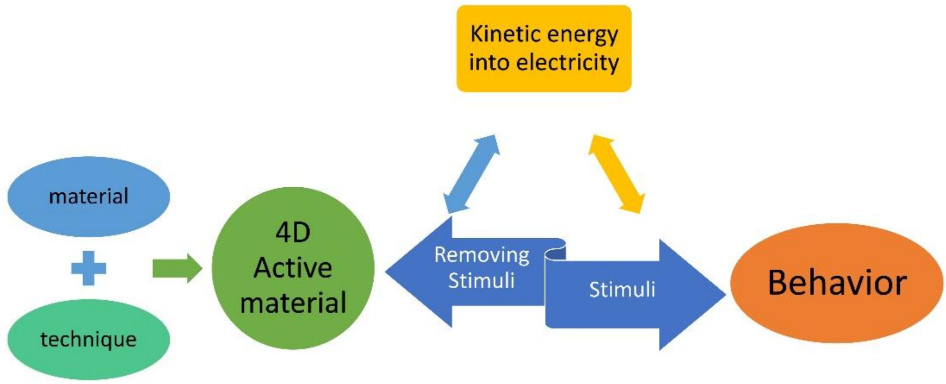


Fig. 10 4DP chart process to generate electricity

this adaptive and return movement in all direction can used to generate energy. So, this case is clearly for upgrading the main concept of 4D system to Four vectors system (4V).

the 4V is meanly converting directions to vectors for upgrading the all properties of dimensions to vectors properties in applications [24].

And while the entropy is increasing in time vector, the system upgraded to 4Vectors can decrease the angle between progress vector extension and undo vector.as shown in fig.11. This angle when decreased all of energy can return without losses

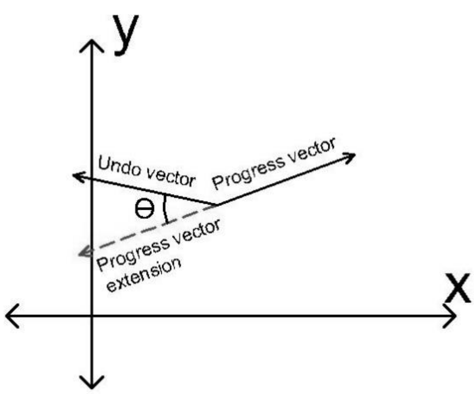


Fig. 11 Vectors of entropy [24].

$$S=k.\log w \qquad (1)$$

$$S=k.\,(\log w).\,\cos\theta \qquad (2)$$

Eq. 1 progress or adaptive equation, and Eq. 2 Return equation

In Eq. 2 When θ getting close to zero the cosine value approaches one and the two equations are equaled, which means double and continuous electrical energy.

And since all interactive systems depend on pre-fabricated building in their units, the infinite multi formation resulting from 4DP is a great step towards liberation from the fixed formation or the one with limited states of change such as electromechanical facade.

While the fixed façade is the main determent of liberation pre fab building, that obstacle Contemporary trends of design [25].

5. Conclusion

The 4D printing process enables innovative and exciting applications that are difficult to achieve using traditional manufacturing processes.

The use of 4D printing technology in the building elements makes the building interact with the surrounding environment without the need for complex and expensive sensors and mechanical systems that have a life span, as they operate independently without external intervene.

Four-dimensional printing is characterized by three main capabilities: self-assembly, self-adaptation and self-repair, which helps to use it in different fields and achieve unprecedented success before.

6. Recommendations

Recommended to making a feasibility study and life cycle cost analysis on both electro-mechanical and quadrilateral cases, Proofing the Saving values.

Doing a study that includes discharging the kinetic energy and reusing it in other operations that require electrical energy without any waste of the amount of energy returning from the 4DP.

Work on studying the direction of energy states through the progress and undo vectors according to the entropic treatment system, with an angle of undo vectors that getting close to zero, so that the cosine of the angle to the correct one to ensure that energy does not lose in any phase

developing the design of 4D measuring tools such as Vector protractor which measures entropy, gravity, curvatures and logarithmic scale, that treats with the four vectors.

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