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DESIGN AND PARAMETERIZATION OF A KINETIC PROTOTYPE THAT INTERACTS WITH CLIMATIC VARIABLES USING NUMERICAL METHODS

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Abstract- Iteration is a nearly essential part of the architectural design process. To gain a deeper understanding of their thoughts, designers frequently use computer-aided prototyping techniques. The definition of links between design parameters is possible with parametric design tools. Using this method, designers can adjust a few of settings, and the rest of the model will automatically adapt. A parametric approach to digital design may enable the creation of complex geometric designs from massive amounts of data. This method facilitates the creation and control of complex and evolving shapes, but it also necessitates a thorough understanding of the creative and technological challenges involved. Using algorithmic reasoning, we want to improve an operational, kinetic prototype in this study. Specifically, we use this approach to propose a coding strategy for modeling a complicated kinetic prototype in interaction with climatic variables. For parametric modeling, we use Rhinoceros, a 3D surface modeling application, and Grasshopper, an editor of algorithmic structures that is strongly connected with Rhino's 3D modeling tools. The results show that by employing this combinatory approach, it is possible to analyze the prototype's functioning mechanism as well as precisely integrate and update the data each time in order to achieve the desired goal.

Keywords: Architectural Design, Kinetic Prototype, Parametric Modeling, Grasshopper.

1. INTRODUCTION

Architectural design is always an iterative process [1, 2]. Designers develop solutions that raise new concerns, which are subsequently investigated in order to provide more refined or perhaps altogether new solutions [3]. Designers frequently employ computer-aided tools to create prototypes that assist them in visualizing their ideas [3, 4]. Yet, the large bulk of these prototypes continue to be constructed in a manner that prevents interactive change [4-6]. When the 3D models being generated are geometrically complex, the problem becomes more serious [7].

Changing one component of such a model typically necessitates extensive low-level changes to its numerous parts [1, 7]. To address this issue, designers have begun to use parametric design software, which allows them to express the relationships between their design's many parameters [2, 3]. The benefit of this method is that the designer needs to adjust merely some few settings before seeing the effects throughout the rest of the model [5, 7].

The software manages these derived alterations, although they are based on associative principles established by the architect-designer [2, 8]. Each suggested design's rationale and intended outcome are defined by correlative and parametric geometry, not just the proposal's outline [7, 8]. This method of design calls for, and helps foster the growth of, high-tech, interactive tools that let designers investigate and improve numerous potential paths with minimal effort [1, 3]. Engaging with parametric and algorithmic processes, on the other hand, necessitates a fundamental shift in attitude from one of modifying design representations to one of encoding design purpose using systematic logic [5, 8].

This paper aims to give a general idea about parametric design and software. Through this principle, we will present a coding method to model a complex kinetic prototype. The method of digital design known as the parametric model permits the creation of intricate geometric designs from huge amounts of data [1, 5, 7]. This information could be architectural, urban, auditory but also environmental [6-8]. This method allows to build and operate intricate and dynamic forms, but it also necessitates a profound understanding of the creative and technological difficulties involved in their construction [2]. As for the parametric modeling tools, they offer a degree of flexibility that is not possible with conventional 3D tools. This allows to create complex shapes, easily modify any geometry and manually rebuild to any degree of difficulty [7]. The first most known software is Rhinoceros. Also known as Rhino, it is a 3D surface modeling application. Reverse engineering, automotive design, naval design, rapid prototyping, graphic arts and multimedia are just a few of the fields in which it has gained favor [8].

It is based on the popular mathematics NURBS (Non-Uniform Rational B-Spline), which allow the construction of free-form organic surfaces compatible with most other computational models used in the industry [6, 8]. The second piece of software is Grasshopper, a graphic algorithm developer that works hand in glove with Rhino's 3D modeling features. In contrast to Rhino Script, which necessitates some familiarity with programming and scripting, Grasshopper can be used by designers without any such background, allowing them to create impressive shapes.

2. METHODS AND MATERIALS

This study aims to model a kinetic prototype from a numerical design that depends on algorithmic reasoning. The advantage of the latter is that it allows to integrate coherence, structure, cohesion, traceability and intelligence in a computerized 3D form.

2.1. Concept and Generating Idea

The use of metaphor in the creation of the prototype has given rise to a generative idea that depends on a geometric abstraction of the structure of a fan as well as its functioning. The following points summarize the various stages of this geometric abstraction:

- Starting point: A tangible metaphor for a refreshment object that is the fan (Figure 1).
- Derivation of the underlying shape: a dynamic shape that can be controlled (Figure 2).
- Derivation of the underlying structure: in this case of study, it is the radial frame (Figure 3).

Figure 1. Fan's model [9]

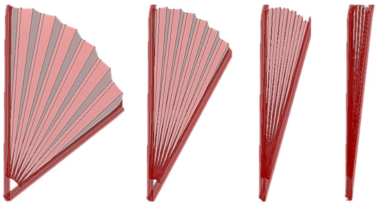


Figure 2. Geometric abstraction [9]

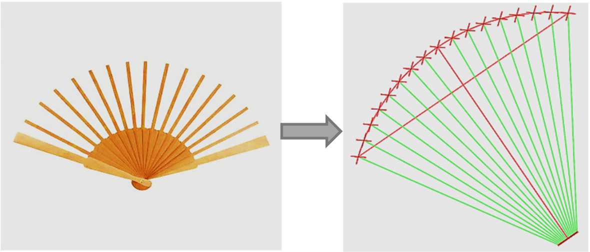


Figure 3. Geometric abstraction of a controlled dynamic shape [10]

2.2. Design of the Prototype by Coding

Through the parametric software Rhino-Grasshopper, we tried to represent the above-mentioned idea by an algorithmic reasoning [11]. The main objective of this digital design is to have a controlled prototype [8, 12]. From the idea of a fan, we made a set of fans that gather around a center of rotation. Then, we chose a hexagonal outline, to help us have a pentagon kinetic [13] and a connection axis with another prototype as illustrated in Figure 4.

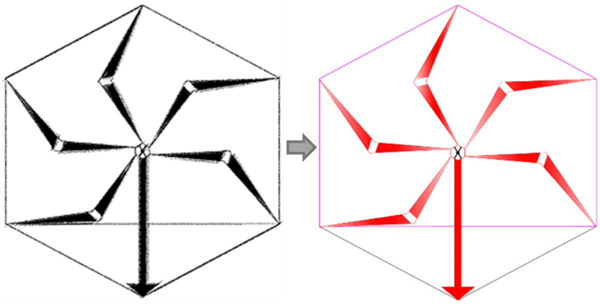


Figure 4. Sketch and explanatory diagram of proposed prototype

2.3. The Stages of Digital Design

- Step 01: Consists of creating the main contours and the center of rotation as shown in Figure 5.

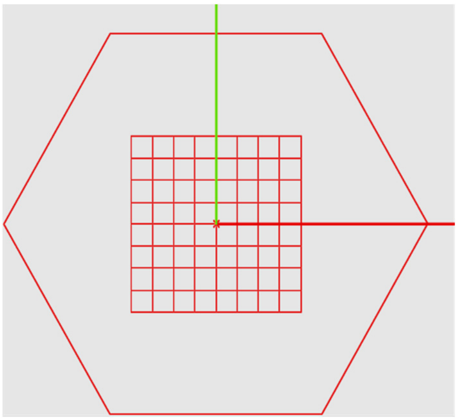


Figure 5. The 1st stage of the digital contour design

- Step 02: Consists of determining the points of angles and making a connection between these points and the center of rotation as shown in Figure 6.

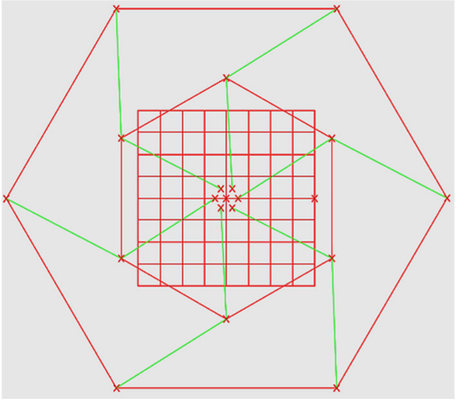


Figure 6. Connection of the axes with the center of rotation

- Step 03: Consists of having rotation limits and making an algorithmic symmetry [12] of the axes in order to get the contours of the fans. We note that the rotation limits are between -25° and 30° (Figure 7).

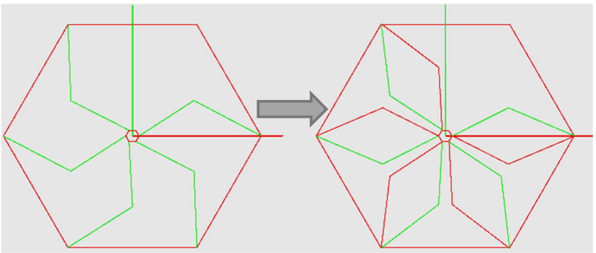


Figure 7. Algorithmic symmetry and rotation interval ($-25<x<30$)

- Step 04: Consists of making the coded contours [14] for each fan (Figure 8).

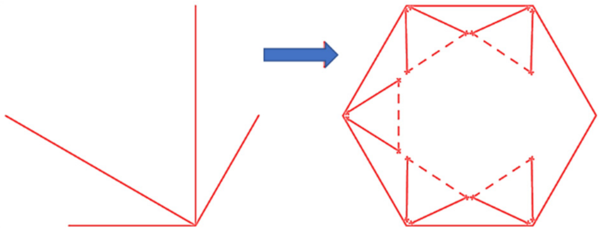


Figure 8. Coded contours of the fans

- Step 05: Creating the algorithms of the 3D fan structure as illustrated in Figure 9.

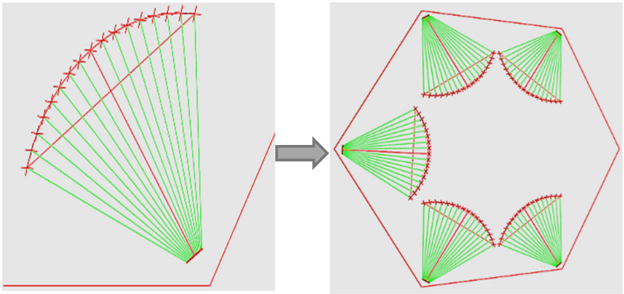


Figure 9. The 2D and 3D fan structure algorithms

- Step 06: Modelling of the fans, and creation of the 3D surfaces (Figure 10).

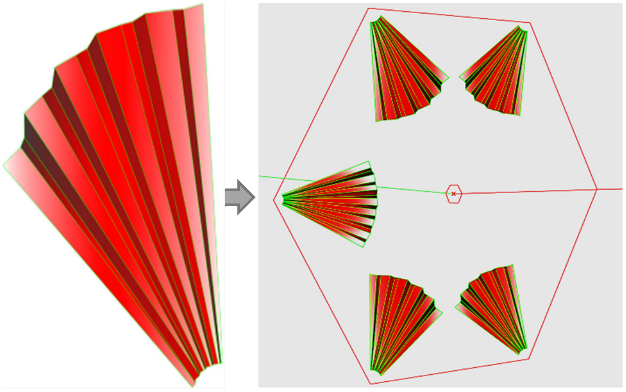


Figure 10. creation of 3D surfaces

- Step 07: Creating another algorithm to obtain fans from the center of rotation (Figure 11).

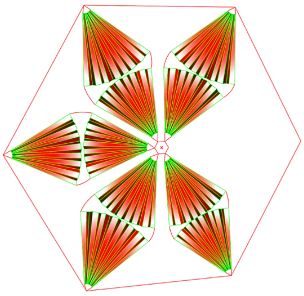


Figure 11. The creation of fans from center of rotation

- Step 08: Consists in digitizing all the extrusion operations to get a coherent prototype (Figure 12).

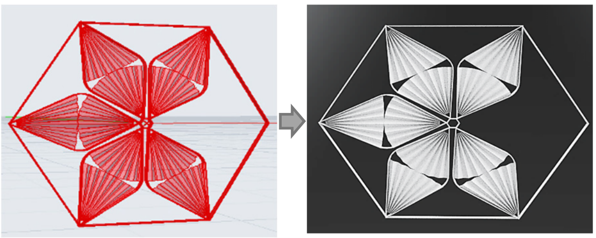


Figure 12. Parametric 3D prototype

- Step 09: Represents the opening test for the prototype (Figure 13).

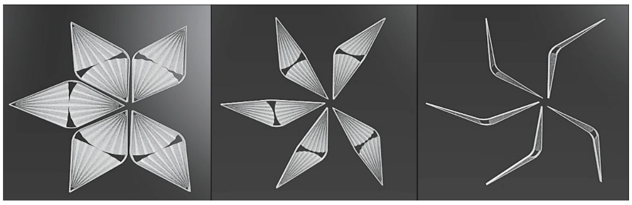


Figure 13. Prototype opening test (Closed - Half opened - Opened) with a rendering V-Ray Rhino

- Step 10: is used to link a number of closed and opened prototypes to have a surface for our solar shading system [15] as shown in Figure 14.

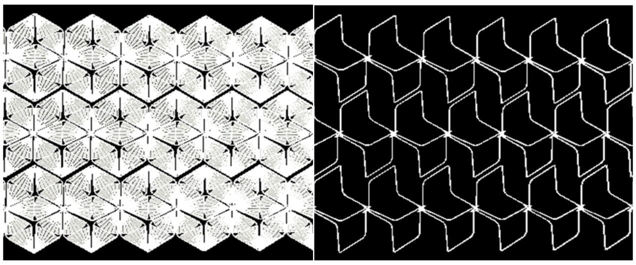


Figure 14. Closed and open parametric surface from a prototype

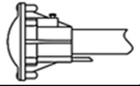
2.4. Operating Mechanism of the Prototype

Parametrically and algorithmically designed models can react with high fidelity to their real-world counterparts when subjected not only to changes in geometric parameters by the user, but also to structural forces, material behavior [16], and thermal and lighting variations [17, 18] as well as to contextual conditions [19]. Because they accurately represent the internal construction logic of the structure in question, parametric models can also be unfolded or translated into geometries that can be digitally fabricated [20]. Through this design mode, we tend to make a numerical simulation for the previously designed prototype in order to test its movement with solar radiation. Before the test, we will try to integrate sunlight sensors at the center of rotation of the prototype in order to have a more sustainable, ecological and economical operation [17, 18, 21].

2.5. Sensor Integration

Due to its sensitivity to solar radiation and full dependents on renewable energy, the use of sunlight sensors helps to have an intelligent, economical and sustainable power system [22-24]. Features of the chosen sunshine and light sensors are detailed in Table 1.

Table 1. Technical features of the sunshine and light sensor [25]

Mounting	27 mm diameter tube Screw tightening
Cable type	3 conductors of 0.22 mm^2
Length of cable	10 meters
Sensing principle	Photoelectric cell (900 nm for sunlight) (560 nm for brightness)
Power supply	from 14 to 24 VDC (Type 15 VDC)
Consumption	0.6 VA max at 15 VDC
Output	* 4/20 mA linear for 0/1000 Watt/m^2 or 0/1500 Watt/m^2 * 4/20 mA linear for 0/10 KLux or 0/100 KLux (according to sensor inscription)
Model	

As for the numerical integration, we will try to define the algorithmic coding for the digital integration of this sensor at the center of rotation of the prototype (Figure 15).

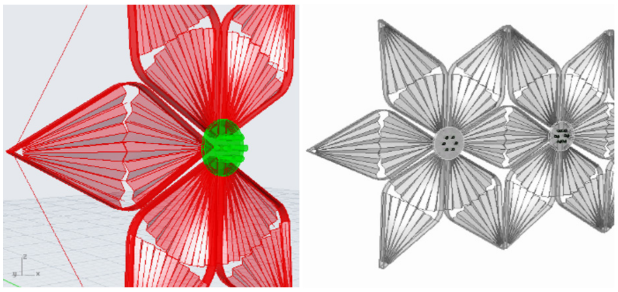


Figure 15. Digital integration of the sensor

3. RESULTS AND DISCUSSION

In this section, utilizing solar radiation [26], we will try to recreate the dynamics of the intelligent prototype as it was previously defined. Using GECO-Ecotect, a Grasshopper plug-in, we chose the shortest day of the year (December 21st, 2021) as well as the longest one (June 21st, 2022) to conduct this numerical simulation. It is important to note that GECO, created by the "UTO" team, has a number of parts for Grasshopper that enable data to go directly between Grasshopper and Ecotect, enabling environmental optimization [6].

3.1. Kinetic Simulation for Summer Period

For this period, we chose the longest day of the year to test the closing of a panel of seven columns whose unit is the prototype designed earlier (Figure 16).

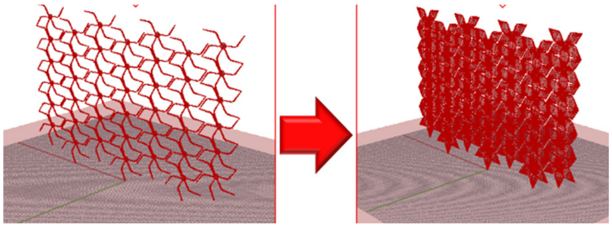


Figure 16. Simulation process in summer (from left to right opened and closed panel)

This simulation is done with respect to the solar radiation intensities. We chose three moments of the longest day where the solar irradiations are important (Table 2).

Table 2. Solar irradiations in the longest day of the year in June [27]

City	Latitude	Longitude	Altitude (m)	Albedo
Oum El Bouaghi	35.88°	7.12°	889	0.2
Month	Day	Sun declination	Sensor orientation (°)	Sensor tilt (°)
June	21	23.44°	South	90°
Hours in True Solar Time	Sun Azimuth	Sun Height	Global Irradiance Tilt (Wh/m^2)	
8h00	-86.2°	37.2°	601	
10h00	-72.6°	61.3°	927	
12h00	0.0°	72.0°	1050	

After integrating all the climatic data into the software, as well as all the data needed to run the simulation, we found the following results:

- In June 21 at 8:00 am: the software marks a weak kinetic in the first part of the south. At the beginning of the day there was a weak closure as illustrated in Figure 17.

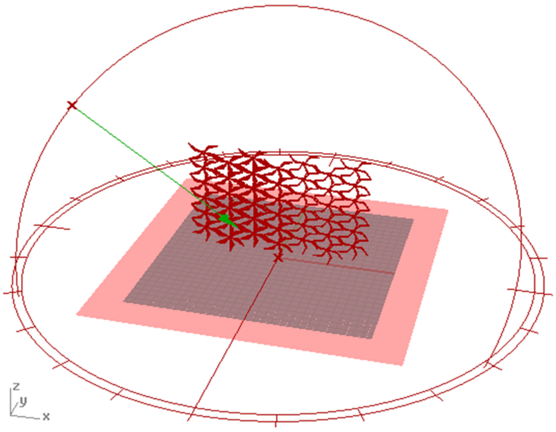


Figure 17. Simulation result on June 21 at 8:00 am

- In June 21 at 10:00 am: When the intensity of the solar rays is stronger, it causes an introduction of a current through the installed sensors which improves the closing of the panel to 50% as illustrated in Figure 18.

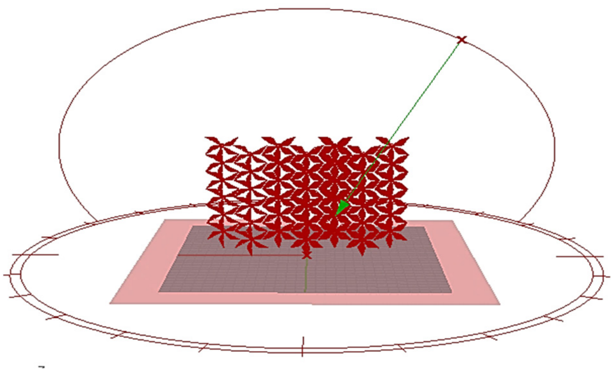


Figure 18. Simulation result on June 21 at 10:00 am

- In June 21 at 12:00: as illustrated in Figure 19, there had been a total closure in the south because of a strong solar irradiation. The solar rays are perpendicular to the panel which gives a 100% closure at the center of this panel [28].

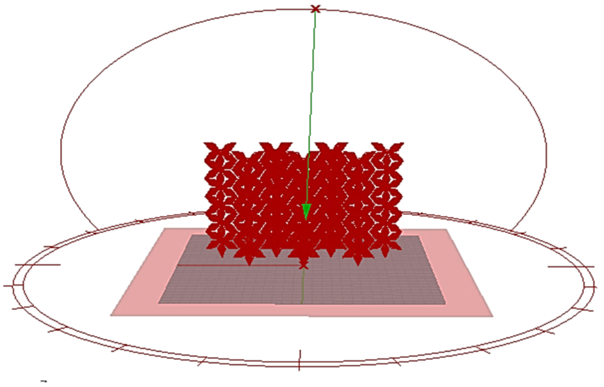


Figure 19. Simulation result on 21 June at 12:00

following Table 3 shows the rotations recorded in summer (on June 21) for each panel (P) according to the test hours.

Table 3. Rotations recorded in summer

	P1	P2	P3	P4	P5	P6	P7
8h00	-20°	-20°	-20°	-10°	0	0	-10°
10h00	0	0	10°	15°	20°	15°	10°
12h00	20°	25°	30°	30°	30°	25°	20°

3.2. Kinetic Simulation for Winter Period

To test the opening of the panel for the winter period we chose December 21, 2021 (Figure 20). In order to carry out a numerical simulation for the kinetics, we chose 03 different times of the day to have a kinetic variation as shown in table 03.

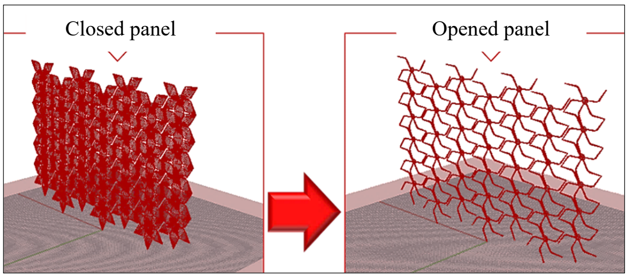


Figure 20. Winter simulation process

Table 4. Solar irradiations in the longest day of the year in June [27]

City	Latitude	Longitude	Altitude (m)	Albedo
Oum El Bouaghi	35.88°	7.12°	889	0.2

Month	Day	Sun declination	Sensor orientation (°)	Sensor tilt (°)
December	21	-23.45°	South	90°

Hours in True Solar Time	Sun Azimuth	Sun Height	Global Irradiance Tilt (Wh/m^2)
8h00	-53.3°	8.0°	113
10h00	-30.2°	24.2°	437
12h00	0.0°	30.7°	562

In the same way, we integrated all the climatic data into the software. The results are as follows:

- In December 21 at 8:00 am: the low intensity of the solar rays gives a weak rotation and thus the panel kinetics is almost 15% (Figure 21).

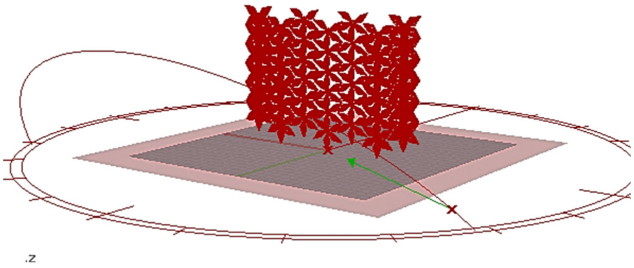


Figure 21. Simulation result on December 21 at 8 am

- In December 21 at 10:00 am: an average increase of solar intensities marks a weak current which gives an opening of 30% (Figure 22).

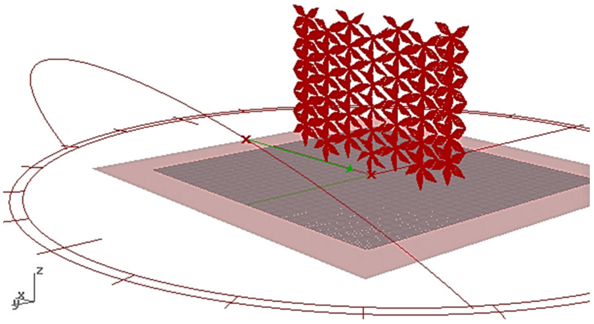


Figure 22. Simulation result on December 21 at 10:00 am

- In December 21 at 12:00: We marked an important rotation in winter at midday which means that there is an important current and thus the kinetic is reached (Figure 23).

The Table 4 shows the rotations recorded in winter (on December 21) for each panel according to test hours.

Table 5. Rotations recorded in winter

	P1	P2	P3	P4	P5	P6	P7
8h00	25°	20°	10°	10°	15°	20°	25°
10h00	15°	10°	5°	0°	5°	10°	15°
12h00	5°	0°	-10°	-15°	-10°	0°	5°

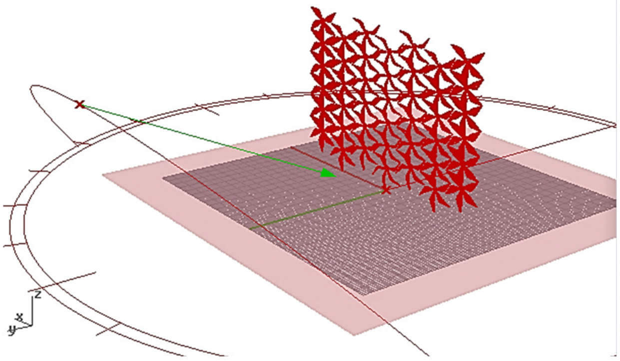


Figure 23. Simulation result on December 21 at 12:00

6. CONCLUSIONS

Through the formulation of parameters and rules, parametric design is an algorithmic technique that specifies, encodes, and clarifies the relationship between design intent and response. Geometric parameters are higher-level entities that are constructed from lower-level mathematical parameters. Examples are points, lines, surfaces and solids. Most current 3D modeling software can parametrically represent and modify geometric constructs of various types. These parametric design tools offer the possibility to express and explore the design intent itself. The numerical simulation tool in combination with the parametric design tool offers us the possibility to test the functioning mechanism of the prototype and to integrate and change the data each time with precision to obtain the desired objective.

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BIOGRAPHIES

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