Chapter

Using Augmented Reality Technology to Construct a Wood Furniture Sampling Platform for Designers and Sample Makers to Narrow the Gap between Judgment and Prototype

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Abstract

AbstractsThe production and design of wood furniture manufacturing includes manufacturing furniture parts and their assembly with appropriate finishing operations; the process requires repeated communication and discussions, as well as furniture sampling and trials, which are indispensable. However, in the sampling process, due to the different understandings of the designer and the sample maker in regard to the size of 2D drawings and the modeling of 3D furniture, the sampling results often differ greatly from the designer's original concept; such errors appear mostly in the prototyping of wooden furniture. In this study, we focus on the wooden chair to explore whether augmented reality (AR) can contribute to the comparison between the virtual and physical shapes in the furniture prototyping process. We hope that by employing AR, the gap between the prototype and the finished furniture will be narrowed. By researching actual furniture prototyping with three furniture designers and two sample makers, this study has defined three furniture prototyping methods in the industry. Based on the basic principles, we recruited 38 designers to participate in the comparison experiments employing the above three different furniture prototypes. The results confirmed that applying the AR technology can effectively narrow the gap between judgment and prototype.

Keywords: augmented reality, product design and manufacturing, wood furniture sampling, virtual and physical comparison, virtual and physical prototyping

1. Introduction

Taiwan's furniture industry has transformed from mass production to small-scale self-owned furniture brands with better design and styling characteristics; in the past, most of the large-scale furniture manufacturers were transferred to Vietnam or the Chinese mainland [1]. As a result of the outward furniture manufacturing and production plants, Taiwanese furniture designers began to produce

Figure 1.
In the sampling process, the designers and sample makers need repeated discussions and corrections to understand the exact proportion and shape of furniture.

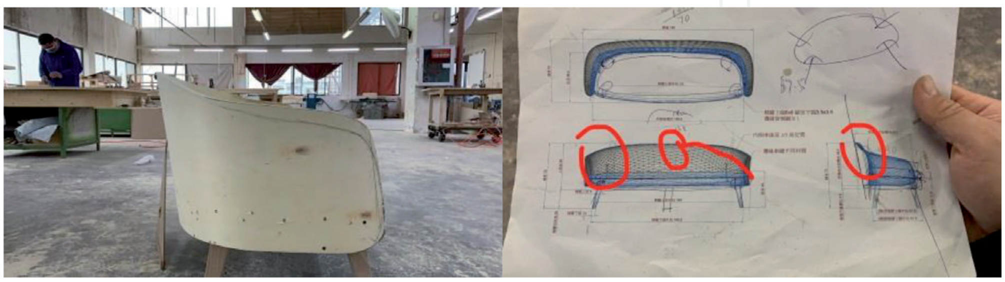


Figure 2.
Due to the lack of an effective discussion tool, the sampling needs repeated detail correction.

"small-volume but diversified" design manufacturing; in cooperation with the furniture factories in the Chinese mainland and Vietnam. This production model has become the main cooperation design mode for Taiwanese brand furniture [2]. In the past, designers and sample makers conducted discussions and trials on furniture sampling based on 2D drawings [3] (see **Figure 1**), which was their main method of communication [4, 5]. Currently, with the mature 3D drawing software, today's furniture manufacturing technology has been greatly improved, and the application of Computer Numerical Control (CNC) has brought more styling changes and possibilities to furniture design and mass production [6–8]; even the most experienced sample makers need to view the 3D furniture simulation to understand the shape and style of the designer's furniture [5].

However, most of these 3D simulations can only present the shape and structure of 3D furniture via 2D paper despite the fact that the furniture has more changes in the curvature of the composite space, especially the curved lines and shapes, which are difficult to present on 2D paper, resulting in the deviation from the 2D blueprint during the real 3D sampling process [9] (**Figure 2**). For example, furniture in the Ming dynasty, such as the Ming-style round-back armchair; when it comes to multiple visual viewpoints to compound one curve, the curvature of the armrest and the backrest cannot be judged in a non-frontal view or a side view [10]. These multi-changing curve shapes and spatial angles present a difficult problem for designers and sample makers in understanding and communication because the maker cannot fully understand the shape and spatial size the designer wants, or achieve the accurate curvature from the 2D surface or the 3D simulation [11]. The only method is visual observation and repeated sampling to create the designed furniture; as a result, there will be significant difference between the initially sampled furniture and the designer's prototype. Meanwhile, the furniture has its own requirements for esthetic quality so a slight difference in curvature will lead to obvious deviation [12]. Moreover, wood furniture, unlike metal steel pipe or plastic injection furniture, cannot be directly formed or extruded by machine [13].

Instead, it still relies on the sample maker's handwork to perform the preliminary sampling, so the spatial cognitive difference in the three dimensions still cannot be overcome [14].

2. Literature review

2.1 Current furniture sampling methods

At present, in the furniture sampling work of the sampling factory, 2D proportional blueprints will be obtained from the designer to print the paper or cut the cardboard [15] (**Figure 3**), and then based on the scale model (ratio 1:1 in the size and appearance) of the physical appearance, the sample makers will do their job according to their rich experience, this process will be corrected after many times of discussion and confirmation [16]. A sample of furniture that is closest to the designer's concept will be supplied to the furniture manufacturer for mass production. However, the sampling of wooden furniture is a 3D manual operation production process by the sample maker; the traditional 2D drawing is converted into the 3D hand-made sampling operation, but the spatial modeling cognitive difference between the 2D drawing and 3D spatial structure is still unavoidable [12, 17, 18]. Any slight deviation will affect the proportion and beauty of the furniture production, so repeated correction on sampling is necessary; discussions and communicate waste a lot of the designer and sample maker's time (**Figure 4**) [19].

Now that multinational design and manufacturing procedures have become an inevitable trend in the current furniture sampling production [20], furniture designers are facing the need for cross-country or off-site cooperation to discuss furniture sampling with the sampling factory [21]. However, due to the absence of actual space comparison, discussions on the 2D drawing will be more difficult because the sample maker cannot precisely grasp what the designer wants to present [9], and only oral dictation or repeated styling corrections are used in the furniture sampling [18]. Furniture sampling is a time-consuming, costly process as the designer has to go abroad for discussions with the sample maker, so an efficient communication platform for the designers and the sampler makers is highly demanded [19].

2.2 Advantages of AR technology when applied to traditional furniture sampling

There are considerable advantages in applying AR technology to traditional furniture sampling. Furniture sampling involves the translation from 2D "planar engineering drawing" into 3D "physical objects" [22]. The application of the AR technology to product development can provide designers with styling and

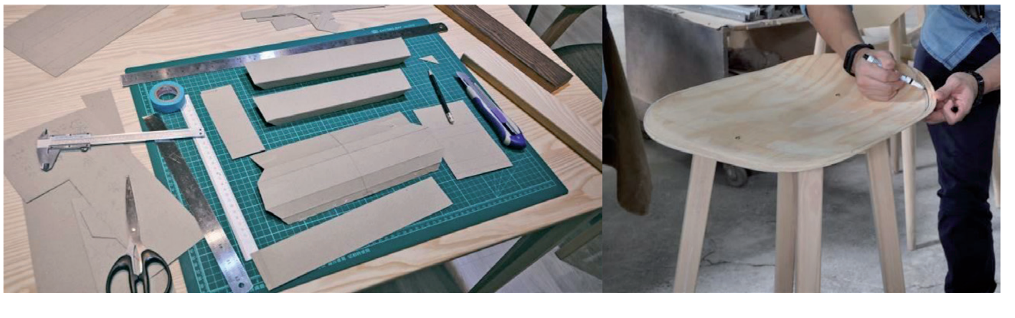


Figure 3.
In furniture sampling, 2D cardboard cutting or various drawings are needed by the sample maker to make judgments.

Figure 4.
The slight deviation in the furniture sampling is difficult to express and convey on a 2D drawing. Repeated sampling is time-consuming and labor-intensive (the top of the figure is the product status of the actual sampling of the furniture design company (STIMLIG); below is the 3D simulation to illustrate the details of the correction).

structural judgments by combining different virtual shapes with existing product models [23]. In the past, relevant research applied AR technology to the spatial layout of furniture [24, 25]. The AR technology can correctly represent the quantitative information and material performance on the shape of furniture [18]. Researchers have even found that AR technology can help designers accurately understand the furniture layout plan in the pre-sales phase [26, 27]. It can effectively save the cost of furniture handling and placement in real space; with AR technology, different furniture items can be quickly replaced to present real-time visual effects corresponding to indoor space [28]. In addition, AR technology can quickly present 3D visual images so the designers are able to get more diverse ideas and spatial discussions [29]; for example, designers can quickly change furniture shapes or components (such as chair legs, chair backs or armrests) [18]. The details of furniture parts can be changed through AR technology to help designers communicate with the sample maker. The relevant literature has confirmed that AR technology can effectively help the furniture maker to interpret the structural state of the furniture, which contributes to the work efficiency and correctness in furniture production, as well as presents the 3D furniture assembly [18, 30]. The animation explains the state of the different furniture components, so that the sample maker can clearly understand the characteristics and key points of the furniture structure [18]. In addition, AR technology can help the maker quickly convert the 2D and 3D drawings and understand the furniture; these visual and spatial advantages can be applied to solve the furniture appearance and structural problems encountered by the sample maker in the process of making furniture [18].

2.3 Application of AR technology in the virtual and physical comparison of the shape

In a recent study, Fernandes explores the user's judgment on virtual and physical objects in a spatial AR environment, and decides through experiments whether inaccurate judgment will occur between virtual and physical objects. The experimental results indicate that inaccurate judgments occur more when the real object cannot be seen, but if the object can be moved and rotated through the

AR operation, the spatial judgment will be more accurate [31]. In addition, some researchers have pointed out that if virtual objects are put into a real environment, people can judge the virtual objects as physical based on past visual experience and realistic 3D images [32], which will help the user understand and innovate in modeling [12, 29, 33, 34]. For example, Ford Motor and Microsoft used the visual features of AR technology to jointly develop a service system for car modeling [35]. By using Microsoft's newly developed head-mounted display, the new product model was combined with the existing developed model [29]. Using this system, the new car design team continuously developed the car's modeling and saved time and cost in development and production, whereas in the traditional car modeling design, several car samples are required [29]. Moreover, when developing XBOX game consoles, Microsoft also applied AR technology to its pre-production test, the internal parts of the game consoles and the circuit board were combined in the console prototype to test whether there were problems such as protruding parts or insufficient internal space [36]. AR also can help engineers and designers discuss and test products together [37, 38] to modify and improve the style and structure of the product [39, 40].

2.4 Purpose of the study

The purpose of this study is to apply the advantages of AR technology in space and vision to reduce the visual spatial difference between the 2D drawing and the 3D modeling during the sampling process of the furniture, when the AR sampling system can help the sample maker directly compare the semi-finished samples with the spatial virtual furniture to get the correct size and curvature of the furniture. The sample maker can use this system to understand and compare the furniture styling before and after the sampling. Based on the 3D virtual furniture model generated by AR, the sample maker can compare and review whether the hand-made sample meets the accuracy of the shape and size designed by the furniture designer. More importantly, it can fully present the correct proportion and shape of the furniture, so that the maker can see the shape and spatial structure of the designer before production, and accurately determine whether the size and shape of the sample are accurate. This study also focused on the comparison of shapes, carried out three different sampling experiments on the shape and structure, to find whether AR technology contributes to confirming the appearance and proportion of sampling furniture.

3. Methods

This study applied AR technology to furniture sampling (**Figure 5**) to determine whether it could effectively assist furniture designers and sample makers in the comparison and discussion of the modeling. The sample maker used AR technology to verify whether the sample was in line with the designer's design and modeling accuracy. The study carried out three different experiments on furniture sampling with 38 designers who had more than 3 years of furniture design and production experience. The aim was to understand whether AR technology is helpful for furniture sampling and physical comparison. The experimental design and data verification of the virtual and physical characteristics of the furniture's basic structure was conducted.

Based on the experiments and subject tests, researchers can use the "visual interface assistance" and "space virtual and reality comparison" features provided by AR technology to understand how to solve the problems in the actual situation of furniture sampling production. They can also understand what problems will occur in the development of furniture sampling, as well as the advantages and visual

Figure 5.
AR can contribute to the comparison between the physical and the virtual shapes in the furniture prototyping process.

characteristics of the visual aid in an AR environment. This technology is also quite simple and convenient in research practice. The system interface of the AR can be presented using a tablet computer (**Figure 5**). Since the carrier is simple and can be used for the furniture sampling process to test the furniture body, this technology will be very helpful for the furniture sampling and design development.

3.1 Participants

In this study, 38 designers with more than 3 years of experience in furniture design and production were asked to serve as participants. Three different sampling experiments were conducted to compare the shapes of the furniture. When designing test questions, the researcher provided two pictures of chairs with the same shape, but the structural elements of the chair in one picture were a scaled 3D drawing (a part of the chair is fine-tuned, for example, tuning 10% of the back of the chair to simulate the error range of sampling). Then the subjects were asked to determine whether the shape was different. The question group was divided according to the three different sampling methods, respectively, comparing the traditional paper 2D furniture drawing with: (1) Sampling Method I: paper 3D furniture blueprint; (2) Sampling Method II: physical 3D furniture (3) Sampling Method III: physical 3D furniture using AR technology. This study explored the error in the judgment of shape during the sampling process based on the three different comparisons.

3.2 Experimental design

Studying the "differences in the comparison of furniture sampling" and taking the chair as the test object.

In this study, the chair was used for furniture sampling and modeling test. The reason was that the shape change of the chair is more diverse and complicated than that of the table and the cabinet [4]. In addition, the structural units of the chair have a rich modeling appearance and surface changes on each component (such as seat, armrest and seat back). Also, the probability of styling errors in the actual sampling program is higher than with other furniture, so this study mainly focuses on the structural decomposition of the chair to understand its structure. The chair was decomposed into different basic structures according to the related literature classification: (1) seat back, (2) armrest, (3) seat surface, (4) chair foot and (5) chair rail. The researchers then separately carried out the experimental simulation on the furniture sampling through the three different sampling methods previously defined. By 3D modeling software pro-e, the modeling parameters were designed to accurately control the shape change of the chair. AR was then used via 3D printing to make the correct virtual shape on the physical furniture structure to simulate the difference in the furniture shapes, in addition to understanding whether the AR technology could effectively reduce the sampling mistakes by the sample makers in the modeling.

3.3 Research questions

In the present study, the following two questions were used:

Which part of the basic structure of furniture is the most difficult to identify? (1) Seat back, (2) armrest, (3) seat surface, (4) chair foot, (5) chair rail.

In comparing the visual display interfaces in the three sampling methods, which is the easiest to distinguish the error on the shape? Respectively comparing the traditional paper 2D furniture drawing with: (1) Sampling Method I: paper 3D furniture blueprint, (2) Sampling Method II: physical 3D furniture, (3) Sampling Method III: physical 3D furniture using AR technology.

3.4 Evaluating test material: comparing the sampling on the chair's shape

This study focuses on the shape recognition of the chair. In the experiment, the shapes of the basic structure of the chair: (1) seat back, (2) armrest, (3) seat surface, (4) chair foot, and (5) chair rail were compared. Two drawings were provided in the test to compare the pairs, one of which is the correct proportion of the furniture surface, and the other is the comparison of the three-dimensional furniture drawings with the partially adjusted components. A slightly different drawing of furniture allows the subject to judge the simulation error of the furniture sampling. The drawing only emphasizes the fine-tuned part of the furniture structure; when testing the seat back, it was presented with a three-dimensional color model, and the overall appearance of the rest was in a dotted line (**Figure 6**), in order to retain the main appearance of the overall shape of the furniture outside the main test component. As the individual parts of the furniture structure did not conform to the real state, the difficulty of the shape recognition was increased. The size, proportion and perspective of the furniture in the various test drawings were the same to facilitate the subsequent judgment of "which part of the basic structure of furniture is the most difficult to identify" as well as the consistency of the analysis and the experimental reliability and validity. Test questions on the modeling difference were used when analyzing: (1) the difficulty of judging the chair's structural shape, and (2) the proportion of error in sampling, to explore the structural components that led to

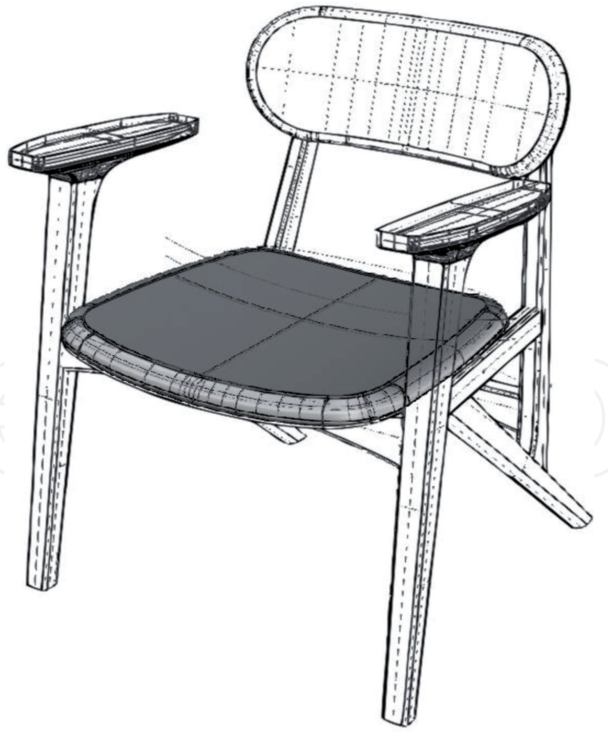


Figure 6.
The overall and parts of the chair structure to be tested are presented in a dotted line (for example, the figure is to test the chair seat).

sampling errors in the chair seat. In addition, the researchers also explored whether the visual conversion from 2D to 3D caused the difference when determining the shape, and how to apply AR technology to the design and sampling of furniture.

3.5 Measurement materials

3.5.1 Five basic structures of furniture chairs

This study used the design chair of the STIMLIG Furniture Company (https://www.stimlig.com/) that was entering the sampling stage to design the test questions. A total of 10 gradients are created according to the five basic structures of the chair, and a new shape was created for each 10% of the chair with micro-adjustment, while the rest remained unchanged. There were five basic structures of furniture chairs: (1) seat back, (2) armrest, (3) seat surface, (4) chair foot, and (5) chair rail. They respectively constructed 10 gradient units and a single drawing was randomly taken to test the subject. Only one model was supplied for comparison when sampling. There were 50 test questions in total.

3.5.2 Test method for sampling

The five basic structures in the furniture chair were tested by the following three different sampling methods to analyze the differences in the shape judgment and the problems that might occur with different furniture components in sampling, as well as the potential possibilities of their technical application. The scale of the difference in shape represents the rate of the sampling error. For example, when the subject could tell the fine-tuning was more than 30% in shape, it meant that the sampling method had only 30% error rate in the shape deviation because the difference below 30% could not be distinguished, so the visual difference and limitation between the 2D drawing and the 3D shape could be determined. After the test was over, the researcher could determine the proportion of the subjects' shape judgment for different sampling comparison methods, as well as the benefit of applying AR to the actual sampling comparison (**Table 1**).

Sampling Method I: comparing the traditional paper 2D furniture drawing with the paper 3D furniture blueprint.

At this stage, the researcher would understand whether shape deviation would occur when comparing the traditional paper 2D furniture drawing with paper 3D furniture blueprint (printed on the 2D paper); the purpose was to find out whether difference between the 2D and the 3D would occur during the sampling process. With the paper-based method, the subjects were asked to judge the shape difference between the left and right objects printed on paper, and the testing method and data were used to analyze which basic structure of the chair was the most difficult to identify or the most likely to cause judgment error.

Sampling Method II: comparing the traditional paper 2D furniture drawing with physical 3D furniture.

At this stage, when comparing the traditional paper 2D furniture drawing with physical 3D furniture (2D vs. 3D), through 3D printing, the accurate physical furniture shape (10% gradual difference each time) was completed and compared with the 2D paper drawing to determine the shape difference between the traditional paper 2D furniture drawing and the physical 3D furniture. This method is closest to the actual sampling state and consistent to the conclusion of a real furniture sampling factory when determining the physical 3D furniture based on the 2D drawing.

Sampling Method III: comparing the traditional paper 2D furniture drawing with physical 3D furniture using AR technology.

In this stage, the researchers amplified the virtual objects based on AR technology applied to the physical 3D furniture printed, so that the subject could determine whether AR contributed to the comparison of the furniture shape. Based on the different ratios between the virtual and the real, the proper ratio of the AR furniture sampling comparison system (10% each time) that needed to be adjusted could be found. Therefore, the subjects could quickly and correctly distinguish the obvious differences in the shape, clarify the virtual and real interface design and make a detailed discussion.

3.6 Constructing the AR furniture sampling system

Based on Unity3D [41], this study developed the AR Furniture sampling system that can be installed on an Android tablet computer. Via tablet computer or other display devices, designers can put their designed 3D furniture model into the system, and make comparisons and discussions through the replacement of different furniture components. In the system, through the back-end server and remote synchronization, the researchers updated the version of the sampling program on

Sampling method type	Original proofing material	Comparison proofing material
1. Sampling Method I	Traditional paper 2D furniture drawing	Paper 3D furniture blueprint
2. Sampling Method II	Traditional paper 2D furniture drawing	Physical 3D furniture (created by 3D printing)
3. Sampling Method III	Traditional paper 2D furniture drawing	Physical 3D furniture using AR technology

Table 1.
Three furniture sampling methods.

different tablets. When the designer updates the designed 3D furniture model, the remote sample maker can also simultaneously update the models and functions in the app. The "designer" and "sample maker" can simulate the functionality that this system should be equipped with in different settings.

3.7 Setting

The AR Furniture Sampling System was set up in the laboratory space (about $3 \times 5\ m^2$), and a 65-inch large display screen was placed in front of the experimental field to present the furniture in 1:1 ratio for the test image of furniture sampling. By the video camera and image recognition technology, the state of the furniture in the AR could be presented. The subject sat in front of the screen with the table and the chair placed in front of the screen; the subject could make the comparison on the furniture identification card on the table with the 3D printing model. After capturing the card, the camera projected the virtual 3D furniture shape onto the 3D printed furniture model for the subject to compare the furniture. Thus, the subject could simulate the furniture-sampling environment; the researchers gave them different sampling tasks in sequence to perform the three different sampling methods to determine the five basic structural units of the chair (**Figure 7**).

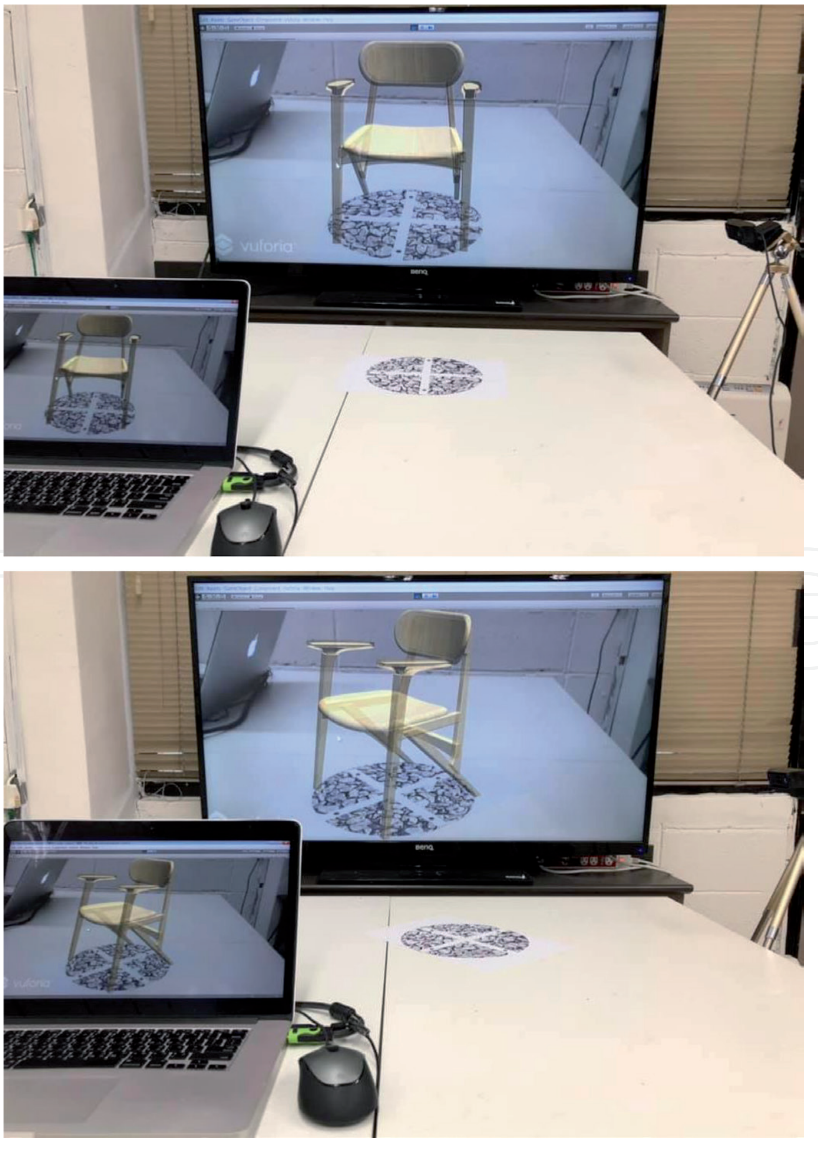


Figure 7.
The AR furniture sampling system setup.

3.8 Data collection and analysis

The results of the experiments have undergone comprehensive recording and subsequent data analysis. The experimental data were used to find out whether the three different sampling methods would cause judgment errors. By the rigorous styling gradient and the small-scale styling ratio change, the researchers controlled the relationships among the three different sampling methods (independent variable) and the judgment errors in 10 modeling scales (dependent variable). In this study, the researchers used different proportions of modeling changes to represent the degree of judgment errors in the sampling; by simulating the deviation of the sampling bodies, the shape judgments of different shapes made visually between 2D and 3D were quantified. In this way, the operation was relatively objective and the experimental limitations on actual sampling were simplified.

4. Results

The experimental results are shown in **Table 2**. The data show different amplitude changes for the overall shape structure of the chair by the three different sampling methods, indicating that they have an influence on the modeling judgment under different visual media displays.

4.1 Judgmental differences of the basic chair structure among the three sampling methods

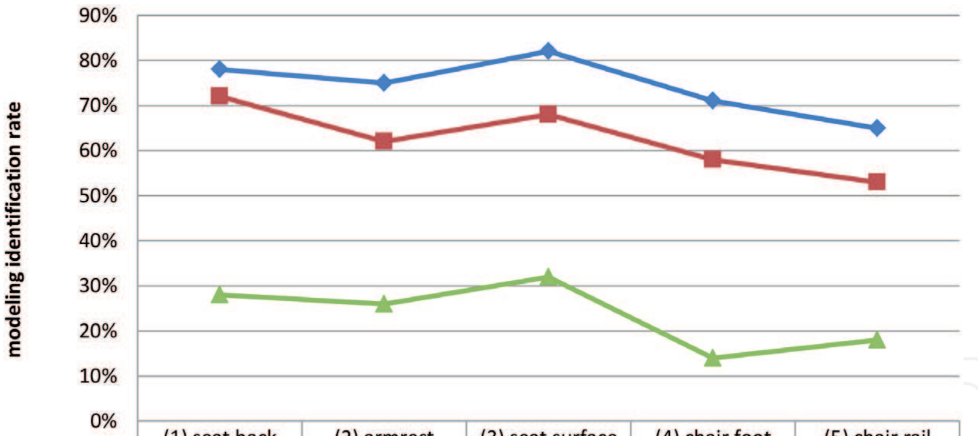
The shapes of the chair reflected in the three sampling methods differ. When the proportion of the difference in the shape that can be recognized is lower (the difference in the shape is more subtle), the more helpful the sampling method is, as it signifies that the differences of the furniture shape are subtle and the subject can immediately distinguish the difference, and in the sampling process, it is easier to find the sampling difference between the 2D drawing and the 3D shape.

4.1.1 Sampling Method I

In the Sampling Method I (**Table 2**), the chair foot (71%) and the chair rail (65%) have the highest recognition level. When the modeling difference reaches an average of 68% or more, the shape difference can be correctly found; the armrest is the second. Only when the modeling difference reaches an average of 75%, can the difference in the shape change be evident between the 2D drawing and the 3D shape. The most difficult to recognize are the seat back (78%) and the seat surface (82%), which require an average of 80% or more for the subject to feel the difference.

4.1.2 Sampling Method II

In the Sampling Method II (**Table 2**), the order of recognition level has changed somewhat. The chair foot (58%) and the chair rail (53%) have the highest recognition level on the modeling difference. When it reaches an average of 55.5%, the difference can be noticed. The armrest (62%) and seat surface (68%) are second; the difference must reach an average of 65% before the obvious difference in the shape change can be felt. The most difficult to identify is the seat back, which requires an average of 72% for the subjects to tell the difference.



	(1) seat back	(2) armrest	(3) seat surface	(4) chair foot	(5) chair rail
Sampling Method I	78%	75%	82%	71%	65%
Sampling Method II	72%	62%	68%	58%	53%
Sampling Method III	28%	26%	32%	14%	18%

Table 2.
Summarized differences in modeling identification of basic structure of furniture.

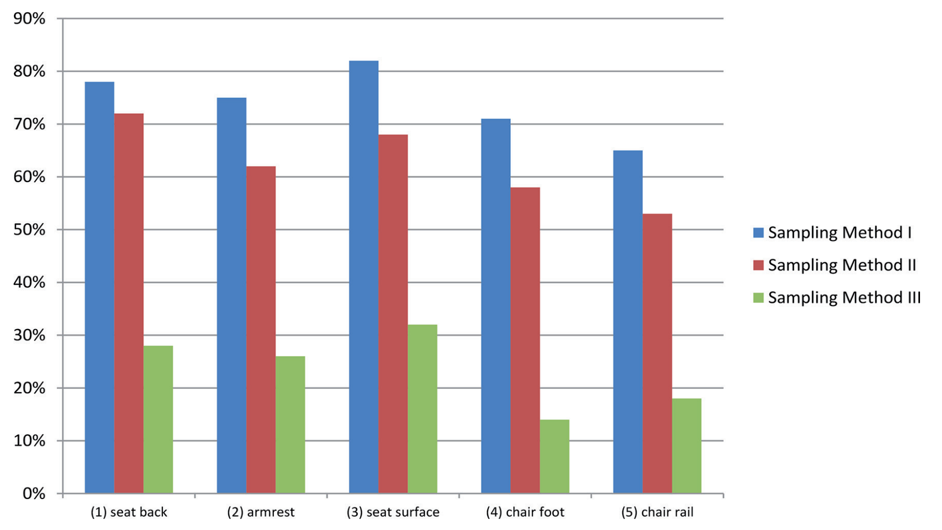


Figure 8.
In the Sampling Method III when AR technology is applied, significant differences (p < 0.05) lower than the others methods (Sampling Method I and II) in identifying the shape can be found.

4.1.3 Sampling Method III

In the Sampling Method III (**Table 2**), in the overall shape structure of the chair, the difference between the basic structures of the chair is greatly reduced. The difference can be obviously felt when it is 28% in the seat back, 26% in the armrest, 32% in the seat surface, 14% in the chair foot and 18% in the chair rail. Generally, when the different structural parts reach an average of 23.6%, the difference can be felt, which is obviously more recognizable than Sampling Method I and Sampling Method II (**Figure 8**).

In the analysis, we conducted the paired-sample *t* test in SPSS 19.0 to compare the different sampling methods in terms of overall mean identifying rate on the comparing test. In the overall identification, it can be found that in the Sampling Method III when the AR technology is applied, significant differences ($p < .05$), lower than the other methods (Sampling Method I and II) in the identifying the shape can be found (**Figure 8**) because the 3D visual aid can quickly show the difference in the shape. In the Sampling Method II, the physical shape comparison and tactile sensation assistance can also be helpful for determining the modeling difference. However, the Sampling Method I focuses on the visual comparison of 2D drawing, which lacks spatially rotated image information and is also difficult for the subject to clarify the differences in some fuzzy modeling areas.

5. Discussion

5.1 Differences in modeling identification of basic structure of furniture

The experiment results confirmed that in the furniture Sampling Method III, the difference can be obviously felt. Especially, it is relatively easy to judge based on the basic rectangular surface, such as the chair foot and the rail because they are rectangular or cylindrical or their shape angle is vertical to the datum plane, so the subjects can have a better understanding of the difference in the shape, and are also more likely to determine and compare the modeling difference based on the symmetry and the relative position and regular angle in the space. It also visually reflects that compared with the absolute judgment, the relative judgment of the shape is easier when determining the space because the relative judgment has a visual reference, and the absolute judgment can only rely on human experience and modeling ability. The application of the AR has provided accurate visual reference for shape, and therefore increased the subjects' recognition and mastery rate of the shape difference.

5.2 Differences in modeling recognition among three sampling methods

When comparing the sampling of the shape, (1) the Sample Method I is consistent with the traditional paper, and it is quite difficult for the sample maker to distinguish the difference in the shape because on the 2D paper drawing it is hard to tell the shape change in the 3D space. Also it is impossible to touch the physical furniture or rotate different perspectives to compare the shape. To create a furniture entity in 3D space, the sample maker needs continuous physical speculation and spatial structure judgment based on the mental rotation. Such a sampling process is a necessary step in the initial furniture sampling process, which is quite difficult and time consuming for the sample maker.

And (2) in the Sample Method II, it is easier to compare the shape between the 2D and the 3D because the sample makers can change the visual perspective by manually rotating the physical furniture model. The visual aid of real shadows and the sensory feedback of physical senses add more sensory information than the 2D paper drawing does, but entails more production cost. Such sampling method is close to the actual sampling in real life and both need a scaled model to determine the difference in styling. Although using 3D printing technology in this experiment can save a lot of time, there will still be increased production cost and time in the actual furniture sampling process. It is helpful for the judgment, but multiple sampling models are necessary for the comparison.

AR's application in the Sampling Method III (3) is quite easy to implement and practice in the real world compared to the previous two sampling methods (**Table 2**) because the virtual body is in the physical comparison area and uses the visual image presented in the 3D space to enhance the difference between the physical and the virtual entities, so the sampler maker can quickly generate visual clues under the slight shape difference and reduce the difficulty in judgment. Meanwhile, there is no need to make a large number of furniture sampling entities in future sampling. The shape of furniture can be presented by the virtual shape, which can greatly reduce the production cost and time.

5.3 Research limitations

There are several research limitations in this study. First, we simulated the form and state of sampling through innovative experimental methods and AR system design, aiming to quantify the objective data on furniture sampling on the shape, but because the size of the 3D printing is much smaller than the actual sampling size, the difference between the visual judgment and the spatial shape was affected. However, this study emphasizes the combination of visual space theories with the practice of technology and materials in application. The researchers are convinced that this does not affect the reliability and validity of the results because we used the same sampling method and provided the subjects with the correct ratio of the production process and the projection on the screen to make styling judgments. It turns out one-to-one proportional sampling experiments are feasible for future sampling design and technical breakthroughs. Second, while the subjects are professionally trained furniture design and production staff, they are still not real furniture sample makers. The sampling experience and handwriting skills may affect the ability to make judgments. However, the real sampler makers in the furniture factory are quite busy, and it is not easy for them to be involved in an experiment for a long time. That is the reason why we were looking for professional designers with similar work experience and styling ability as the subjects. Since this study emphasizes the shape comparison between the 2D and 3D under visual space, these subjects have the same ability as the sampler makers to determine the shape and are quite familiar with the design and sampling of furniture. We believe this can make up for the lack of real sample makers, but in future experiments, if funding and time permit, we still hope to conduct experiments with real sampler makers. Third, there is quite a variety of furniture and we only tested a chair, whose shape will affect the results of the sampling comparison data. Therefore, our main research results focus on the comparison of the sampling methods to understand whether AR technology is helpful for the sampling of furniture, but cannot fully explain the deviation of the basic structure of the furniture that is most likely to occur in the furniture sampling process. However, the structure of the furniture can still correspond to its basic shape, which is also an experiment to be carried out in future research because the basic shape (such as column, square, ellipsoid, cylinder, spindle and rectangular) is different in visual judgment; for instance, due to the lack of the right-angled structure, the ellipse is more difficult to identify and distinguish the difference in shape than the rectangular. Therefore, in the future research, this study will simplify the understanding of the model and increase the validity of the experiment through multiple visual viewpoints and modeling. However, in order to avoid focal vagueness in this study, we only focus on the basic structure of furniture rather than a unit body. Fourth, in the study, judgment on the proportion of furniture is used to determine the sampling mistakes, but there will inevitably be subtle differences which cannot be completely subdivided by the overall proportion. For example, the scaling extent at the edge of the chair back may be larger than that in the middle, but this study is only based on the overall chair back, which will cause some slight difference in the shape data. In the future, we must seek more objective software analysis to get a more precise design, but in general, this is an innovative and simple experimental method.

6. Conclusions

AR technology has been applied to many innovative product designs, and is expected to evolve with the future development in the integration of virtual and real environments. The novel devices include Microsoft HoloLens, HTC VIVE Pro, and VR Oculus Rift. The development and emergence of these technological devices reflect the potential of using AR or VR to solve industrial production problems in the future. Moreover, these devices will blur the boundaries between virtual and real integration, and increase the number of gestures and innovative interfaces, which could make the manufacturing process more intuitive, and make the manual operation more flexible. Future users will have more options in operating the AR interface of tablets.

In addition to the consumer side in the design process, AR is used in different product development and modeling discussion. Previous researches have pointed out that AR is helpful for the designer's continuous design and redesign in product development [12, 29, 34, 35]. However, in the literature exploration, the researchers found that in the current stage of AR in the furniture sampling and manufacturing production, we have not seen any application of similar concepts. Therefore, we believe that furniture sampling and manufacturing is an excellent research field with great design possibility, especially because the furniture sampling involves the design and processing of furniture production. For example, in furniture product development and styling continuation design, there are many details to consider; at present, it is still difficult for wooden furniture production to overcome the physical shape difference and master the space scale of furniture sampling because wooden furniture has the following characteristics: first, the sampling of its initial prototype relies on the subjective judgment and the handcraft of the special sample maker, thus resulting in a significant difference between the sample of the furniture prototype and the blueprint. Second, wooden furniture contains many complex structures such as composite curved surfaces, curved wood shapes, and gradient bends. It is difficult for 2D drawings to present the spatial structure and modeling concept of 3D furniture, so the spatial cognitive misunderstanding may lead to inaccurate judgments of the sampling appearance. Third, wooden furniture often uses the mortising technique to assemble and connect furniture parts, and the mortising structure is often hidden within the furniture and cannot be directly seen. Due to the above special factors, the sampling of the furniture often requires repeated discussions and trials. In this context, this study is aimed at the research and knowledge construction of furniture sampling in the framework of AR technology in the comparison between physical and virtual reality. Using the systematic experimental method has defined the knowledge structure and specific operational application strategies of AR technology in the comparison of furniture shape sampling, as well as the "difference between modeling" and "virtual reality" to study the topic of furniture styling. The results show that the application of AR to furniture sampling has obvious benefit for the mastery and judgment of the furniture modeling.

This research has confirmed that AR technology is more helpful in the sampling and development of furniture, especially in the visual and styling aspects. This study has developed a set of rigorous sampling methods for AR technology based on the "physical comparison" and the "furniture sampling development", and

	Disadvantages of traditional furniture sampling	Advantages of applying AR technology to furniture sampling
Spatial cognitive difference	The sample maker follows the 2D drawing and the 1:1 simulation prototype output drawing as the aid for the sampling of the furniture, but due to the manual manufacturing process, differences between the sampling prototype and the design prototype may easily occur due to the difference in space and modeling.	AR technology can combine the virtual design prototype in 3D space with the real sampling prototype, which can provide modeling corrections and discussion, and reduce spatial and visual errors caused by direct translation from 2D drawing to stereoscopic space modeling.
Communication barriers	The communication barriers between the designer and the sample maker may be due to different professional backgrounds, opinions, and locations. Thus more sampling errors will occur and repeated corrections are necessary.	When using AR technology to establish a "common image language" between different professions, we can improve communication efficiency and quality, reduce sampling errors caused by poor communication, and examine the demand for mass production of furniture and structure more objectively.
Regional restrictions	Traditional sampling relies on the face-to-face communication between the designer and the sample maker; they directly examine the physical prototype for discussion and correction. However, if the location of the sample is far away, it will take a lot of time and money to travel back and forth and the sampling process may be lengthened.	On the platform that integrates the virtual and real entities, we can overcome the limitations of location, time and space, to save money and time costs, provide better-optimized design communication quality, and shorten the sampling process.
Materials	The same materials as the real furniture are used in traditional sampling. If we want to try different material textures and color effects, multiple sampling prototypes will be needed, which is time-consuming and costly.	We can use computing and computer virtual to replace furniture materials, color, surface and different sets of parts in real-time, which is fast and cost-effective.

Table 3.
Advantages and disadvantages of applying AR technology to furniture sampling.

continues this concept to gain an in-depth understanding of 2D and 3D vision and space under the guidance of how to use AR technology to design media-assisted interfaces on furniture sampling. The advantages offered by AR in furniture sampling are listed below (**Table 3**).

6.1 Providing the relative shape judgment and spatial visual reference for the sampler maker

AR technology can provide a reference for the sample maker in the comparison of the furniture shape, and quickly construct the relative state between the virtual furniture shape and the physical one. In addition to helping master the furniture type, it can also increase the iterative correction and the basis for the shape adjustment.

6.2 Deploying flexible furniture components in real time

AR technology can quickly change the component's shape, adjust the proportion, material and shape of the furniture, and even complete the disassembly simulation. These 3D animations can help the sample maker quickly understand the shape and assembly set by the furniture designer. The concept of the furniture design can be quickly and effectively conveyed to the producer.

6.3 Providing long-distance space formation discussion

The AR System can synchronize sampling images to different participants to view and discuss in different sampling locations, which can be used simultaneously by multiple people. With their own tablet displays (**Figure 5**), users can view from different angles and discuss together without interfering with each other. In the future construction of the AR sampling system, the modeling annotation and visual aid guidance can be added to point out the problems of sampling and details during remote discussion. Currently, Taiwan or European furniture design workshops are developing towards a simple and diverse trend of manufacturing and off-site production; AR technology will have much potential and developments in remote discussion and sampling, whose applications will once again give it a new opportunity for research and development.

Therefore, in future furniture design, in addition to the accuracy of the spatial scale of the sampling, AR will play a more important part in its application in the development of new modeling and styling design. More in-depth research and modeling analysis will be conducted on these characteristics in the future.

Conflict of interest

The authors declare that they have no conflicts of interest.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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