Influence of Shape Characteristics on Disassembly Efficiency of Joint Cube Puzzles Depends on Different Situations

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ABSTRACT

Ready-to-assemble (RTA) furniture is favored by consumers because of its convenient transportation and lower price. Its box packaging can reduce transportation costs, reduce the risk of damage in the process of transportation, and has greater flexibility in sales. At the same time, it provides conditions for customers to assemble furniture by themselves, making the assembly work easier. In recent years, the demand for RTA furniture has grown worldwide. Due to the COVID-19 pandemic, the trend of working from home has skyrocketed, which has increased the demand for space-saving home office furniture in modular form. With the rapid development of economy and the rhythm of life is accelerating, people's demand for products has become much clear. Most people don't want to spend too much time on thinking about how to use a complex product. For people who move frequently and have busy schedules, time savings and affordability are important factors in choosing a product. Therefore, RTA Furniture is a good choice for them.

Compared with traditional furniture, RTA Furniture has simpler structure and fewer parts. Because of the seemingly simple structure and components, assembly and disassembly errors often occur. In the assembly process, people can refer to the instructional guides or use virtual reality (VR) system to avoid errors. Or use instructions manual to learn how to assemble.

However, the disassembly process is usually without any hint, which requires users to use their own spatial abilities and understanding. Unlike assembly, disassembly

is often easily overlooked. Especially when moving, people are often faced with a large number of items that need to be disassembled. As users' spatial abilities and understanding vary, the time taken for disassembly and the number of errors will be different. It is important to consider how to improve the efficiency of disassembly. Therefore, it is necessary to consider how to improve the efficiency of disassembly. Both cube puzzles and RTA furniture have similar shape characteristics. It is precisely because of these similar shape characteristics that people get easily confused when an error occurs in the disassembly process. Therefore, the author studied the cube puzzles.

Many studies have found that the existence of shape characteristics will affect the efficiency of assembly. However, there are no discussions on the disassembly of cube puzzles.

The purpose of this study is to determine whether the shape characteristics affect the difficulty for users during disassembly, that is, whether shape characteristics have an effect on disassembly efficiency. It aims to find a method that under limited conditions can improve disassembly efficiency.

In order to verify whether the presence of shape characteristics the disassembly efficiency, the author conducted a disassembly process experiment with seven different types of joint cube puzzles (marked Types A, B, C, A1, A2, D and D1). The experiment was divided into three groups with a total of 56 participants from different countries. The author used video recordings to observe the time spent by the participants in disassembling the joint cube puzzles and the number of errors and analyzed the data.

The three joint cube puzzles (marked Types A, B and C) for Experiment 1 were from previous studies. Type A had only vertical straight-line-form characteristics. In Type B had curves appeared. Type C had axial symmetrical triangles and semicircles added on its joints. All three joint cube puzzles could be opened via multiple components at the same time. And these three joint cube puzzles have been validated in previous experiments on assembly, the presence of the shape characteristics can improve the assembly efficiency. The reason for using this set of cube puzzles in Experiment 1 was to know if the presence of the shape characteristics would improve the efficiency of disassembly when using the same set of cube puzzles for disassembly experiments. One-way ANOVA (analysis of variance) was used to analyze the data of experiment 1. The results show that the existence of shape characteristics did not improve the efficiency of the disassembly.

For this reason, a new hypothesis was proposed. If a cube puzzle can only be opened by one part, that is to say, limit one key clue as the starting step of the disassembly task. Do the shape characteristics of the joints have an impact on the disassembly efficiency. New cube puzzles, Types A1 and A2, were developed based on Type A. Type A1 had only vertical straight-line-form characteristics. Type A2 was the same as Type A1, except for a semicircle was added at the joint of the key clue. In Experiment 2, two sets of cubes were compared (Types A and A1, Types A1 and A2). When the cube puzzles were limited to have no shape characteristics added the joints, the disassembly efficiency was compared between the cube puzzle with multiple openings (Type A) and the cube puzzle with only one key clue (Type A1). When the cube puzzles were limited to only one key clue, the disassembly efficiency was compared between the cube puzzle without shape characteristics on the joints (Type A1) and the cube puzzle with shape characteristics added at joint (Type A2) was compared.

Experiment 2 aimed to find whether the shape characteristics had a positive effect on the disassembly under the limited condition. Independent Samples t-test was used to analyze the data of experiment 2. The results show that, when a cube puzzle that could be opened via multiple parts, shape characteristics had no positive effect on disassembly efficiency. However, when a cube puzzle with only one key clue part that was labeled, shape characteristics had a positive effect on disassembly efficiency.

In order to verify whether this conclusion can be applied to other cube puzzles, a new set of cube puzzles (Types D and D1) were developed. The same results as the comparison between Types A1 and A2 in Experiment 2. This can reinforce the findings of Experiment 2.

Through three groups of experiments, it was found that when the cube puzzles were limited to only one key clue, the shape characteristics at the joint of the key clue were more easily noticed. Owing to the shape characteristic, the disassembly interference was reduced.

This study is a basic study and the discovery elements will support to be one of method to disassemble DIY furniture.

CONTENTS

LIST OF PAPERS AND CONFERENCES

Journals

Yimin Wang, Peng Jiang, Takamitsu Tanaka: Influence of Shape Characteristics on Disassembly Efficiency of a Joint Cube Puzzle, Design Research, No.82, 2021

International Conferences

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CHAPTER 1

INTRODUCTION

1.1 Research Background and Objectives

Ready-to-assemble (RTA) furniture has become one of the fastest growing furniture markets in the world. In recent years, RTA furniture has become popular among young people. And the demand for RTA furniture has grown worldwide. Ready-to-assemble (RTA) furniture is favored by consumers because of its convenient transportation and lower price. Its box packaging can reduce transportation costs, reduce the risk of damage in the process of transportation, and has greater flexibility in sales. At the same time, it provides conditions for customers to assemble furniture by themselves, making the assembly work easier.

Due to the COVID-19 pandemic, the trend of working from home has skyrocketed, which has increased the demand for space-saving home office furniture in modular form. With the rapid development of economy and the rhythm of life is accelerating, people's demand for products has become much clear. Most people don't want to spend too much time on thinking about how to use a complex product.

Today's young people are different from the past. Due to the change in their jobs, they rent more frequently. They move more frequently than those who own their own houses[1].

For people who move frequently and have busy schedules, time savings and affordability are important factors in choosing a product. Compared with traditional furniture, RTA Furniture is easier to assemble and disassemble[2]. Therefore, RTA Furniture is a good choice for them.

Ease to assembly and disassembly is an important consideration for users of furniture. Easy assembly and disassembly can significantly improve the efficiency of the users to assemble and disassemble the furniture, thus increasing user satisfaction. In the prevalent era of online shopping, users can check the detailed description of the products on various websites as well as reviews to determine whether to buy the product. If the number of bad reviews is high, it will have a negative impact on the user who is considering buying the products and thus discourage the purchase. This is important not only for the users but also for the manufacturer. User satisfaction directly determines whether there are good sales or not. Therefore, improving the portability of assembly and disassembly is important for both users and manufacturers.

According to CSIL's report "The European Market for RTA Furniture", the value of RTA furniture consumption in Europe reached €14 billion in 2015. Overall, the RTA furniture market is (immediately) superior to the "fully assembled" furniture market in Europe as a whole. (The score for the period 2010-2015 was +13%) According to Furniture/Today, 80% of consumers aged 25-34 in each income category purchase RTA furniture. Of these users, 61% stated that the primary reason for buying RTA furniture was its lower price; and 82% expressed satisfaction with RTA furniture[3].

The latest report on the Europe (RTA) Furniture market provides an analysis of the market outlook trends for the period 2017-2021. RTA furniture is also selling well in

Europe due to lower prices. Also, the global RTA furniture market is expected to grow steadily over the period. Increasing global population and increasing demand for space utilization has also led to continuous growth in the sales of RTA furniture[4-5].

On the other hand, the advantages of RTA furniture over traditional furniture are obvious. RTA Furniture is more robust and easy to assemble. Due to the lower price of transportation and manufacturing, customer demand continues to increase [6]. Due to the growing trend of small pitch apartments, consumers are in greater need of furniture that is easy to assemble and disassemble. RTA furniture is characterized by its simple construction and lower number of parts. The simplicity and similarity of parts reduce assembly costs and avoids the waste associated with a small number of parts. And it can be made up of a limited number of pieces of furniture[7]. Its scope of application is broader than that of traditional whole furniture[8].

There are many furniture related products need to be assembled and disassembled in life. For example, beds, cabinets, sofas, bookshelves, computer desks, toys, outdoor items, dining tables, and much more. When the user is ready to assemble, the proper assembly procedure will be to sort the parts of all the items and take out the instruction manual. The instruction manual will usually indicate the order and method of assembly of the various parts of the product, with diagrams for reference. The user follows the steps explained in the instruction manual to assemble.

Designers often prefer to rely on product manuals to guide users through the product. But most people are lazy. Manuals often contain a lot of technical vocabulary or text that is too long, and users are often confused by that vocabulary and get bored.

At the end of a busy day, they don't want to do something as time-consuming and laborious as reading a manual. Think that most of the rules of use can be understood by common sense.

For saving time, they prefer to try to assemble the product directly based on their understanding of the product. When they rush to assemble the product, it is easy to make mistakes. For example, they may mix up parts with similar shapes or sizes, or they may make a mistake and damage the parts, causing unnecessary damage. In this case, the wrong parts need to be disassembled and reassembled. When an assembly error occurs, you will often carefully study the details of the instructions until the assembly is completed correctly. When an assembly error occurs, it is frustrating and irritating to check the cause of the error and reassemble until the assembly is complete.

In case of assembly errors, people can refer to the manual or use virtual reality (VR) systems to make it easier[9]. However, when disassembling, there is also the problem that similarly shaped or similarly sized parts may cause disassembly errors, which is easy to be ignored. Repeated errors can cause negative emotions, attention to detail and anxious [10-11]. In this case, people should try to disassemble the parts by trial and error. If errors continue to occur, it will be necessary to try again and again. This makes it more difficult to use. In this case, it is necessary to improve the efficiency of disassembly to increase the user's satisfaction and comfort with the product.

When people move, to reduce costs and save time, they often need to disassemble furniture and transport as few times as possible. And the impact of the disassembly process on product design is a recognized fact. It affects recycling, maintenance, repair, and reuse of components and materials[12]. Disassembly is a prerequisite for the reuse of items. Therefore, from the planning stage of product design, disassembly also needs to be evaluated to ensure that products are designed with beneficial disassembly properties, are environmentally friendly, and are not difficult to recycle, promoting recycling[13]. However, when products are not known about product construction and how to assemble or disassemble a product, they can be easily damaged if forced blindly[14]. This results in reduced product usage. It also wastes resources. Therefore, improving the efficiency of assembly and disassembly is very important for product design.

To this end, it is first necessary to discuss what causes affect the efficiency of assembly and disassembly.

Mortise-and-tenon joinery is a traditional interlocking joining technique used in a wide variety of designs, such as architecture, furniture, and toys. Such as architecture, furniture, toys, etc. Widely recognized for its versatility and reduced labor costs. Easy to assemble and disassemble[15-17]. The structural features of the protruding and recessed portions of its joints can also be used as a seismic design, which helps to resist lateral movement and horizontal compressive stresses due to earthquakes[18]. The method of interlocking technique can make a beneficial contribution to the design of smooth construction joints, among which the material links smoothly. By doing so, the aesthetic value of architecture is no longer affected by connection. This method will also be more effective in using materials and improving building speed[19]. Such structures are also often found in the design of children's toys and furniture. Interlocking joints are often designed as simple structures because of the need for easy assembly and disassembly. It also reduces wear and tear on the joints. This makes them more practical[20].

Due to joint cube puzzles and RTA furniture have similar characteristics: simple construction, similar part shapes, and a smaller number of parts. These characteristics also lead to user confusion and susceptibility to assembly or disassembly errors when assembling and disassembling. Therefore, the author used joint cube puzzle as a research object.

Basic considerations need to be discussed first before the research methodology can be clarified. Disassembly can be made more efficient if it is considered in advance at the product design stage. And existing research has established Disassembly by Design (DFD) guidelines designed to provide product designers with advice on various design considerations that may be incorporated into designs that can be disassembled with assistance[21].

A method for designing disassembled products was proposed. Applying the fundamentals associated with task analysis and motion time measurement to the disassembly of several different consumer products can save significant time. It facilitates the disassembly of end-of-life products and maximizes the use of materials in the supply chain at the lowest environmental cost[22].

An interactive system can also be used in disassembly designs. The time taken for disassembly is used as an indicator to calculate the efficiency of each design using Motion Time Measurement (MTM). It can improve the efficiency of the designer's design solution. Also, multiple design solutions can be provided based on the customer's design preferences[23].

Related research has found that shape, color, and size can provide clues for assembly and disassembly with limited visual information. This can influence the user's design imagination. When color and size information is limited, shape can provide effective clues or be considered as the only key clue[24].

This study focuses on whether shape has a positive effect on disassembly efficiency when limiting color and size to quantitative.

The existence of similar shape has been proved to be one of the reasons that affect the efficiency of assembly and disassembly. Designers should consider these minor changes [25].

Factors affecting assembly have been explored in detail in studies related to "ease of assembly" and "user assembly errors". In the study of the effect of variables on joint cube puzzles difficulty, four key variables, "positive space", "negative space", "open form" and "closed form", were used. This has been shown to affect the difficulty of the joint cube puzzles[26].

Besides, the presence of shape characteristic at the joints in cube puzzles can affect the efficiency of the cube puzzles assembly. It has been found that when only vertical straight-line shape characteristics are present in a cube puzzle, the efficiency of assembly can be improved if shape changes are added as guiding cues at the joints of the cube puzzles. In other words, the presence of shape characteristic at the joints has a positive effect on the assembly of the cube puzzle. Cube puzzles take less time to complete assembly and the number of errors in the assembly process is significantly reduced[27-29].

However, the disassembly of joint cube puzzles has not been discussed yet. Therefore, this study is a new study on the disassembly of joint cube puzzles. In order to avoid inefficient operations and overuse of materials, increasing the disassembly efficiency can be considered as one of the important steps to extend the product life. Reducing the disassembly time and associated costs will increase the economic feasibility of extending the product life[30].

The purpose of this study is to determine whether the presence of shape characteristics added at the joints affects the efficiency of the joint cube puzzles when it is being disassembled. Whether the addition of shape characteristics to the joints has a positive effect on the disassembly efficiency. The purpose of this study was to find a method that would maximize the efficiency of disassembly under limited conditions.

In this study, we first used three different shape variations of the previously studied joint cube puzzle. They are labeled Type A, B, and C. Their volumes, dimensions, and colors are identical. Type A has only vertical linear features. curves are present in Type B. Type C incorporates axially symmetrical triangles and semicircles in its joints. All three types of jointed cube puzzles can be opened by multiple parts at the same time. The number of parts is equal, all five pieces. The three joint cube puzzles have been proven in previous assembly experiments that the presence of shape features can improve assembly efficiency. This was reflected in the fact that cube puzzles with shape features take less time to complete the assembly and make fewer errors when assembled.

Therefore, it was believed that the presence of shape features has a positive effect on assembly.

In order to know whether the presence of shape characteristics improves the efficiency of disassembly when using the same set of cube puzzles for disassembly experiments. The three cube puzzles were subjected to disassembly experiments. The data will be counted and analyzed.

Here, the author made two hypotheses. Hypothesis one, the presence of shape characteristics has a positive effect on disassembly, i.e., the presence of shape features can improve the efficiency of disassembly. Hypothesis two, the presence of shape characteristics has no positive effect on disassembly, i.e., the presence of shape characteristics does not affect the improvement of disassembly efficiency. In the case where hypothesis two holds, it will be necessary to develop a new cube puzzle with some new designs and adjustments to its structure to continue the discussion of the effect of shape characteristics on the disassembly efficiency.

1.2 Thesis Overview

Based on the above background, this study aims to determine whether the addition of shape characteristics at the joints affects the efficiency of the joint cube puzzle during disassembly. Whether the addition of the joint shape characteristics has a positive effect on the efficiency of disassembly. To find a way to maximize the disassembly efficiency under limited conditions. We hope that this research can be applied to future furniture construction designs and improve the efficiency of furniture disassembly for consumer convenience.

Chapter 1 Introduction:

This chapter introduced the background of this paper and describes the originality and novelty of this study based on the existing knowledge.

Chapter 2 Literature Review:

This chapter presented research related to disassembly design. It included the existing methods of disassembly design. By analyzing and discussing the previous knowledge, the methodology and objectives of this research were identified.

Chapter 3 Research Methodology & Experiments and Results:

This chapter highlights the research methods used in this study as well as the detailed experiments.

In order to verify whether the presence of shape characteristics the disassembly efficiency, the author conducted a disassembly process experiment with seven different types of joint cube puzzles (marked Types A, B, C, A1, A2, D and D1). The experiment was divided into three groups with a total of 56 participants from different countries. The author used video recordings to observe the time spent by the participants in disassembling the joint cube puzzles and the number of errors and analyzed the data.

The three joint cube puzzles (marked Types A, B and C) for Experiment 1 were from previous studies. Type A had only vertical straight-line-form characteristics. In Type B had curves appeared. Type C had axial symmetrical triangles and semicircles added on its joints. All three joint cube puzzles could be opened via multiple components at the same time. And these three joint cube puzzles have been validated in previous experiments on assembly, the presence of the shape characteristics can improve the assembly efficiency. The reason for using this set of cube puzzles in Experiment 1 was to know, if the presence of the shape characteristics would improve the efficiency of disassembly when using the same set of cube puzzles for disassembly experiments. One-way ANOVA (analysis of variance) was used to analyze the data of experiment 1. The results show that the existence of shape characteristics did not improve the efficiency of the disassembly.

For this reason, a new hypothesis was proposed. If a cube puzzle can only be opened by one part, that is to say, limit one key clue as the starting step of the disassembly task. Do the shape characteristics of the joints have an impact on the disassembly efficiency. New cube puzzles, Types A1 and A2, were developed based on Type A. Type A1 had only vertical straight-line-form characteristics. Type A2 was the same as Type A1, except for a semicircle was added at the joint of the key clue. In Experiment 2, two sets of cubes were compared (Types A and A1,Types A1 and A2). When the cube puzzles were limited to have no shape characteristics added the joints, the disassembly efficiency was compared between the cube puzzle with multiple openings (Type A) and the cube puzzle with only one key clue (Type A1). When the cube puzzles were limited to only one key clue, the disassembly efficiency was compared between the cube puzzle without shape characteristics on the joints (Type A1) and the cube puzzle with shape characteristics added at joint (Type A2) was compared.

Experiment 2 aimed to find whether the shape characteristics had a positive effect on the disassembly under the limited condition. Independent Samples t-test was used to analyze the data of experiment 2. The results show that, when a cube puzzle that could be opened via multiple parts, shape characteristics had no positive effect on disassembly efficiency. However, when a cube puzzle with only one key clue part that was labeled, shape characteristics had a positive effect on disassembly efficiency.

In order to verify whether this conclusion can be applied to other cube puzzles, a new set of cube puzzles (Types D and D1) were developed. The same results as the comparison between Types A1 and A2 in Experiment 2. This can reinforce the findings of Experiment 2.

Chapter 4 Analysis and conclusions:

This chapter provided a conclusion and analysis based on the data from the experimental results in Chapter 3. It was found through three sets of experiments that when the cube puzzle was limited to one key clue, the shape characteristics at the key clue connections were more easily noticed. Due to the shape characteristics, the disassembly interference was reduced. Based on this finding, it can be used as a fundamental research to become one of the methods for DIY furniture disassembly.

Chapter 5 Future Work:

This chapter discussed how the methods of this study can be applied to new self-assembled products in the future. In addition, in-depth consideration of the shortcomings was provided to prepare for further design optimization

Appendix:

The appendix of this chapter was divided into appendix A and appendix B

Appendix A: we provide data for each participant in the split experiment.

Appendix B: we provide complete statistical analysis of the three experiments.

1.3 Definition of Terms

We used the following terms in this study:

Shape characteristics: in this study, it represents the shape added at the joint of the cube puzzle, which is different from the vertical straight-line-form characteristics. In addition, the vertical straight-line-form characteristics is considered to be no feature in the cube puzzle.

Key clue: refers to the shape characteristics was added at the joint of the cube puzzles, and this is unique in the cube puzzle. The disassembly task can be used to guide the participants to quickly find clues.

Positive effect: it refers to that the time taken to complete the disassembly task is shorter and the number of errors is less. It is considered that the shape characteristics have a positive effect on the disassembly task and it can improve the disassembly efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction of Chapter 2

In this chapter, the methodology of the study was discussed in the following sections. The prior research was discussed and analyzed to show the novelty of this study. In order to clarify the evaluation criteria in the next steps of the research. The characteristics of the cube puzzles used also be described and classified in detail in this chapter.

2.2. Previous Study

Due to the increase in product categories, furniture and toys are a good challenge for making everyday items[31-32]. Instructions for use provided by the manufacturer are often the key to the usability of the product. And these instructions often use diagrams to show the structure of the product. The instructions remove unnecessary details. Therefore, this kind of information limits the human information processing system. This includes perception and visual reasoning. However, due to the lack of intuitive instructions, the designed instructions are often difficult for users to understand. Therefore, the use of visual instructions can help users easily understand the use of the product[33]. The visual design has been applied in cognitive science and human-computer interaction. Similar methods are also used in the design of an automated roadmap [34-37]. Well designed instructions can use various charts (such as arrows) to effectively convey the structure of the product and the spatial relationship between its components[38]. It can make users pay attention to the part structure and use order [39]. Compared with text, graphics are more indicative of space and operation [40-41].

Related research has found that shape, color, and size can provide clues for assembly and disassembly with limited visual information. This can influence the user's design imagination. When color and size information is limited, shape can provide effective clues or be considered as the only key clue[42].

Factors affecting assembly have been explored in detail in studies related to "ease of assembly" and "user assembly errors". In the study of the effect of variables on joint cube puzzles difficulty, four key variables, "positive space", "negative space", "open form" and "closed form", were used. This has been shown to affect the difficulty of the joint cube puzzles[43].

Besides, the presence of shape characteristic at the joints in cube puzzles can affect the efficiency of the cube puzzles assembly. It has been found that when only vertical straight line shape characteristics are present in a cube puzzle, the efficiency of assembly can be improved if shape changes are added as guiding cues at the joints of the cube puzzles. In other words, the presence of shape characteristic at the joints has a positive effect on the assembly of the cube puzzle. Cube puzzles take less time to complete assembly and the number of errors in the assembly process is significantly reduced[44-46].

2.3. Design of Joint Cube Puzzles

Fig 2.1 showed the three cube puzzles used in the prior study, labeled in this study as Types A, B, and C. In prior research on the presence of shape on assembly efficiency, it has been shown that shape has a positive effect on assembly efficiency, i.e., the presence of shape can improve assembly efficiency.

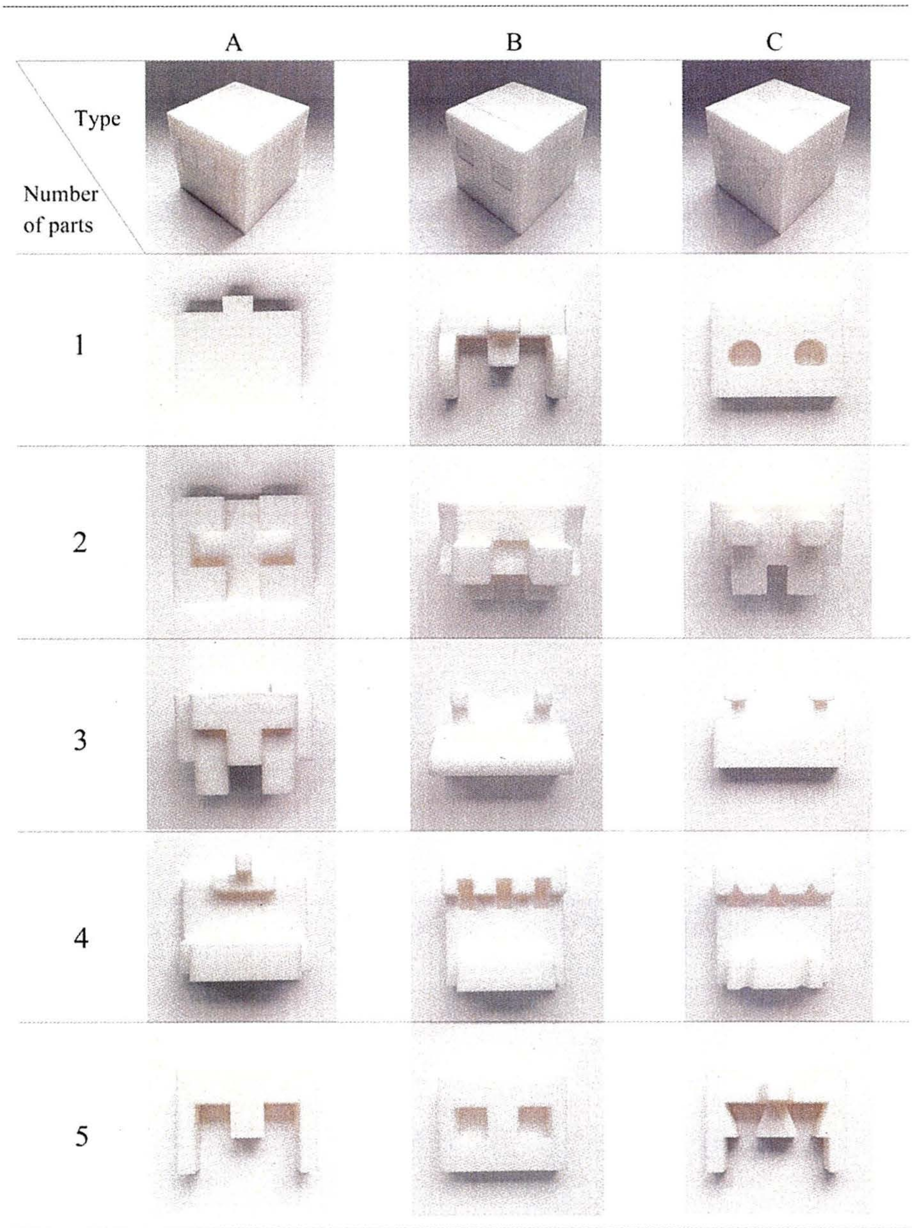


Fig 2.1 Conceptual models in prior research.

Type A had only vertical straight-line-form characteristics.

Type B had curves that appeared.

Type C had axial symmetrical triangles and semicircles added on its joints.

All three joint cube puzzles could be opened via multiple components at the same time. And these three joint cube puzzles have been validated in previous experiments on assembly, the presence of the shape characteristics can improve the assembly efficiency.

The purpose of using this set of cube puzzles is to know whether the existence of shape characteristics will improve the efficiency of disassembly when using the same set of cube puzzles.

This set of cube puzzles were used in Experiment 1.

Fig 2.1 showed new cube puzzles, Types A1 and A2, were developed based on Type A.

Type A1 had only vertical straight-line-form characteristics.

Type A2 was the same as Type A1, except for a semicircle was added at the joint of the key clue.

Types A1 and A2 could not be opened via multiple parts, there was only one key clue part that was labeled. That is to say, when disassembling these two cube puzzles, the key of each cube puzzle must be found before the next operation can be carried out.

The reasons for redeveloping Types A1 and A2 were explained in detail in the next chapter. This set of cube puzzles were used in Experiment 2.

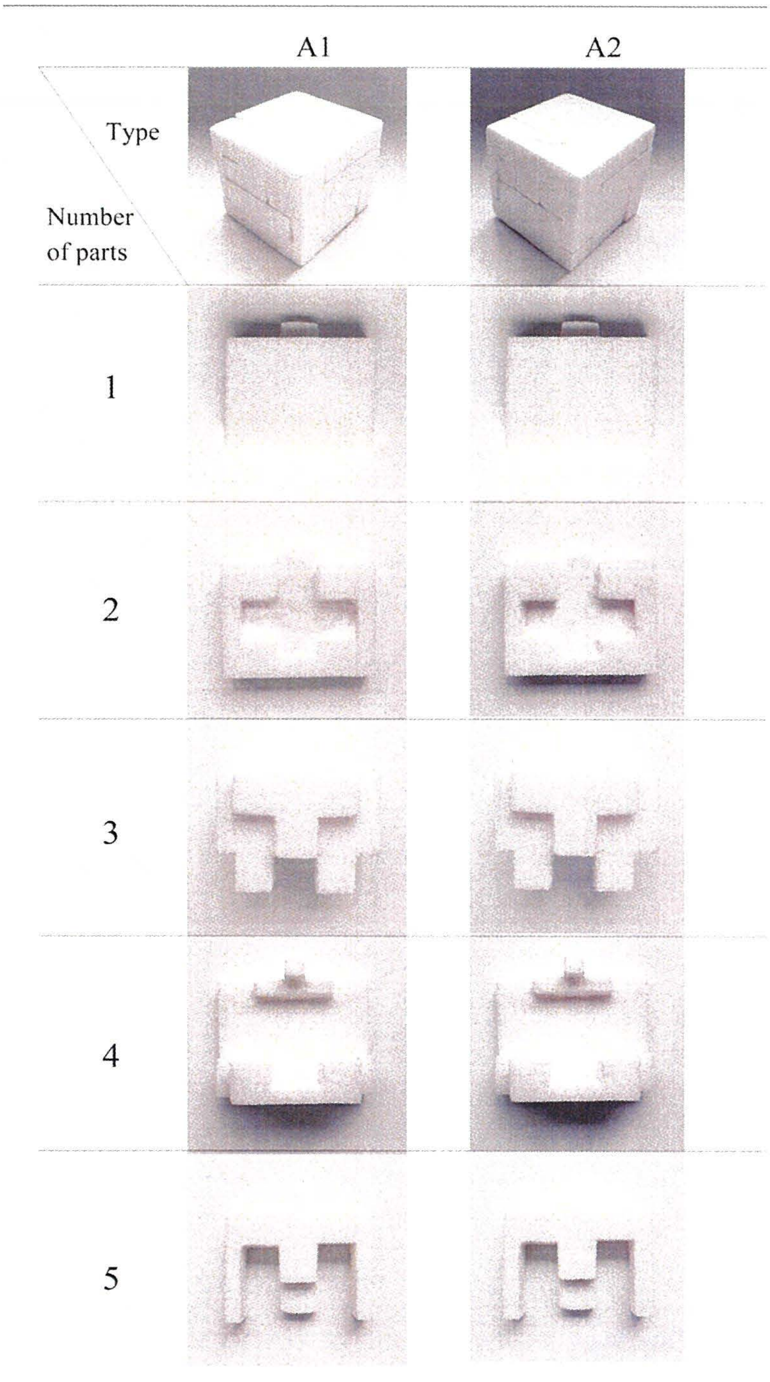


Fig 2.2 Cube puzzles (Types A1 and A2) developed based on Type A.

Fig 2.3 showed a completely new set of cube puzzles, Types D and D1. Type D had only vertical straight-line-form characteristics. Type D1was the same as Type D, except for a semicircle was added at the joint of the key clue.

Types D and D1 could not be opened via multiple parts, there was only one key clue part that was labeled. That is to say, when disassembling these two cube puzzles, the key of each cube puzzle must be found before the next operation can be carried out. Types D and D1 consist of three parts. The reasons for redeveloping Types D and D1 were explained in detail in the next chapter. This set of cube puzzles were used in Experiment 3.

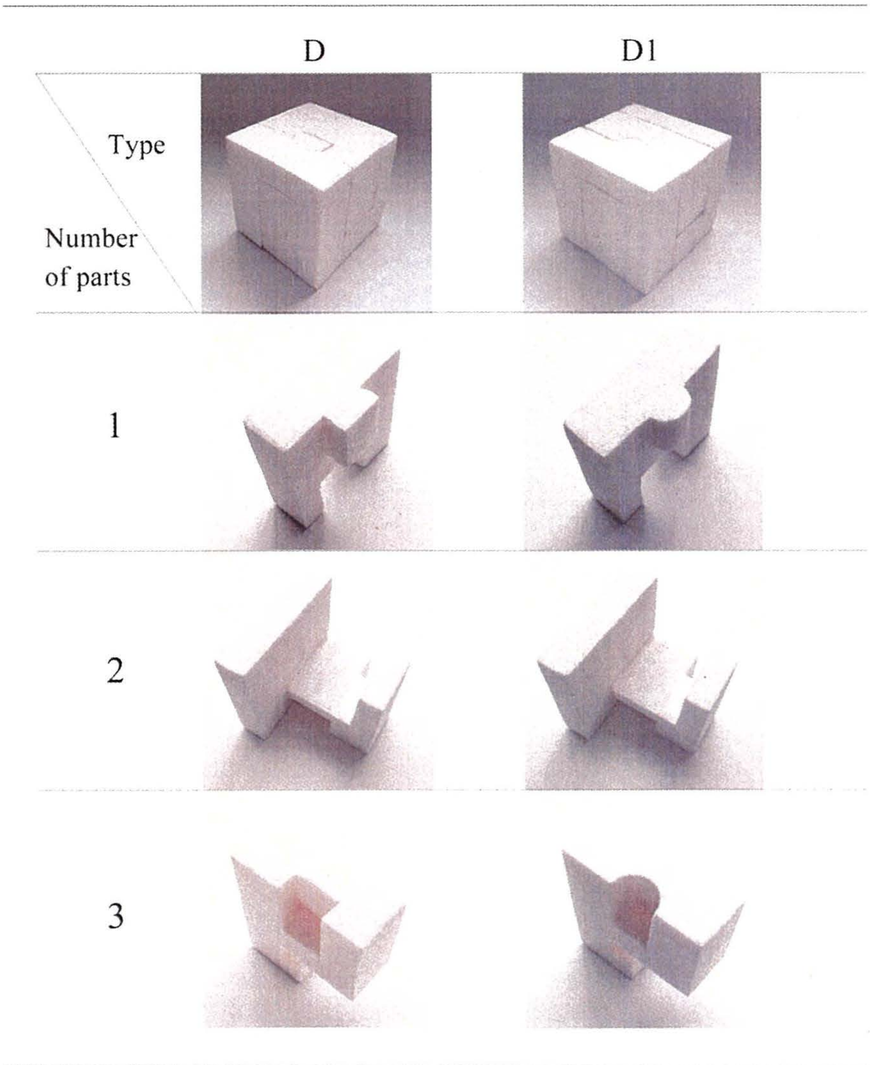


Fig 2.3 Cube puzzles Types D and D1.

CHAPTER 3

RESEARCH METHOD

3.1. Introduction of Chapter 3

In this chapter, the methodology of this study was presented. To verify whether the presence of shape characteristics has a positive effect on disassembly and whether it can improve the efficiency of splitting. Three sets of disassembly experiments were conducted on seven cube puzzles. A total of 56 participants were involved, each eight corresponding to one cube puzzle. The time and the number of errors during the experiment were observed. Compare the characteristics and differences between the cube puzzles used in each set of experiments. The experimental data will be analyzed and counted. Besides, the means of the analysis of the experimental data and the results of the experiment are presented.

The first observation experiment of disassembly was conducted using the three cube puzzles from the prior study. It has been known that the presence of shape characteristics has been shown to have a positive effect on assembly efficiency, i.e., to improve assembly efficiency, when assembling experiments in the prior study. The purpose of using this set of puzzles was to know whether the presence of shape characteristics improves disassembly efficiency when using the same set of puzzles. Therefore, two hypotheses can be put forward.

1: The disassembly of this set of cube puzzles, with the same structure, in which the shape characteristics being added at the joints have a positive effect on disassembly efficiency, i.e., the disassembly efficiency can be improved.

2: On the premise that the structure of this group of cube puzzles remains unchanged, the shape characteristics added at the joints have no positive influence on disassembly efficiency, i.e., it cannot be proved that the disassembly efficiency can be improved.

The discussion is not continued in the case where assumption the first holds. The set of cube puzzles will be redesigned in the case where assumption the second holds. A new set of cube puzzles needs to be developed and the properties of the relationship between the shapes and disassembly discussed.

The hypothesis was verified by the following experiment.

3.2 Experiment 1

3.2.1 Experiment Cube Puzzles

The three joint cube puzzles (Types A, B, and C) for Experiment 1 were from previous studies. And these three joint cube puzzles have been validated in previous experiments on assembly, the presence of the shape characteristics can improve the assembly efficiency.

The reason for using this set of cube puzzles in Experiment 1 was to know if the presence of the shape characteristics would improve the efficiency of disassembly when using the same set of cube puzzles for disassembly experiments.

As described in the previous chapter, Type A had only vertical straight-line-form characteristics. Type B had curves that appeared. Type C had axial symmetrical triangles and semicircles added on its joints. As shown in Figure 3.1, all three joint cube puzzles could be opened via multiple components at the same time. The differences between Types A, B, and C are marked with red lines.

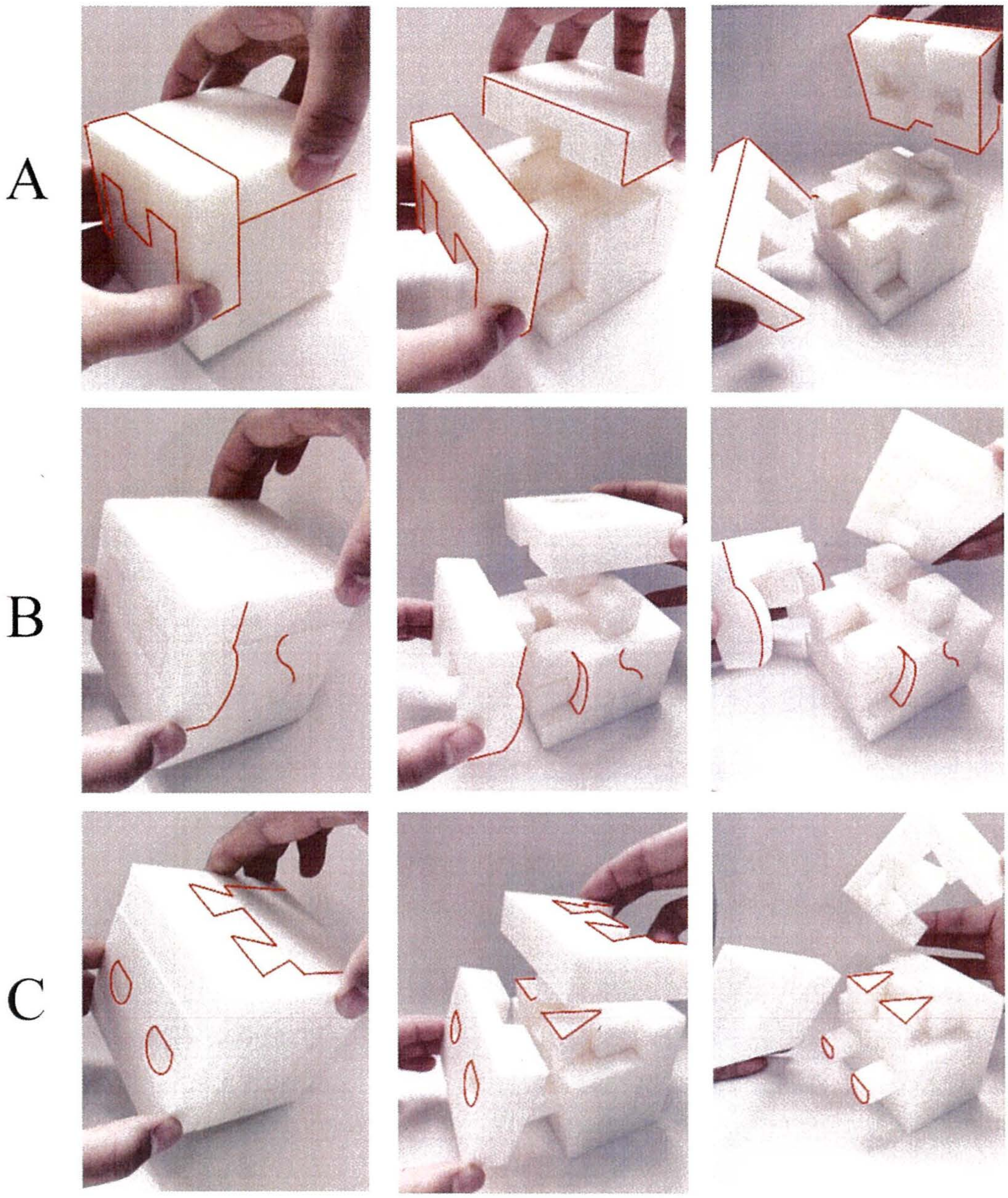


Fig 3.1 Details of Types A, B, and C.

3.2.2 Experiment Procedure

A total of 24 participants participated in Experiment 1. According to the pilot study in Chapter 1, all participants' age was between 25 - 34. Existing research shows that users aged 25-34 prefer to choose RTA furniture that can be assembled freely[47]. Therefore, the age range of the participants was set between 25-34. As shown in Figure 3.2, 3.3, and 3.4, every 8 participants corresponded to one cube puzzle.

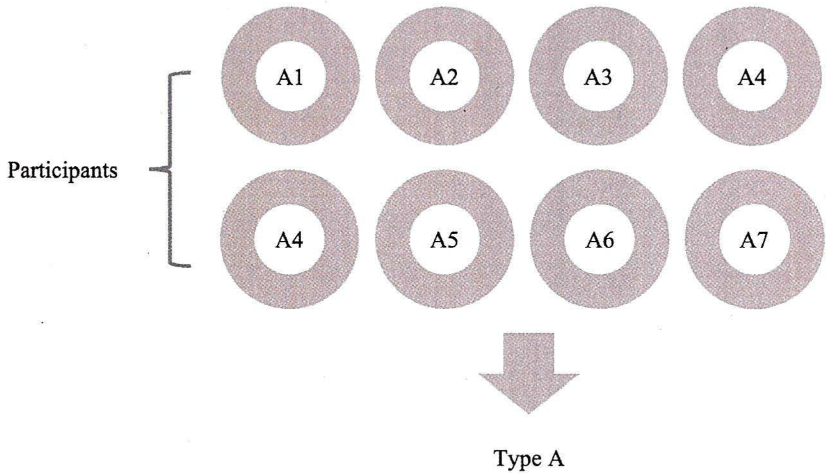


Fig 3.2 Participants of Type A.

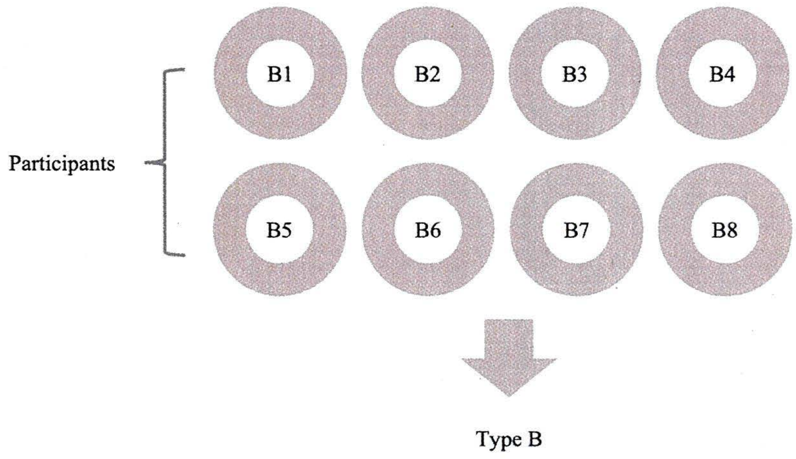


Fig 3.3 Participants of Type B.

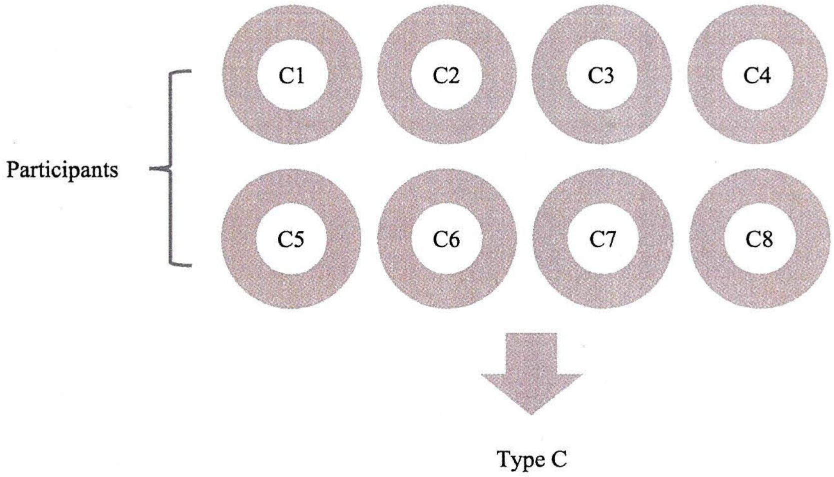


Fig 3.4 Participants of Type C.

The start of disassembly to the completion of the experiment was filmed and recorded. Cube puzzles were placed randomly on the table without prompting prior to the start of the experiment (Figure 3.5). Participants saw the cube puzzle to be dismantled for the first time. After all participants have completed the disassemble experiment, the data will be analyzed and organized.

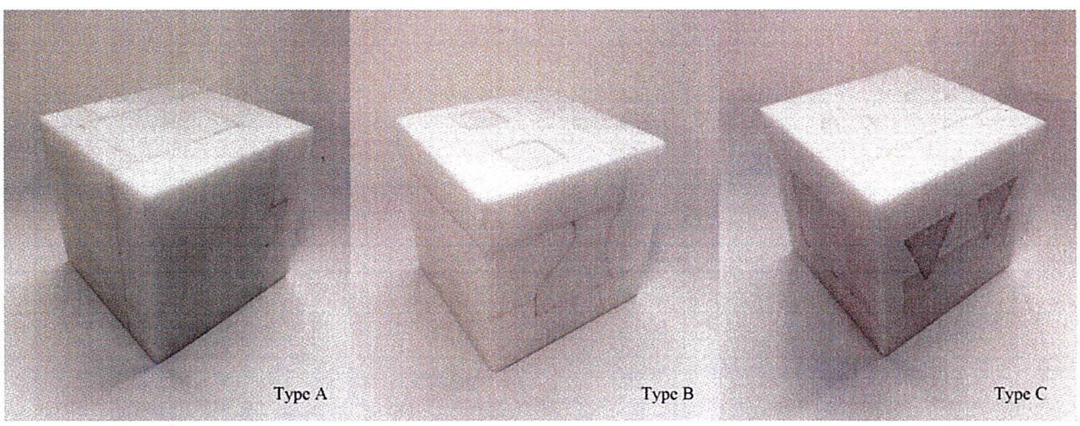


Fig 3.5 Randomly placed cube puzzles Types A, B, and C.

3.2.3 Statistical Analysis

The disassemble experiment was completed and the result statistics was shown in Table 1. The numbers of errors during the experiment and the time duration to complete the disassemble experiment were recorded for the 24 participants.

Table 1. Result of Types A, B, and C

Participants	A1	A2	A3	A4	A5	A6	A7	A8
Time Duration(s)	12	8	10	6	12	14	13	7
Numbers of Errors	0	0	0	0	0	1	0	0
Participants	B1	B2	B3	B4	B5	B6	B7	B8
Time Duration(s)	22	9	21	7	14	17	14	7
Numbers of Errors	1	0	2	0	0	0	0	0
Participants	C1	C2	C3	C4	C5	C6	C7	C8
Time Duration(s)	16	12	24	15	24	17	38	10
Numbers of Errors	0	0	1	0	1	0	2	0

The data were collated, the data were analyzed scientifically using One-way ANOVA (analysis of variance). Whether the presence of a shape characteristics had a positive effect on the disassemble of this set of cube puzzles was determined by the average time and average numbers of errors that participants used to disassemble Type A, B, and C.

3.2.4 Results of Experiment 1

whether there were significant differences in average times and average numbers of errors between Types A, B, and C. The results are as follows (Table 2): The mean difference is significant at the 0.05 level. A statistically significant difference was found in average time [A ($M=10.250$, $SD=2.964$), B ($M=13.880$, $SD=5.915$), C($M=19.500$, $SD=9.008$), ($F(2,21)=4.174$, $p=0.030<.05$)]. However, there were no signifi cant differences in the average numbers of errors [A($M=0.130$, $SD=0.354$), B($M=0.380$, $SD=0.744$) , C ($M=0.500$, $SD=0.756$) , ($F(2,21)=0.700$, $p=0.508>.05$)].

Table 2 One-way ANOVA Analysis for Types A, B, and C

Type A-B-C		N	M(s)	SD	df	F	P-value
Time	A	8	10.250	2.964	2,21	4.174	0.030
	B	8	13.880	5.915			
	C	8	19.500	9.008			
Errors	A	8	0.130	0.354	2,21	0.700	0.508
	B	8	0.380	0.744			
	C	8	0.500	0.756			
N: Number of participants; M: Mean; 2=second(s) ; SD: Standard Deviation; df: degree of freedom; P-value: Significance							

The post hoc test showed (As shown in Table 3), in the "Average Time" section, the mean difference between each Type, the lower and upper bounds of the 95% confidence interval, and the p-values. Multiple comparisons showed that Type C had a significantly higher mean average time than both Types A and B (A-C, p=0.009<.05; B-C, p=0.096<.05), but the difference between the mean average time of Types A and B was not statistically significant (A-B, p=0.274>.05).

Table 3 Post Hoc Tests for Types A, B, and C (in the "Average Time" section)

Post Hoc Tests / Multiple Comparisons					
Dependent Variable: Time					
(I) Type	(J) Type	Mean Difference (I-J)	**P-value**	95% Confidence Interval	
				Lower Bound	Upper Bound
A	B	-3.625	**0.274**	-10.330	3.080
	C	-9.250*	**0.009**	-15.960	-2.540
B	A	3.625	**0.274**	-3.080	10.330
	C	-5.625	**0.096**	-12.330	1.080
C	A	9.250	**0.009**	2.540	15.960
	B	5.625	**0.096**	-1.080	12.330

3.2.5 Discussion of Experiment 1

The analysis of the results revealed that these three cube puzzles of Experiment 1, Type B, and C with curves and shape characteristics added to the joints, were not significantly different from Type A without shape characteristics when they were disassembled. Although shape characteristics were added to the joints of Type B and C, the presence of shape characteristics did not improve the disassembly efficiency. In other words, the presence of shape characteristics had no positive effect on the disassembly. Besides, it was observed that almost every participant started the experiment without overthinking, but subconsciously disassemble the cube puzzles.

Although the average time results showed that disassemble Type B and C took more time than disassemble Type A, there was no significant difference in the average numbers of errors between these three cube puzzles. Therefore, a completely new set of cube puzzles were needed to continue the discussion of the effect of shape characteristics on disassembly.

3.3 Experiment 2

3.3.1 Experiment Cube Puzzles

From the results of Experiment 1, it was learned that Types A, B, and C had no positive effect of shape characteristics on disassembly in the experiment. Types A, B, and C could be opened via multiple components at the same time with no direction limit. Since Type A could be opened via multiple components at the same time with no direction, there are fewer constraints between parts. Constraints can be used as a strong cue to limit the possible actions that can be taken. It can guide actions and simplify interpretation[48]. Therefore, constraints were added to the design of the new cube puzzle. So that the effect of shape characteristics on disassembly efficiency can be observed under constrained conditions.

Experiment 2 will change this structure: the ability to could be opened via multiple components at the same time will instead be restricted to one key cue as the starting step. Unlimited random openings in any direction were not possible. In other words, when disassembled, the key cue must first be found before the next step can be taken. Since Type A has only vertical straight-line form characteristics, only Type A will be continued for discussion and analysis.

Based on Type A, Type A1 and A2 were developed.

Figure 3.6 presented the details and features of Type A and Type A1. As the same as Type A, Type A1 had only vertical straight-line-form characteristics. The parts marked with red and green lines in Type A can be disassembled at the same time or separately, in no particular order. It should be noted that the parts marked with red and green lines in Type A1 correspond to the parts marked with red and green lines in Type A. The part with the red line in Type A1 was the key clue for the start of the disassembly task. This part must be found at the start of the disassembly task before a part marked with a green line or other parts can be disassembled.

A

A1

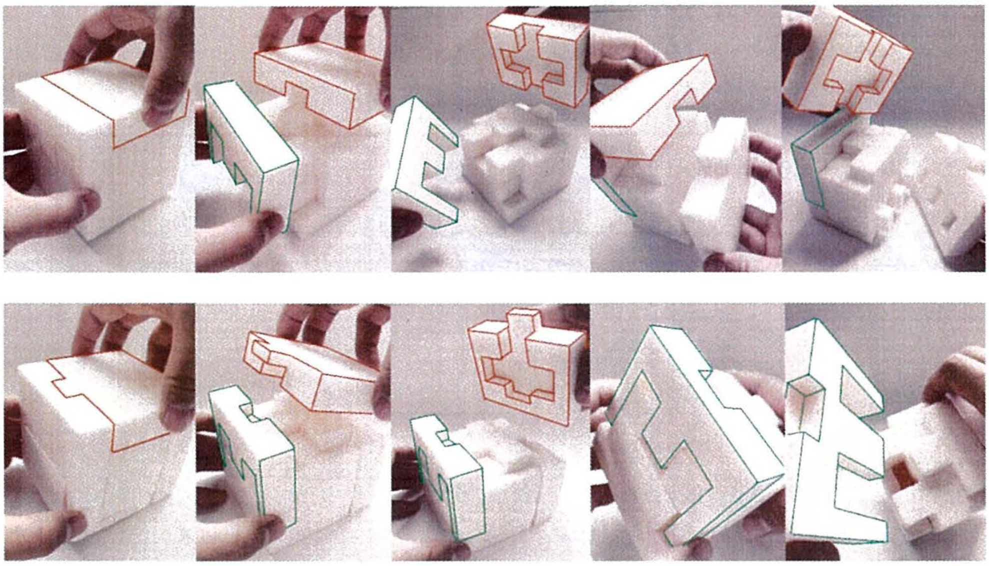


Fig 3.6 Comparison of Types A and A1

Figure 3.7 presented the details and features of Type A1 and Type A2. People can easily perceive symbols with their eyes[49]. Type A2 and type A1 have the same characteristics except for the different shapes added at the key clues. At the joint of the key clue, Type A2 was added with a semicircle shape. The shape of a line was different from that of vertical straight-line-form characteristics. The added semicircle can be used as a symbol different from the vertical straight-line-form characteristics.

It should be noted that the parts marked with red lines in Type A1 correspond to the parts marked with red lines in Type A2. The part with the red line in Type A1 and Type A2 was the key clue for the start of the disassembly task. This part must be found at the start of the disassembly task before other parts can be disassembled.

A1

A2

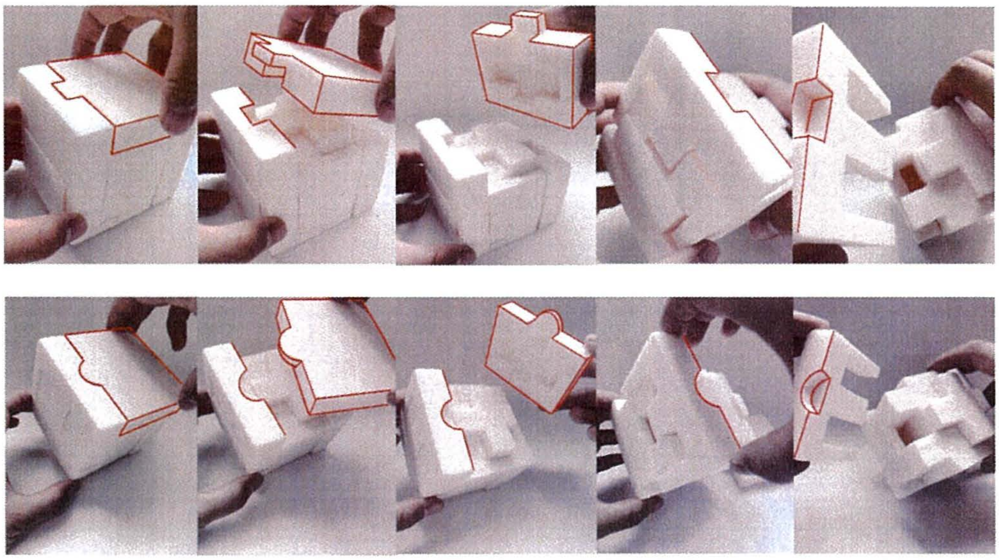


Fig 3.7 Comparison of Types A1 and A2

3.3.2 Experiment Procedure

Since the data of Type A was from Experiment 1, in order to complete the disassembly task of Type A1 and A2, eight new participants aged 25-34 were selected to participate in each task of Experiment 2. As shown in figures 3.8, and 3.9, there was a cube puzzle correspond to every eight participants.

The start of disassembly to the completion of the experiment was filmed and recorded. Cube puzzles were placed randomly on the table without prompting prior to the start of the experiment (Figure 3.10). Participants saw the cube puzzle to be dismantled for the first time. After all participants have completed the disassemble experiment, the data will be analyzed and organized.

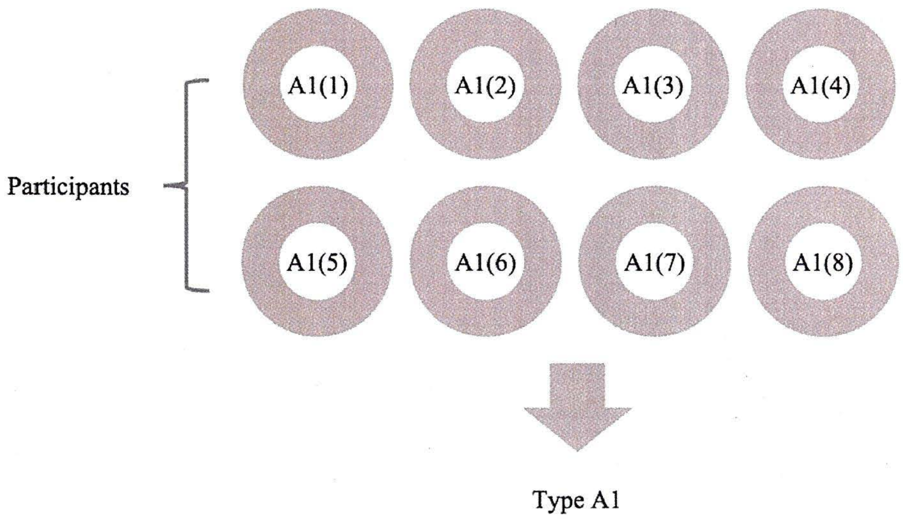


Fig 3.8 Participants of Type A1

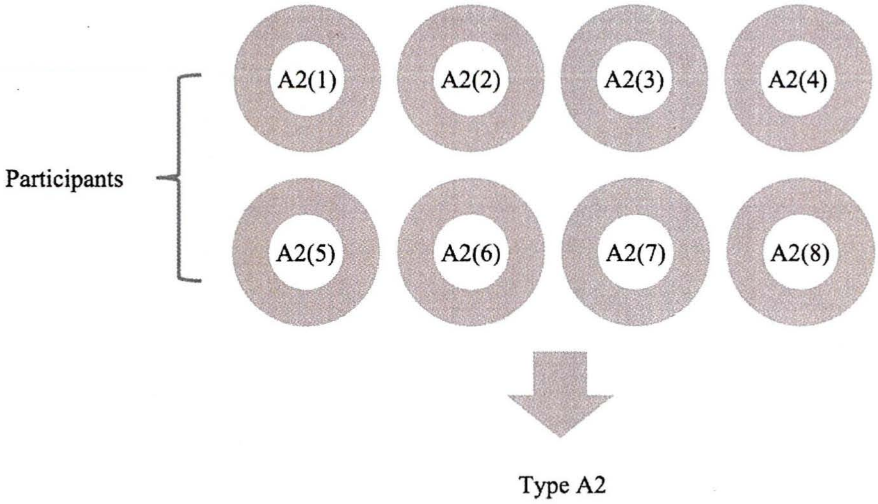


Fig 3.9 Participants of Type A2

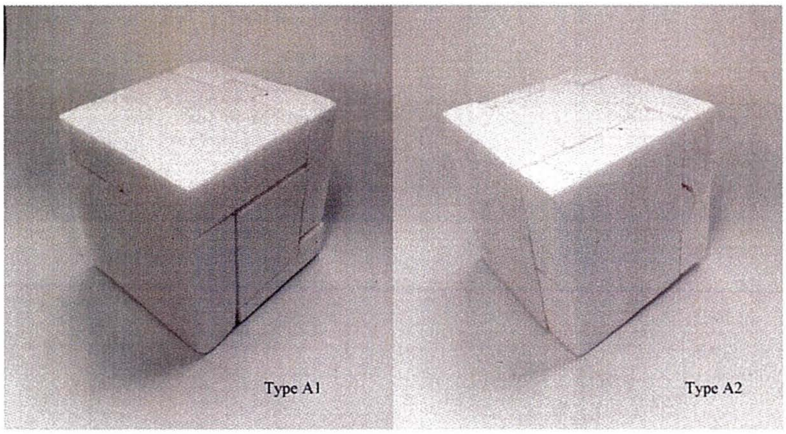


Fig 3.10 Randomly placed cube puzzles Types A1 and A2

3.3.3 Independent Samples Test

The disassemble experiment was completed and the result statistics was shown in Table 4. The numbers of errors during the experiment and the time duration to complete the disassemble experiment were recorded for the 16 participants.

Table 4. Result of Types A1 and A2

Participants	A1(1)	A1(2)	A1(3)	A1(4)	A1(5)	A1(6)	A1(7)	A1(8)
Time Duration(s)	20	15	8	17	9	13	23	15
Numbers of Errors	3	4	3	7	2	2	5	8
Participants	A2(1)	A2(2)	A2(3)	A2(4)	A2(5)	A2(6)	A2(7)	A2(8)
Time Duration(s)	10	5	7	11	9	11	6	14
Numbers of Errors	2	0	0	5	1	3	2	3

The data were collated, the data were analyzed scientifically using Independent Samples t-test. Whether the presence of a shape characteristics had a positive effect on the disassemble of this set of cube puzzles was determined by the average time and average numbers of errors that participants used to disassemble Type A, A1 and A2(the data of Type A was from Experiment 1).

3.3.4 Results of Experiment 2

Types A and A1 were compared.

Comparison 1:

The time taken and number of errors committed during the disassembly of Types

A and A1 were statistically analyzed. An independent samples t-test was conducted to analyze whether a signifi cant difference existed between Types A and A1.

The results are shown in Table 5. The mean difference was set at 0.05. Type A (M=10.250, SD=2.964) that could be opened via multiple components at the same time was compared to Type A1 (M=15.000, SD=5.099) that could be opened with only one key clue. A statistically significant difference was found between Types A and A1 in terms of Average Time (t(14)=-2.278, p=.039). Type A1 (M=4.250, SD=2.252) had a signifi cantly higher mean average number of errors than Type A (M=0.130, SD=0.354), (t(14)=- 5.118, p=0.000). These findings provide evidence that the disassembly efficiency of Type A1 is lower than that of Type A.

Table 5. Independent Samples t-test for Types A and A1

Type A-A1		N	M(s)	SD	t	df	P-value
Time	A	8	10.250	2.964	-2.278	14	0.039
	A1	8	15.000	5.099			
Errors	A	8	0.130	0.354	-5.118	14	0.000
	A1	8	4.250	2.252			
N: Number of participants; M: Mean; 2=second(s) ; SD: Standard Deviation; df: degree of freedom; P-value: Significance							

Types A1 and A2 were compared.

Comparison 2:

The time taken and number of errors committed during the disassembly of Types A1 and A2 were statistically analyzed. An independent samples t-test was conducted to analyze whether a significant difference existed between Types A1 and A2. The results are shown in Table 6. Type A1 (M=15.000, SD=5.099) with only rectilinear shape characteristics was compared to Type A2 (M=9.130, SD=2.997) with a shape characteristic (a semicircle) added at the joint of the key clue part. A statistically significant difference existed between Types A1 and A2 in terms of average time (t(14)=2.810, p=.014), indicating that the average time taken to disassemble Type A1 was signifi cantly higher than that for Type A2. Type A1 (M=4.250, SD=2.252) had a significantly higher mean average number of errors than Type A2 (M=2.000, SD=1.690), (t(14)=2.260, p=.040).

These findings provide evidence that the disassembly efficiency of Type A2 is higher than that of Type A1.

Table 6. Independent Samples t-test for Types A1 and A2

Type A1-A2		N	M(s)	SD	t	df	P-value
Time	A1	8	15.000	5.099	2.810	14	0.014
	A2	8	9.130	2.997			
Errors	A1	8	4.250	2.252	2.260	14	0.040
	A2	8	2.000	1.690			

N: Number of participants; M: Mean; 2=second(s) ; SD: Standard Deviation; df: degree of freedom; P-value: Significance

3.3.5 Discussion of Experiment 2

The analysis of the results revealed that in comparison 1, Type A and A1 have only vertical straight-line-form characteristics. There were no shape characteristics added at the joint of the parts. The difference was that Type A could be opened via multiple components at the same time without direction limitation. Participants can easily disassemble Type A via multiple directions. The participants disassemble Type A for the first time, and obviously did not think too much when disassembling Type A, but subconsciously disassembled it.

Type A1 had only one key clue. As the first step of the disassembly task, the participants must find the part of the key clue before they can continue the disassembly task. Because there was no hint, and the shape characteristics were only vertical straight-line-form characteristics, participants spent more time searching for key clues in the process of disassembly. Therefore, it took more time to disassemble Type A1 than to disassemble Type A. There were also more errors. There was a significant difference between the average time and the average number of errors in the disassembly task.

In comparison 2, both Type A1 and A2 have only one key cue at the start step. There were no shape characteristics added at the joint in Type A1. Type A2 part had a shape characteristics added at the joint: a semicircle. Participants were looking for key clues during both the disassembly of Type A1 and A2. Because the shape characteristics added at the joints of the Type A2 part was different from the vertical straight-line-form characteristics, participants spent less time finding the key cue for Type A2 than for Type A1. There were fewer errors. The average time and the average number of errors in the disassembly task were significantly different between Type A1 and A2. In this case, the presence of shape characteristics had a positive effect on disassembly, i.e., the presence of shape characteristics improved the disassembly efficiency.

3.4 Experiment 3

3.4.1 Experiment Cube Puzzles

The experimental results in the previous chapter showed that the shape characteristics that were added to the joints have a positive effect on the disassembly efficiency when the cube puzzle has only one key cue, i.e., the shape characteristics can improve the disassembly efficiency. To verify whether this conclusion can be applied to other cube puzzles, a whole new set of cube puzzles needs to be developed to continue the discussion.

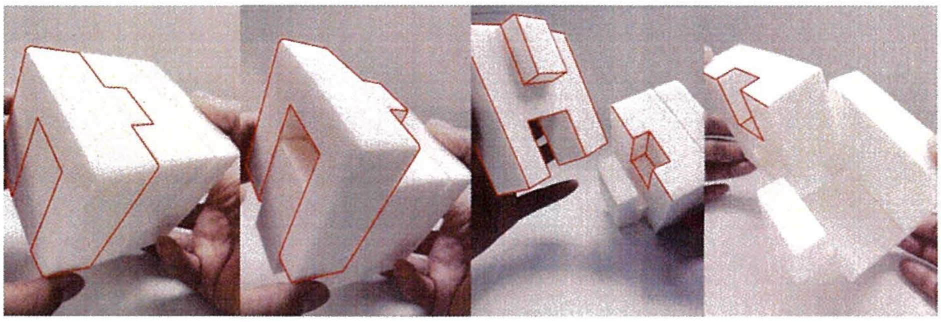
In both Experiments 1 and 2, the number of parts was 5. Therefore, it was necessary to develop a set of cube puzzles with a different number of parts to be verified and discussed again, regardless of whether the cube puzzles used could be opened via multiple components or had only one key clue at the starting step. To make it easier to observe, a group of cube puzzles with less than 5 parts will be developed. And there is only one key clue at the starting step.

Two new cube puzzles have been developed (Types D and D1). Similar to Types A1 and A2, both Types D and D1 have only one key cue at the starting step. There were no shape characteristics added at the joint in Type D. Type D have only vertical straight-line-form. Type D1 part had a shape characteristics added at the joint: a semicircle.

The details of Types D and D1 were compared as shown in figure 3.11. The parts marked with red lines were key cues for the start of the disassembly task.

This part must be found at the start of the disassembly task before other parts can be disassembled. The purpose of experiment 3 was to determine whether the shape characteristics affect the efficiency of a cube puzzle when it is composed of three parts.

D



D1

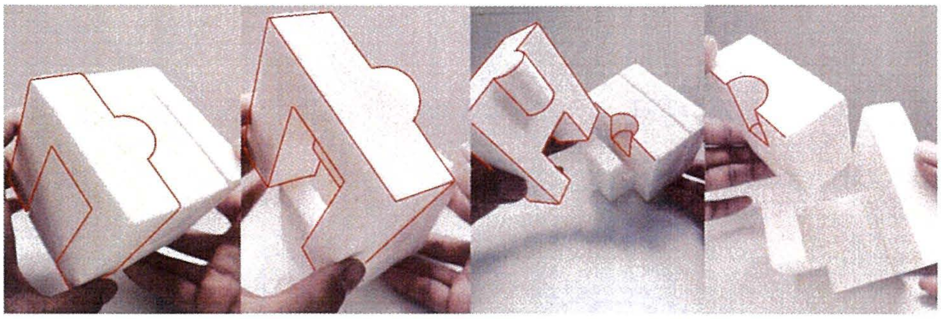


Fig 3.11 Comparison of Types D and D1

3.4.2 Experiment Procedure

To complete the disassembly task of Types D and D1, eight new participants aged 25-34 were selected to participate in each task of Experiment 3. As shown in figures 3.12, and 3.13, there was a cube puzzle correspond to every eight participants.

The start of disassembly to the completion of the experiment was filmed and recorded. Cube puzzles were placed randomly on the table without prompting before the start of the experiment (Figure 3.14). Participants saw the cube puzzle to be dismantled for the first time. When participants have completed the disassemble experiment, the data will be analyzed and organized.

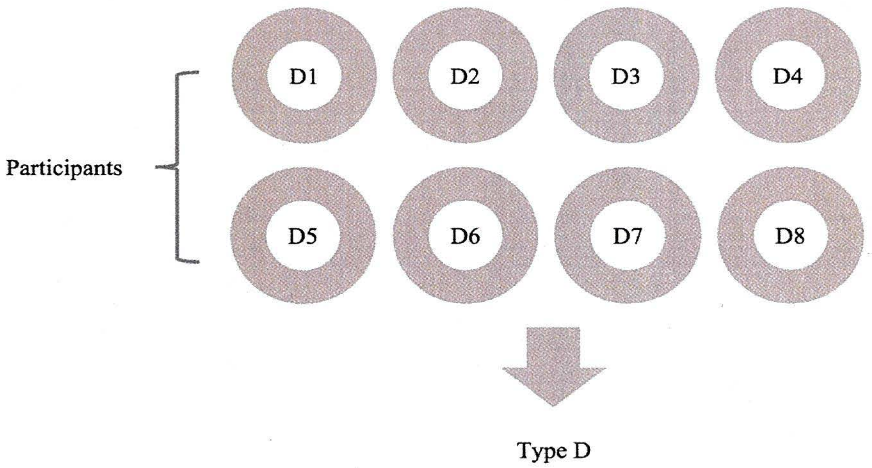


Fig 3.12 Participants of Type D

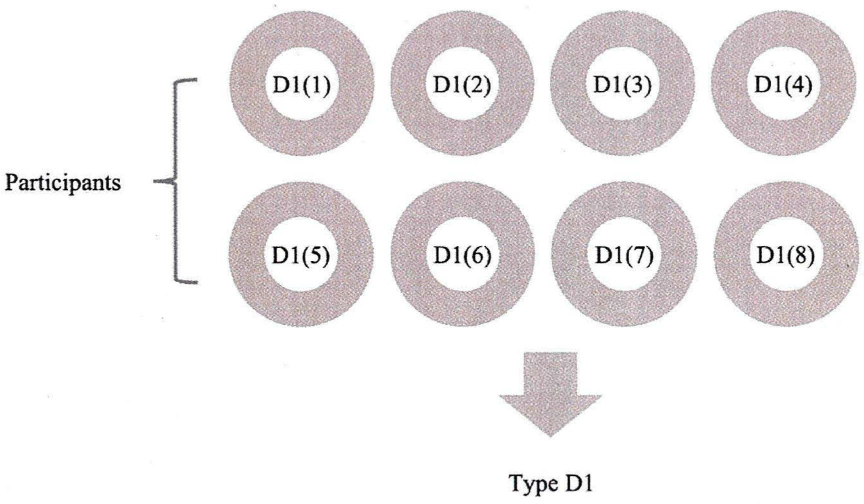


Fig 3.13 Participants of Type D1

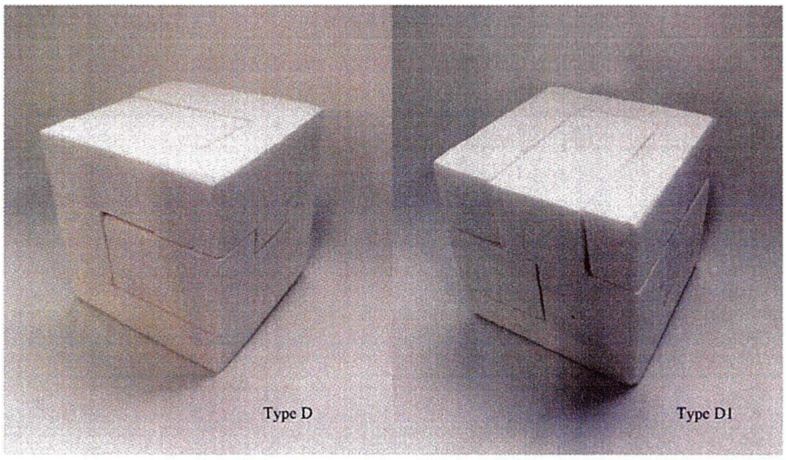


Fig 3.14 Randomly placed cube puzzles Types D and D1

3.4.3 Independent Samples Test

The disassemble experiment was completed and the result statistics was shown in Table 7. The numbers of errors during the experiment and the time duration to complete the disassemble experiment were recorded for the 16 participants.

Table 7. Result of Types D and D1

Participants	D(1)	D(2)	D (3)	D (4)	D (5)	D (6)	D (7)	D (8)
Time Duration(s)	37	30	16	6	8	6	13	13
Numbers of Errors	14	9	6	6	7	2	9	8
Participants	D1(1)	D1(2)	D1(3)	D1 (4)	D1 (5)	D1 (6)	D1 (7)	D1 (8)
Time Duration(s)	4	7	3	5	7	3	9	10
Numbers of Errors	2	2	1	3	1	2	2	4

The data were collated, the data were analyzed scientifically using the Independent Samples t-test. Whether the presence of shape characteristics had a positive effect on the disassemble of this set of cube puzzles was determined by the average time and average numbers of errors that participants used to disassemble Types D and D1.

3.4.4 Results of Experiment 3

The time taken and number of errors committed during the disassembly of Types D and D1 were statistically analyzed. An independent samples t-test was conducted to analyze whether a significant difference existed between Types D and D1. The results are shown in Table 8. Type D (M=16.130, SD=11.457) with only rectilinear shape characteristics was compared to Type D1 (M=6.000, SD=2.673) with a shape characteristic (a semicircle) added at the joint of the key clue part. A statistically significant difference existed between Types D and D1 in terms of average time ($t(14)=2.434$, $p=.029$), indicating that the average time of Type D1 was significantly higher than that of Type D. Moreover, Type D (M=7.630, SD=3.420) had a significantly higher mean average number of errors than Type D1 (M=2.130, SD=0.991), ($t(14)=4.369$, $p=.001$). These findings provide evidence that the disassembly efficiency of Type D1 is higher than that of Type D. In this case, the shape characteristics had a positive effect on the disassembly efficiency, proving that shape characteristics improve efficiency of disassembly.

Table 8. Independent Samples t-test for Types D and D1

Type D-D1		N	M(s)	SD	t	df	P-value
Time	D	8	16.130	11.457	2.434	14	0.029
	D1	8	6.000	2.673			
Errors	D	8	7.630	3.420	4.369	14	0.001
	D1	8	2.130	0.991			
N: Number of participants; M: Mean; 2=second(s) ; SD: Standard Deviation; df: degree of freedom; P-value: Significance							

3.4.5 Discussion of Experiment 3

As the same as Types A1 and A2, both Types D and D1 have only one key cue at the start step. There were no shape characteristics added at the joint in Type D. Type D1 part had a shape characteristics added at the joint: a semicircle. Participants were looking for key clues during both the disassembly of Types D and D1. Because the shape characteristics added at the joints of the Type D1 part was different from the vertical straight-line-form characteristics, participants spent less time finding the key cue for Type D1 than for Type D. There were fewer errors. The average time and the average number of errors in the disassembly task were significantly different between Types D and D1. In this case, the presence of shape characteristics had a positive effect on disassembly, i.e., the presence of shape characteristics improved the disassembly efficiency.

3.5 Conclusion of Chapter 3

In this chapter, the methodology of this study was presented. To verify whether the presence of shape characteristics has a positive effect on disassembly and whether it improves the efficiency of disassembly. Three sets of disassembly experiments were conducted by performing a 7 cube puzzles. The time and number of errors during the experiments were observed.

The results showed that when participants disassembled the cube puzzle that could be opened via multiple parts, although the cube puzzles with shape characteristics took more time to disassemble, the average number of errors was not different. Thus, the shape characteristics had no positive effect on the disassembly effciency. However, when participants disassembled a cube puzzle that had only one key clue part and a shape characteristic on this part, the latter had a positive effect on disassembly effciency, that is, the shape made the disassembly process more effcient.

CHAPTER 4

ANALYSIS AND CONCLUSIONS

4.1 Introduction of Chapter 4

In this chapter, each of the three experiments was be analyzed. The video data from the participants are used to analyze what really caused the difference between the average time and the average number of errors.

4.2 Analysis of Experiments

4.2.1 Analysis of Experiment 1

In order to verify whether the presence of shape characteristics affects the efficiency of the disassembly task under different conditions, seven different cube puzzles were used to perform the disassembly experiment.

Observing the video recordings of the experiment, some common characteristics of the participants during the disassembly experiment were found. Almost all of the participants did not think much about the three cube puzzles when they were disassembling, but did so subconsciously. It was also observed that the participants' hands tended to move from the middle to the both sides of the puzzle when they were disassembling. As shown in Figure 4.1.

Since this set of cube puzzles could be opened via multiple components at the same time with no direction limit and the parts of the cube puzzles were not constrained by each other, they could be easily disassembled from any direction. The number of errors during the disassembly process was very low. Therefore, it was considered to be less difficult in terms of difficulty of disassembly. This can also be considered as the reason why there were significant differences in the average times.

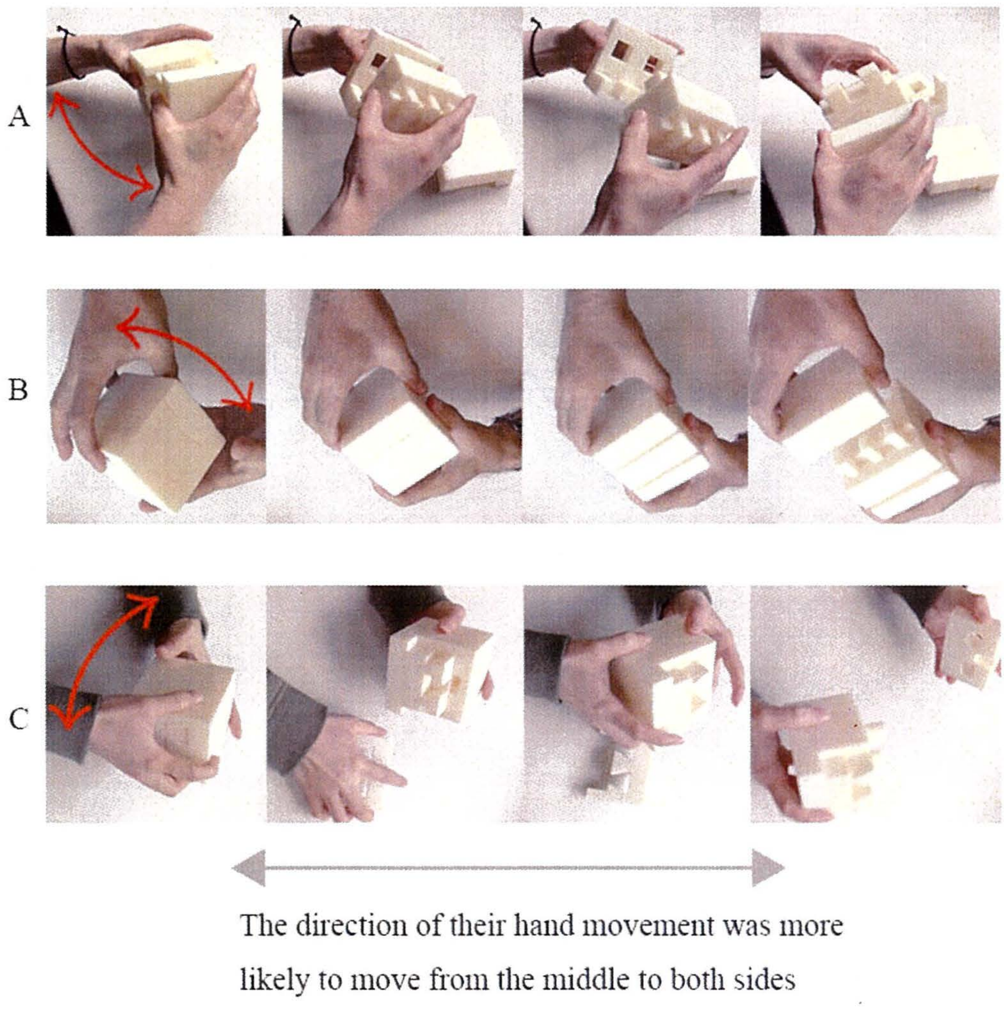


Fig.4.1 Video Capture of The Recording of Types A, B and C

However, when counting the time spent on disassembling this set of cube puzzles, it was found that it took the least time to disassemble Type A, and more time to disassemble Types B and C, which were added shape characteristics at the joints. Since the parts of the cube puzzle were not bound to each other, the difficulty of disassembly was low, and participants invested little time in thinking.

Thus, in the same state of mind, the shape characteristics of the parts added at the joints was a hindrance to the disassembly task. As a result, participants were able to complete the Type A disassembly quickly. Disassemble Types B and C took more time than Type A because they were hindered by the added shape characteristics of the joints. This can be considered the reason why there were significant differences in the average times.

Executing this experiment caused us to notice the potential for similar processes applied to various daily life goods and furniture that could be assembled with dovetail joints or dado joints made of wood or other materials. As shown in Figure 4.2. Different joints can be designed according to different requirements.

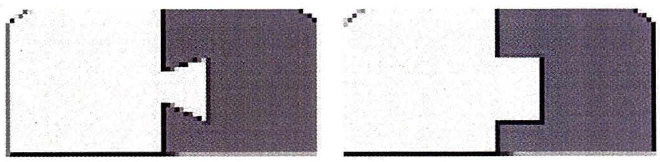


Fig.4.2 Basic Shape of Dovetail Joint and Dado Joint

4.2.2 Analysis of Experiment 2

In Experiment 2, the average time and average numbers of errors for Type A and Type A1, Type A1 and Type A2 were compared.

In the comparison between Type A and Type A1, this was shown in Figure 4.3.

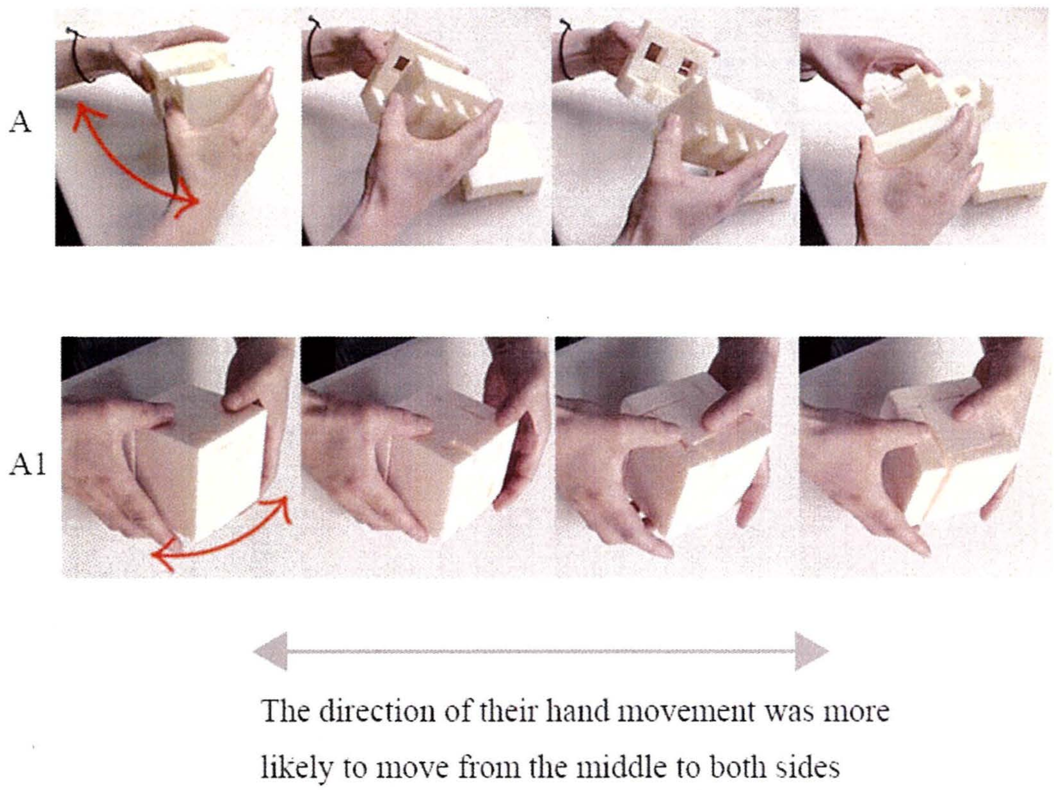


Fig.4.3 Video Capture of The Recording of Types A and A1

Similarly, Almost all of the participants did not think much about the cube puzzles when they were disassembling, but did so subconsciously. It was also observed that the participants' hands tended to move from the middle to the both sides of the puzzle when they were disassembling.

Since Type A could be opened via multiple components at the same time with no direction limit and the parts of the cube puzzle were not constrained by each other, they could be easily disassembled from any direction. The number of errors during the disassembly process was very low. Disassembly task was less difficult.

Type A1 had only one key clue part as the starting step of the disassembly task. The participants had to find the key clue first.

As shown in Figures 4.4, participants repeatedly tried to disassemble Type A1 multiple times without any prompts when disassembling it. Due to the increased disassembly interference, more time was spent on disassembling Type A1 and more errors were occurred. This can be considered the reason why there were significant differences in the average times and average numbers of errors.

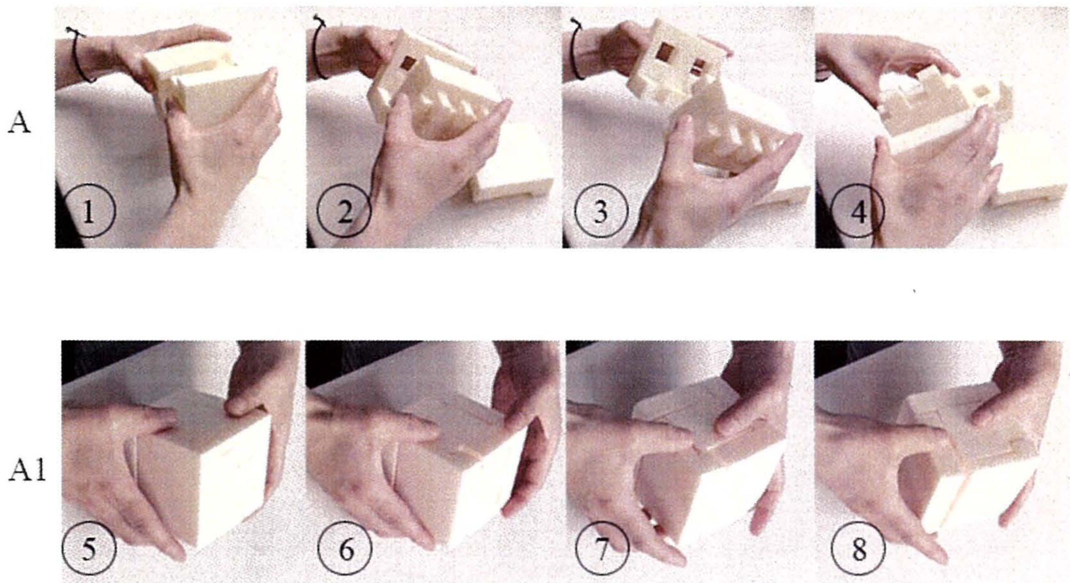


Fig.4.4 Disassembly step comparison for Types A and A1

In the comparison between Type A1 and Type A2, this was shown in Figure 4.5. Similarly, Almost all of the participants did not think much about the cube puzzles when they were disassembling, but did so subconsciously. It was also observed that the participants' hands tended to move from the middle to the both sides of the puzzle when they were disassembling.

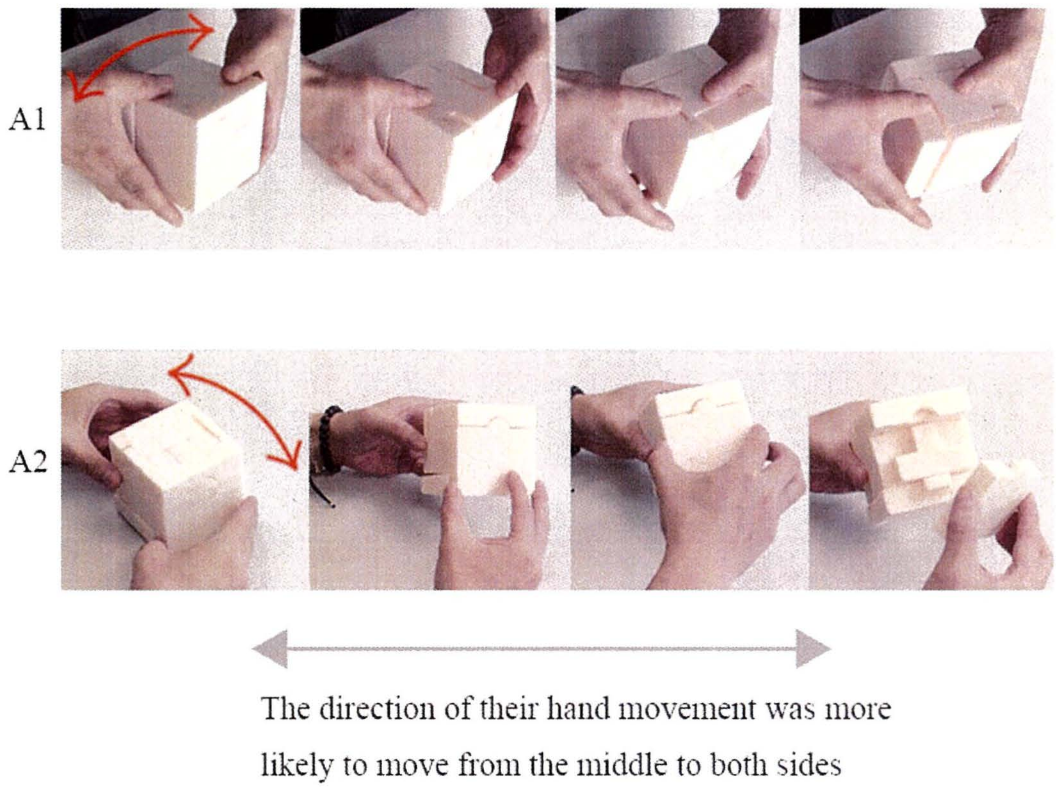


Fig.4.5 Video Capture of The Recording of Types A1 and A2

Both Type A1 and Type A2 had only one key clue part as the starting step of the disassembly task. The participants had to find the key clue first.

There were errors in disassembling both Types A1 and A2. When disassembly errors were occured, participants started to observe the cube puzzles. The shape characteristic at the joint of the key clue in Type A2 were more easily noticed. Owing to this shape characteristic of Type A2, the disassembly interference was reduced.

Therefore, it took less time and fewer errors to disassemble Type A2. As shown in Figures 4.6.

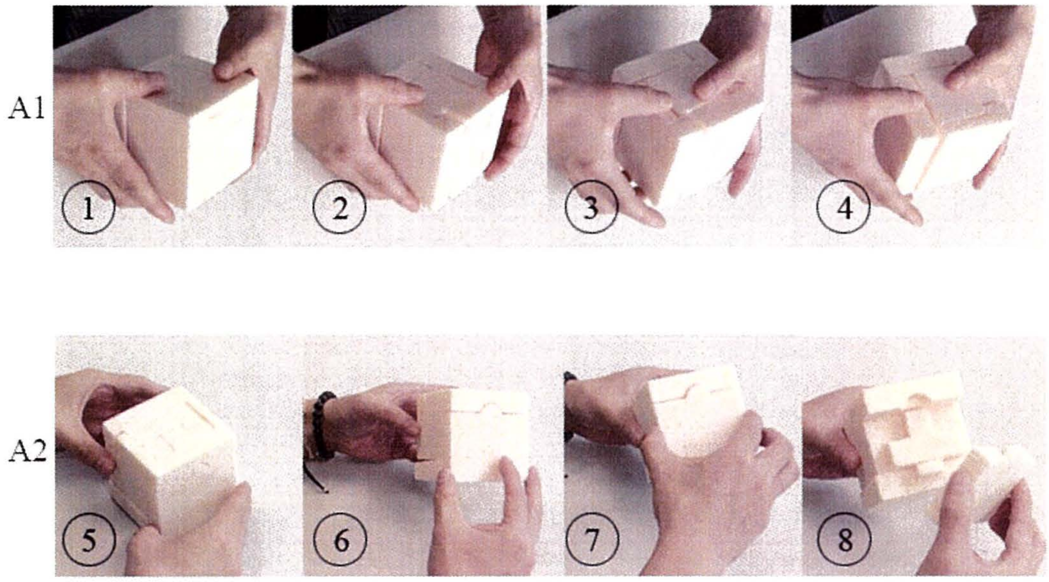


Fig.4.6 Disassembly step comparison for Types A1 and A2

The results showed that when participants disassembled a cube puzzle with only one key clue part that was labeled, it had a positive effect on disassembly efficiency, that is, labeling the first shape to be moved made the disassembly process more efficient.

4.2.3 Analysis of Experiment 3

The experiment 2 showed that the shape characteristics that were added to the joints have a positive effect on the disassembly efficiency when the cube puzzle has only one key cue, i.e., the shape characteristics can improve the disassembly efficiency. To verify whether this conclusion can be applied to other cube puzzles, a whole new set of cube puzzles were developed to continue the discussion in experiment 3.

The average time and average numbers of errors for Types D and D1 were compared.

In the comparison between Types D and D1, this was shown in Figure 4.7. Similarly, Almost all of the participants did not think much about the cube puzzles when they were disassembling, but did so subconsciously. It was also observed that the participants' hands tended to move from the middle to the both sides of the cube puzzle when they were disassembling.

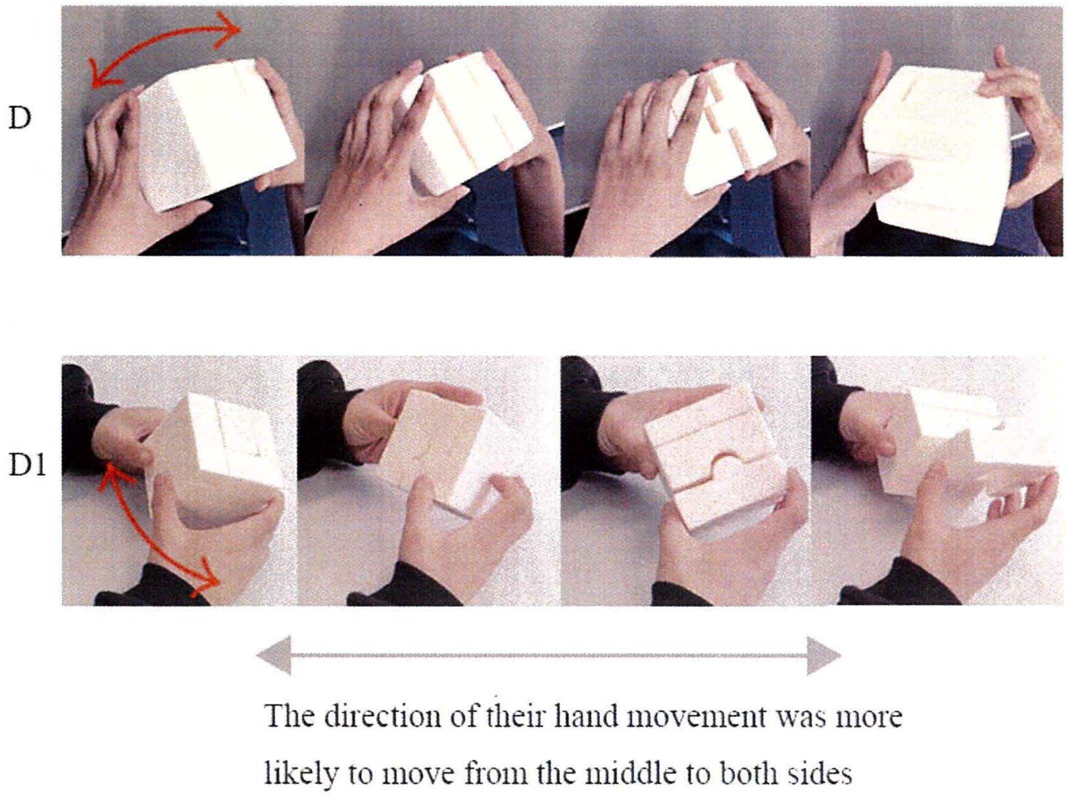


Fig.4.7 Video Capture of The Recording of Types D and D1

Both Types D and D1 had only one key clue part as the starting step of the disassembly task. The participants had to find the key clue first.

There were errors in disassembling both Types D and D1. When disassembly errors were occured, participants started to observe the cube puzzles. The shape characteristic at the joint of the key clue in Type D1 were more easily noticed. Owing to this shape characteristic of Type D1, the disassembly interference was reduced. Therefore, it took less time and fewer errors to disassemble Type D1. As shown in Figures 4. 8.

D

D1

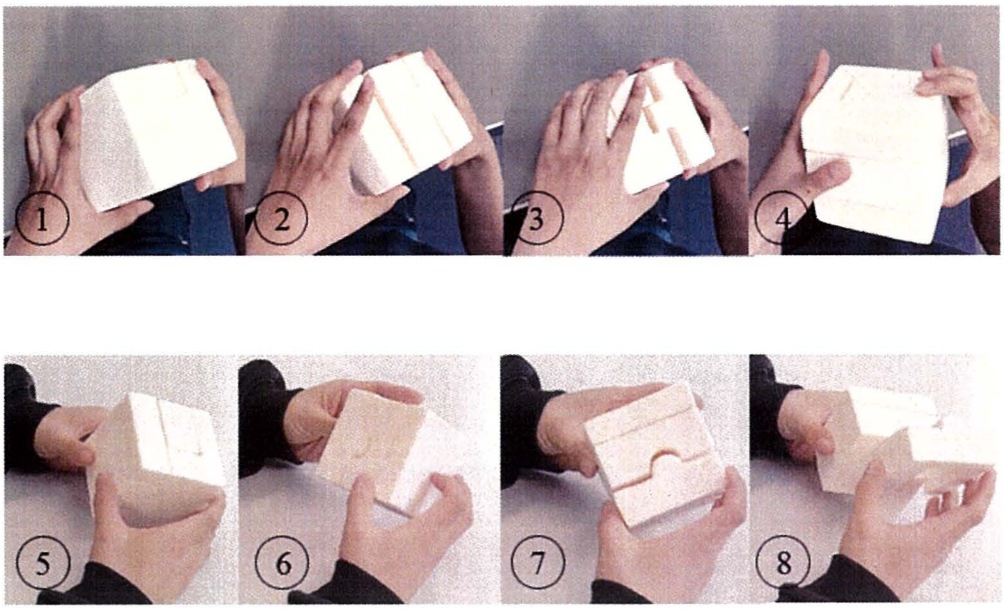


Fig.4.8 Disassembly step comparison for Types D and D1

The comparison between Experiment 3 and Experiment 2 yielded the same results. This can reinforce the conclusion of Experiment 2.

4.3 Discussion

From the results of three experiments, we can see that although there were only eight samples for each cube puzzle disassembly, it was such clear that the influence of shape characteristics on the disassembly of cube puzzles depends on different situations.

When a cube puzzle that could be opened via multiple parts, there were no significant differences in the average numbers of errors. That is, shape characteristics had no positive effect on disassembly efficiency.

However, when the cube puzzles were limited to only one key clue, the shape characteristics at the joint of the key clue were more easily noticed. Owing to the shape characteristic, the disassembly interference was reduced. Shape characteristics had a positive effect on disassembly efficiency. That is, shape characteristics was added at the first shape to be moved made the disassembly process more efficient.

CHAPTER 5

FUTURE WORKS

5.1 Conclusion

This paper pointed out that the existence of shape characteristics affects the effciency of the disassembly process under different conditions. To verify this hypothesis, seven different cube puzzles were used to carry out the disassembly process experiments. In the experiments, the authors compared the average time taken and number of errors committed during the disassembly process.

When cube puzzles that could be opened via multiple components at the same time with no direction limit were disassembled, although it took more time to disassemble the cube puzzles with shape characteristics added at the joint, there was no difference in the average number of errors. Shape characteristics had no positive effect on disassembly effciency, that is, the existence of shape characteristics could not improve the effciency of disassembly. However, when cube puzzles with only one key clue part as the starting step of the disassembly task were to be disassembled, a shape characteristic different from the vertical straight-line-form characteristic was added to this part. This shape characteristic provided clues to participants who repeatedly searched for parts that could be opened. In this case, the disassembly interference was reduced, facilitating the disassembly process. Thus, shape characteristics had a positive impact on disassembly effciency, that is, shape characteristics was added at the first shape to be moved made the disassembly process more efficient. We expect that the conclusions of this study could be applied in the structural design of furniture in the future. Improving the efficiency of furniture disassembly and being convenient for consumers to use.

5.2 Future Works

In order to apply this research theory to practical design in the future, it is necessary to conduct a profound study. At the preliminary stage of design, not only the convenience of assembly and disassembly should be taken into consideration, but also the users should be considered. Though people aged 25-34 preferred buying RTA Furniture, the survey did not take into consideration whether or not they had design experience. Based on the theory of the left and right hemispheres of the brain, people treat the same object with different perspectives. Therefore, grouping participants according to whether they have design experience or not, is a method that can be further studied. Furthermore, the size of the shape characteristics needs to be discussed. In this study, sizes of all the shape characteristics and key clues were same. Different sizes may have different effects on cube puzzle disassembly. These issues and details will continue to be studied in the future.

APPENDIX A

In Appendix A, the time and the number of errors that participants disassemble each cube puzzle in the three experiments of this study are provided. As shown in table Appendix 1- Appendix 7.

Table Appendix 1. Result of Type A

Participant Number	Time Duration(s)	Numbers of Errors
A(1)	12	0
A(2)	8	0
A(3)	10	0
A(4)	6	0
A(5)	12	0
A(6)	14	1
A(7)	13	0
A(8)	7	0

Table Appendix 2. Result of Type B

Participant Number	Time Duration(s)	Numbers of Errors
B(1)	22	1
B(2)	9	0
B(3)	21	2
B(4)	7	0
B(5)	14	0
B(6)	17	0
B(7)	14	0
B(8)	7	0

Table Appendix 3. Result of Type C

Participant Number	Time Duration(s)	Numbers of Errors
C(1)	16	0
C(2)	12	0
C(3)	24	1
C(4)	15	0
C(5)	24	1
C(6)	17	0
C(7)	38	2
C(8)	10	0

Table Appendix 4. Result of Type A1

Participant Number	Time Duration(s)	Numbers of Errors
A1(1)	20	3
A1(2)	15	4
A1(3)	8	3
A1(4)	17	7
A1(5)	9	2
A1(6)	13	2
A1(7)	23	5
A1(8)	15	8

Table Appendix 5. Result of Type A2

Participant Number	Time Duration(s)	Numbers of Errors
A2(1)	10	2
A2(2)	5	0
A2(3)	7	0
A2(4)	11	5
A2(5)	9	1
A2(6)	11	3
A2(7)	6	2
A2(8)	14	3

Table Appendix 6. Result of Type D

Participant Number	Time Duration(s)	Numbers of Errors
D(1)	37	14
D(2)	30	9
D(3)	16	6
D(4)	6	6
D(5)	8	7
D(6)	6	2
D(7)	13	9
D(8)	13	8

Table Appendix 7. Result of Type D1

Participant Number	Time Duration(s)	Numbers of Errors
D1(1)	4	2
D1(2)	7	2
D1(3)	3	1
D1(4)	5	3
D1(5)	7	1
D1(6)	3	2
D1(7)	9	2
D1(8)	10	4

APPENDIX B

In this Appendix B, complete statistical analysis data of three experiments are provided, including one-way ANOVA program and its multiple comparison and correlation analysis data, and Independent Samples T-Test. As shown below:

One-way ANOVA Results of Time Duration for Types A, B, and C

```
ONEWAY Time BY Type
  /STATISTICS DESCRIPTIVES
  /MISSING ANALYSIS
  /POSTHOC=LSD ALPHA(0.05).
```

Oneway

Descriptives

Time

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	8	10.25	2.964	1.048	7.77	12.73	6	14
B	8	13.88	5.915	2.091	8.93	18.82	7	22
C	8	19.5	9.008	3.185	11.97	27.03	10	38
Total	24	14.54	7.289	1.488	11.46	17.62	6	38

ANOVA					
Time					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	347.583	2	173.792	4.174	0.03
Within Groups	874.375	21	41.637		
Total	1221.958	23			

Post Hoc Tests

Multiple Comparisons						
Dependent Variable: Time						
LSD						
(I) Type	(J) Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A	B	-3.625	3.226	0.274	-10.33	3.08
	C	-9.250*	3.226	0.009	-15.96	-2.54
B	A	3.625	3.226	0.274	-3.08	10.33
	C	-5.625	3.226	0.096	-12.33	1.08
C	A	9.250*	3.226	0.009	2.54	15.96
	B	5.625	3.226	0.096	-1.08	12.33

*. The mean difference is significant at the 0.05 level.

One-way ANOVA Results of Numbers of Errors Duration for Types A, B, and C

```
ONEWAY Errors BY Type
  /STATISTICS DESCRIPTIVES
  /MISSING ANALYSIS
  /POSTHOC=LSD ALPHA(0.05).
```

Oneway

Descriptives								
Errors								
	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
A	8	0.13	0.354	0.125	-0.17	0.42	0	1
B	8	0.38	0.744	0.263	-0.25	1	0	2
C	8	0.5	0.756	0.267	-0.13	1.13	0	2
Total	24	0.33	0.637	0.13	0.06	0.6	0	2

ANOVA					
Errors					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.583	2	0.292	0.7	0.508
Within Groups	8.75	21	0.417		
Total	9.333	23			

Post Hoc Tests

Multiple Comparisons						
Dependent Variable: Errors						
LSD						
(I) Type	(J) Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
A	B	-0.25	0.323	0.447	-0.92	0.42
	C	-0.375	0.323	0.258	-1.05	0.3
B	A	0.25	0.323	0.447	-0.42	0.92
	C	-0.125	0.323	0.702	-0.8	0.55
C	A	0.375	0.323	0.258	-0.3	1.05
	B	0.125	0.323	0.702	-0.55	0.8

*. The mean difference is significant at the 0.05 level.

Independent Samples T-Test Results of Time Duration for Types A and A1

```
T-TEST GROUPS=type(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=time
  /CRITERIA=CI(.95).
```

T-Test

Group Statistics					
	Type	N	Mean	Std. Deviation	Std. Error Mean
Time	A	8	10.25	2.964	1.048
	A1	8	15	5.099	1.803

Independent Samples Test										
Types A-A1		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Time	Equal variances assumed	1.08	.316	-2.278	14	.039	-4.75	2.085	-9.222	-0.278
	Equal variances not assumed			-2.278	11.246	.043	-4.75	2.085	-9.327	-0.173

Independent Samples T-Test Results of Numbers of Errors Duration for Types A and A1

```
T-TEST GROUPS=type(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=errors
  /CRITERIA=CI(.95).
```

T-Test

Group Statistics					
	Type	N	Mean	Std. Deviation	Std. Error Mean
Errors	A	8	.13	.354	.125
	A1	8	4.25	2.252	.796

Independent Samples Test											
Types A-A1		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Errors	Equal variances assumed	14.648	.002	-5.118	14	.000	-4.125	.806	-5.854	-2.396
	Equal variances not assumed			-5.118	7.345	.001	-4.125	.806	-6.013	-2.237

Independent Samples T-Test Results of Time Duration for Types A1 and A2

```
T-TEST GROUPS=type(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=time
  /CRITERIA=CI(.95).
```

T-Test

Group Statistics					
	Type	N	Mean	Std. Deviation	Std. Error Mean
Time	A1	8	15.00	5.099	1.803
	A2	8	9.13	2.997	1.060

Independent Samples Test										
Types A1-A2		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Time	Equal variances assumed	1.213	.289	2.810	14	.014	5.875	2.091	1.390	10.360
	Equal variances not assumed			2.810	11.321	.017	5.875	2.091	1.288	10.462

Independent Samples T-Test Results of Numbers of Errors Duration for Types A1 and A2

```
T-TEST GROUPS=type(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=errors
  /CRITERIA=CI(.95).
```

T-Test

Group Statistics					
	Type	N	Mean	Std. Deviation	Std. Error Mean
Errors	A1	8	4.25	2.252	.796
	A2	8	2.00	1.690	.598

Independent Samples Test										
Types A1-A2		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Errors	Equal variances assumed	1.060	.321	2.260	14	.040	2.250	.996	.115	4.385
	Equal variances not assumed			2.260	12.987	.042	2.250	.996	.099	4.401

Independent Samples T-Test Results of Time Duration for Types D and D1

```
T-TEST GROUPS=type(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=time
  /CRITERIA=CI(.95).
```

T-Test

Group Statistics					
	Type	N	Mean	Std. Deviation	Std. Error Mean
Time	D	8	16.13	11.457	4.051
	D1	8	6.00	2.673	.945

Independent Samples Test										
Types D-D1		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Time	Equal variances assumed	7.150	.018	2.434	14	.029	10.125	4.159	1.204	19.046
	Equal variances not assumed			2.434	7.760	.042	10.125	4.159	.481	19.769

Independent Samples T-Test Results of Numbers of Errors Duration for Types D and D1

```
T-TEST GROUPS=type(1 2)
  /MISSING=ANALYSIS
  /VARIABLES=errors
  /CRITERIA=CI(.95).
```

T-Test

Group Statistics					
	Type	N	Mean	Std. Deviation	Std. Error Mean
Errors	D	8	7.63	3.420	1.209
	D1	8	2.13	.991	.350

Independent Samples Test										
Types D-D1		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Errors	Equal variances assumed	4.002	.065	4.369	14	.001	5.500	1.259	2.800	8.200
	Equal variances not assumed			4.369	8.167	.002	5.500	1.259	2.607	8.393

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