CONSIDERATION OF IMPORTANCE OF CONCEPTUAL DESIGN

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ABSTRACT: Producing innovative new products is a way for companies to survive and continue generating revenue in today's competitive global market. The ability to develop innovative products, which bring about success for manufacturers, often depends on the ability to nurture new ideas and concepts, embody them, and evolve them into new products. Companies that allow designers to spend time creating and discussing several design alternatives are one step ahead of companies that do not. The process of drawing up a concept occurs before the design process, and the quality of products, cost, and delivery time in later processes are strongly affected by whether the concept is good or poor. Then what should be considered in the conceptual design? The following are some of the various factors considered in the stage of conceptual design where an image is gradually established: 1) how to evolve the overall concept, 2) the layout, 3) the overall design, 4) the mechanism to be used, 5) the drive system to be used, 6) the control system to be used, and 7) how to meet the cost target. The problem here is how to generate ideas in this process of drawing up a concept. Young designers often say that they think up ideas while drawing a layout using a computer-aided design (CAD) system. From the beginning, they sit in front of a CAD system and start drawing as ideas pop into their head. It is true that CAD is a convenient tool. Its functions are being improved year by year, and its simulation function has become more practical and easier to use. CAD is an essential tool for ensuring the quality of design; it gives designers an excellent command of drawing, erasing, adding, and rotating lines. It enables them to quickly start working.
However, we start the conceptual design in a different way. We recommend designers to draw up a concept using sheets of paper and a pencil. Namely, they should draw lines on sheets of paper until an image of the outline of their design is established in their mind. Because this is still a trial-and-error stage, it is more efficient and effective to visualize ideas by hand-drawing, which only requires an ambiguous sense, atmosphere, and kansei (feelings), than to define ideas graphically by inputting quantitative data into a CAD system. In this study, we will discuss 1) the boundary between conceptual design and detailed design, 2) the appropriateness of using 3D CAD for conceptual design, 3) the techniques used to embody concepts using 3D CAD, and 4) an example of the innovation of the machine design process in manufacturing.

Keywords: Education technology research, Conceptual design, CAD system, Rough sketching, Kansei

1. INTRODUCTION

Throughout history, humans have created products using a design system based on drawings. The organizations to which the designers belong, design cultures, design techniques, the shape of products to be designed, and even manufacturing processes are affected by the design system. Because the performance of database and network systems has been improved by recent progress in three-dimensional (3D) computer-aided design (CAD) technology, now, the largest-ever amount of information can be processed in a short time.

Conventionally, the amount of information handled by a designer was limited due to technological limitations. Also, the amount of information was limited by the organizations to which the designers belong, design cultures, and design techniques, to enable the efficient handling of information. In the future, technological limitations will be significantly eased and it will become necessary to newly construct or reconstruct a design system that is most suitable for the new environment. However, it will be a challenge to construct/reconstruct a design system which is closely related to existing design techniques, know-how, and peripheral systems.

The process of drawing up a design concept occurs before the design process, and the quality of products, cost, and delivery time in later processes are strongly affected by whether the concept is good or poor. We recommend that designers draw up a design concept using sheets of paper and a pencil. That is, they should draw lines on sheets of paper until an image of the outline of their design is established in their mind. The designers can continue drawing whatever comes to mind. Because this is still at the trial-and-error stage, it is more efficient and effective to visualize ideas by hand-drawing, which only requires general outlines, than to define ideas graphically by inputting quantitative data into a CAD system.

In this study, we will discuss 1) the boundary between conceptual design and detailed design, 2) the appropriateness of using 3D CAD for conceptual design, 3) the techniques used to embody concepts using 3D CAD, and 4) an example of the innovation of the machine design process in manufacturing.

2. BOUNNDARY BETWEEN CONCEPTUAL DESIGN AND DETAILED DESIGN

Conceptual design is a process of considering how to embody the required specifications into products. Designers first draw the conceptual design of the mechanisms of mechanical devices and electric circuits on sheets of paper by hand-drawing before starting the detailed design using CAD. Because this process is done using sheets of paper and general drawing tools, it is difficult to link the conceptual design to the later processes, or refer to and utilize the ideas examined in the past.

Currently, products are manufactured and traded not only in Japan but on a global scale. In order to deal with the issues associated with globalization, such as the increase in the variety of products, the overseas transfer of development and production lines, and price wars with rival companies, there is an urgent need to innovate manufacturing processes.

The quality of conceptual design largely affects not only the quality and cost of products, but also the man-hours required for later development processes. Therefore, it is necessary to determine the exact quality and cost of products in the conceptual design phase before proceeding to the detailed design phase.

Designers need a certain level of experience in product development so that they can design products with a clear understanding of the boundary between conceptual design and detailed design. Young designers may have difficulties in defining this boundary.

The definitions of conceptual design and detailed design are given in a number of books about design. However, it is difficult for designers to fully understand what conceptual design and detailed design are, unless they have on-the-job experience because the definitions vary according to the products to be developed.

The following will help designers define the boundary between conceptual design and detailed design.

1) Conceptual design is a continuing process of considering how to meet the requirements for products. Designers sometimes feel like they are taking three steps forward and two steps back until they reach a certain level where finished products can be imagined from the concepts.

2) Detailed design is a process of embodying the concepts into products. Little reworking is required, and designers should keep moving forward.

Particularly, in the conceptual design phase, it is necessary 1) to solve any concerns about design and 2) to plan how to address such concerns. Recently, the requirements for products (multiple functions and low cost) have increased, along with the requirement of the reduction of development time. Under such conditions, designers often find it difficult to resolve certain issues during the detailed design phase even if the solutions to such issues were planned for in the conceptual design phase. Considering the requirement of shortened development time, issues that cannot be resolved in the conceptual design phase can hardly be resolved during the detailed design phase.

Therefore, young designers should recognize that taking sufficient time to consider conceptual design is a quick route to the successful development of products. They should not rush into the process of detailed design using 3D CAD.

3. APPROPRIATENESS OF USING 3D CAD FOR CONCEPTUAL DESIGN

Producing innovative new products is one way for companies to survive and continue generating revenue in today's competitive global market. The ability to develop innovative products, which bring about success for manufacturers, often depends on the ability of manufactures to nurture new ideas and concepts, embody them, and evolve them into new products.

Companies that allow designers to spend time creating and discussing several design alternatives are one step ahead of companies that do not. In a survey on conceptual design targeting machine manufacturing companies, 92% of the companies answered that by doing so, greater benefit is achieved, since many design alternatives are discussed in the conceptual design phase.

Unfortunately, however, design teams often determine the final design candidate without spending sufficient time discussing design alternatives because of tight development schedules. This has considerable impact on the later processes. If mistakes are made in the determination of the final design candidate, and inappropriate product ideas are carried forward to the next phase, significant issues will arise later on.

Most companies recognize the benefits of using 3D CAD in the conceptual design phase where sets of different ideas and tools are needed. Since the emergence of powerful 3D parametric modeling tools on the market, most of the efforts to improve functions have been concentrated on adding new functions to those tools. Such new functions are focused on creating CAD models that contain a wealth of detailed data which can be utilized throughout the whole design process.

However, the tools used in the conceptual design phase should be flexible and intuitive. It is important for designers to freely consider and ponder various options without fear of making mistakes because the mistakes made and corrected in this phase will lead to the improvement of the final design.

When using 3D parametric modeling tools, designers are often forced to determine design ideas too early. Therefore, designers prefer using two-dimensional (2D) tools for conceptual design in many cases, namely, they still draw design ideas on sheets of paper or engineering notes.

Although some may think such methods are outdated, they allow anyone to participate in the discussion of design concepts and to generate ideas one after another without fear of making mistakes. The disadvantage of these methods is the difficulties in making modifications to the generated concepts. It is difficult to develop the ideas into better ones based on the feedback from collaborators.

In order to address diverse needs, many designers involved with conceptual design use several types of 2D and 3D tools, which are different from those used in the detailed design phase. Because those CAD tools are not compatible with each other, the reconstruction of models is often required. Recently, new modeling paradigms for conceptual design have been developed that are compatible with each other and have functions for modifying designs easily. Those user-friendly and intuitive tools will help designers to generate concepts quickly and easily.

4. EMBODIMENT OF CONCEPTUAL DESIGN USING 3D CAD

The first step in conceptual design is to extract the requirements for the unit to be designed from product specifications and arrange them. Next, designers develop concepts considering the functionality, durability, maintainability, and cost of the products. The concepts for the unit are turned into concrete ideas mainly by drawing rough sketches.

When concrete ideas about component configuration are provided, it becomes easy to choose the optimum mechanism from among several candidates because the advantages and disadvantages of each mechanism are made clear.

While drawing rough sketches is an excellent technique for conceptual design, it is often necessary to solve the issues of space for arranging the components either before or during the process of the embodiment of concepts. Even if good ideas are generated on how to structure a unit, such ideas cannot be adopted if the unit does not fit in the given space.

When there is a certain mechanism that significantly affects the quality of products, designers may prefer to first design that mechanism and then the peripheral components, so that the peripheral components fit with the mechanism.

However, such a design process may not work in some cases, such as when downsizing is a key requirement for the products. Unless all mechanisms are arranged in a balanced position, 1) the shape of components will be complicated, resulting in an increase in cost, and 2) both the assembling performance and maintainability will be degraded. Even skilled designers often find it difficult to deal with issues of space.

Reworking during the detailed design phase should be avoided especially when the design of products is complicated. It is important for designers to solve the issues of space and to have an image of the complete 3D plans in their mind while they are drawing rough sketches of the concrete ideas of components. 3D CAD can be used for carrying out conceptual design efficiently.

4.1 Drafting plan using 3D CAD

The following is an example of design procedures using 3D CAD.

1) Create a solid model of a space for the unit to be designed using 3D CAD.
2) Create a solid model of a space for each functional block in the unit and assign a space to each functional block.
3) Lay out the rough shape of major components, actuators, and the mechanisms utilized from existing products.
4) This layout does not have to be the final one because it is aimed at checking the available space. However, the configuration of peripheral components should be considered in this layout.
5) Do not make the shape of major components too detailed at this point because the shape of major components will be modified in the later process of arranging peripheral components.
6) Therefore, define the shape of major components to the extent that it is possible to see if all the components will fit in the space.

As above, the visualization of the space for each functional block using 3D CAD will help designers to embody concepts and to adjust the space for adjacent units.

In conceptual design, the best component configuration should be selected from various patterns. Designers often generate options and eliminate unrealistic ones in their mind, and then further narrow the options by drawing rough sketches of prospective ideas. However, even the ideas eliminated in the designers' mind may turn out to be realistic when they are examined using 3D CAD. Also, more ideas will be generated through the visualization of ideas using 3D CAD, and more opinions will be provided by other designers.

Even after the basic component configuration has been determined, there are enormous varieties of arrangement patterns, the order of assembling, and detailed configurations of the components. The effective use of 3D CAD should not be limited to modeling.

4.2 Imaging output when using 3D CAD

It is important to use 3D CAD in an effective way so that it helps designers to develop concepts in the conceptual design phase.

Proper output at proper timing is essential for efficient design processes. Strength analysis by computer-aided engineering (CAE) is an example of output. If strength analysis is performed and problems are found in the latter stage of detailed design when most components have already been designed, the results of analysis can affect not only the analyzed components but also the components placed at the periphery.

To avoid this, it is recommended to perform strength analysis using the concept models of components in the early stage of design so that designers can see whether those components will work well or not, before designing peripheral components. Although it means that a component is subjected to strength analysis several times, reworking can be avoided throughout the design process of the whole unit.

Also, drawings are an output which is as important as 3D plans for designers.

1) Designers should ask themselves whether they have considered the dimension criteria, dimension tolerance, geometric tolerance, and surface treatment of each component while they prepare 3D plans.

2) Designers should also ask themselves whether they tend to prepare 3D plans first and postpone the preparation of drawings in the detailed design phase.

3) If the dimension criteria and dimension tolerance of components have not yet been specified on drawings in the latter stage of the conceptual design phase, or in the detailed design phase, the conceptual design is not yet complete.

Each line in drawings represents a specific intention of the designer. There is no unnecessary line or dimension. Similarly, each surface of a solid in 3D plans represents a specific intention of the designer.

If a product has a structure that requires a number of dimension tolerance values and geometric tolerance values to be specified on drawings, the product cost will increase. Also, if a product has a structure that is largely affected by the dimensional variations of components, it will be difficult to ensure mass production quality.

During the process of detailed 3D design, it is especially important for less experienced designers to realize that the quality of components is guaranteed by drawings, and that the quality of products depends on the component configuration.

When some designers work with the same required specifications, the output may vary from designer to designer because there are a number of design solutions that meet the required specifications. The appropriate use of 3D CAD will help designers to increase the options of design solutions and to select the best one from among those options.

5. INNOVATION OF MACHINE DESIGN PROCESSES IN MANUFACTURING

The following is an example of the ideal design process that we propose for a smooth conceptual design.

5.1 Clarification of required specifications and constraints

(1) Physical understanding of phenomena and

constraints
The expected phenomena are evaluated numerically. For example, in the design of a bipedal robot that walks up and down stairs, the expected phenomenon is that the robot lifts one foot high enough before it touches the next step on the stairs, moves it forward, and then lowers it to the surface of the next step while the other foot is still on the previous step.

(2) Quantification of required specifications
Required specifications are converted to quantitative design values. For example, 1) if an abstract requirement is "a bipedal robot that maintains its posture even if its batteries run out", 2) the concrete expression which can be converted to quantitative design values is "a bipedal robot with its intersection of the perpendicular line from the center of gravity with the ground plane always within the ground contact area of the foot while it is walking".

5.2 Examination of design specifications

(1) Design of concepts
The goals for the machine to be designed are specified by considering the "works" (the intended objects of the movement of the machine), the intended movement, and the range of use. It is recommended that the goals be specified according to 5W1H questions (when, where, who, what, why, and how) so that no necessary goals are missed or duplicated. Note that specific names should not be used at this point.

(2) Clarification and prioritization of design specification items
The following have to be clarified in this step; 1) the parts for which the conditions for the "works" (processing speed, position, number of objects, and acceleration rate) must be specified; 2) the parts for which intended movement (position, resolution, turning radius, and pressure) must be specified; 3) the parts for which the range of use (user, installation site, maintenance, environment of usage, price, mass, and lifetime) must be specified. After listing up all design specification items, the items are then prioritized in the order of closeness to the "works".

(3) Conversion of design specifications into numerical values
Quantitative expressions (for example, "less than ** kg of weight" instead of "as light as possible") should be used for specification items. The basis for the specifications should also be clearly indicated, since this will help designers to understand what needs to be changed when rework occurs.

5.3 Conceptual design

(1) Clarification of necessary functions
The necessary functions are broken down into elements, in the order from the one closest to the "works", to the extent required for the embodiment of concepts. For example, the "works" of the walking function of a robot are its feet and the ground. The walking function is broken down into three components; 1) lifting a foot off and lowering it to the ground, 2) moving a foot forward and backward with respect to the other foot, and 3) shifting the center of gravity while one or both of its feet are on the ground.

(2) Embodiment of concepts
Because most of the intended movement of a machine is periodic movement, timing diagrams of a cycle of movement are prepared for designing the functions which are broken into elements in order to realize the intended movement. For example, the walking function of a bipedal robot is divided into two elements, namely, 1) moving a foot and 2) shifting the center of gravity. To design the first element, a diagram of the absolute displacement between the ground contact surface of a foot and the ground, and a diagram of the relative displacement of the ground contact surface with respect to a reference point on the robot are needed. To design the second element, a diagram of the position coordinates of the center of gravity on the xy-plane and a diagram of the relationship between the shift of the center of gravity and the contact time are needed. Note

that the mechanisms should not be considered first in the preparation of timing diagrams because designers' thinking may be limited by first focusing on the mechanisms.

5.4 Mechanism design

Appropriate mechanisms are selected from existing ones and combined, to realize the timing diagrams. Not only logical thinking but also active information gathering is required in this phase.

5.5 Verification of compliance with required specifications and design specifications

In this phase, designers check whether the design meets the required specifications and the design specifications for the items, such as strength, natural frequency, strain, and weight.

5.6 Preparation of a tree diagram of components

In a tree diagram, the functions to be designed are grouped into blocks and organized into a hierarchical tree structure. The functions are broken into elements, and even into concrete components. During this process, designers prepare a plan drawing and determine the reference plane and the specifications, including dimensions, weight, and materials. Note that the tree diagram should be organized in the order of closeness to the "works".

5.7 Overall review

1) After the completion of each process, it is necessary to make sure that all team members share the information.
2) Because design time is also limited, all team members should agree in advance on the time allocation and the decision making process should controversial issues arise.

6. CONCLUSIONS

In this study, we have 1) confirmed the importance of conceptual design and the usefulness of drawing rough sketches, 2) proposed an effective use of 3D CAD for the embodiment of concepts, and 3) proposed the innovation of machine design process on the basis of the above two points. We hope these proposals will be helpful for designers.

In order for us to switch over to a new design system efficiently, it is necessary to understand where we are now and where we are going. Without accurate recognition of existing techniques and new technologies, we will take the wrong path and waste precious resources. Success without adequate process is worse than failure.

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