Comparison Between VR and CAD Product Representation On Subject Preference Via Discrete Choice Experimentation

José E. Lugo[1] , Luis E. Gutiérrez[2] , Iván Herrero[3] , Héctor A. Rivera[4]

[1]Human Centered Design Laboratory, Department of Mechanical Engineering, University of Puerto Rico at Mayagüez, jose.lugo2@upr.edu
[2]Human Centered Design Laboratory, Department of Mechanical Engineering, University of Puerto Rico at Mayagüez., luis.gutierrez6@upr.edu
[3]Human Centered Design Laboratory, Department of Mechanical Engineering, University of Puerto Rico at Mayagüez, ivan.herrero@upr.edu
[4]Human Centered Design Laboratory, Department of Mechanical Engineering, University of Puerto Rico at Mayagüez, hector.rivera84@upr.edu

Corresponding author: José E. Lugo, jose.lugo2@upr.edu

Abstract. Engineering design is affected by the technological tools that designers use to represent their product. Virtual Reality (VR) technology offers a detailed way of viewing a product and achieves a higher level of subject immersion when interacting with the product in an virtual environment. Computer Aided Design (CAD), on the other hand offers the designer an enhanced level of detail that allows for the creation of two-dimensional and three-dimensional representations which replace sketches and representations made by hand. Both formats, then, offer different degrees of product representation realism. This work will compare product preference in VR and CAD environments for a range of coffee cup designs. The product preference is gathered via a Discrete Choice Experiment(DCE). The subjects are categorized by gender, and previous CAD and VR experience. Designs of coffee cups were parameterized and the subjects where shown two cups at a time and asked to inspect them and choose the one they like the most. This process was applied for both VR and CAD environments. The data of 108 subjects was collected then analyzed. This analysis points to the fact that that there are significant preference differences between VR and CAD. This work contributes to understanding how different product representations affect subject preference. Designers in the early design timeline are impacted in this paper as they can mimic the use of DCE with VR and other product representations.

Keywords: Descrete choice experimentacion, product representation, virtual reality, subject preference

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1 INTRODUCTION

Currently, there are multiple tools that designers can use for people to interact with a product before it is finished (e.g CAD, VR, AR and 3D printing) that are being used more frequently as time goes on. These take into account the most relevant characteristics of the product, such as shape, color, size, aesthetics and use judgment. CAD-made designs can accurately represent the shape of a product, but 2-dimensional images may not be very descriptive when it comes to people's perception, although CAD models allow for better accuracy by having realistic representations on computer. On the other hand, VR and augmented reality (AR) studies involve interaction with real-world objects that could not be performed purely virtually [7], they have more immersion than CAD representations.
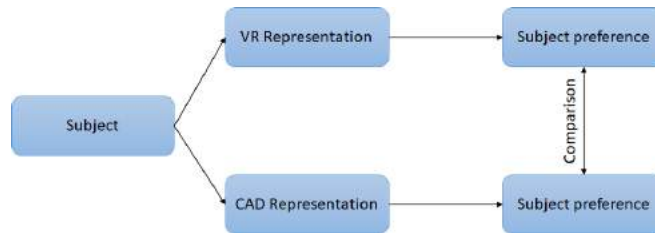
Figure 1: Comparison between VR and CAD representations.

Figure 1 shows the comparison between CAD and VR representations that take place in this study. The main objective of this research is to compare and contrast the subject preference data between CAD and VR representations. It was done through Discrete Choice Experiment (DCE), which presents two or more options to subjects to choose from and subjects choose the product that they like the most. Subjects compared coffee cup designs in VR and CAD renderings. Coffee cups were chosen as they are considered a familiar product for the experiment subjects. The null hypothesis that this work will be testing is: for a simple object (a coffee cup) the type of representation (CAD or VR) does not influence the subject decision. In other words, we are testing whether the type of representation has an effect on the subject's decision-making or not. If our results support the alternative hypothesis, it means that the type of representation does play a role in the subject's decision, while if the results support the null hypothesis, it indicates that the type of representation does not have an effect on the subject's decision.

2 BACKGROUND

2.1 Computer Aided Design

Through CAD software a person can make modeling of drawings and designs. However because CAD representations resemble the shape, color, and texture of the recreated design in detail, a precise level of realism and visual detail is obtained. There are multiple software in which CAD representations can be made and this makes it easier for novice engineers and designers to recreate parts. Visual interaction is achieved through controls such as a mouse and keyboard, which allow for the rotation of the part and thus, provides the ability to see it clearly in 3D. CAD visuals can accurately represent the form of a product, but require more time to create than hand sketches [11]. Kansei engineering has used CAD models (as well as VR) for kitchen design [1]. CAD models have also been used to generate realistic renderings and computer sketches of a vehicle and a coffee carafe to study their impact on customer judgment [18] and in the modeling of wheel rim preference [10]. The proficiency of CAD to save, communicate and render realistic virtual prototypes allows for easier communication and review of proposed design decisions via design reviews. However, the use of virtual prototypes is limited by the realism of the human computer interface [2]. Three dimensional CAD virtual prototypes

are low cost and provide significant information, yet are hindered by the interface between the viewer and the virtual environment. This interface is comprised of the visual output displayed by the virtual environment and the control input of the viewer [2].

2.2 Virtual Reality

VR is a simulated environment with a real appearance, in which objects, scenes,and places can be recreated for the subject, who then has a heightened level of immersion in what is being shown. The use of VR technology has become an important tool for product designers [25, 2]. This has turned the HMD's into useful devices and recent advances have placed them within reach of the general public, which contrasts with the CAVE configuration, one that is expensive and not portable. The affordability and low cost of HMD devices compared to CAVE enables it to be useful for modeling big scale prototypes without much need for physical space [2]. Further, VR setup using HMD are easy to move, which makes them more effective for research laboratories with limited space.

VR has been used in a case study in applications with DCE to quantify subject's perception [24]. This implies being able to record peoples behavior in their product selection, and thus sensing preferences of people and identifying how the data obtained is correlated [4]. VR technology has partnered with engineering designers to model their designs [12]. The introduction of VR-based methodologies in the early stages of product development is gaining momentum, with recent research focused on overcoming implementation challenges in academia and industry. For example, assembly errors in engineering designs [2], VR in cardiopulmonary resuscitation training [3], product representation [24], 3D objects manipulation [7], creation of low cost environments for engineering and construction [6],high quality prototypes design [19], among others.

2.3 Discrete Choice Experimentation

DCE is a method of obtaining subject preference that offers the ability to directly capture the effect of a product attribute on subject preferences. Mathematically it is a quantitative technique for obtaining individual preferences. It enables researchers to discover how people value the selected attributes of a program, product or service by asking them to indicate their choice about different hypothetical alternatives [13]. The techniques used to obtain judgment preferences have generally emerged in order to understand subject or consumer demand for new product attributes with which they are already familiar. A new product that is under development with variable attributes is an ideal option to experiment with a group of people to recognize the most marked preference for the consumer or consumers.

DCE's require respondents to declare their choice on sets of hypothetical alternatives. Each alternative is described by various characteristics, known as attributes, and the responses are used to infer the value assigned to each attribute. Compared to other established preference techniques that require the individual to rank or rate the alternatives, a DCE presents a reasonably simple task and one that more closely resembles a real-world decision [13]. Currently, we find recent works that involve DCE for the subject's preference with representations in VR in Landscape and Urban Planning [17], bottle design [24], quantification of symmetry, parallelism and continuity for 3D product representations [23], among others.

2.4 Multinomial Logit Model

Multinomial Logit Model is a member of the family of Generalised Extreme Value family models, and is one of the most used models forms [5]. While Luce was the first to derive the Logit formula [9], later Marschak showed that the model is consistent with utility maximisation [14] and Mc Fadden [15, 16] showed that the form of the Logit formula necessarily implies the use of the type I extreme value (Gumbel) distribution for the unobserved part of the utility. There are multiples approaches leading to the derivation of the Logit choice

probabilities. Train uses explicit integration of the multivariate cumulative distribution of the different $\epsilon_{j,n}$ for $j \neq i$ over the distribution of ϵ_i [22]. The Multinomial Logit choice probability for alternative i and decision-maker n is given by:

$$P_n(i) = \frac{e^{\beta_{i,n}}}{\sum_{j=1}^{I} e^{\beta_{j,n}}}$$

where the fact that the choice probabilities no longer involve the error terms ϵ_n means that the model can be estimated and applied without the use of simulation.

The mixed logit model is defined on the basis of the functional form for its choice probabilities. Through mixed logit we can calculate the utility U that person n obtains from alternative j in choice set J be denoted in the usual way as:

$$U_{nj} = \beta_{n'} x_{nj} + \epsilon_{nj}$$

where x_{nj} is a vector of observed attributes, β_n is a corresponding vector of utility coefficients that vary randomly over people, and ϵ_{nj} is a random term that represents the unobserved component of utility. The unobserved term ϵ_{nj} is assumed to be distributed in extreme value. Under this assumption, the probability that person n chooses alternative i, conditional on β_n, is the logit formula:

$$Q_{ni}(\beta_n) = \frac{e^{\beta_n x_{ni}}}{\sum_{j \in J} e^{\beta_n x_{ni}}} \tag{1}$$

For example, consider two different brands of coffee (attribute 1) offering the same two flavors (attribute 2) for a total of $2 - levels - per - attribute^{2-attributes} = 4$ alternatives available (full factorial). Assuming all other attributes equal (e.g. price), a DCE survey to measure the effect of brand and flavor on consumer preferences could consist of subjects choosing the coffee they like the most among up to (4-stimuli/2-options)= 6 choice sets with different combinations of two alternatives (full profile). The information provided by respondents is used to measure the effect of each attribute on subjects stated choices by means of binary response regression models [22, 8].

3 METHODOLOGY

3.1 Study Procedure

For the experiment, the Human Centered Design Lab was modified to guarantee a safe distance between subject and instructor. All furniture was removed and two desks were left, providing extra space for the subject and instructor. The subjects of the experiment had privacy and ample space for the development of the experiment as shown in Figure 4. Further, a dividing wall was placed between the subjects and the experiment instructor to minimize the risk of Covid-19 transmission. The experiment procedure was submitted to the campus Institutional Review Board (IRB). The detailed information of the experiment was submitted for evaluation. Once IRB approval was received, focus shifted to subject recruitment, which consisted of sending emails through the campus mass email system. Subjects interested in participating completed a form indicating their name, email address, study area, gender, age, and VR and CAD proficiency. A total of 228 subjects completed the form, of which 37.9% belonged to Non-Engineering Disciplines, 31.3% to Mechanical Engineering and 30.8% to Other Engineering Disciplines. Of those 228 subject, 108 were selected to participate in the experiment. Their selection was based on their expertise with VR and CAD as shown in Table 1. After subjects completed the recruitment form, they were added to Table 1 and were scheduled to go to the laboratory facilities. The order of the experiment (starting with VR or CAD) is defined by subject number, as shown
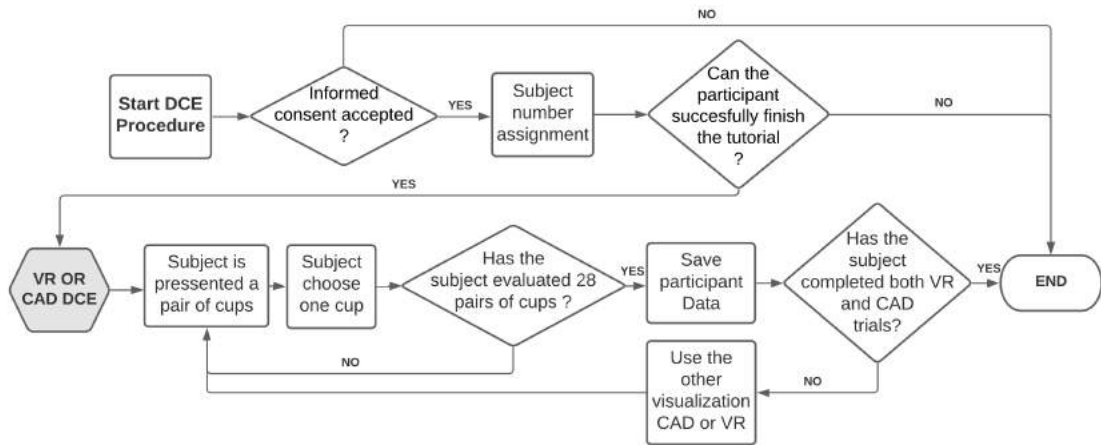
Figure 2: DCE Study Procedure.

in Table 1. The experiment consists of all possible combinations of the coffee cups from Table 2. The DCE procedure is described in Figure 2 and explained in more detail through this section.

The experiment recorded each subject's choices. The data was then loaded into a Matlab script [22] that calculated the height, width and curvature utility β_n for each person in the respective environment (VR or CAD). The following sections provide more details of the study.

3.1.1 Subject Recruitment

For this study, subjects interested in participating needed to fill out a recruitment survey which asked basic demographic information (e.g. gender), study area, and previous experience with VR and CAD. Both questions regarding experience aimed to determine whether the experiment would be the subject's first time using the technology, whether they already had some experience with it, or whether they were a regular VR or CAD user.

The objective of classifying the subjects was to have a balanced experiment, starting from the premise that a person with a study area of mechanical engineering would not have the same understanding of CAD compared to a person with a non-engineering background. Once the participants completed the recruitment survey, Table 1 was used to insure an even gender split for participants. Later, they were further classified with a number which indicates their experience with VR and CAD. In this way, six groups of nine were made for women and six for men, for a total of 108 participants. The subjects that participated in the experiment had to have normal or corrected-to-normal vision, and were given a $10 gift card for their time.

3.1.2 Cup Parametric Model

A cup parametric model was made in Autodesk Inventor 2020 CAD software. The main purpose of its creation was to make a parametric model that could generate all 8 cup designs, varying on three parameters (height, radius and curvature). The first thing we did was a cup model with completely flat edges, that is, without curvature. In this way, through the revolution command, we could generate an 'L' shape inside the cup without a handle. We made the measurements of the cup and generated its properties from three independent factors (height, radius and curvature). After having generated the inside of the cup, the handle was generated. It was

**Table 1**: Experiment Fixed Factors.

GENDER	CAD	VR	NAME	#	SUBJECT NUMBER	DATE	ORDER
F	First Time	First Time		1	1111		VR
		Some Experience		2	1121		
		Regular VR User		3	1131		
	Some Experience	First Time		4	1211		
		Some Experience		5	1221		
		Regular VR User		6	1231		
	Regular CAD User	First Time		7	1311		
		Some Experience		8	1321		
		Regular VR User		9	1331		
M	First Time	First Time		10	1112		CAD
		Some Experience		11	1122		
		Regular VR User		12	1132		
	Some Experience	First Time		13	1212		
		Some Experience		14	1222		
		Regular VR User		15	1232		
	Regular CAD User	First Time		16	1312		
		Some Experience		17	1322		
		Regular VR User		18	1332		

done through a bezier curve and then, through the sweep command, we were able to obtain the solid of the adjusted handle. It was parameterized depending on the height, radius and curvature of the cup to maintain continuity in the CAD model. Figure 3a shows the parametric model used in this work, wherein the height, radius and curvature with predetermined values from Table 2 are presented. The handle position adapts its shape as described previously.

3.1.3 Parameters Value Selection

When examining cups available in the marketplace, their distinctions primarily lie in size, handle shape, and decorative design such as images or inspiring/funny texts. However, for this study, the focus is solely on the external structure of the cup. Thus, the image or message on the cup is not being considered. The parameters being studied are height, radius, and curvature because they directly affect the external shape of the cup. Each of these parameters contained two levels, high and low, with values in mm for each of them. Eight cups were developed with this information by combining the levels for the parameters of height, radius, and curvature. The levels for the parameters were based from a group of off-the-shelf cups so they seem familiar to the subjects.

Figure 3b shows the eight possible cups with which the DCE study will be carried out. Here, subjects would be able to choose which cup they liked the most. In the experiment, the subject's preference was identified by analyzing the factors of the height of the cup, its radius and curvature. These factors had two levels associated to them: high and low, which took binary values with zeros being the low levels and ones the high levels.
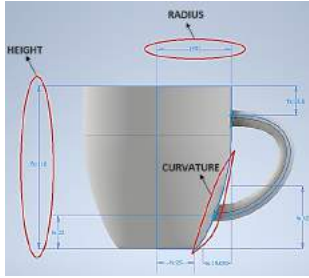
(a) Parametric model of the cup used in the experiment.
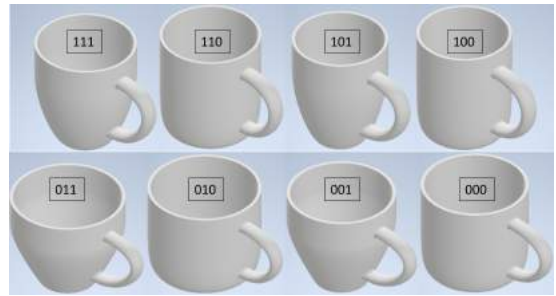
(b) Cups Designs identified with levels from Table 2

**Figure 3**: Parametric model and generated cup designs.

Table 2: Definition of parameters and levels for 8 cups.

N	Height (mm)	Radius (mm)	Curvature (mm)	Levels
1	85	45	0	000
2	85	45	42	001
3	85	50	0	010
4	85	50	42	011
5	110	45	0	100
6	110	45	42	101
7	110	50	0	110
8	110	50	42	111

The subjects participating in the experiment would be able to see two cups at the same time. All possible combinations of pairs of cups, 28 sets, are shown to each subject.

3.1.4 Experiment Setup

The experiment took place at the Human Center Design Laboratory in the mechanical engineering department of the University of Puerto Rico at Mayagüez campus. The laboratory representatives completed the CITI Program, which provides training for students conducting research involving minimal risk with people before starting the experiment. The experiment information was submitted to the IRB, which approved the study protocol on February 1, 2021. The laboratory setup complied with government health regulations for COVID-19, featuring two desks separated by over six feet, with a barrier between them to ensure privacy for the test participants. The experimental configuration is shown in Figure 4. Participants used an Intel® Core™ i7-6800K processor with 16 GB installed RAM, 1 TB disk storage, and an NVIDIA Geforce GTX 1080 graphics card Pascal™. For VR immersion, participants used the Oculus Rift S HMD, along with a headset cable, two touch controllers, an Ares M1 gaming keyboard, speakers, and a conventional mouse.
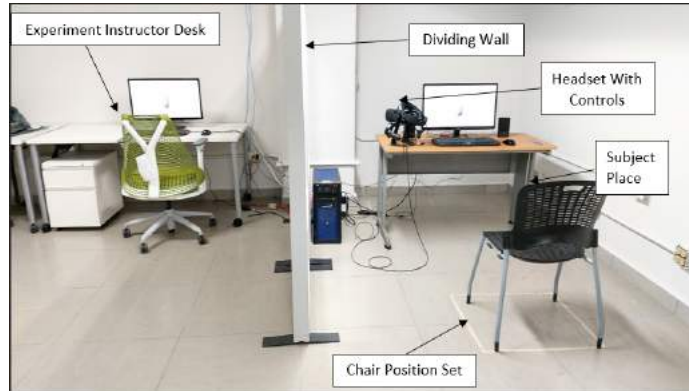
Figure 4: Laboratory experiment setup.

3.1.5 Environment Construction

For the environment construction, Unity (game engine software) was used because it provided resources that expedited the development process. For instance, the use of the Unity Asset store enabled us to quickly access prefabricated assets which contain scripts, 3D models, and configurations. By using the free Oculus Integration package from the Asset Store, it was possible to quickly incorporate the use of the Oculus Rift and the Touch controllers into the Unity Environment. Once this package was appropriately installed to Unity, the Rift headset became the main camera allowing users to see the virtual surroundings just by moving their heads. Additionally, it recognizes the Oculus Touch controllers as inputs, which allows the users to move the controllers with their hands causing 3D models of hands to move in the virtual environment. These hand models have animations for when the user is pressing buttons on the Touch controllers which emulate hand movements such as grabbing virtual objects and pointing. Using the Oculus Integration asset early in the development phase helped in the testing and debugging of the entire environment as it allowed developers to see what participants would see to make sure aspects of scale and interactions all worked appropriately.

In terms of building the actual environments, it was decided to create virtual scenes in which the object of study would seem natural. In the case of this experiment, cups were used throughout the study. For the virtual reality environment, it was decided that a virtual coffee shop would best represent a real-life situation. The coffee shop virtual model was created so that the colors could be altered, and the tables moved around to better suit the experiment needs. For the 2D environment, we emulated a CAD environment by observing the colors, tabs, and movements within real CAD software. This creates a difference in setting between VR and CAD. We acknowledge that the CAD users did not interact with the model in the context of a coffee shop, as was done with the VR users. However, the nature of each tool is such that in VR, an environment is chosen for visualization, while in CAD, such an option is not commonly available, and the models are explored in a contentless setting. Therefore, we maintained consistency with what each tool provides. While this limitation may affect the generalizability of our results to other settings, we believe that our findings still hold relevance for the comparison between VR and CAD in terms of user experience and design feedback.

The cups were created in CAD software and imported as 3D models into Unity. Additionally, tutorials for the subjects were developed and included for both environments. Both tutorials included slides that were made using PowerPoint and imported into Unity as images. The virtual reality tutorial made use of all the buttons and interactions that were used during experimentation to introduce participants to the Touch controller. This tutorial included various challenges which could not be skipped without completion. For the CAD environment an introductory video was filmed and added into Unity.

Even though the Asset Store provided some basic code, the project required new code to be written for specific interactions and data acquisition. The code was written in Virtual Studio, and it allowed for the most crucial functions of the Unity experimentation environments, such as allowing the participants to select their favorite cups, saving that information in spreadsheets for each participant, and randomizing the next cups that the participant would have to evaluate.

4 CATEGORICAL DATA ANALYSIS

A total of 108 subjects participated in the experiment, 54 men and 54 women. The total number of observations were: 108 subjects $\times$ 2 sets of cups $\times$ 28 matches = 6,048, this is the total number of data collected in the experiment. The null hypothesis put forward was that, for simple objects, the type of representation would not influence the subjects' decision. In the experiment we have significant p-values to the analysis of β's, background and subjects' decision time. For each subject, a utility beta (β) was obtained for each cup factor (β height, β radius and β curvature), 108 subject's $\times$ 3 cups factors. The β's were estimated through mixed logit estimation by hierarchichal bayes procedure [22], this makes it possible to determine how strong each quantification is in relation with subject judgments of the level of each cup's factors, in terms of utility estimates β. The Unity code output contains the matrix design that feed the Matlab Train code [20]. This way the categorical data was analyzed with Matlab software [21, 22].

4.1 Paired T-Test of β's

After obtaining the β's estimated for each subject, a pairwise t-test was performed to compare CAD vs VR. This comparison was done through the analysis of the β's results of CAD and VR. Table 4 contains the information.

4.1.1 Male Subject Analysis

Fixed and random factors were taken into account for analysis of the male subjects' data as shown in Table 3. The subjects have the following distribution : 24 mechanical engineering students, 21 students from other engineering disciplines, and 9 students from other non-engineering majors.

Table 3: Experiment Male Subjects Factor Information.

Factor	Type	Levels	Values
AGE	Random	17	19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 36, 38
STUDY AREA	Random	3	Mechanical Engineering, Non Engineering Disciplines, Other Engineering
ORDER	Fixed	2	CAD, VR
VR PROFICIENCY	Fixed	3	First Time, Regular VR User, Some Experience
CAD PROFICIENCY	Fixed	3	First Time, Regular CAD User, Some Experience

Paired T-test: β *Height CAD*, β *Height VR*

There is a significant difference between β *Height CAD* and β *Height VR*, this may be because, in VR, it is easy to appreciate and compare the heights of the two cups that are being compared, but in CAD it is more complicated, much more so when the subject interacts with the cups, and by enlarging them, loses reference to the cup in its original form. Figure 5a shows us an interval plot of the β's for *Height CAD* and *Height*

Table 4: Pair T-test Results.

| β	Mean	SD	T-value	P-value	Data
β Height CAD	-0.902	1.797	$= 7.86$	< 0.0001	Male
β Height VR	-1.422	1.310			
β Radius CAD	-6.031	1.851	$= 52.56$	< 0.0001	
β Radius VR	-15.041	3.108			
β Curvature CAD	-12.286	7.004	$= -15.75$	< 0.0001	
β Curvature VR	-8.766	6.233			
β Height CAD	-2.423	3.217	$= 4.89$	< 0.0001	Female
β Height VR	-2.672	2.843			
β Radius CAD	-9.035	2.982	$= -11.12$	< 0.0001	
β Radius VR	-5.077	3.207			
β Curvature CAD	-4.901	4.158	$= 0.50$	$= 0.618$	
β Curvature VR	-5.261	4.791			
β Height CAD	-1.081	2.207	$= 14.81$	< 0.0001	All
β Height VR	-1.581	1.856			
β Radius CAD	-10.278	3.860	$= -22.84$	< 0.0001	
β Radius VR	-4.654	2.833			
β Curvature CAD	-8.251	5.349	$= -8.02$	< 0.0001	
β Curvature VR	-5.703	3.909			

VR. Here, there is a change with respect to type of environment, after which the data suggests that male subjects in CAD and VR representations have a tendency to choose the cups with less height. However the utility β *Height VR* given to the height of the cup is stronger in the VR environment. This is likely, in part, because the proportion of the cups in VR is not lost, that is, in the interaction with the cups in VR both cups are always in the same scale. On the other hand, in CAD representation, they could move the cup closer or further away, thus losing the original proportion of cup setup.

**Paired T-test:** β **Radius CAD,** β **Radius VR**

In Figure 5b we can see that the difference is significant (Table 4 confirms it) and when compared with Figure 5a the gap between CAD and VR is much more visible for the Radius factor. Male participants in the experiment tended, on average, to choose cups with the low value for radius in CAD and VR, however the utility β *Radius VR* is significantly stronger than the CAD counterpart. This difference can be also due to the fact that the Radius proportion between the two cups shown in VR is not lost, in the interaction with the cups in VR both cups are always in the same scale.

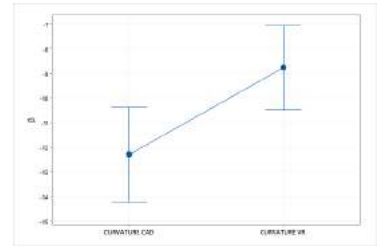**Paired T-test:** β **Curvature CAD,** β **Curvature VR**

There is a significant difference between β *Curvature CAD* and β *Curvature VR* (see Table 4). Figure 5c shows the interval plot of the Curvature factor for male subjects in CAD and VR. Unlike the previous two interval
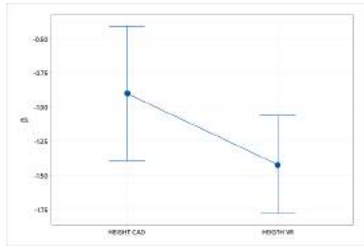
(a) Interval plot of β Height CAD, β Height VR.
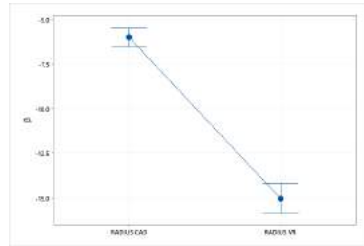
(b) Interval plot of β Radius CAD, β Radius VR.

(c) Interval plot of β Curvature CAD, β Curvature VR.

Figure 5: Male subject's β comparisons.

plots for Height and Radius factor, the CAD environment has a higher magnitude β. We can say that both for VR and CAD, the male subjects prefer cups without curvature. However, in CAD, the utility is stronger. This can be in part because the curvature factor, different from height and radius, can be observed in both CAD and VR without loosing the perception of the curvature while exploring the cup in CAD or VR. Since, in CAD, the perception of the other factors is morphed while moving the cups, subjects seemed to mostly use the curvature as a decision factor.

4.1.2 Female Subject Analysis

Fixed and random factors were taken into account for the analysis of the female subjects' data, as shown in the Table 5. The subjects have the following distribution: 13 mechanical engineering students, 14 students from other engineering disciplines, and 27 students from other non-engineering majors.

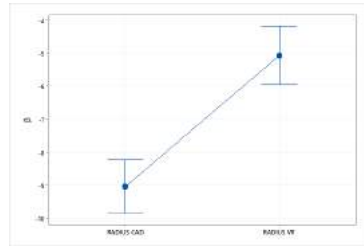**Table 5**: Experiment Female Subject Factor Information

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Factor	Type	Levels	Values
AGE	Random	15	19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 31, 32, 34, 35
STUDY	Random	3	Mechanical Engineering, Non Engineering Disciplines, Other Engineering
ORDER	Fixed	2	CAD, VR
VR PROFICIENCY	Fixed	3	First Time, Regular VR User, Some Experience
CAD PROFICIENCY	Fixed	3	First Time, Regular CAD User, Some Experience

**Paired T-test: β Height CAD, β Height VR**

There is a significant difference between β Height CAD and β Height VR, thus rejecting the null hypothesis. Figure 6a shows the interval plot and we can see the significant differences between CAD and VR. This behavior is similar to the male subjects and is likely, in part, because the proportion of the cups in VR is not lost, as explained previously.
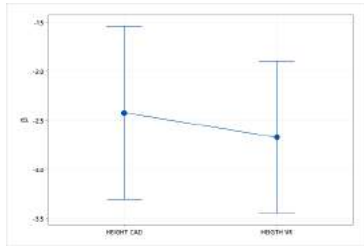
(a) Interval plot of β Height CAD, β Height VR.

(b) Interval plot of β Radius CAD, β Radius VR.
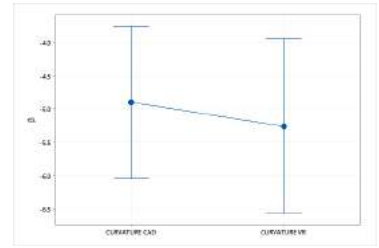
(c) Interval plot of β Curvature CAD, β Curvature VR.

Figure 6: Females subjects β comparisons.

Table 6: Experiment All Subjects Factor Information.

Factor	Type	Levels	Values
GENRE	Fixed	2	Female, Male
AGE	Random	18	19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 35, 36, 38
STUDY	Random	3	Mechanical Engineering, Non Engineering Disciplines, Other Engineering
ORDER	Fixed	2	CAD, VR
VR PROFICIENCY	Fixed	3	First Time, Regular VR User, Some Experience
CAD PROFICIENCY	Fixed	3	First Time, Regular CAD User, Some Experience

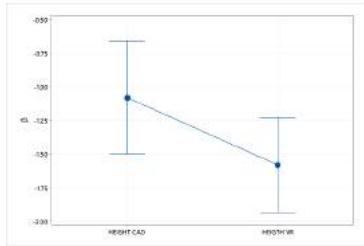**Paired T-test: β Radius CAD, β Radius VR**

Also here there is a significant difference between β Radius CAD and β Radius VR (see Table 4). In Figure 6b we can see that in comparison with β Height CAD and β Height VR, the differences for the radius factor of the cup is more noticeable and the slope is inverse. Female participants in the experiment tended, on average, to cups with the low value for radius, however, the radius factor was more important in the CAD environment than in the VR environment.

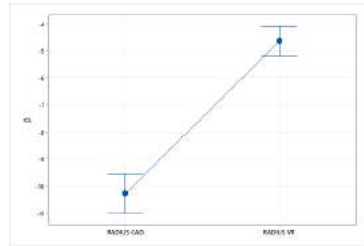**Paired T-test: β Curvature CAD, β Curvature VR**

The results of the Pair T-test did not yield statistical significance (refer to Table 4). As evidenced by Figure 6c, the boxplot displaying the differences in curvature factor illustrates that Female subjects did not exhibit significant differences in curvature preference between CAD and VR. Consequently, it can be inferred that the preference of female subjects towards the curvature of the cups remained consistent across both environments. Notably, the female participants' preference leaned towards low curvature cups, regardless of the environment.
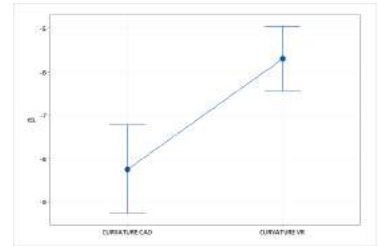
4.1.3 All Subjects Analysis

The present analysis combines the two preceding gender-segregated datasets.

(a) Interval plot of β Height CAD, β Height VR.

(b) Interval plot of β Radius CAD, β Radius VR.

(c) Interval plot of β Curvature CAD, β Curvature VR

Figure 7: All subjects β comparisons.

Paired T-test: β Height CAD, β Height VR

Similarly to Males and Females, the null hypothesis was rejected (see Table 4) as there were significant differences between β Height CAD and β Height VR, which may be attributed to the ease of comparing cup heights in VR as opposed to CAD, as demonstrated by the interval plot in Figure 7a where both representations tended to prefer lower height cups, albeit with significant differences between CAD and VR across all subjects.

Paired T-test: β Radius CAD, β Radius VR

The study found significant differences between CAD and VR for the radius factor (see Table 4). Subjects chose cups with smaller radius in both environments, but the utility for radius was higher in CAD (see Fig. 7b). This difference was more noticeable compared to the height factor. This could be because radius is a predominant factor in CAD for making preference decisions.

**Paired T-test: β Curvature CAD, β Curvature VR**

The combined male and female datasets show a significant difference in the pair t-test of curvature between CAD and VR (refer to Table 4), which is not observed in the female dataset alone. The trend in Figure 7b is reflected in Figure 7c. The study suggests that curvature is a more dominant factor for subjects in the CAD environment when making preference decisions compared to the VR environment.

4.2 Subject Background Analysis

In section 4.1 we were able to appreciate how height, curvature and radius factors impact results, and compared their impact between CAD and VR environments. In this section we will see how a subject's background impacted results in all, male and female subjects. No significant data and factors were obtained for male subjects, however significant factors were obtained when analyzing for all subjects and female subjects.

Significant Female Subject Results

Performing analysis of variance, we find that in the β Radius CAD factor in the study area the p-value is at borderline of alpha of 0.05. The study shows a p-value $= 0.065$ (see Table 7), which suggests that the study area of the subject impacts the β Radius CAD factor. Figure 8 shows the direction in which the mean of the β's in each level of destination area changes with respect to the β Radius CAD factor. From the boxplot we can infer that other engineering students rely much more on the radius factor to choose their preferred coffee cup than subjects within the field of Mechanical Engineering, and those from a non-engineering background.
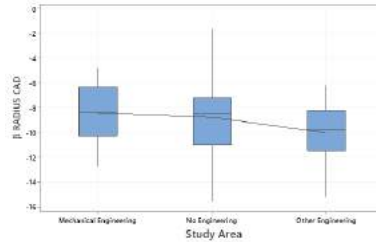
Figure 8: Boxplot β *Radius CAD*, Study Area Female Subjects

Significant All Subjects Results

The analysis of variance for all subjects with the β *Radius CAD* factor is presented in Table 8. The results suggest that the VR proficiency of the subjects has a significant impact on the β *Radius CAD* factor, indicating that the subject's decision regarding the radius in the CAD environment is influenced by their VR proficiency. Table 9 shows that the VR proficiency of the subjects somewhat impacts the β *Radius VR* factor, with a p-value of 0.056. The radius factor is the most affected by the participants' VR expertise among the female subjects and all subject categories. Figure 9 illustrates the behavior and direction of the mean levels of the VR proficiency factor. It shows that first-timers and some-experience subjects have a strong negative utility, whereas regular VR users have much less negative utility. This could be because more experienced VR users are better able to utilize the tools provided by the technology to effectively visualize the cup and make a decision, while first-timers and some-experience subjects rely heavily on single metrics, resulting in less distributed utility between factors.

## 4.3 Time Paired T-test Analysis Between CAD and VR

To analyze the times of all the subjects that participated in the experiment, we performed a paired T-Test to compare the decision time in CAD vs VR. Among the results, we found that female subjects take less time to make their choices than male subjects, we also found that, for male subjects, the choice times were not significantly different for CAD vs VR.

Table 7: Analysis Of Variance For *Radius CAD*, Using Adjusted SS For Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
AGE	14	131.714	133.629	9.545	1.21	0.313
STUDY	2	39.363	46.751	23.375	2.97	0.065
ORDER	1	2.027	4.609	4.609	0.59	0.449
VR PROFICIENCY	2	25.158	14.982	7.491	0.95	0.396
CAD PROFICIENCY	2	21.603	21.603	10.801	1.37	0.267
Error	32	251.463	251.463	7.858		
Total	53	471.328				

Table 8: Analysis Of Variance For β *Radius CAD*, Using Adjusted SS For Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
GENRE	1	3.20	22.76	22.765	1.66	0.201
AGE	17	317.35	313.80	18.459	1.34	0.187
STUDY	2	25.23	56.99	28.496	2.08	0.132
ORDER	1	17.54	17.99	17.989	1.31	0.256
VR PROFICIENCY	2	91.70	99.31	49.654	3.62	0.031
CAD PROFICIENCY	2	13.42	13.42	6.711	0.49	0.615
Error	82	1125.44	1125.44	13.725		
Total	107	1593.88				
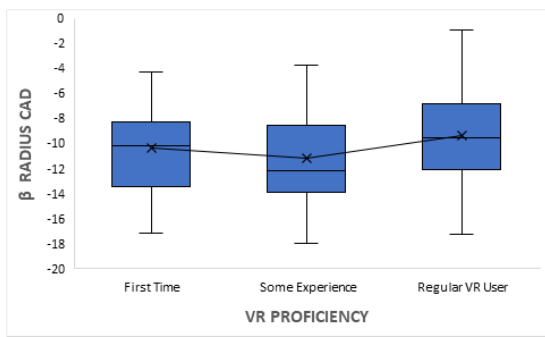
(a) Boxplot β *Radius CAD*, *VR Proficiency*
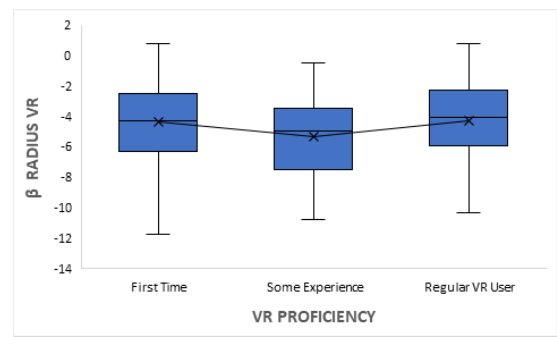
(b) Boxplot β *Radius VR*, *VR Proficiency*

Figure 9: Boxplot's for VR Proficiency.

Female and male decision time comparisons

With a mean decision time in CAD of 9.309 seconds and standard deviation of 7.725, the female subjects made decisions slightly faster than male subjects, who clocked-in a mean decision time in CAD of 10.112 seconds, with a standard deviation of 9.779. In VR the female subjects had a mean decision time of 7.725 seconds with a standard deviation of 6.951, the male subjects, in turn obtained a mean decision time for VR of 9.696 seconds with a standard deviation of 8.995. These results show that choice times in VR were less than the times in CAD for both male and female subjects. This could be due to the fact that interaction in VR with the cups is more realistic and, therefore, when viewing the cups, subjects interact with it for less time in VR than in CAD.

We recorded a mean of 1.584 with a standard deviation of 9.595 for the estimation of paired difference for women. The data yielded a T-value of 6.42 and a P-value less than 0.0001, indicating a significant difference between the times taken in CAD and VR for female subjects. This finding is below our level of significance and suggests that realistic visualization in VR reduces decision-making time significantly for female participants. This is desirable as consumers typically spend a short amount of time choosing a product.

Table 9: Analysis Of Variance For β *Radius VR*, Using Adjusted SS For Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
GENRE	1	4.325	0.421	0.4211	0.05	0.823
AGE	17	96.253	123.920	7.2894	0.87	0.604
STUDY	2	7.740	13.820	6.9101	0.83	0.440
ORDER	1	10.069	10.103	10.1033	1.21	0.274
VR PROFICIENCY	2	46.716	49.725	24.8626	2.98	0.056
CAD PROFICIENCY	2	10.516	10.516	5.2582	0.63	0.535
Error	82	683.366	683.366	8.3337		
Total	107	858.985				

All subjects time

The study compared CAD and VR choice time for all subjects using a paired T-test. CAD choice time averaged 9.711 seconds with a standard deviation of 9.553, while VR choice time averaged 8.711 seconds with a standard deviation of 8.097. The paired T-test yielded a T-value of 5.68 and a P-value less than 0.0001, indicating significant differences between CAD and VR choice time. Overall, the results suggest that VR significantly reduces choice time compared to CAD. As discussed previously, a shorter decision-making time is desirable.

4.4   Time Changes Along the Experiment

During the experiment, the election times behaved as a decreasing curve with respect to the number of confrontations. Each subject made 28 decisions for CAD and VR, respectively. Figures 10, 11 and 12 show how the election time decreases as the confrontations progress. The times in CAD are slightly higher than those in VR. Once the subjects compare the first set of cups, they become familiar with the environment in which they find themselves and it is easier for them to make the choice. This causes time to decrease as the number of confrontations increases.

It is important to note that to mitigate the potential learning effects, we took several measures. Firstly, we counterbalanced the order of the evaluations across participants, which ensured that half of the participants evaluated the CAD before the VR, and the other half evaluated the VR before the CAD. This helped to minimize the effect of familiarity or fatigue due to repeated evaluation of the same model. Additionally, we provided participants with sufficient practice time via a tutorial for each environment before the evaluation to familiarize themselves with the task and the environment. This helped to reduce the potential impact of initial learning effects.

5   DISCUSSIONS AND LIMITATIONS

Based on the results obtained, it was possible to verify that, even for a simple product, there are significant differences in the effect that its medium of representation has on the subject. This means that the null hypothesis of this study is rejected. Specifically, the realistic and immersive VR environment was found to significantly impact the preference of a subject. Therefore, designers should take this into consideration when selecting an environment for subject preference studies.

The analysis of subject background revealed significant differences in all subjects in relation to the radius factor and the subjects' proficiency in VR. These findings suggest that when employing novel subject study environments, it is important to investigate the background of the subject, as it may explain their behavior with
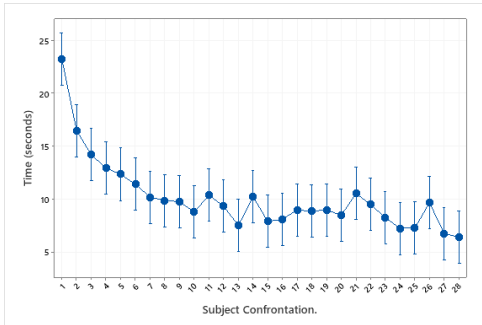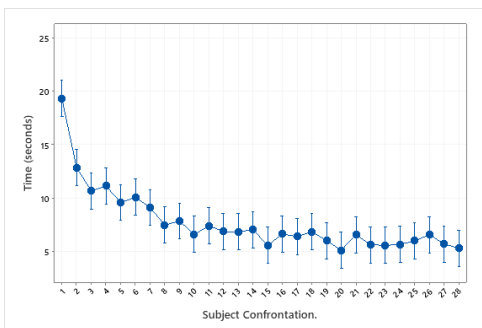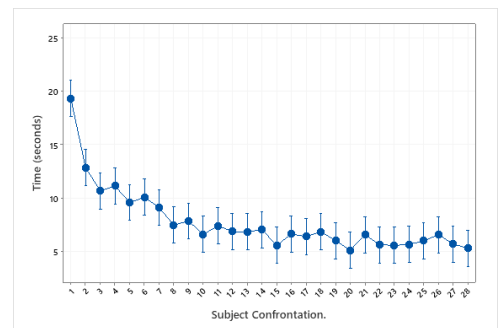
(a) Time vs Confrontations CAD
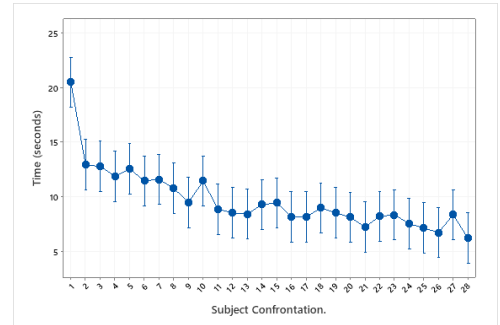
(b) Time vs Confrontations VR

Figure 10: Time vs Confrontations Male Subjects.

(a) Time vs Confrontations CAD

(b) Time vs Confrontations VR

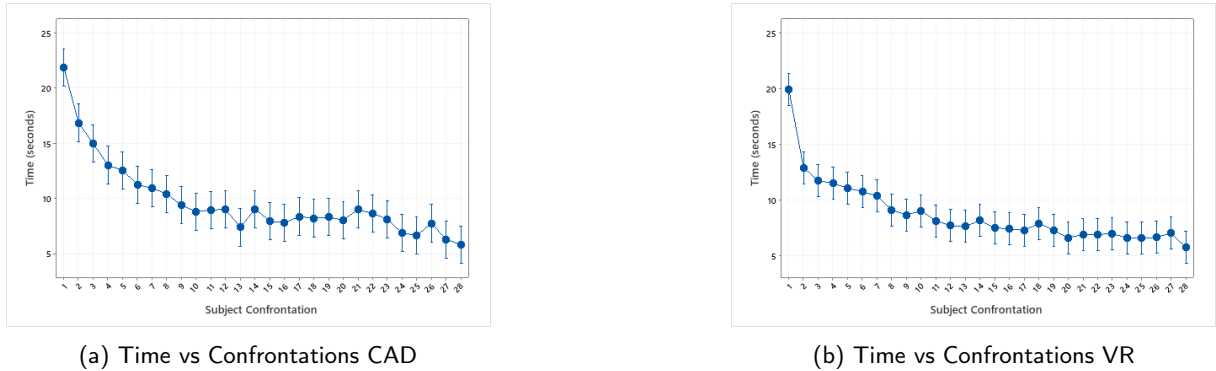**Figure 11**: Time vs Confrontations Female Subjects.

respect to certain features. Designers can gather background information through a survey or by selectively testing subjects with specific desirable backgrounds to improve their subject preference models.

In general, the data revealed that subjects could perceive product characteristics differently in VR and CAD environments, even when the product is the same. Notably, differences in feature visualization were significant, with VR being favored due to its ability to better facilitate comparisons between product attributes. Specifically, in CAD, it was difficult to compare the radius of one cup with respect to another, which resulted in significant differences in the cup radius factor depending on whether CAD or VR was used.

One limitation of the study is that the VR environment simulated a coffee shop while the CAD environment resembled a CAD software interface, as discussed in section 3.1.5. Another limitation is the sample size, as although 108 subjects is a good size, having more subjects could further strengthen the results, but was not feasible due to time and budget constraints. Additionally, since the study focused on coffee cups, the generalization of the results is limited to this product, and further studies on different product types are necessary to establish more comprehensive trends. Nonetheless, these results provide a preview of trends that warrant further investigation.

6 CONCLUSIONS AND FUTURE WORK

This study demonstrates how the visual features of a simple product, such as height, radius, and curvature, can be used to gauge a subject's preference through Discrete Choice Experiment (DCE). We obtained the

(a) Time vs Confrontations CAD

(b) Time vs Confrontations VR

Figure 12: Time vs Confrontations All Subjects.

utility beta of subject's judgments and the probability of choice for each subject for each factor in both VR and CAD environments. The primary contribution of this work is to capture the decision-making process of the subject and determine the extent to which the visualization environment influences it. Our findings suggest that design characteristics such as the cup's height, radius, and curvature may impact the subject differently in VR compared to CAD. This is valuable information for the field of design, and the proposed methodology can be replicated to gain a better understanding of the effects of visualization mediums on decision-making.

In future studies, more complex products such as cars or industrial machinery will be examined. Other types of representations, such as AR or rapid prototyping, will also be considered to compare tangible and virtual representations. Additionally, factors like color, shape, construction materials, and surface finish will be taken into account.

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