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Affordable 3D VR Technology for Sensible Design
－An Approach to Designing an End-User Oriented Service Space

3D VR 기술을 이용한 서비스 공간의 감성적 디자인

So-Yeon Yoon*† ·Johye Hwang**·Jung A Park***

윤소연*†·황조혜**·박정아***

Department of Architectural Studies, University of Missouri-Columbia*

미주리 주립대학교 건축학과*

College of Hotel & Tourism Management, Kyung Hee University**

경희대학교 외식경영학과**

Industrial Technology Research Institute, Hannam University***

한남대학교 산업기술연구소***

Abstract

Today's Virtual Reality(VR) technology has become considerably more affordable and sophisticated with rapidly advancing computer technology. Photo-realistic visual representations along with real-time interactivity are now achievable without special programing knowledge and expensive equipment. The purpose of this paper is to establish how simple, credible user testing methods based on VR simulations can be utilized to improve design decision making towards more sensible design solutions for end-users. Results of a case study demonstrate the value of potential user-testing feedback in a simulated 3D virtual service space, i.e., restaurant interior. User feedback from the VR simulation includes preferences in table location, privacy, and values of seating preferred tables. A new design framework incorporating an empirical testing method for service spaces is presented. The overall design process, the development of the VE, and the user testing method and findings are discussed. This study provides useful guidances for future efforts in the areas where such technology may benefit to understand end-user feedbacks in design process.

Keywords : Virtual Reality, Simulation, Evidence-based, User-centered, Service Space, Spatial configuration

요 약

최근 가상현실 시뮬레이션 기술은 컴퓨터 테크놀로지의 급속한 발달과 더불어 시각적 표현과 인터랙션의 성능은 정교화 되는 동시에, 고급 장비나 전문 지식에 의존하지 않고도 사실적인 구현이 가능한 단계까지 발전해 왔다. 본 연구는 저가의 비용으로도 가능한 가상현실 시뮬레이션 테크놀로지를 바탕으로, 시각적 현실감이 뛰어난 시뮬레이션으로 서비스 환경을 구현하여 제시함으로써 실제사용자 즉, 엔드유저의 감정적인 반응을

† 교신저자 : 윤소연 (미주리 주립대학교 건축학과)
E-mail : YoonS@missouri.edu
TEL : +1-573-882-7542
FAX : +1-573-884-6679

파악하고, 그러한 과정을 기존의 디자인 프로세스에 접목하는 방안을 제안하는데 그 목적이 있다.
본 논문에서는 실제 레스토랑 디자인 프로젝트의 사례를 통해 가상현실 테크놀로지를 사용한 시뮬레이션의 구체적인 개발과정 및 적용과정을 살펴보았다. 이를 통해 사용자 경험에 관한 데이터를 수집하고 분석하는 과정 그리고 시뮬레이션을 통한 결과 적용 시 고려해야 할 사항에 대해서 소개하고 있다. 본 연구는 사용자의 감정적인 반응이 중요시 되어야 하는 디자인 분야에 3차원 가상현실 시뮬레이션이 도입될 경우 유용한 지침을 제공할 수 있으리라 기대한다.
주제어 : 가상현실, 시뮬레이션, 사용자 중심, 환경디자인, 서비스 공간 디자인

1. Introduction

Today's advanced three-dimensional(3D) Virtual Reality(VR) technology offers a new opportunity for designers who are interests in capturing end-users' responses during the design process. VR is considered as an effective substitute for physical prototypes of built-environments as well as any 3D goods. Without expensive equipment, specialized software, or programming skills, high quality simulations have become possible at a much more affordable cost than the past.

Developing real-scale prototypes of products or environments for testing with real users can get substantially complicated. Especially, when the nature of the product is bulky or highly customizable, building an examinable prototype is seldom feasible regardless of the importance in understanding how end-users would take it. At the same time, it is also true that user testing has been exercised with real-scale mockups of built-environments for special cases in spite of the substantial costs, time and efforts involved to build. Three dimensional computer models developed in standard 3D Computer-Aided Design applications can be conveniently converted into interactive simulation to bring realistic spatial experience; design elements for functional and emotional responses from real users can be examined.

With a VR technology presented in this study, we propose an innovative design process integrating a user-testing method into the process as a rational approach to more sensible design to end-users in a service space.

Most designers value the importance of user experience. End-user satisfaction for commercial goods as well as service spaces is considered an important criterion for successful design. However, design decisions are often relying on the designer's prior experience with similar projects and/or the client's input, which is indirect, subjective, and possibly misleading. A realistically represented environment can offer the opportunity to bridge the gap between designers' assumptions and real users' responses to the environment. By conducting case-specific, empirical testing with users, designers can obtain useful information regarding how typical customers, especially for commercial interiors, interact with the environment. The "typical users" can report their responses, instead of articulating their needs and responses, which are rarely possible otherwise.

The goal of this study is to provide a framework for the design process model utilizing VR based user testing integrated through the process. The study presents a framework for designers as well as researchers interested in users' emotional responses to the design outcome utilizing readily available yet effective technology. Empirical findings from case-specific user testing, together with designers' professional insights, assure sensible design solutions with a greater chance of user satisfaction. Furthermore, accumulated knowledge from such empirical findings can make significant contributions to the advancement of the knowledge base in the design field, which enables designers to make more responsible design decisions in the future.

2. Background

2.1. Sensible Design for Servicescapes

Designing with users' perception in mind is not new. The term, *user-centered design* has been broadly used with a variety of methods under a broad philosophy across design fields. While there can be a spectrum of ways in which end-users affect the design process and outcome, the essence of user-centered design is the users' involvement in the design process. In other disciplines including architecture and interior design, *evidence-based design* is another term considered as an effort towards user-centered design. Evidence-based design, known as a design process that uses credible knowledge from research and practice(Hamilton, 2003) that often emphasizes user experience, has recently gained increased attention.

User experience can be viewed from two distinct dimensions: objective performance(functionality) and subjective satisfaction(emotional perception). The emphasis of the current study is on users' emotional perception on the design outcome via *sensible design.* The assumption can be easily made that highly functioning systems are supposed to make users feel good about using them while helping them work efficiently with fewer mistakes(Yoon, 2007). However, it is also important to note that numerous products that are highly effective and efficient were once developed and disappeared from the market because they were not emotionally accepted by end-users.

Despite the positive association between users' subjective satisfaction and a good performance, no matter how smart the product or the environment, a good design emotionally perceived by its users as "poor" is considered a "poor" design.

While functionality tests can be a costly yet irreplaceable part of most design domains, emotional aspects of user experience has been often secondary in spite of its significance. The focus of testing for sensible design should rather be on finding more satisfactory design outcomes than discovering performance problems. Performance attributes in spatial design can demonstrate how well the environment is designed for better performance with consideration for human-factor or safety.

Performance dimensions are far more critical than others for some environments including operating rooms or nurse stations where medical errors and patient falls are closely related to the spatial design. Emerging technology driven environments also require careful examination of new spatial needs and performance considerations.

For most service spaces, qualified design professionals with experience tend to come up with acceptable performances. However, sensible design for users are difficult to take into account for certain types of service spaces without end-users feedback. Previous studies have shown that 'servicescapes', physical environments of service spaces, play significant roles in customers' impression formation(Bitner, 1992). There are certain types of products and spaces that calls for more attention for sensible design. and it offers unique merits. Servicescapes are good examples where positive emotional reponses of end-users make substantial contributions to service values.

2.2. Design Mockups for User Testing

Design decision makers tend to have their own images of the design and it use that can be different from end-users' perception of the design outcome. User testing is the very means for the designer to keep his or her own image of the design object from being the design goal. The users' subjective responses to designed spaces can assure the emotional quality of design outcomes beyond their reasonable functionality.

If real-size, working mockups are available, subjective emotional responses are normally assessed by simple questionnaires or interviews. One of the most common methods is users' ratings. Spatial designs can be tested to compare the rating responses among different design options with interactive mockups. Data and knowledge derived from nonacademic user testing can inform practitioners for useful yet immediate design decisions. However, with proper documentation and attention to the issues of credibility－e.g., reliability and validity, user testing can foster more responsible design for both design practitioners and researchers by enabling them to base their decisions on empirical evidence.

Despite the substantial costs involved, full-scale physical mock-ups have been adopted as the best solution to assure the quality design solutions. There are special types of projects that benefit from physical mockups such as repetitive patient rooms for large-scale healthcare facilities or galleries for art museums to assure the quality of the final design being installed.

Physical mock-up spaces continue to offer unique opportunities. However, there are obvious shortcomings for physical mock-ups besides the substantial costs. First, testing alternative environmental variables and design options can cause additional costs and time for modifications. Second, it is typically a limited small area instead of the entire project, whereas each space tends to have unique contexts. Third, disposal of demolition waste becomes another issue against today's sustainable design. Last, in some cases, user testing has been done with mock-ups, but mostly it is a challenge because the site is determined by the availability and convenience for the design and construction team.

Today's advancing computer/network technology provides higher quality and much easier access to virtual mockups for user testing than before. Despite the fact that computer-mediated simulations yet provide filtered experience involving human-computer interaction issues, 3D virtual reality technology has come a long way to ever sophisticated visual quality in affordable hardware and software environments available today.

Previous research claims(Majumdar et al., 2006; Maldovan et al., 2006) that the main design issues why full-scale physical mockups are built, including spatial layout and functionality issues, can be successfully replaced by VEs for significantly lesser cost and time. In addition, testing multiple design options and user testing can be effectively performed. Environmental psychologists and marketers have shown that simulated environments lead to results similar to what would be found in actual environments(Bateson and Hui, 1992). Majumdar et al.(2006) addressed that the significant advantage of the VE is its real-time modification capability to the design based on the participants' feedback, as well as the ease in verifying alternate ideas on the issue.

2.3. Experience with VR Mockups

Virtual Reality(VR) is defined as any system that allows users to interact with virtual objects in a computer-generated, 3D environment. While the terms 'Virtual Environment' and 'Virtual Reality' are often used interchangeably, the term Virtual Environment(VE) is generally preferred by academic communities to emphasize the experience or the 3D space, rather than the enabling Virtual Reality(VR) technology for interactive experience.

To some people, VR is limited to the "immersive VR system," which uses special devices such as Head Mounted Display(HMD), Data Gloves, 3D Audio, or multiple large projective displays to enhance the experience or realism often found with 3D stereoscopic features. To others, VR refers to real-time interactive 3D graphics technology in general, including immersive VR and non-immersive VR, i.e., desktop VR. VEs are known to engage the user with the unique technology characteristics called "presence"－a sense of being there. The degree of the presence sense is greater for immersive VEs with larger displays or HMDs.

Studies in interactive marketing indicate that consumers feel an enhanced sense of being there while interacting with 3D products, resulting in a stronger "virtual experience"(Biocca et al, 2001; Li et al., 2001). As a result, consumers interacting with 3D products were found to be more confident in their attitudes toward the product information presented(Kim & Biocca, 1997). Li et al.(2001) noted that virtual experience consists of vivid, involving, active, and affective psychological states occurring in an individual interacting with VEs. Virtual experience is known to let users respond to the computer-generated 3D environment in a similar way to how they respond in a real environment. Yoon et al.(2008) also reported that users who were asked to review furniture design in a VE showed significantly

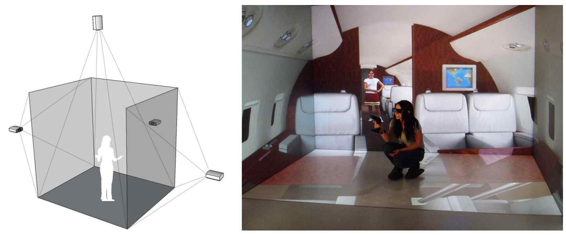

Figure 1. Four-wall CAVE system configuration(left) and an application example(right)

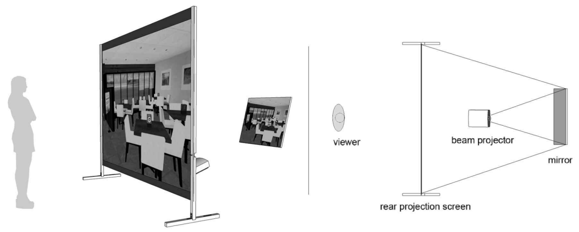

Figure 2. Affordable one-wall VE system

higher levels of confidence on their decisions compared to a 2D, image-based method.

An immersive VR system such as CAVE(Figure 1) that allows stereoscopic display with multiple polarizing screens, projectors, high performance computers and coordinating software may cost much more to build than a plywood mockup. For example, a four-wall system requires four screens with frames, eight beam projectors, a special input device, special software, and computers. To create such an immersive VE as CAVE, it used to cost up to half a million. As VEs continue to become less expensive with convincing realism, research and development groups have been using them in various fields including military training, medicine, education, entertainment and design.

Even today, a CAVE like four-wall immersive system can easily range from $200,000 to $500,000. A single-wall VR system also can provide a sense of presence in real-scale to a reasonable degree but can be developed for a fraction of the costs for multi or curved wall systems. More affordable single-wall VR systems tend to have a narrower field of vision compared to multi-wall systems. However, they offer a unique opportunity because they are much more portable. Such portable VR systems can be taken to remote sites to conveniently collect user feedback. Figure 2 demonstrates a more affordable, one-wall system utilized in the current study.

Previously, projects utilizing immersive VEs had to be generously funded and were done in research labs where specialized immersive VR systems were accessible or in joint efforts with industry partners. Advanced technology and increasingly popular use of 3D CAD in design practices made it possible to create real-time interactive and real-scale virtual mockups without special skills or a large budget.

3. Case Study

3.1. A Design Process Model

As a case study, a restaurant dining area was chosen for user testing with a VE. User testing with VEs can be conducted simply for immediate design decisions between alternative solutions, but this study adopted a simple social science research methodology to derive credible evidence for design of similar cases. Thus, reliability and validity were examined to assure that the result should be consistent if it were to be repeated by others, and it must reflect the issues one wants to test.

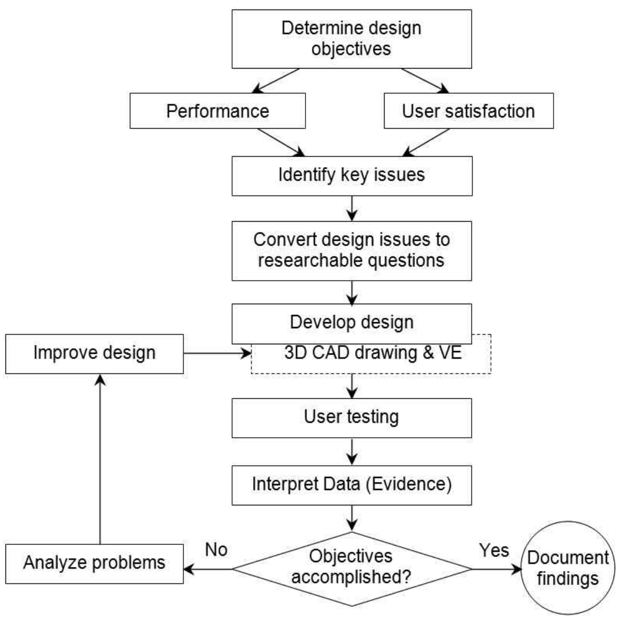

Figure 3. A user-centered design process flow chart

Sensible design for users should be considered throughout the design process. In such design process, how user testing can be directed and findings are interpreted need to be determined from the beginning. As shown in the below chart(Figure 3), usability goals need to inform key design issues that convert into researchable questions with user testing. By adopting user testing with emphasis on customer experience, more sensible design decisions towards successful servicescape can be made. The elements of the servicescape including spatial layout, aesthetic appeal, and functionality, are determined by the interior designer and the client. For user testing aiming for more satisfying servicescape, the initial design idea developed in a standard 3D CAD system needs to be converted to a VE. User testing can be conducted anywhere with a portable real projection system screen, a beam projector, and a joystick. Based on the collected data from the user testing, the designers can arrive at a final design solution or alternative solutions that can be retested after necessary revisions are made to the previous design.

Spatial layout from table configuration is considered a significant factor that influences restaurant customers' psychological and behavioral aspects(Robson, 2004). In this study, users' emotional responses were operationalized by customer satisfaction measures. Researchers have emphasized the role of the servicescape for customer satisfaction and profitability to the service provider. Robson(2004) noted that in general, restaurant customers prefer comfortable, secure and interesting environments. Privacy, defined as "selective control of access to the self or to one's group"(Altman, 1975), is known to be an important psychological trait related to seating choices. Where a customer is seated is likely to influence his or her perceived privacy in response to desired privacy. Some locations are more exposed to other tables, and others limit possible contacts with others. Seating choices in response to privacy preferences can be considered significant information toward designing a sensible physical environment for service users.

Figure 4. Restaurant dining VE views and spatial layout

3.2. Developing a Virtual Space Mockup

A VE of a restaurant interior was developed to investigate users' feedbacks on different table locations in regard to their privacy preferences. A medium-sized (1,000 sqf dining area) restaurant was chosen for the case study. Figure 4 shows a screenshot of the VE representing the proposed design.

The dining area of a restaurant was modeled after the initial design proposal. Twelve combinable square tables(36"x36") were placed in a 1,000 sqf space with different physical conditions varied by architectural anchors(window or wall), number of adjacent tables, and adjacency to other areas such as kitchen, restroom, and entrance. To examine participants' preferences, 12 tables were alphabetically labeled, and three tables were placed in private rooms. Figure 4 displays still shots of the interactive VE of the dining hall and space layout.

In our case study, the 2D CAD drawing of the restaurant was first converted to 3D Studio MAX. The 3D model was created in 3D Studio Max and exported to EON Reality using the EON Raptor plug-in. The 3D model and lighting was refined in both 3D Studio Max and EON Reality. The virtual restaurant was run on an EON VR viewer projected onto a six feet by eight feet screen from the back. Participants browsed the simulated space using a joystick to navigate and change viewing angles. The experimental setting is demonstrated in Figure 2.

3.3. Testing Design Issues and Findings

While any design issue can be determined and investigated based on established studies, the current explores customer privacy/seating preference was identified as a key design issue: the design must effectively facilitate privacy needs and seating preferences in order to promote user satisfaction. Three key questions were generated to be examined; First, what are the characteristics of commonly preferred and avoided table locations by customers? Secondly, would individual privacy preferences influence customers' preferences in table locations? Lastly, would customers seated in preferred table locations be willing to spend more for the same service?

In addition to literature review on privacy and seating choices, the proposed above questions were tested using a series of survey questions during and after the VE experience. The survey questionnaire consisted of two parts: 1) privacy preference questionnaire independent of this study and 2) user feedback questionnaire asking participants' seat preferences for high privacy tables in the simulated restaurant.

Pedersen's(1979) privacy scale and Wulf's(1977) seat preference measure were employed. The original privacy scale comprises 30 items rated by a five-point semantic differential method on individual desired privacy. Wulf's(1977) seat preference scale rates each table on a seven-point Likert scale. Satisfaction for tables offering highest and lowest privacy was operationalized as willingness to pay a higher price using a seven-point scale.

Sixty-six undergraduate students(27 males and 39

Table 1. Preferences toward table locations

Table location*			Most favorite table location: Frequency (percent)	Least favorite table location: Frequency (percent)	Preference rating of each table location	
Table label	Privacy level	Physical condition			Mean	S.E.
A	Low	With view Near restrooms	0 (0%)	15 (22.7%)	3.26^{a}	.228
B	Medium	No view	1 (1.5%)	1 (1.5%)	3.70^{ab}	.151
C **	Low	Near kitchen	4 (6.1%)	8 (12.1%)	2.95^{a}	.191
D	High	Private dining room	9 (13.6%)	2 (3.0%)	4.56^{cd}	.217
E	Medium	With view	1 (1.5%)	1 (1.5%)	4.30^{bc}	.118
F	Low	No view	0 (0%)	5 (7.6%)	3.74^{ab}	.170
G	Low	No view Near entrance	0 (0%)	15 (22.7%)	3.09^{a}	.180
H	High	Private dining room	5 (7.6%)	2 (3.0%)	4.45^{bcd}	.210
I	High	With view	27 (40.9%)	0 (0%)	5.89^{f}	.174
J	Medium	No view	16 (24.2%)	2 (3.0%)	5.61^{ef}	.163
K	High	No view	2 (3%)	0 (0%)	5.11^{de}	.173
L **	High	Private dining room	1 (1.6%)	15 (22.7%)	3.70^{ab}	.235
Total			66 (100%)	66 (100%)		

*: Preference ratings are significantly different by table location($p<0.000$)

**: As a result of regression analysis, privacy preference was a significant predictor of table location preference($p<0.05$)

a,b,c,d,e,f: significantly different at significance =0.05 based on Tukey's B test for post hoc analysis

Table 2. ANOVA result: differences in preference ratings by table location

Dependent Variable: Preference Rating

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Table Location	676.656	11	61.51	26.68	.00
Error	1795.971	779	2.31		

females) attending a Midwestern university in the U.S. participated in the experiment. Survey questions were answered while they "walked" through the space(using a joystick) or after the navigation.

Descriptive analysis was used to examine participants' preference ratings of table location. As shown in Table 1, Table "I" was found as the favorite, followed by Table "J". Both table locations are more private than the others, while the table next to a window(Table "I") was preferred over the one next to a wall(Table "E"). Tables "A" and "G" were rated as least favorite tables, followed by "C". Tables near the restroom(Table "A") or entrance(Table "G") were found to be the least favorable locations. Both are in high-traffic areas with less privacy. Table "C", next to the kitchen, was also rated very poor because of less privacy, but traffic was expected to be less than "A" or "G". Based on ANOVA results in Table 2, participants reported significant differences among the preference ratings by each table($p<0.05$).

The desire for a private table was examined by a series of regression analyses. Table preferences were operationalized by measuring satisfaction on two table locations: high privacy(Table "I") vs. low privacy(Table "F"). A confirmatory factor analysis was conducted for the privacy scale. Out of 30 original privacy items(Pedersen, 1979), six items were kept for analysis because of good construct validity(factor loadings $\geq$ 0.7), scale reliability(Cronbach's Alpha = 0.80) and alignment with Pedersen's factors. Overall results indicated that individuals' privacy preferences are not a strong predictor for their seating preferences. As an exception, however, male participants' privacy preference is a strong indicator of their dissatisfaction(Table 3). While there are no significant gender differences in table location preferences, males seeking high privacy demonstrated a strong tendency against a table location surrounded by other tables(Table 4).

With the reference price of $20, participants answered that they would be willing to pay more if they were seated where they would like to be seated(M=$1.74, S.E.=0.28). One-sample t-test results indicated that there was a significant difference from $0.00($p<.000$). This confirms that effective table layout can contribute to higher store profitability.

The case study confirmed that customers' varying experiences and satisfaction levels are influenced by where they sit in a restaurant. It was found that there are common seating characteristics preferred among individuals seeking different levels of privacy-tables situated against a window or wall to anchor them to secure personal space are most preferred, whereas tables in higher traffic areas such as near restrooms, entrances, or kitchen are least preferred. Evidence also showed the significance of table layout for increased profitability. Based on the findings, design adjustments can be made to improve satisfaction on the less preferred seats, such as adding plantings or partitions to block traffic or differentiating sight lines with raised floors.

When alternative design solutions are developed, it is possible to use different social science research methodology to conduct comparative testing. While findings from user testing may not bring entirely new knowledge from the designer's general assumptions, the empirical evidence should increase sensitivity to user

Table 3. Mean differences : males vs. females

Measure	Males (n=27) Mean (SD)	Females (n=39) Mean (SD)	F-value	p
Table F (Lowest Privacy)	4.0 (1.0)	3.87 (1.51)	.16	.69
Table I (Highest Privacy)	6.04 (1.32)	6.31 (1.15)	.79	.38

One way ANOVA was conducted to compare satisfaction on the two table locations between female and male groups(Table 3).

Table 4. Regression results: Privacy preference as a predictor of table location preference

Outcome Variable: Satisfaction		Predictors: Individuals' Privacy Preferences B	β	t	p	R^2
Table F (Lowest Privacy)	Total	.18	.09	.69	.50	.007
	Males	-.89	-.61	-3.80	<.001	.38***
	Females	.32	.09	.56	.58	.009
Table I (Highest Privacy)	Total	.18	.09	.69	.49	.007
	Males	.48	.26	1.30	.21	.07
	Females	-.10	-.04	-.23	.82	.001

experience throughout the design practice process and allow designers to make more responsible decisions.

While perspective renderings and floor plans cannot evoke enough realism to ask users for such spontaneous behaviors as finding favorite or avoided seats, the VE provides viewers to experience the simulated environment. User feedback data obtained from the VE experience allows designers and the client to base their key decisions on empirical evidence rather than assumptions.

4. Conclusions

The goal of sensible design proposed in this study is a process that the design practitioner undergoes in order to find emotionally satisfying design solutions for more users based on user testing and research findings rather than providing general design guidelines. By practicing sensible design, designers will be able to make more responsible choices supplementing their professional insights with credible evidence. Such efforts can contribute to the advancement of the design field in addition to benefit end-users of the improved design products. So far, very little efforts have been towards the design of service spaces focusing on higher customer satisfaction with better servicescapes.

In proposing a design framework utilizing a user testing protocol with an real-scale VE, we addressed the main hindering factors including substantial expenses, unfamiliarity with the process, and the lack of sensitivity to subjective satisfaction aspects of the space usability. Physical or virtual mockups are always adopted in the design process partially because value and usefulness of developing a mockup are often unclear and there are additional costs involved.

This case study demonstrates the promise of an affordable yet effective computer-mediated simulation for user testing during a restaurant spatial configuration design process. Sensible design should also allow designers to receive greater trust in the design outcome by the client knowing how the decisions are derived.

Our study is an effort to advance emotionally sensitive design to servicescpaes for end-users and designer by exploring a framework utilizing affordable VR technology as an extension of standard design protocol. Based on today's widely adopted 3D CAD technology, VR technology offers practical means to capture user feedback with 3D models developed during the design process. Rapidly advancing technology allows practitioners and researchers tremendous opportunities to explore diverse design issues using the combination of real-scale, computer-mediated interactive 3D simulations, consumer psychology and applicable social science research methodologies. As a result, new knowledge and important findings can be contributed to the field and for designers to come up with better products that work emotionally as well as functionally for more users in the future.

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