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A Study of Dynamic Sculpture Prototyping Tools

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Abstracts. With the development of computer-aided design technology, more and more designers and artists have created installation art full of dynamic beauty to enrich the urban landscape, such as dynamic sculpture. This kind of dynamic sculpture needs to spend a lot of time and energy of the producer to produce digital models and product animation. This results in the artists not being able to utilize their creativity well. In order to propose an effective auxiliary design tool to reduce the artist's workload, this study first conducts a literature review on related theories and proposes a design method based on constrained morphology through curves. Based on this method, a complete design process was designed and a browser-based design tool, KINETICIST, was developed. Finally, user experiments were conducted in this study. The result proves that KINETICIST has qualified user experience performance under the dimensions of effectiveness, ease of interaction, and ease of learning, and has practical value.

Keywords. *computer-aided design tool; kinetic sculpture; design tool; Interaction design*

1.Introduction

With the arrival of the digital age, computer science and technology have been penetrating into the fields of industrial design, product design, graphic design and so on, and eventually expanding to the field of public art. More and more public artists have introduced science and technology into art creation, and the expression forms of public art works have become more and more diversified and complex.

The purpose of this study is to lower the threshold of dynamic sculpture design so that more people can participate in it. This study expands the research content of dynamic product design, and the output results improve the design efficiency, which has academic theoretical value and application prospect.

This study makes the following contributions:

- A workshop on modelling dynamic sculpture was conducted, which resulted in the behavioral habits and existing difficulties of art creators in the process of modelling dynamic sculpture.
- Invented a parametric design method based on skeleton, users can quickly generate 3D model and computer animation of dynamic sculpture by drawing curves and adjusting parameters in two steps.

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- A high-fidelity interface prototype of the tool "KINETICIST" was designed based on the systematic tool design model approach.

2. State of art

Computer-Aided Design (also known as CAD) is a design method that uses a computer system to assist the user in analyzing, creating, editing modifying or enhancing a design. Learning CAD software is not an easy task as far as the experience of using the software is concerned[2] . In the contemporary booming digital manufacturing community, non-engineers are also relying on CAD software to create models. However, these people generally lack experience with the software and have a poor experience with it.

As the demand for collaborative design continues to grow, the cloud-based nature of CAD software has become a trend in design software. It represents the integration of industrialization and informatization, and can improve the technical level of the equipment manufacturing industry, which is an important development direction in the future.[3] It is an important development direction in the future.

At the same time, the need to print models from CAD were realized. CAD allows model data information to be imported into CAM (Computer Aided Manufacturing software) to drive equipment to print geometric parts.

Productivity tools such as photoshop and sketchup are commonly used in today's creative activities. However, UX designers generally lack a systematic design approach towards productivity tool-based products.

3.Research on dynamic sculpture design methods

In order to investigate a simple method for designing workbench sculptures, this study recruited eligible users to participate in a workshop together to discuss how to design dynamic sculpture prototypes using CAD technology. After the implementation of the workshop, we quantitatively and qualitatively analyzed the participants' process of designing dynamic sculpture prototypes, and discussed and summarized some consensus.

3.1 Design workshop

3.1.1 Recruitment

The registration information and forms were distributed through BBS forums on campus and microblogging groups related to industrial design majors. Finally, five industrial design students (three males and two females) were invited, distributed in the first and second years of postgraduate studies. All of them are proficient in modelling software.

3.1.2 Workshop process

The seminar consisted of two sessions. In the first session each participant was asked to introduce one of their favorite dynamic artists or designs to the group and explain why, and then answer open questions. In the second session participants were asked to design similar 3D models based on the assigned dynamic sculpture material and using modelling tools they were familiar with. The third session was feedback and discussion, where the researcher discussed with the participants the difficulties and insights gained during the design process.

3.1.3 Assessment and analysis of workshop results

In the process of inviting designers to freely design 3D models of dynamic sculptures, two different design approaches emerged among the participants.

The first is a top-down design approach: start by designing from a conceptual sketch, using curves in the tool as axes and contours for the sculpture, and quickly sketching out an outline to constrain the shape. The units are then arranged and modelled according to the layout of these basic elements.

The second is the bottom-up design idea: start designing from the components of dynamic sculpture, and then through several attempts of the whole, finally get a satisfactory effect.

After discussion we found that the first method of using curve constrained morphology is more flexible in design. However, it is less efficient in modelling and it is more difficult to modify the morphology again after the design is completed. The second one can help designers to realize some regular shapes, which is more efficient. The disadvantage is that the modelling designed by this method is more stereotyped.

3.2 Dynamic sculpture design method

By summarizing the results of the pre-study, this study proposes a design method based on "skeleton". The meaning of "skeleton" is to use simple curves to abstractly express the shapes of the three basic components of dynamic sculpture, namely, axis, outline, and monolith, as shown in Fig. 1.

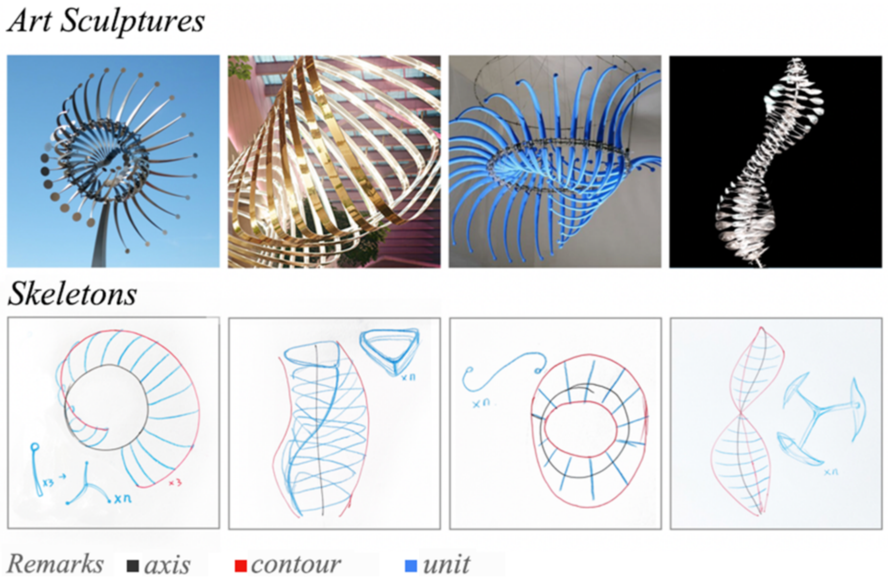

Figure 1 Framework Diagram of Skeleton Based Design Methodology

As shown in Fig. 2, the basic design process based on the "skeleton" design consists of the following steps.

- Drawing curves. The user draws curves within the tool interface, which represent the axes and contours of the envisioned dynamic sculpture.
- Skeleton generation. The skeleton consists of axes, contour lines, a number of lines representing monomers starting from the axes and ending on the contours, requiring the user to customize the number of monomers to be generated.
- Unit assignment. Based on the generated skeleton, a specified 3D model is automatically generated at the position of several lines representing the monomer.
- Generate animation. Click the Start Motion button, the monolith will automatically rotate around the axis at a constant speed to get the final simulation animation.

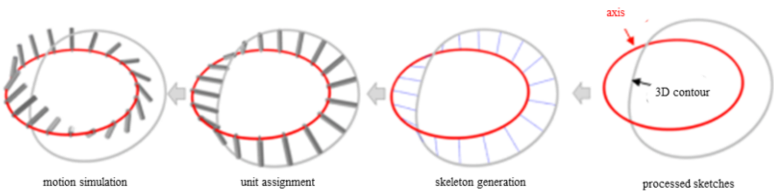

Figure 2 Flowchart of Skeleton Based Design Methodology

4.System design and development process

Based on the guidance of the systematic tool design model proposed by the author in the previous article, the author completed the tool requirements sorting and process design, and completed the high-fidelity interface design of the entire system. With the help of a collaborative team, we developed KINETICIST (Sculptor), a dynamic sculpture design tool for use in the browser, based on an open-source web graphics library.

4.1 System design goals

The target users of this tool are non-professional users such as product design students, installation art enthusiasts, and artists. In the end, the ultimate goal is for designers to obtain the production products they want through tools. Using the method of tool positioning formula, the core positioning of our tool is: KINETICIST = "efficiency" tool software that serves "product designers" and is used to improve "dynamic sculpture prototype design".

4.2 Usage process analysis and redesign

According to the author's review, in the conceptual design process of dynamic sculptures, depending on the sophistication and use of the product, the production process of dynamic sculptures can be abstracted into three stages: low-fidelity prototype, high-fidelity prototype, and production data. According to the efficiency design principles summarized by the author in the tool design principles, designers should consider the impact of different demands on product quality on efficiency when designing software interactions. The product in the low-fidelity prototype stage has the lowest level of precision. The product contains sketches and skeletons. Most of the interactions in the scene occur at this stage, and the user's degree of freedom in operation should be the highest. The products of the high-fidelity prototype stage include three-dimensional models and computer animations, which should allow the running user to fine-tune and retain a certain degree of freedom, but the entire operation process should be streamlined. The products in the production data stage include transmission mechanism models and data files. The products are the most stable, so the user has the lowest degree of freedom. The operations are mainly simple operations such as one-click generation.

4.3 Clustering module

When designing tool modules, the author summarized the abstract behaviors based on the types of components that appeared in the entire process, and summarized the tool modules that will appear in the KINETICIST interface. The author arranges the production modules from left to right and from top to bottom according to the order in which the components are produced. At the same time, the tool blocks that need to be operated back and forth between the two modules are summarized on one side to ensure the simplicity of the user's operation line.

4.4 High-fidelity interface display

The target users of this software have limited modeling experience and parametric design experience. Therefore, the interface design adheres to the principles of simple and clear visualization, color and style. The UI high-fidelity summary of this design is shown in the figure. The figure shows that the entire system layout consists of five parts: Top bar, Tool bar, Right bar, Canvas, and Bottom bar.

According to the different operating objects, the author uses the tab component (Tabs) to divide the overall interface into a single design interface and a secondary interface for the design skeleton (Fig. 3.).

Unit design interface Skeleton design interface

Figure 3. System layout

4.5 Software system framework and development

The author and his cooperating team developed the computer generation toolkit KINETICIST based on the open source WebGLlibrarythree.js (r86). Our tool runs in a browser, Chrome (V61) for this article. The configuration of the test system is Windows7SP1x64, Intel E33.2GHz 4-core CPU and 8GB RAM. Our tool is currently running in the locally configured server.

The entire project is developed based on the WebStorm platform. WebStorm is a JavaScript development tool owned by JetBrains. The modified results can be updated synchronously in the browser. In KINETICIST's interaction design, in order to reduce visual interference to users, some interface modules will only appear when the corresponding objects in the canvas are clicked. In order to achieve this interactive effect, the system draws on the publish-subscribe model (Publisher & Subscriber) during the development process. The publish-subscribe model refers to the object (Subscriber) that wants to receive notifications. It subscribes to the topic through custom events based on a topic, and the event is activated. The object (Publisher) notifies each Subscriber object that subscribes to the topic by publishing topic events. In the publish-subscribe model, publishers and subscribers do not know the existence of each other and they only communicate through the message broker.

The entire front-end system is mainly composed of four main modules. The tool interface system (interface system), canvas view (scene), core graphics (core graphics), event channel object (event channel), their relationship is shown in Fig. 4.

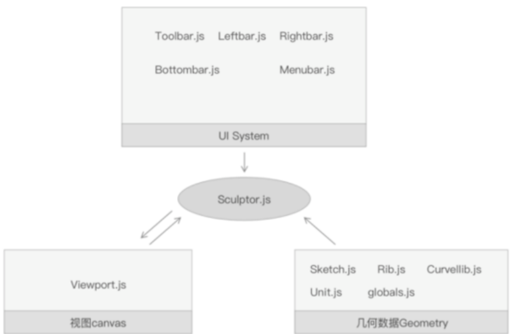

Figure 4. System diagram framework

5. Results presentation and user feedback

Based on the design methodology proposed above, this research team, with the help of a collaborative team, developed KINETICIST (Sculptor), a dynamic sculpture design tool for use on browsers, based on the open-source Web graphics library. The target users of this tool are aimed at non-professional users such as product design students, installation art enthusiasts, and artists. In this chapter, we will specifically demonstrate the process of using KINETICIST (Sculptor) and evaluate the effectiveness of our tool from the perspective of user experience through design experiments.

5.1 Results presentation

5.1.1 Software use process

The flow of using the main functions of the software is shown in Fig. 5 below. The monolithic design process is independent of the overall dynamic sculpture design process for the sake of reducing the user's learning costs and cognitive load. If the designer does not design the 3D model of the monolith within the tool, the system will use the default one to generate the model.

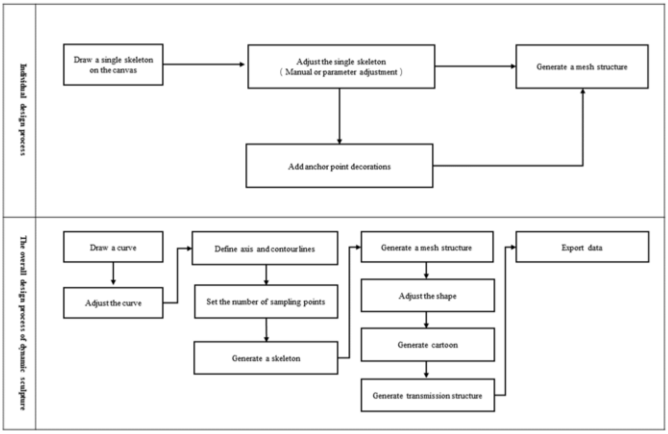

Figure 5. The main flow of using the software.

5.1.2 Software operating procedures

The design process can be divided into four stages, the first stage is a sketch. As in Fig. 6, click the toolbar button to add a preset parametric curve "Ring Knot" and a circular curve directly to the scene. Then modify the curve style.

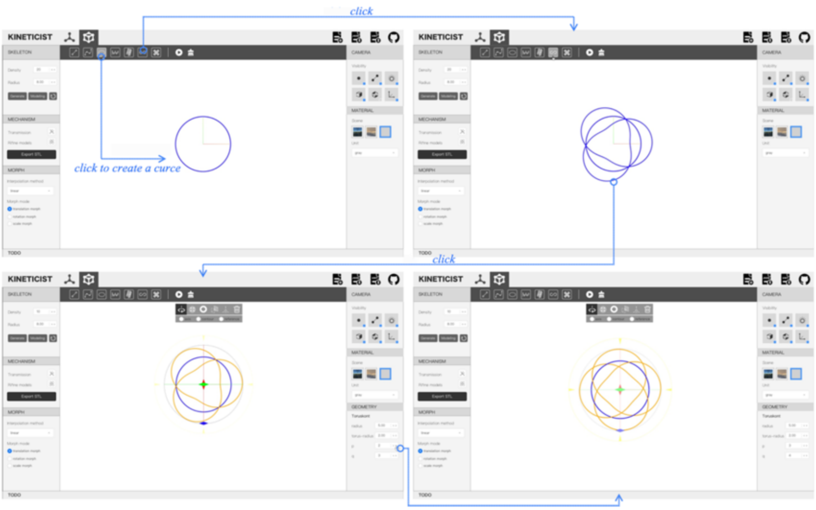

Figure 6. Sketch Stage Operation Methods

The second stage is the skeleton design stage. Click on the two curves you have just added, the Top-toolbar component will appear in the upper area of the canvas, the selected curves will be defined as axes by the component, and the curves will turn red after the setting is completed (Fig.7).

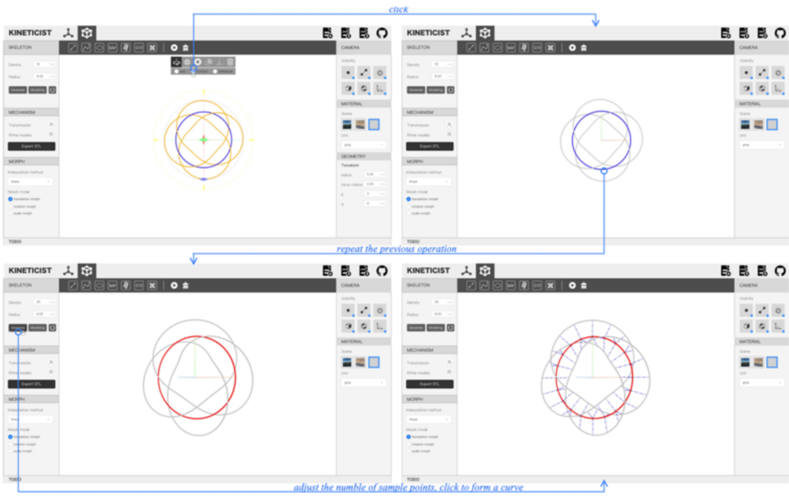

Figure 7. Skeleton design stage operation

The third stage is the high-fidelity prototyping stage. Click Modeling button in the left property bar, the system will automatically generate the default 3D model according to the skeleton. Click the Animation Play button in Toolbar, the monobloc will automatically rotate around the axis at a constant speed, and click the Mechanism Generation button in the left property bar to generate the transmission mechanism (Fig.8).

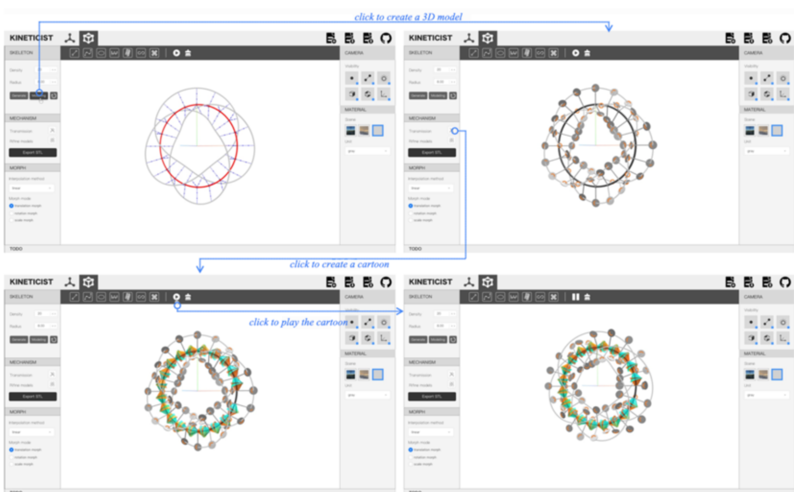

Figure 8. How the high-fidelity prototyping phase operates

Phase 4 Data Export Phase. After clicking the export json button in Topbar, the browser automatically downloads the json format file of the dynamic sculpture model as a whole, as shown in Figure 5-4. The design tool also supports exporting the bearing model data of the single unit in stl format separately (Fig. 9).

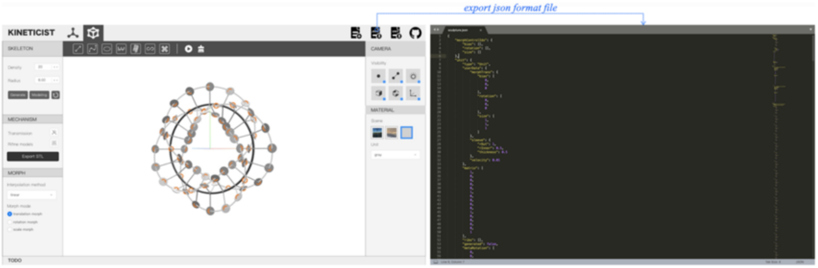

Figure 9. How to operate the data export stage

5.2 Usability testing

5.2.1 Testing process

Twelve users were recruited for the test experiment, all of whom were students from industrial design programs with some experience in modelling software. 20 minutes were given to introduce the basic functionality, interface elements, and operational procedures of our system.

The tasks of the test are as follows:

- Use the Curve tool to draw two spatial curves
- Selecting and defining axes and contours in the scene
- Confirmation of skeleton generation
- Control of parameter adjustments to the number of lifting units
- Adjusting contour lines in the scene
- Confirmation of model and animation generation

At the end of the user experience, a feedback questionnaire was completed as required. The user experience was measured on a seven-point Likert scale, ranging from 1 to 7 on a scale of "very poor" to "very good". The question design of the questionnaire is shown in Fig. 10.

Usability Dimension	Question description		Scores						
			1	2	3	4	5	6	7
Validity	Q1	I can use this system to create simple kinetic sculpture designs.							
	Q2	The prototypes I was able to design using this system met my design expectations.							
	Q3	Improved my design efficiency through tools.							
Interactivit y	Q4	I can understand the interface layout and interaction of the tool							
	Q5	I can understand the concepts of contours, axes, and units.							
	Q6	I can understand the function of each module and realize adjusting parameters.							
Ease of learning	Q7	I can quickly learn how to use the system							
	Q8	I was able to quickly learn this design process based on contour and axis modeling							
	Q9	I can quickly learn how to modify my own designs to obtain more design solutions							

Figure 10 Question setting

5.2.2 Analysis of test results

All questionnaires were statistically and analytically analyzed, mainly using the SPSS data statistical analysis software to calculate the mean and standard deviation of the ratings of each topic, and then comparing the mean of the ratings of each topic through the one-sample t-test. The experimental results are shown in Table 1 below.

Table 1 Data collected

Availability Dimension	serial number	Mean	(statistics) standard deviation	summed mean value	Summed standard deviation	t	Sig.(2) tailed)
validity	Q1	4.944	1.552	4.55	1.513	2.698	0.010
	Q2	3.883	1.543				
	Q3	4.833	1.231				
interactivity	Q4	4.611	1.200	4.722	1.309	4.054	0.000
	Q5	4.722	1.420				
	Q6	4.611	1.364				
Ease of learning	Q7	4.611	1.577	4.611	1.366	3.289	0.002
	Q8	4.611	0.979				
	Q9	4.611	1.539				

The results show that our tool has basically gained users' affirmation in the three usability dimensions of effectiveness, ease of interaction, and ease of learning, and the tool's performance is qualified.

5.3 Prototype effect inspection

5.3.1 Experimental design

To verify the effect of kinetic sculptures designed using our tool. We invited two designers with similar design skills and asked one of them to use the system to create a prototype design of a dynamic sculpture, and the other designer needed to use Rhino and Keyshot (product rendering software) to design and prototype the design. Contains 3D model design and computer animation.

By gathering test users, we showed users the works of two designers (including pictures and videos), and then used a similar seven-point Likert scale to ask the test users to express their opinions on the dynamic sculpture prototype designed by Rhino and the "KINETICIST" design. The dynamic sculpture computer animation is evaluated. The evaluation criteria are divided into 1 to 7 points from "very inconsistent" to "very consistent". The design of the questionnaire part is as shown in the Table 2.

Table 2 Question setting

Question description		Scores						
		1	2	3	4	5	6	7
Q1	I think the shape of the dynamic sculpture is complicated.							
Q2	I think the overall shape of the dynamic sculpture in the video is very beautiful.							
Q3	I think the movement effect of the dynamic sculpture is beautiful.							

5.3.2 Analysis of experimental results

This experiment used the independent sample t test, and a total of 8 design students with certain aesthetic abilities were recruited. This test method was used to test the difference in the data obtained by the two groups of unrelated sample subjects. The experimental results are shown in the table. The experiment shows that the overall beauty and dynamics of the dynamic sculpture models and computer animations designed using our tools are not significantly different from traditional tools, and the results are statistically significant (Table 3).

Table 3 Experimental data

Question number	**Mean**	**Standard deviation**	**t**	**P value**
	A(n=8)	B(n=8)		
Q1	6.00±50.76	4.50±1.60	2.393	0.038*
Q2	5.13±0.83	4.38±1.30	1.371	0.192
Q3	5.13±0.83	4.50±1.41	1.077	0.3
	*P<0.05**p<0.01			

6. Conclusion and future work

This study develops the basic functions based on the design idea of minimum viable product (MVP). At present, the development of dynamic sculpture art is still relatively early, and the creativity and imagination of artists are still not fully stimulated.

KINETICIST enables designers and artists to create dynamic and kinetic sculptures easily and efficiently. The tool's design process is simplified, and it can automatically generate 3D models and computer animations based on user-drawn curves and adjusted parameters.

The high-fidelity interface prototype of the tool allows designers to control the design details and effects more accurately, improving the quality of their creations. Additionally, KINETICIST is easy to learn and use, allowing more people without prior computer-aided design experience to participate in the creation of dynamic sculptures. This can enrich cityscapes by adding more dynamic and kinetic art installations, while also promoting eco-design by raising public awareness and appreciation for this type of art. Overall, KINETICIST is a useful tool that can contribute to sustainable design practices and promote eco-design.

The ultimate goal of this study is to lower the threshold of dynamic installation design and promote this art discipline, thus summarizing the direction of future work:

- At present, the types of dynamic sculptures studied in this paper are limited, and it is hoped that KINETICIST will be able to support more forms of dynamic sculpture design in the future, which will really promote the development of dynamic design.
- We hope to invent standardized mounting components that are easier to install in our future work.
- Our work can be combined with AR technology so that designers can observe the dynamics of their designs in actual real-life scenarios directly through mobile AR program

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