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Concurrent Design Strategy in Vacuum Cleaner Development

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***Abstract* —** In recent years, the environmental pollution issue has been paid more and more attention, one of them is the air pollution. It brings many dust precipitate issue into the indoor, it also increases the demand of the vacuum cleaner market indirectly, and it has continued to gain popularity. At first, this article analyse the image criterion to define the market position of the product, the user of our target setting is the middle-aged. We use Morphological Analysis and the Finite Structure Method (FSM) to acquaintance the design of the vacuum cleaner and how it composes. Through objective screening, we choice out the ideal proposal; simultaneously, we use the objective tree to decide, Analytic Hierarchy Process (AHP) to find out the design standard and method of weighting, in the way to design the questionnaire once again and to find out the best design modelling and the combination. Finally, we use schematic diagram, the computer assistance design to devise the concretization, also carry on the color plan and the whole appraised, in the way to obtain the optimization design. The research demonstrated that, this vacuum cleaner can conform to the middle-aged demand, through this series of methods, we can elimination the majority uncertainty, and also the feasibility of the gain in output.

Keywords — Concurrent Design, Vacuum cleaner, Objective tree, Analytic Hierarchy Process, Morphological chart method, Finite Structure Method

I. INTRODUCTION

People use mop, broom, cleaning rag… and so on in the traditional way to clean, but those tools are not only poor in the clean effect, but also wastes time, and even worst, aggravates the labor. Then the vacuum cleaner has been invented, the vacuum cleaner is a reduced effort, common cleaning tool at present t. Taiwan has already entered into the population ageing society for over a decade. The National development Committee's indicated that, Taiwan will achieve “the Elderly Society” in 2018; the bridged will be over 20% threshold, and become “the Ultra Elderly Society” in 2025. At that time, Taiwan will be approximately have 4.73 million senior citizens, which are equal to a fifth people in our nation is old people [1]. Whereas human's physiology and psychological change starts from the middle age, which are the vision degenerate, the hearing declines, and the muscle intensity drops…and so on. The market has not yet appears the vacuum cleaner design for maturation and old age people so far, so how to designs the perfect one for them, that is the issue our researches wish to discuss.

II. DESIGN METHODS AND PROCESS

The study demonstrate the design strategy based on concurrent design in the case study of vacuum cleaner. The flow chart for the design process is shown in Fig 1.

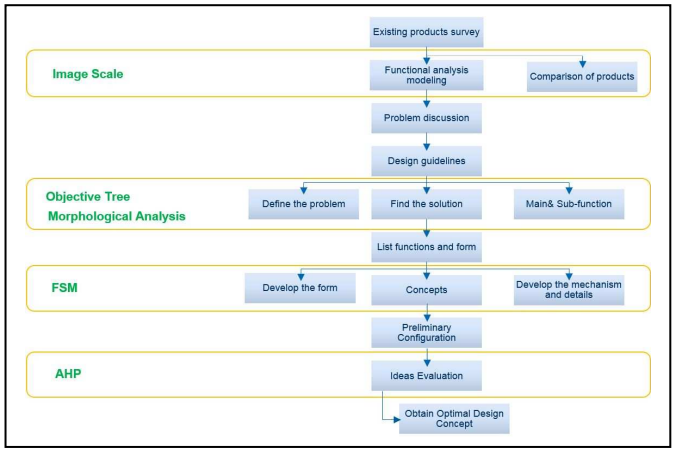

FIG 1. DESIGN PROCESS

III. THEORETICAL BACKGROUNDS

A. Image scale method

Listing all products on the market, and according to it property put in x axis or y axis. The x , y axis signify different meaning, the graphics and proportionate clearly shown the differences between the products[2]. This article refers to Shiao professor of research [3] of the scale image scale figure.

B. Objective Tree Analysis

The aim of the objectives tree method is to clarify design objectives and sub-objectives, and the relationships between them. The procedure is as follows [4] :

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1) Prepare a list of design objectives. These are taken from the design brief, from questions to the client, and from discussion

2) Order the list into sets of higher-level and lower-level objectives. The expanded list of objectives and sub-objectives is grouped roughly into hierarchical levels.

3) Draw a diagrammatic tree of objectives, showing hierarchical relationships and interconnections. The expanded list of objectives and sub-objectives is grouped roughly into hierarchical levels.

C. Morphological Analysis

Morphological Analysis is reorganizing or combining all of the possible solutions to achieve a variety of design proposals. This method can generate a lot of design options and feasible solutions. Based on the content of a problem, Morphological Analysis produces a matrix that can solve the problem. The steps are as follows [5]:

1) List the functional characteristics after the product has been disassembled.

2) According to the functions and features, list the methods that can be efficacious.

3) Make a form for the possible secondary solutions.

4) Combine the options and choose the optimal solution.

D. Analytic Hierarchy Process

Through the group discussion, collecting the advice of experts and decision makers. And assessment and evaluation issues simplifying the problem as a factor level. And then the scale of the two elements of the level of comparison, quantified after the establishment of a matrix than to obtain the weight of each element [5]. The Analytic Hierarchy Process operation can be divided into the following five steps:

1) Step 1: Define the decision-making problem.

2) Step 2: Create a hierarchical structure.

3) Step 3: Create a pairwise comparison matrix. Table 1 is the evaluation measurement and relative definition of AHP.

4) Step 4: Calculate the eigenvalues.

5) Step 5: Conformance test

TABLE 1 EVALUATION MEASUREMENT AND RELATIVE DEFINITION OF ANALYTIC HIERARCHY PROCESS.

Evaluation measurement	Definition
1	Equal importance
3	Slight importance
5	Essential importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate value

Eigenvalues in step 4 can be calculated in the following ways:

- Eigenvalue and Eigenvector
- Saaty proposed four approximation problem-solving methods: Normalization of the Row Average (NRA), Average of Normalized Columns (ANC), Normalization of the Geometric Mean of the Rows (NGM), and Normalization of the Average Reciprocal of Columns.

The consistency test in step five is to make sure that the evaluation results are consistent when the experts are conducting pairwise comparisons, which means that the experts' preference for criteria is transitive. Saaty suggested that consistency index (C.I.) and consistency ratio (C.R.) be used for the test. If C.I. and C.R. are both less than 0.1, it means that the pairwise matrix is consistent. If the matrix is not consistent, the equation of C.I. and C.R. is as follows:

$$C.I. = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

λmax is the largest eigenvalue of the matrix.

n is matrix order (number of parameters).

$$C.R. = \frac{C.I.}{R.I.} \quad (2)$$

C.R. < 0.1→ OK
C.R. = Consistency ratio
C.I. = Consistency index
R.I. = Randan index

Where n is the number of evaluation criteria; R.I. is random index whose value increases if the number of criteria increases, as shown in Table 2.

TABLE 2 RANDOM INDEXES.

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

IV. FINITE STRUCTURE METHOD

By the product to achieve the function of the required functions for the development of the basis of modeling, and will be limited to a certain number of changes in the structure to pursue the possible shape of the product. There are five steps to proceed [6]:

1) To determine the main function of the product you want to design.

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2) Branch of the main function of several minor functions of the combination, and it's limited to a certain amount.

3) The basic structure of the combination of the limited function is expanded in the case of three variables.

4) To ensure that the diversification of modeling at the same time, also consider the original design of the product.

5) Choose a best possible solution.

V. Case Study

A. Market Survey and Trend Prediction

Vacuum cleaner is a device that utilizes an air pump to create a local vacuum that absorbs dust and dirt, often on the floor of the carpet and on a tile floor and a smooth surface. This method of converting electrical energy into mechanical energy and transmitting it to the product, using the energy that the motor is turning out and turning it into a force of absorption, can also be applied to the design of many products [7].

This study is for the collection and investigation of the vacuum cleaner on the market, divided into both wired and wireless, list the weight, price, capacity ... and so on, then the corresponding user to do suction and price analysis, and then get the main design The objectives are shown in Table 3 and Table 4.

List all pictures in the image scale method, shown in Fig 2.

1) Horizontal axis : Low price → High price
(According to the questionnaire results : NT$ as standard)

2) Vertical axis : Low suction → High suction
(According to the questionnaire results : 400w as standard)

According to image scale method analysis, we could know the different of Vacuum Cleaner on market. In order to develop the product strategy, we will develop the product strategy through the non-technical innovation, such as modeling, operation, color, texture, attachments and other sensory images. This research will follow this direction as the development focus The According to the product located in the image scale analysis of the location, you can understand and observe the difference between the market products.

B. Identify the Headings

Based on the respect of the elderly groups, we call the silver-haired family, wise men, senior citizens, the elderly, the older generation, the average person said that the elderly, refers to people over sixty-five years of age [8]. At present at home and abroad more and more attention to the elderly and related issues, in the 45 to 65-year-old crowd that middle-aged, aged 60 years of age or older people. For the middle and high years of physiological degradation, such as vision degradation, hearing loss, muscle strength decreased. In the use of home appliances on the need for different functional modeling or interface design to increase the use of home appliances in the elderly on the convenience and security. At present, there is no vacuum cleaner designed for middle-aged people, and the change of the psychological condition of middle-aged and old students cannot be ignored. The study hopes to design a vacuum cleaner designed for middle-aged and old people.

TABLE 3 Market Survey (wireless type)

PICTURE					
ITEM	MUJI XJC-Y010	Dyson mattress HH08	LG VR94070NCAQ	HITACHI PVSC200T	Electrolux ZB3013
PRICE	6400	15900	29900	9899	10900
WEIGHT(KG)	1.3	1.63	7.9	2.8	2.63
SIZE(mm)	200x139x995mm	144x395x208mm	300x440x316	170x270x1100	278x218x263
FILTER	EPA Filter	HEPA Filter	Washable Four layers HEPA14	Dust box	Dust box
POWER(W)	90	350	200	300	300
Dust collection capacity(L)	•	0.41	1.2x3	•	0.5
Charging time (HR)	6	3.5	4.5	4	4
Maximum working Time(min)	57	20	40	40	35
Warranty	1 year	2 years	•	•	•

TABLE 4 Market Survey (wire type)

PICTURE					
ITEM	Electrolux ZUOM9922CB	Miele SDAE1-15	Panasonic MC-CL733	KOLIN TC-R1105C	HITACHI CV-AM14
PRICE	29900	14500	4690	2900	1490
WEIGHT(KG)	5	4.5	3.6	5.5	4.8
SIZE(mm)	374x233x267	200x220x420mm	256x290x220	360 x 245 x 260	450x312x274
FILTER	Washable HEPA 13	HEPA 13	HEPA	Dust box	Dust bag
POWER(W)	200/1400	1200	450	160	350
Dust collection capacity(L)	•	•	0.7	1.8	•
Charging time (HR)					
Maximum working Time(min)					
Warranty	2 years	2 years	•	1 year	•

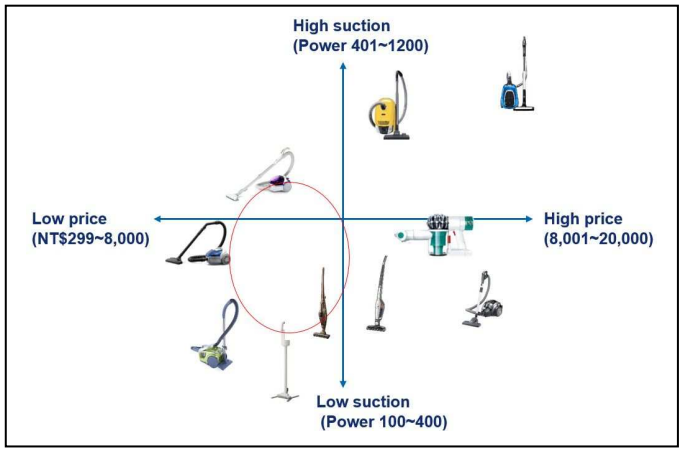

FIG 2. Image scale

C. User survey and statistical results

Mainly for the 45-year-old vacuum cleaner users to do the survey, the effective questionnaire for the 12, finishing results shown in Figure 3.

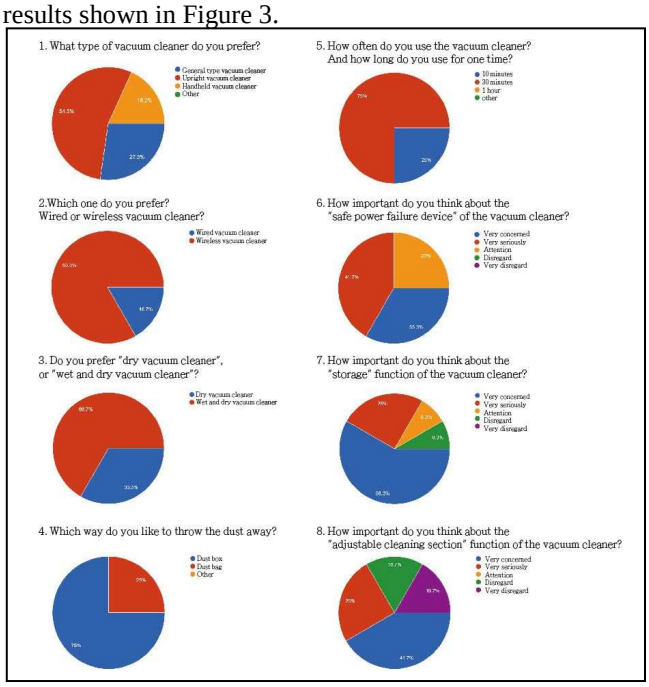

FIG 3. QUESTIONNAIRE RESULTS

silver-haired family, wise men, senior citizens, the elderly, the older generation, the average person said t

D. Product Positioning

According to the above analysis, summed up the following production direction:

1) Overall safety considerations: weight, safe power function ... and so on.

2) Wireless vacuum cleaner design for the development direction.

3) Vertical vacuum cleaner design for the development direction.

4) Design dust collection method will be dust box.

5) Handle the convenience of operation and human considerations.

6) Storage function.

E. Black box diagram

Black box diagram are used to clarify the procedure hidden between the input and the output of the vacuum cleaner. The desired use process is shown as a "black box" process in Fig 4.

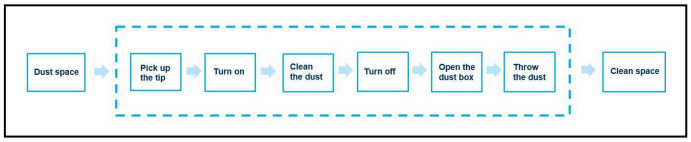

FIG 4. BLACK BOX DIAGRAM

F. Identify design elements

According to the above analysis to set the main ethnic groups and models, the continuation of the design requirements will be divided into the following two:

1) Demand : necessary function

2) Wishes : unnecessary function

Add demand and wishes into the design project, the following total target tree, as shown in Fig 5.

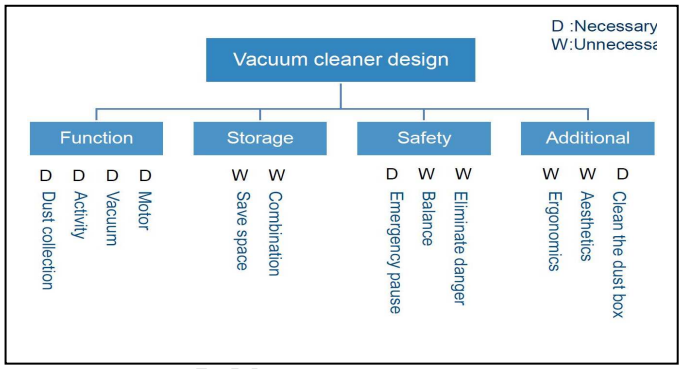

FIG 5. IDENTIFY DESIGN ELEMENTS

And then for the items for detailed analysis, as shown in Fig 6:

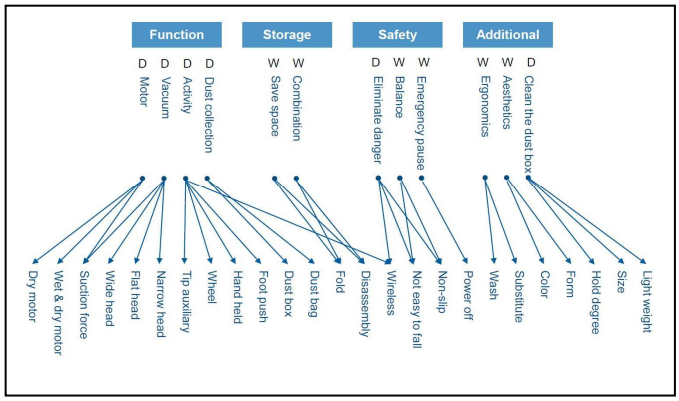

FIG 6. OBJECTIVE TREE ANALYSIS

After the analysis of the above links, you can set the target set, as shown in Table 5:

G. Conceptual development and integration analysis

With four design objective: Function, Storage, Safety and Additional, through the AHP method to explore the importance. And the C.R. is < 0.1, means questionnaire data have credibility. The order of importance is Safety, Function, storage and Additional. As shown in Table 6.

And then use the limited structure analysis method to find out all feasible combinations, remove the combination is not suitable. M: motor unit, S: dust collection unit, V: vacuum unit, as shown in Fig 7A & 7B.

Table 5. Design Objective, Function and Criteria.

Design Objective	Design Function	Design Criteria
Function	Activity	Light weight
		Caster
		Wireless
	Vacuum	350W
	Adapt to different environments	Variety of sizes head
	Wet & dry vacuum	Wet & dry motor
Storage	Can be combined	Deformable
	Not occupy space	Body compact
Safety	Eliminate danger	Wireless
		Emergency pause button
		Non-slip design
	Balance	Slightly larger wheels
		Center of gravity in below
Additional	Easy to clean	Washable dust box
	Aesthetics	Color planning
		From design
	Ergonomics	Hold degree
		Size
		Easy to use

Table 6. Building a pairwise comparison matrix.

	Function	Storage	Safety	Additional	Geometric mean	weight	C.R.
Function	1	3	1/3	7	1.622	0.28	0.059
Storage	1/3	1	1/7	3	0.610	0.11	
Safety	3	7	1	5	3.201	0.56	
Additional	1/7	1/3	1/5	1	0.31	0.05	

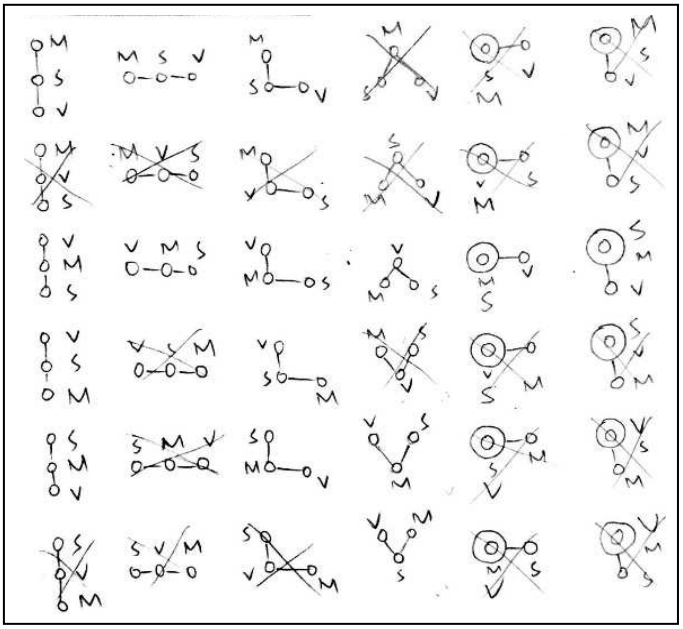

FIG 7A. BASIC ARRANGEMENTS

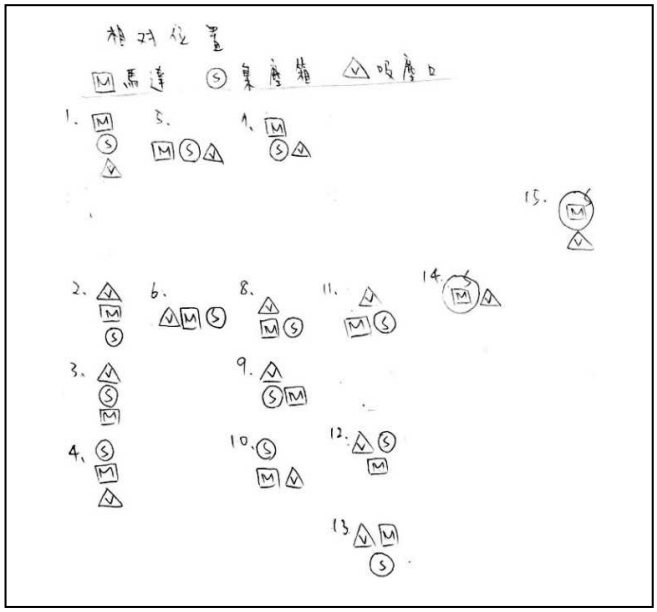

FIG 7B. BASIC ARRANGEMENTS

In order to the combination of modeling unit more specific to the designer, shown in Fig 8.

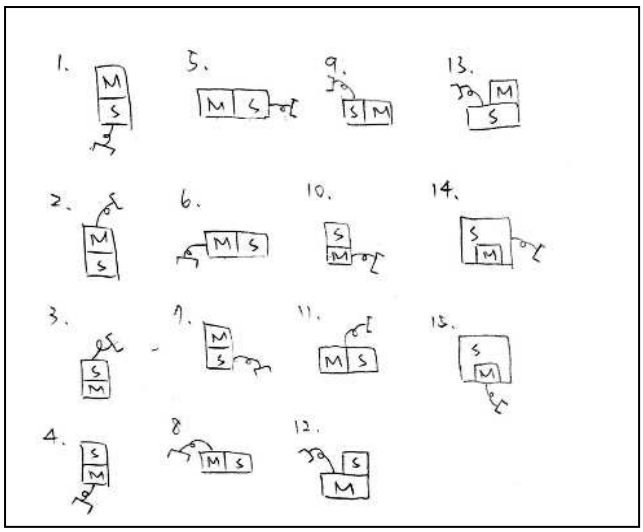

FIG 8. CONFIGURATION FOR FINITE STRUCTURE METHOD

As the industrial design is not entirely like art as only ornamental purposes, still need to meet the functional needs of the shape to be rationalized. Through the type of chart method not only help to achieve the aesthetic and aesthetic design of industrial products, but also a diversified, time-saving, effort of high efficiency practices, so this study using this technique to complete the development of product modeling, As shown in Table 7.

Table 7. Morphological chart

	1	2	3	4	5	6
A. Grip	Square tube	Round tube	Arc tube	Handle		
B. Connection	Hose	Hard tube				
C. Collection	Dust bag	Dust box				
D. Type	Handheld	General	Vertical			
E. Wire	Wireless	With wire				
F. Discard	Open from the below	open from the right & left	Rotate open	Drawer	Open from the top	Triangle opening
G. Motor	Dry type	Wet & dry Motor				

After the combination of matching, meet the demand for the program for the following six suitable programs, as shown in Fig 9.

1) *A3*B1*C2*D3*E1*F1*G2*
2) *A3*B1*C2*D3*E1*F4*G2*
3) *A3*B1*C2*D3*E1*F6*G2*
4) *A4*B1*C2*D3*E1*F1*G2*
5) *A4*B1*C2*D3*E1*F4*G2*
6) *A4*B1*C2*D3*E1*F6*G2*

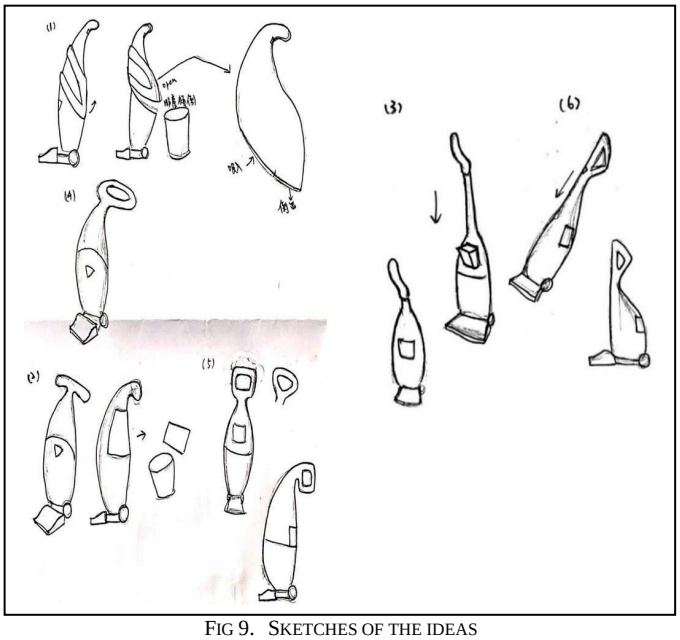

FIG 9. SKETCHES OF THE IDEAS

H. Obtain the best solution

Through 12 questionnaires to choose the optimal selection from six ideas. The (1) idea is obtain the highest weight total score, shown in Table 8.

Table 8. Find the best design

Completely not matched : 1 , Not matched : 2 , Medium : 3 , Matched : 4 , Completely matched : 5

	Idea					
	(1)	(2)	(3)	(4)	(5)	(6)
Function (0.28)	5	5	3	5	4	5
Storage (0.11)	3	2	5	1	1	5
Safety (0.56)	5	4	4	4	5	4
Additional (0.05)	5	4	4	3	2	5
Weighted total score	4.78	4.06	3.83	3.9	4.15	4.44

VI. FINALLY PRESENTED

A. Engineering drawings and 3 D modeling

As shown in Fig 10.

B. Color planning

In this study, we consult PANTONE published in the 2017 color trends. After voting for ten men and ten women, we obtain SERENITY and PEACH ECHO are most popular, shown in Fig 11. At last, we will use the user selected color to put on the optimized shape, as shown in Fig 12.

VII. CONCLUSION

The study represent the case design of vacuum cleaner by applying concurrent design strategy. Through the design process, various method and approach are used to help designers to clarify the problem hidden inside the black box furthermore to reach the optimal solution. After the design process, the vacuum cleaner is suitable for the middle and elderly conformed to the previous design specification and thus the problem was solved. The most important thing is that, the whole process is visible. After obtaining the ability, one can continue the designed steps and makes the design more complete. Business and companies feel trustworthy when the design process is visible and the overall design quality is manageable.

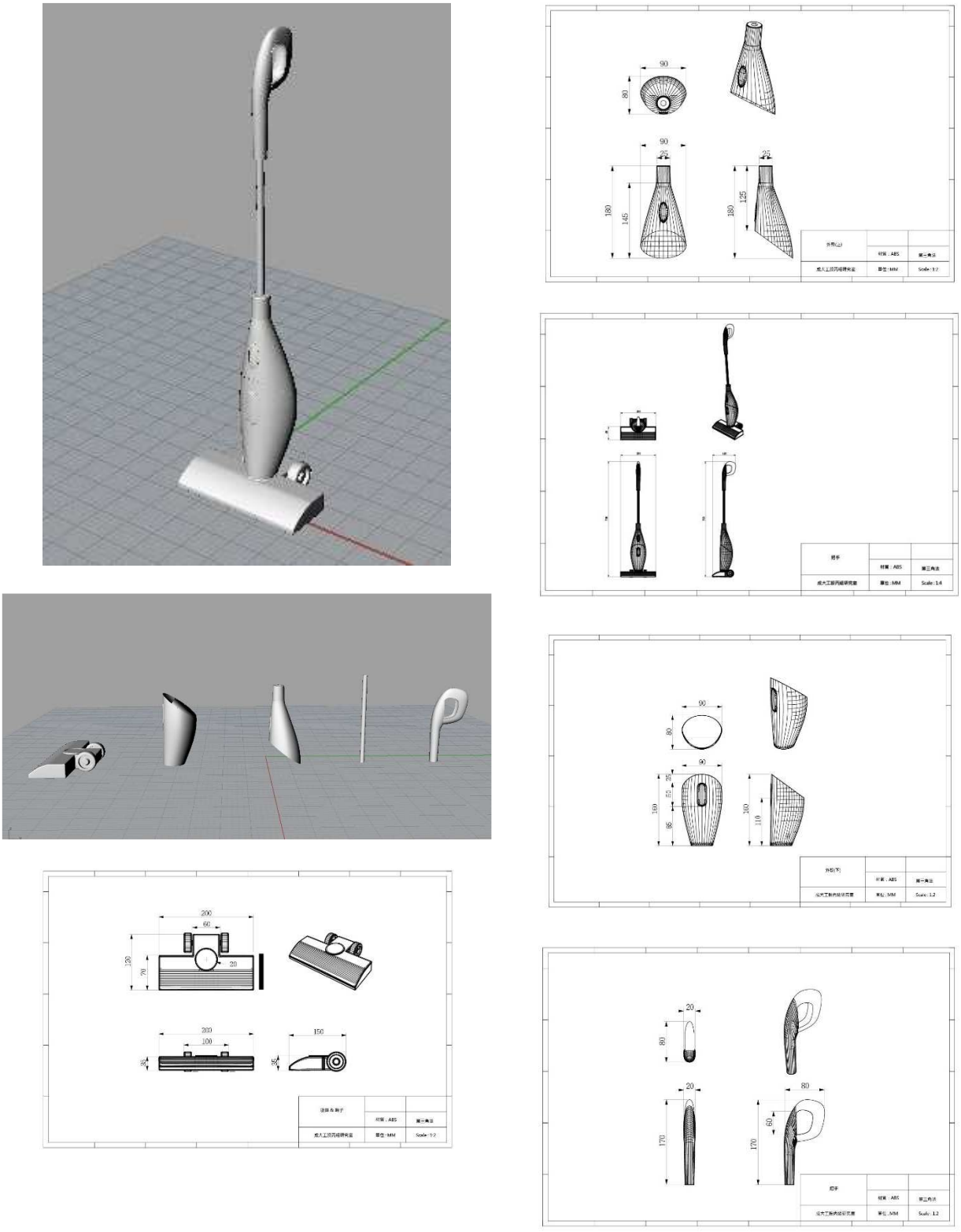

FIG 10. 3D MODELING AND ENGINEERING DRAWINGS

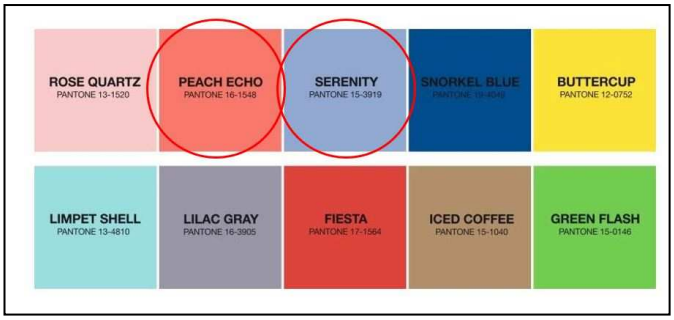

FIG 11. PANTONE POSTED 2017 COLOR TRENDS

FIG 12. FINAL RENDERING

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