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Examination of User Emotions and Task Performance in Indoor Space Design Using Mixed-Reality

Kyung-Tae Lee, Chang-Han Park and Ju-Hyung Kim *

Department of Architectural Engineering, Hanyang University, Science and Technology Hall, 222 Wangsimni-ro, Seoul 04763, Republic of Korea; ktlee0422@hanyang.ac.kr (K.-T.L.); wonderboy0@naver.com (C.-H.P.)
* Correspondence: kcr97jhk@hanyang.ac.kr; Tel.: +82-02-2220-0304

Abstract: Given the COVID-19 pandemic and the resulting social distancing measures with inevitable telecommuting, capturing user emotions is essential as it affects both satisfaction and task performance. Therefore, the purpose of this study was to analyze emotions and task performance in terms of dislike and personalized decision-making in indoor spaces. To facilitate experiments with participants, a mixed-reality environment was utilized with the Pleasure, Arousal, Dominance (PAD) test and cognitive tests. The results of the experiment conducted on 30 subjects identified that aroused and discontented emotions dominated in non-preferred spaces, but pleased, important, and autonomous emotions arose in personalized spaces, as determined through sentimental analysis and statistical methods. Although negative emotions were present in the aversion space, attention and execution abilities were high compared to the personalized space, but working memory was low. By conducting stepwise regression analysis, it was found that working in a visually unfavorable space, which caused an increase in controlled or controlling emotions, improved short-term work efficiency. In addition, important emotions did not have a positive effect on any task performance. However, with pleased and contented emotions in a personalized indoor space, long-term work efficiency was increased, as explained by the Yerkes-Dodson law.

Keywords: indoor space design; decision-making; mixed reality; emotion; cognitive test; PAD test; stepwise regression analysis; Yerkes-Dodson law

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1. Introduction

With the onset of the COVID-19 pandemic in 2020, more companies have implemented remote work, and as indoor time increases, there is a growing trend of users seeking to establish an environment in which various indoor work and activities can be carried out smoothly [1]. In particular, as changing indoor environments can also affect users' emotions and physiological conditions, research on which indoor environmental factors are convenient and efficient for users in terms of work is continuously ongoing [2,3].

In the past, the focus was mainly on analyzing the optimal conditions based on the changes in human states that occur with changes in indoor environment such as facilities, temperature, and humidity [4,5]. However, there has been a lack of analysis of the psychological states related to how humans perceive space regarding factors such as wall, floor color, ceiling height, and material, which actually determine the design and atmosphere of the space [2]. This is because there have been limitations in the systems and technologies that can change indoor space design in real time. However, with the introduction of augmented reality technology and the development of devices and environments that can change space design through virtual reality, mixed reality, etc., it has become possible to change space design in real time reflecting the client's opinions [6]. Reflecting this, in many previous studies, a virtual-reality environment was constructed and various studies were conducted, showing little difference from the results in real environments [7,8]. However, since virtual reality constructs a new environment within a Head Mount Device and therefore lacks realism, it would be more user-friendly to actively utilize mixed reality by constructing a virtual environment in a real space [9,10]. Thus, during an experiment involving cognitive experiences in both virtual reality and the real world, physiological responses such as heart rate and skin conductance were measured. The results revealed no significant differences in these physiological reactions among the participants in the experiment [11]. Moreover, according to Hong et al., (2021), the utilization of mixed-reality (MR) technology in outdoor urban settings resulted in no noteworthy variation in the evaluation of the soundscape compared to the physical environment [12]. The results suggest that subjective evaluation using MR technology can produce sufficiently valid results [10]. Overall, these results suggest the applicability of MR technology to progressive and practical research to identify interactions between indoor space design, task performance, and emotional state.

However, previous studies have focused more on analyzing the situation when certain parts of the indoor space configuration factors, such as walls and materials, change, rather than analyzing the design itself that appears when the overall parts of the space change. Furthermore, to determine whether a person is able to maintain a state of rest, emotional and physiological indicators were analyzed in relation to the environmental conditions. Notably, people adjusted indoor environments and changed spatial compositions to understand task performance changes according to spatial alterations. Duyan and Ünver (2016) found that wall color affected students' attention, with purple and red walls leading to higher work performance [13]. Marchand et al. (2014) also identified the negative influence of low ceilings on listening and reading tasks [14]. Furthermore, through analyzing participants' brainwaves and cognitive performance while varying factors such as seating arrangement, window placement, and spatial layout, it was determined that there were no significant differences in work efficiency concerning changes in design. Nevertheless, the analysis of EEG data consistently identified notable and meaningful alterations in brain activity patterns when participants were exposed to various design variables, especially in tasks that required encoding information in short-term memory [15]. Although these studies have examined the impact of individual indoor space elements on task performance, there is a lack of research on the comprehensive design of indoor spaces that considers all relevant factors. Therefore, it is necessary to create an optimal indoor space that takes into account all of these factors to maximize work efficiency.

The emotions that users feel in each space are directly related to their satisfaction with the space, so it is important to understand sentimental state in various ways according to the indoor space design. Emotions vary depending on the individual, so emotional language is used for qualitative analysis. Emotional language can be obtained by interviews or various tests such as the Profile of Mood States or the Pleasure, Arousal, Dominance (PAD) test, which were performed for quantitative analysis in a previous study [16]. In previous studies, emotions, work efficiency, and behavior patterns were mainly analyzed as the indoor environment changed with equipment and humidity [7], but since humans are highly influenced by visual stimuli, it is important to understand the changes in human emotional states felt as the space design changes [2,4,17]. In analyzing the effects of indoor spaces, white or blue tones of indoor spaces were found to elicit positive emotions [18,19], while green spaces were found to evoke feelings of being in nature, making the space feel more expansive and inducing a sense of calm [20]. It has also been observed that natural materials, such as wood and marble, and patterns, such as triangles and diamonds, can enhance users' sensory experiences [4,21]. Conversely, excessively bright or high-contrast colors create pressure effects and negative emotions, and glare and spilling light from poorly installed windows interfere with visual performance and create distractions [22]. However, there have been few cases where emotional indicators were analyzed to present the optimal spatial design for high work performance. Therefore, it is necessary to understand how the emotions felt in each space affect human behavior and work efficiency in order to comprehend the influence of visual stimuli resulting from changes in spatial design on users' states in a practical manner.

Understanding the work efficiency and emotional state of users in visually perceived unwelcoming spaces and personally decided spaces can lead to the discussion of spatial construction methods, which can be directly applicable in the current society where telecommuting is increasing. Therefore, this study aims to use mixed reality to investigate (1) the differences in emotions between non-preferred spaces and spaces selected by individuals, (2) whether there are differences in task efficiency, and (3) the impact of positive and negative emotions on work according to different tasks.

The research design for this study is as follows, in line with the research objectives. First, based on theoretical considerations and previous research, the number of participants who could participate in the experiment was determined, and the experiment was designed based on a pre-survey and a mixed-reality environment. Second, to identify the emotions experienced in the experimental space, emotions were quantitatively measured through a PAD experiment. Third, task performance was measured through four cognitive tests. After conducting the normality tests to see if there were significant differences among the spaces, *t*-tests and Mann–Whitney analyses were conducted. Finally, stepwise regression was performed based on the significant emotions in each performance to identify the significant emotions in task performance for each space. Ultimately, this will lead to the development of practical design solutions for indoor space configuration that can induce certain emotions and enhance work efficiency, both in academia and in practice.

2. Materials and Methods

2.1. Design of Experiment

The objective of this research is to determine the emotional state and work productivity in varying indoor environments. To show the indoor environment design changes in real time to subjects, the entirety of the experiment was progressed by adopting a mixed-reality environment. Mixed reality is a form of extended-reality technology that merges the characteristics of virtual reality and augmented reality and enhances the realism of the user's environment by adding virtual hologram data [9,10]. Therefore, in this study, a virtual environment was mapped onto the actual indoor space so that it could be viewed with Microsoft's Hololens 2 mixed-reality device (Figure 1a). The front portion of HoloLens 2 is composed of glass, while the back portion is composed of hardware. The front display in front of the user's field of view is made of transparent glass, allowing users to obtain actual environmental data while simultaneously projecting hologram data onto the display to provide mixed-reality data [2]. Devices hold their own computer performance, so they can operate without connecting to other computers. Therefore, mixed reality enables users to interact with both the real and virtual environment, allowing them to partake in the experiment in both reality and immersion [9]. The size of the indoor room utilized in this study was 5500 mm × 7000 mm × 3600 mm at H University, and 3D design tools were used to establish a space design composition in the same manner as the list of pre-survey results, allowing participants to make their own decisions (Figure 1b). Due to the high level of realism, users were able to move sufficiently within the respective space and fully experience the environment before conducting emotional surveys and cognitive tests. Moreover, in making decisions regarding spatial configuration, various factors were altered by moving or changing the field of view, allowing the experiment to be visually conducted by reflecting the holographic situation.

This study examined a decision-making space created by an individual and a non-preferred space comprised of the results of a preliminary survey. The subject of the preliminary survey is an indoor space composition believed to be optimal for working from home. The preliminary survey items utilized in the spatial configuration were selected based on previous theoretical studies and discussions with interior design experts, focusing on the most used colors and materials. On a 5-point scale, respondents rated their preferences for wall color, wall and floor material, and ceiling height for interior space composition categories. Overall, 205 people in their 20s and 30s who worked from home for more than a year due to COVID-19 participated in the survey. Since this study aimed to examine work efficiency in personal spaces in the future, it was important to construct the space in a way that reflected the opinions of individuals who had relevant experience, specifically those who had experience with remote work. The survey was conducted through targeted sampling, visiting companies that had implemented remote work practices. Survey requests were made to individuals within these companies, and upon confirming their affiliation, an online link was provided to participate in the survey. This method was employed from March to May 2022, spanning a duration of two months. As shown in Figure 2, the mean (Mean) and standard deviation (Std) for each configuration of the indoor space design were then calculated. The preference for the room constituted by a red wall (M = 1.89, Std = 0.899), a tile floor (M = 2.885, Std = 1.034), a concrete wall (M = 3.106, Std = 0.927), and a low ceiling (M = 3.454, Std = 0.927) was the lowest.

(**a**) (**b**)

Figure 1. Device utilized in the experiment and the mixed-reality environment shown. (**a**) Summary of Mixed-Reality Head Mount Display; (**b**) Images of the indoor space shown through the device.

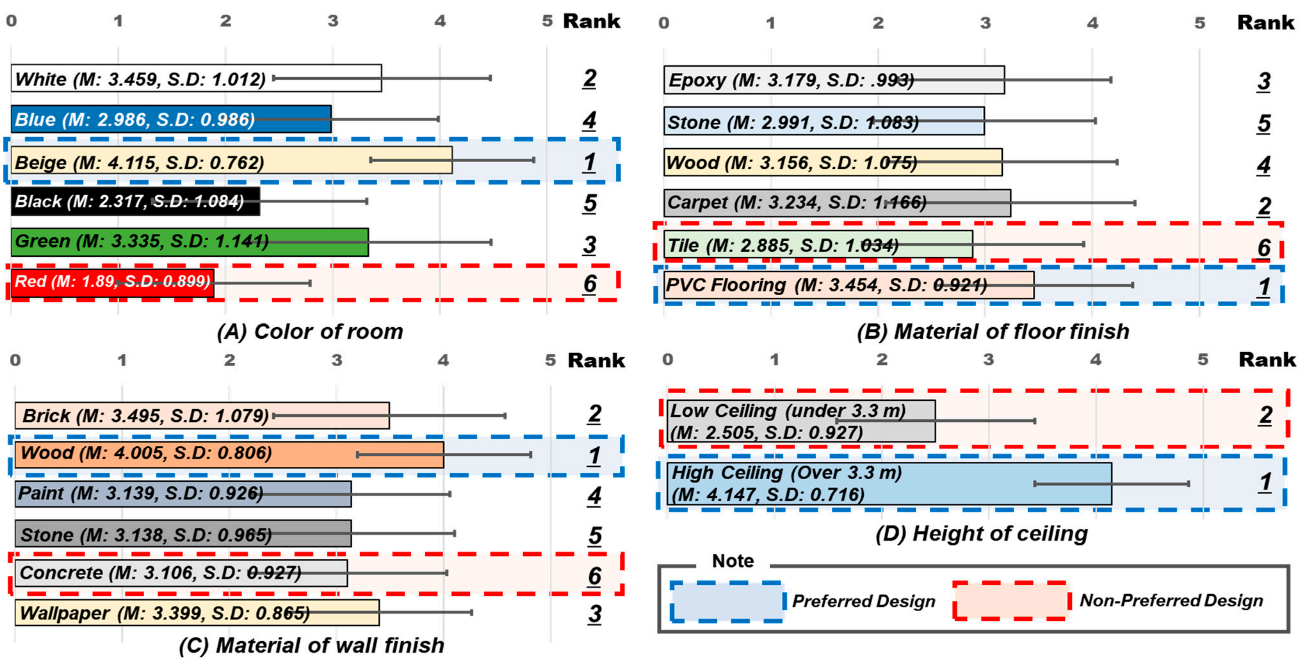

Figure 2. The results of the preliminary survey.

Then, an experiment was conducted based on the non-preferred space in the survey results and the space decided by subjects in the mixed-reality environment. The protocol of the experiments is shown in Figure 3: (1) Experiment participants were selected who met the criteria who had experienced telecommutes for more than one year and who agreed in advance. (2) After explaining the process of the experiment, the operation method of Hololens 2 was explained to increase the device adaptation. (3) By changing the spatial composition factors shown on the device, the subject was asked to constitute a room that they judged to be highly work efficient. (4) To identify the emotion in the indoor space design, the Pleasure, Dominance, Arousal (PAD) test, which was developed by Mehrabian and Russell (1974), was conducted against two experimental spaces (the non-preferred design from the pre-survey and the personal decision-making space) [23]. (5) Four cognitive tests were conducted in each space to determine work efficiency [2]. The experimental setup allowed both the PAD test and the four cognitive tests to be conducted within the HoloLens 2. By conducting the experiments while participants had sufficient visual access to the virtual environment through the HoloLens 2, it was possible to directly assess the emotions and work efficiency experienced by participants in that space. The high level of realism provided by the HoloLens 2 enhanced the reliability of the experimental results [12].

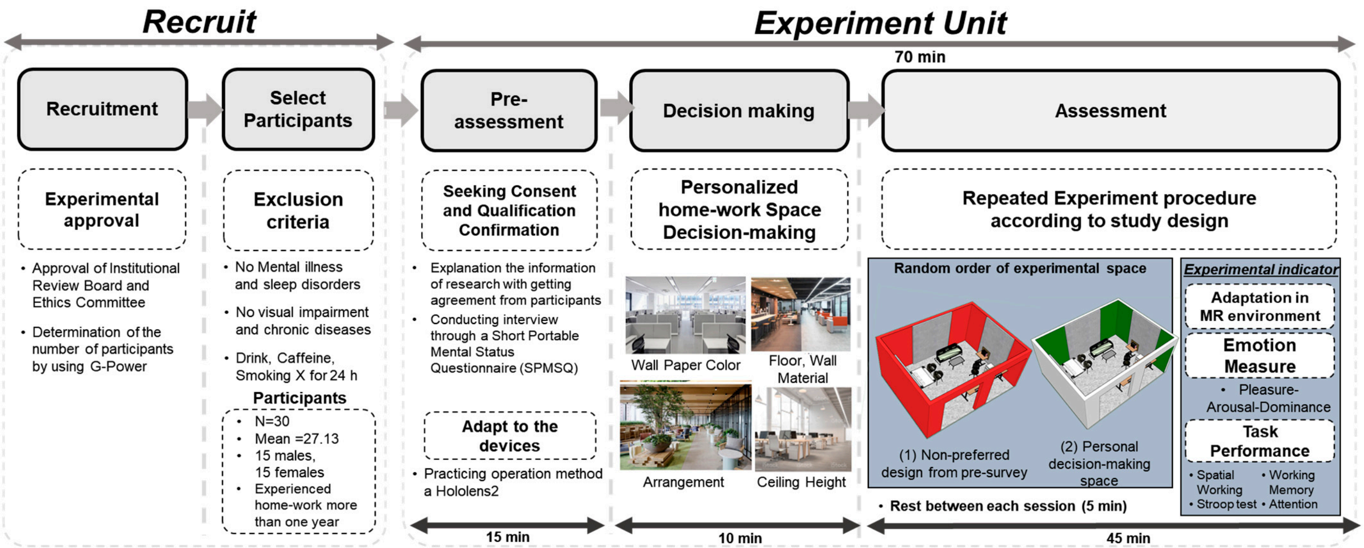

Figure 3. Experiment protocol.

2.2. Data Collection

As this study was conducted on humans using devices that could cause dizziness, the entirety of the experimental process was first confirmed by an Institutional Review Board (HYUIRB-2022202-005). Through this, 30 subjects with more than a year of telecommuting experience were recruited, and experiments were conducted on them with full agreement of subjects. The sample size was obtained using G-power 3.1 according to the number of participants in similar previous studies [4]. All participants in the experiment were individuals who had actively volunteered to participate among those who had previously participated in the preliminary survey. Participants were randomly contacted and invited to participate in the experiment. All of the participants in the experiment were without mental illness, lack of sleep, and visual chronic disease; had abstained from alcohol and smoking for 24 h; and had no problems with basic perception. The Short Portable Mental Status Questionnaire (SPMSQ), Appendix A, was administered to ensure that participation in the experiment was not problematic [24].

In total, 15 men and 15 women comprised the experiment's participants. Based on young individuals, their mean age was 27.13 years, and their standard deviation was 2.55 years (22–34 years old). Before participating in the study, it was confirmed that all participants had given their assent voluntarily, and the anonymity of all participants was maintained. In addition, participants without claustrophobia, motion sickness, and vertigo due to the Head Mount Display (HMD) experience were sought. Participants who did not satisfy this criterion were subsequently eliminated from the experiment. In addition, to improve their adaptation to the device and virtual environment, participants provided operating times [25].

To determine how the non-preferred space comprised of pre-survey materials and the space where individuals made decisions were perceived, participants were first asked to describe their emotions in each space. After that, a PAD test was administered to assess the emotion more precisely and quantitatively.

On a seven-point scale, the PAD test was used to evaluate 18 emotions across three categories in each space (Table 1, Appendix B). The PAD scale does not attempt to gauge emotions, but rather measures the user's mood by evaluating the levels of pleasure, arousal, and dominance elicited by environmental stimuli [23]. Therefore, pleasure can be experienced as static intrinsic satisfaction, arousal as "excited" and "stimulating," and dominance as "activity liberation" [26].

Table 1. Types of emotions handled by PAD tests.

Aspect, Dimension	Item		
Pleasure–displeasure	Happy–unhappy	Pleasure–annoyed	Satisfied–unsatisfied
	Contented–melancholic	Hopeful–despairing	Surprised–bored
Arousal–non arousal	Stimulated–relaxed	Frenzied–sluggish	Awake–sleepy
	Excited–calm	Jittery–dull	Aroused–unaroused
Dominance–submissive	Controlling–controlled	Uncrowded–crowded	Dominant–submissive
	Influential–influenced	Important–awed	Free–restricted

As shown in Figure 4, task performance was identified by conducting four cognitive tests: the Spatial Working Memory test, the Stroop effect test, the Go/No-Go visual reaction time test, and the Reading Span test. Although there may be limitations in evaluating work efficiency based on professional expertise or the nature of the tasks, the cognitive tests used in this study have been widely utilized as tools for assessing work efficiency based on previous research findings. Especially considering previous studies that found no significant difference between performance and efficiency in task execution and cognitive testing, there is no limitation in evaluating work efficiency based on this foundation [12,27]. The Spatial Working Memory test was developed by Salthouse, Babcock, and Shaw (1991) to determine whether subjects sensitively accept and solve information in a space [28]. The Stroop effect test measures the executive ability with which the participants recognize dissonance between color and character, whereas the Go/No-Go visual reaction time is an indicator of short-term and instantaneous attention that determines if the response to an alternative stimulus that complies with the rule can be suppressed [7]. The Reading Span test, which was developed by Daneman and Carpenter in 1980, is used to evaluate long-term working memory in conjunction with working memory and reading abilities [29].

On the basis of each experiment, the answer's accuracy and response time were determined, and Equation (1) was used to unify and compare space-specific work efficiency results.

$$Learning\ Performance = \left[(Accuracy)^{0.5} * \frac{1}{(Response\ time)^{0.5}} \right]^2 * 100 \quad (1)$$

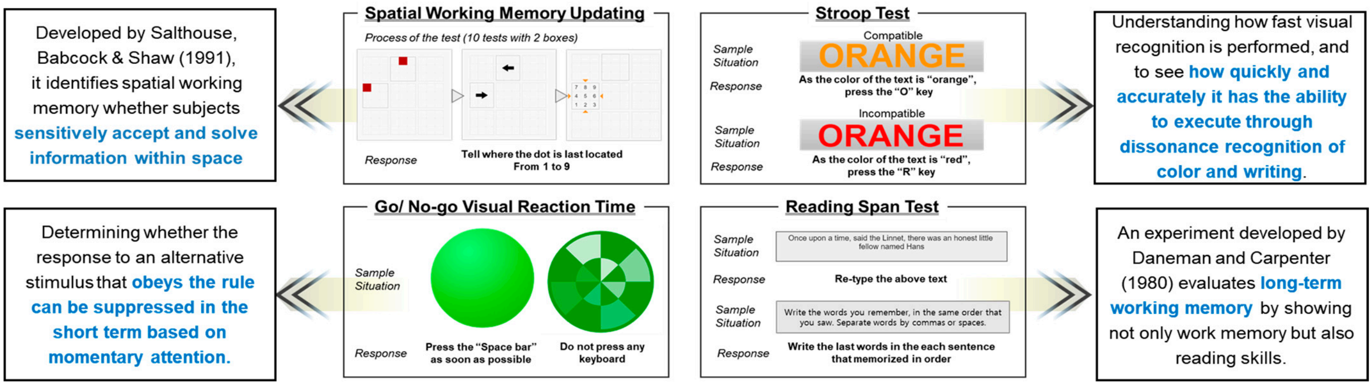

Figure 4. Explanation of the cognitive tests to measure task performance.

2.3. Data Analysis

First, sentimental analysis was conducted on how participants perceived the experimental space in which they made decisions and the non-preferred indoor space developed through a preliminary survey. Sentimental analysis is a method for analyzing human psychology based on text-mining and lexical analysis of the emotions or topics contained in text obtained by interviews [30]. To conduct this analysis, R-studio was used, and the interview contents were first tokenized. Moreover, the KNU Korean Emotional Dictionary created by Gunsan University was applied to classify the emotions felt in each space. The KNU dictionary consists of a total of 14,843 emotional vocabulary and is widely used in Korean-based text-mining, which classifies the sensitivity of the standard Korean dictionary with 89.45% accuracy applying bi-directional long short-term memory (BI-LSTM) [31].

Next, analysis for PAD and work efficiency according to indoor space design were expressed by applying the Statistical Package for the Social Sciences (SPSS) 26.0. In order to see the internal reliability of the answers of the participants who performed the PAD test, Cronbach's alpha was examined according to the category of space. When the value is more than 0.6, it is judged that the response of participants is sufficiently reliable [32]. Consequently as shown in Table 2, the participants' responses to the emotions they experienced in each space were deemed sufficiently reliable, and this was confirmed when analyzing the research results.

Table 2. Cronbach's alpha results of the PAD test.

	Non-Preferred Design Space in the Survey	Personal Decision-Making Design Space
Pleasure	0.846	0.768
Arousal	0.650	0.643
Dominance	0.602	0.620

The Kolmogorov–Smirnov test (K-S test) was conducted to ascertain the normality of the gathered data in order to identify emotion and work efficiency differences according to the indoor space design [33]. After ensuring normality, a *t*-test was administered to examine significant differences in work productivity and emotions based on space. Alternatively, if normality could not be established, the Mann–Whitney test, one of the nonparametric analyses, was performed [7].

Last, a stepwise regression analysis was performed to determine the effect of emotions that demonstrated significant differences in work productivity in each space. Prior to conducting the regression analysis, a correlation analysis was performed based on the score results. This was performed to assess the relationships and dependencies among the results, as correlation analysis allows for the identification of dependencies between variables [34]. Therefore, in this study, a Pearson correlation analysis was conducted to examine these relationships. Stepwise regression analysis creates a regression model using only independent variables with high influence significance and sequentially selects or eliminates variables based on only practical considerations [33]. When multiple variables are input into multiple regression models, regression analysis is performed by matching the significance of the variable and removing low-importance independent variables, thereby identifying the effect of the significant independent variable on the dependent variable [32].

3. Results

3.1. Analysis of Emotional Differences according to Indoor Space Design

Figure 5 shows the results of the sentimental analysis felt in the space based on the interview content. Participants in the experiment felt intense and scared in the non-preferred space constructed by the preliminary survey. In other words, it was identified that they mainly felt negative emotions. On the other hand, it was found that only 3% of negative emotional language was used in the space where individuals made their own decisions, and participants felt comfortable, neat and secure. Through this, it was found that the results of the preliminary survey and the degree of perception of participants were similar, and the experimental environment used in this study can be seen as representative.

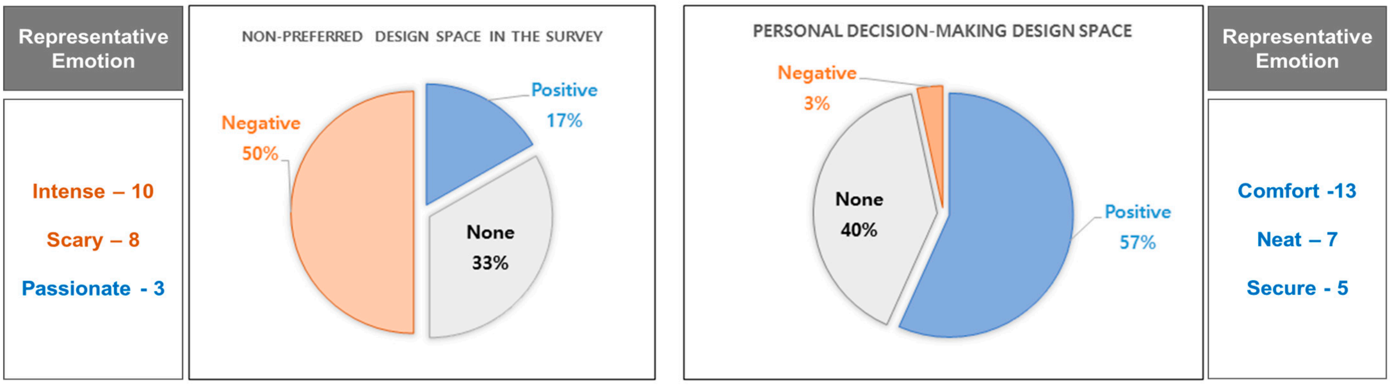

Figure 5. Results of the sentimental analysis according to the participants' interviews.

After that, a normality test was conducted to determine if there was a significant difference between emotions according to each experimental space. As a consequence of administering the K-S test, it was determined that normality was not guaranteed for certain PAD test emotions. Consequently, nonparametric statistics were employed to assess the emotional disparities between each space. Therefore, the Mann–Whitney test was conducted in two spaces, and Table 3 displays the results of the analysis.

First, it was determined that all emotions associated with pleasure displayed statistically significant differences. In other words, there was a significant difference between the individual's decision-making space and the non-preferred space in terms of pleasure emotions, and individuals could experience happy, pleased, and satisfied emotions in the individual's decision-making space. Regarding arousal, it was discovered that there was no significant difference between the feelings of sluggish and awake. On the other hand, in terms of peaceful feelings and feelings of rest, it was possible to discern that they were calm and relaxed feelings in the space created by individuals, whereas they were more aroused in the space that was not preferred. In terms of dominance, for the influential and dominant emotions, it was determined that there were no significant differences between the two spaces. In addition, participants perceived that they were controlled in the non-preferred space, whereas they perceived that they had control over the space they chose and deemed that the chosen space was important and extremely autonomous.

Table 3. Mann–Whitney results of the PAD test.

	Pleasure											
	Happy		**Pleased**		**Satisfied**		**Contented**		**Hopeful**		**Released**	
Experiment	1	2	1	2	1	2	1	2	1	2	1	2
Mean	2.07	5.83	3.47	5.80	2.43	6.03	1.83	5.77	2.67	5.47	2.00	6.20
Standard deviation	0.868	0.95	1.613	0.925	1.104	0.890	0.874	0.971	1.398	1.306	0.871	0.847
Average rank	1.25	3.6	1.98	3.62	1.32	3.43	1.20	3.33	1.68	3.40	1.25	3.52
p-value	0.000 *		0.000 *		0.000 *		0.000 *		0.000 *		0.000 *	
	Arousal											
	Relaxed		**Calm**		**Dull**		**Awake**		**Sluggish**		**Aroused**	
Experiment	1	2	1	2	1	2	1	2	1	2	1	2
Mean	2.00	5.37	2.13	5.40	2.73	3.87	4.77	4.33	3.80	4.63	5.20	3.90
Standard deviation	0.910	1.377	1.196	1.221	1.388	1.737	1.478	1.398	1.730	1.671	1.424	1.447
Average rank	1.33	3.25	1.23	3.07	1.85	2.55	2.78	2.50	2.55	2.97	3.33	2.52
p-value	0.000 *		0.000 *		0.006 *		0.193		0.170		0.001 *	
	Dominance											
	Controlled		**Influential**		**In Control**		**Important**		**Dominant**		**Autonomous**	
Experiment	1	2	1	2	1	2	1	2	1	2	1	2
Mean	4.63	2.10	5.07	4.77	1.80	5.07	3.30	5.10	3.00	2.40	3.50	5.70
Standard deviation	1.629	0.923	1.081	1.501	0.805	1.617	1.368	1.094	1.742	1.354	1.480	0.837
Average rank	3.33	1.68	2.85	2.80	1.37	3.45	2.03	3.48	2.50	2.13	1.62	3.18
p-value	0.000 *		0.100		0.000 *		0.000 *		0.195		0.000 *	

Note: Experiment 1—Non-preferred space, Experiment 2—Decision-making space/*: p-value < 0.05.

3.2. Comparison of Task Efficiency according to Indoor Space Design

The results of four cognitive tests carried out indoors were used to obtain a measure of learning performance. First, the normality test was conducted by applying the K-S test. Consequently, normality was satisfied according to all work efficiencies. It is found that all tasks satisfied normality (spatial working memory: 0.100, execution ability: 0.200, attention: 0.111, working memory: 0.178).

After that, a paired t-test was conducted according to the space for the results of each task, as shown in Table 4. The study revealed that there was no notable variation in the spatial working memory. Furthermore, the research indicated that task productivity (execution and attention) in the non-preferred environment was relatively high for two types of tasks, excluding tasks related to working memory. This result indicates that users perceived the form of the indoor space since the design was changed. Although the efficiency in the personal decision-making space was relatively high in the long-term working memory, the performance was high in the non-preferred space in the short-term execution and attention ability.

Table 4. Results of the paired t-test according to the space.

Working Type	**Average**		**Standard Deviation**		t	p
	Non-Preferred	**Decision-Making**	**Non-Preferred**	**Decision-Making**		
Spatial working memory	3.186	2.949	1.729	1.506	1.547	0.102
Executive ability	14.790	14.275	4.088	4.044	27.966	0.000 **
Attention	14.762	14.530	1.707	1.765	4.602	0.000 **
Working memory	0.916	1.301	0.660	0.492	2.815	0.042 *

Note: *: p-value < 0.05, **: p-value < 0.001.

3.3. Identification the Impact of Emotion on Work Efficiency through Stepwise Regression Analysis

To examine the influence of emotional indicators on work productivity, a stepwise regression analysis was carried out. The analysis used emotional factors present in both the non-preferred and decision-making environments, as well as executive, attention, and working memory scores, which displayed noticeable variations in response to alterations in the design. In this study, the focus was on identifying significant independent variables that influenced the values of the dependent variable rather than predicting the values of the dependent variable itself. Therefore, it was more important to identify meaningful variables than to emphasize the R-squared (R^2) value [34].

As mentioned earlier, a Pearson correlation analysis was conducted to examine the correlation between task performances in different spatial conditions as dependent variables. The results, as shown in Table 5, indicated that there was minimal correlation between work efficiency values in both the disliked space and the decision-making space. In other words, a lack of correlation or dependency was observed among the various task performance measures. Therefore, regression analysis was performed based on the individual work efficiency results.

Table 5. Result of the Pearson Correlation analysis based on task performance.

	Non-Preferred Space			**Decision-Making Space**		
	Executive	**Attention**	**Working Memory**	**Executive**	**Attention**	**Working Memory**
Executive	1			1		
Attention	0.038	1		0.250	1	
Working Memory	0.150	0.060	1	0.268	0.166	1

Initially, the analysis focused on identifying emotions that influenced task performance in the non-preferred environment (Table 6). As shown in Figure 6, during the executive ability analysis, the autonomous and controlled emotions had an effect. The autonomous emotion showed a negative impact, and the controlled emotion showed a positive impact, which shows that the less autonomy in a space and the higher the degree of control, the higher the execution ability. In terms of the ability to maintain attention, it was discovered that feeling relaxed had a significantly adverse effect, while feeling in control had a significantly beneficial effect. In other words, the less relaxed and the more controlled participants felt in the non-preferred space, the more positive attention was acquired. Furthermore, with regards to working memory, it was observed that dull emotion had measurable impacts, while feeling calm had detrimental impacts. Consequently, it was discovered that when in non-preferred environment, being too relaxed, calm, and independent led to poorer outcomes, and having a tranquil state of mind did not yield any positive effects on the outcomes.

Table 6. Summary of Stepwise Regression model in the non-preferred space.

Model		**Unstandardized Coefficient**		**Standardized Coefficients**	***t***	**Significance**	**Collinearity Statistics**	
		B	**Std. Error**	**Beta**			**Tolerance**	**VIF**
Executive	Model Summary: R^2 = 0.587, F = 7.095, significance of model = 0.003, Durbin-Watson = 1.845							
	(Constant)	50.931	6.920		7.360	0.000		
	Autonomous	−2.824	1.096	−0.411	−2.576	0.016	0.955	1.047
	Controlled	2.094	0.979	0.341	2.140	0.042	0.955	1.047
Attention	Model Summary: R^2 = 0.333, F = 6.736, Significance of model = 0.004, Durbin-Watson = 1.755							
	(Constant)	55.017	4.078		13.491	0.000		
	Relaxed	−8.957	2.440	−0.815	−3.670	0.001	0.501	1.995
	In control	7.165	2.757	0.577	2.599	0.015	0.501	1.995
Working memory	Model Summary: R^2 = 0.676, F = 11.389, Model Significance = 0.000, Durbin-Watson = 2.179							
	(Constant)	41.496	3.528		11.763	0.000		
	Dull	5.190	1.092	0.720	4.752	0.000	0.874	1.144
	Calm	−2.664	1.268	−0.318	−2.101	0.045	0.874	1.144

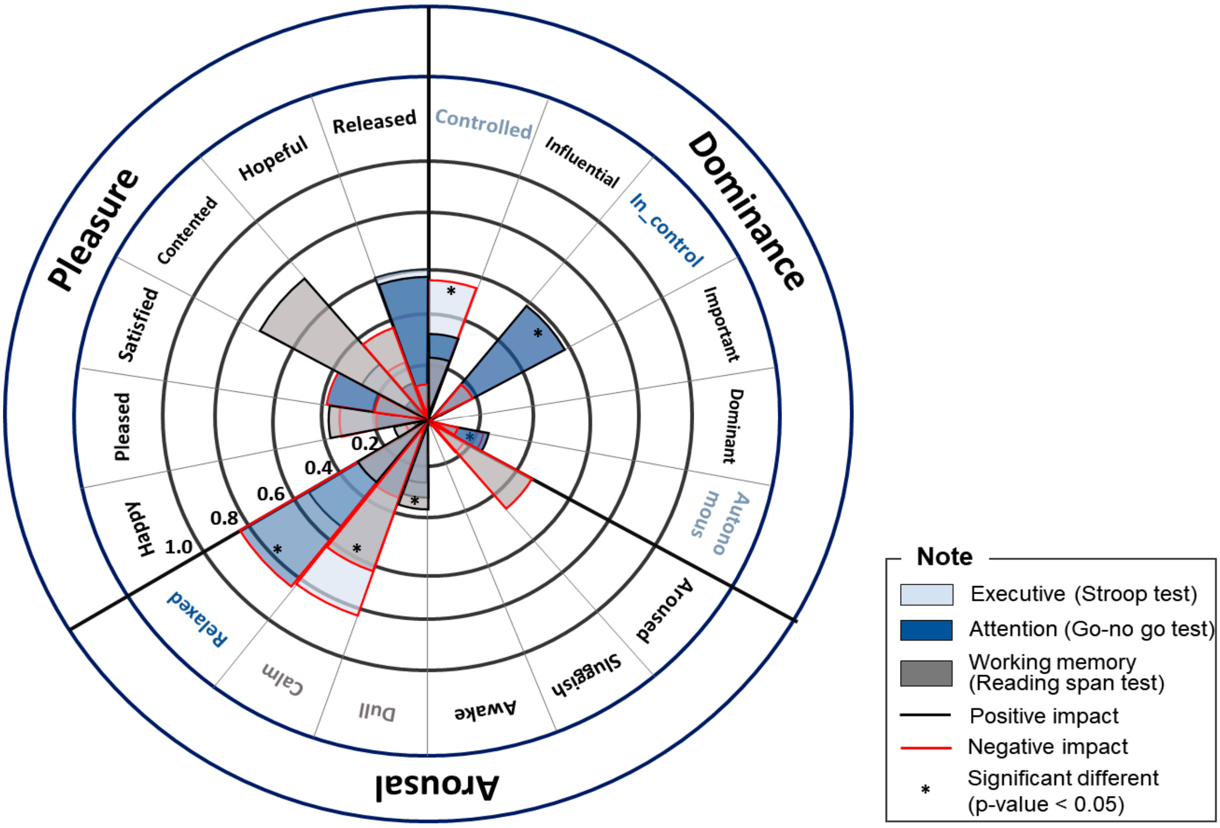

Figure 6. Stepwise regression analysis results in the non-preferred space.

The analysis was conducted in the same way as in the individual-decided space (Table 7). As shown in Figure 7, first, in the case of executive ability, the analysis showed a negative impact with the 'feeling important' emotion, and pleasure and arousal showed a positive impact. It was found that the higher the positive emotions in the space decided by the individual, the better the performance. However, it is difficult to confirm that positive emotions led to good results in this task as their competence was not high compared to the non-preferred space. Similarly, the relaxation emotion had a positive impact, and 'feeling in control' showed a negative impact on the performance of attention ability. Hence, being more relaxed led to better attention ability. However, since the performance was superior in the non-preferred environment, it is not easy to conclude that the peace resulting from the individual's decision-making space resulted in better outcomes. Finally, it can be seen that working memory showed a quantitative impact with pleasure and content, and the 'feeling important' emotion showed a negative impact. Unlike the results of the previous study, it was found that working memory had a high performance in an individual-decided space, so positive emotions (pleased, contained) had a high impact on long-term tasks. Moreover, the study revealed that the emotion of considering the space as significant had a negative influence on all job-related performance measures, but this impact was statistically significant only in the individual decision-making indoor space.

Table 7. Summary of Stepwise Regression model in the Decision-making space.

Model		Unstandardized Coefficient		Standardized Coefficients	t	Significance	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
Model Summary: R^2 = 0.564, F = 7.658, significance of model = 0.027, Durbin-Watson = 2.057								
Executive	(Constant)	36.477	11.064		3.297	0.003		
	Pleased	6.702	2.228	0.620	3.008	0.006	0.636	1.572
	Aroused	0.888	1.176	0.129	0.756	0.047	0.934	1.071
	Important	−5.650	1.936	−0.618	−2.918	0.007	0.602	1.660
Model Summary: R^2= 0.435, F= 9.709, significance of model = 0.009, Durbin-Watson = 1.909								
Attention	(Constant)	39.700	7.324		5.421	0.000		
	relaxed	3.586	1.592	0.494	2.252	0.033	0.649	1.541
	In_control	−1.766	1.355	−0.286	−1.303	0.044	0.649	1.541
Model Summary: R^2 = 0.578, F = 8.039, significance of model= 0.019, Durbin-Watson = 2.336								
Working memory	(Constant)	21.137	13.121		1.611	0.119		
	Pleased	4.366	2.251	0.404	1.940	0.043	0.636	1.573
	Contented	4.123	1.770	0.401	2.329	0.018	0.931	1.074
	Important	−3.968	1.919	−0.434	−2.068	0.039	0.625	1.601

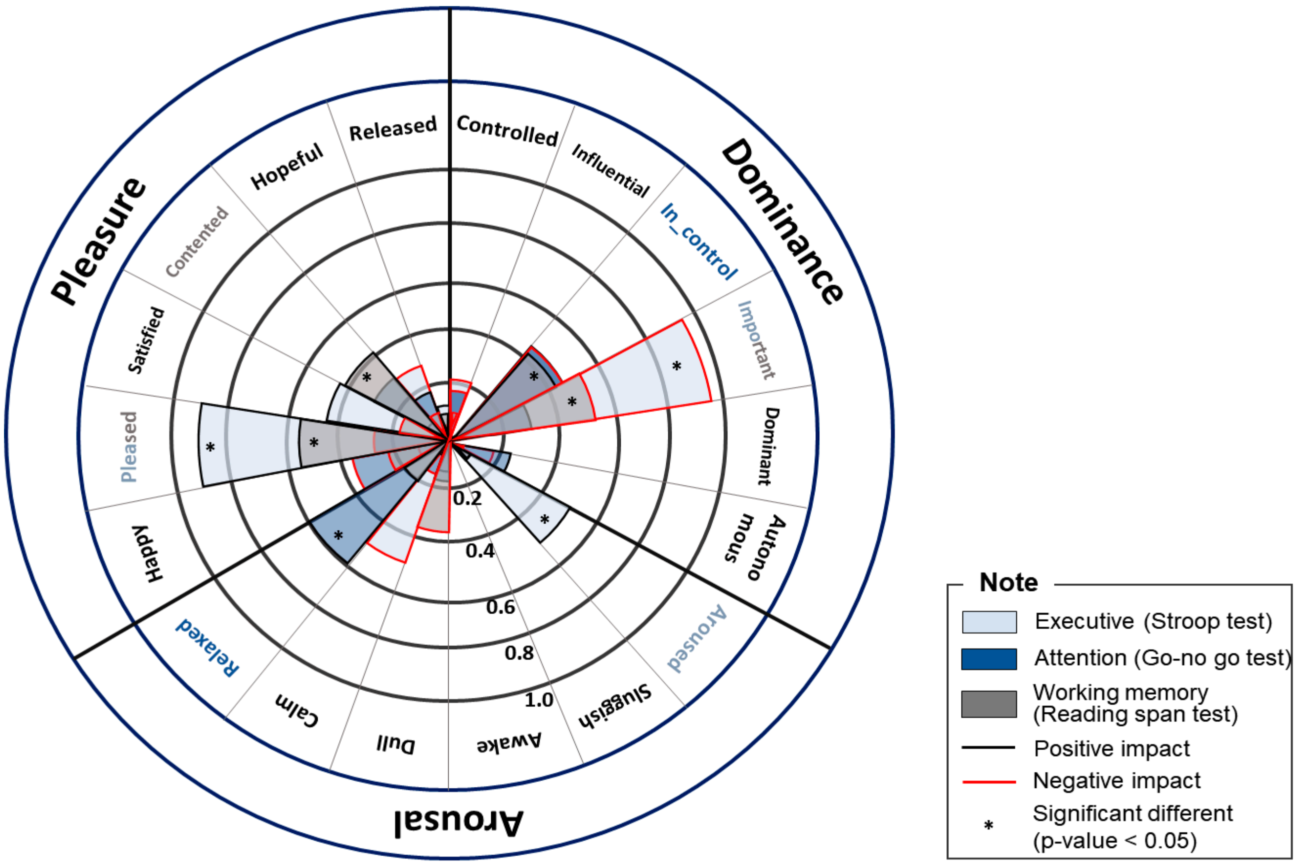

Figure 7. Stepwise regression analysis results in the decision-making space.

4. Discussion

The objective of this research was to examine the link between human emotional responses and work productivity, with the aim of identifying ways to create indoor environments that promote optimal work performance in the context of telecommuting, which has become more prevalent due to the outbreak of infectious diseases. Thus, through diverse statistical techniques, the study identified not only emotional markers of human responses but also work performance outcomes that varied based on alterations in the design of indoor spaces. To measure work productivity, standard cognitive assessments were administered, which have been frequently utilized in prior research studies. Emotional responses, on the other hand, were evaluated through the use of linguistic imagery and the

PAD (Pleasure, Arousal, Dominance) test, which participants completed as they moved through various indoor spaces [23,35]. By analyzing the findings of this investigation, it was feasible to examine how changes in visual cues in indoor environments influenced the connection between emotional responses and work productivity. This can suggest what psychological aspects should be considered in order to create an indoor space with high work efficiency for the development of indoor space design.

This research employed two typical settings, namely the non-preferred space and the personal decision-making space, which triggered psycho-physiological responses. Furthermore, alterations made to the indoor spatial design in the mixed-reality setting tested using HoloLens 2 in this investigation prompted the experimental subjects to engage in visual thinking. In other words, the research revealed that humans can alter their sensory and emotional experiences through visual elements of space, such as color, texture, pattern, and shape [36]. The space that was determined through an initial survey or the space for personal decision-making can also undergo changes in response to visual sensations, leading to individual likes and dislikes, which can have an impact on emotions as well [37]. The outcomes of the initial survey, depicted in Figure 1, indicate that a significant number of individuals favored a serene and tranquil environment with beige and white colors, consistent with previous research. Conversely, vivid and stimulating colors were perceived as unfavorable and ineffective [2]. Consequently, by amalgamating the research findings, Figure 8 illustrates the conceptual framework that demonstrates the correlation between emotions and work efficiency based on the environmental setting.

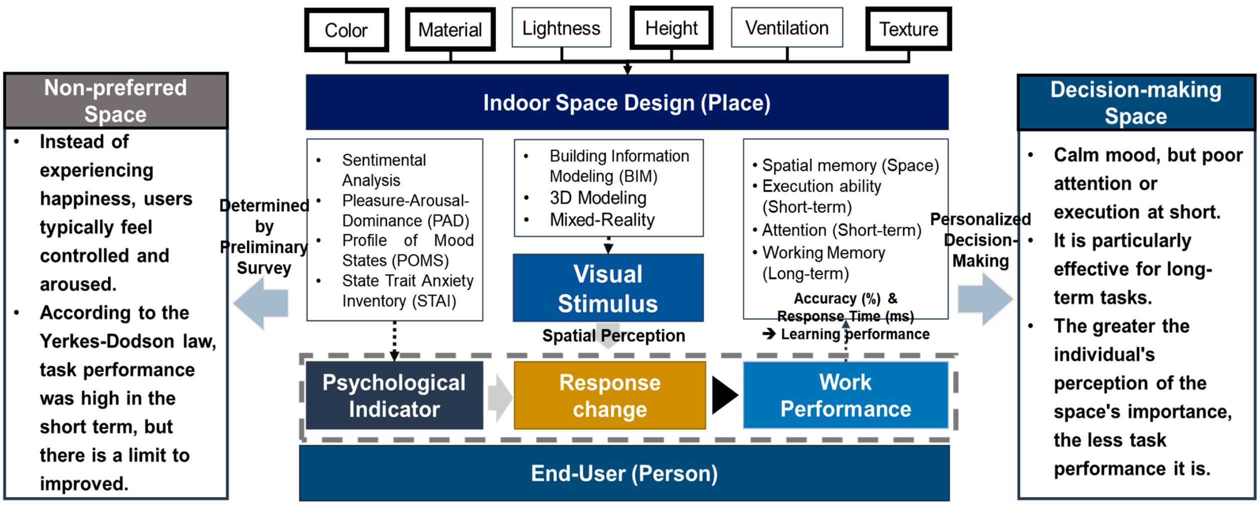

Figure 8. Conceptual framework between emotion and task efficiency according to indoor space design.

The participants in this study reported similar emotions to those in the preliminary survey. It was observed that the non-preferred environment evoked feelings of being controlled, alert, and influential, which resulted in subdued emotions compared to the relaxed and calm environment. Negative emotions arising from non-preferred spaces have a detrimental effect on execution and attention but can have a motivating impact on short-term work. Therefore, it is important to distinguish the type of work being performed and not perceive negative emotions in non-preferred spaces as having an entirely negative and stimulating effect on work.

According to the Yerkes-Dodson law, stress can enhance performance up to a certain level, but beyond that, it leads to decreased efficiency and reduced performance in complex tasks [38]. However, efficiency remains stable for simple tasks once a certain level of performance is attained. In the short term, visually stimulating but uncomfortable stimuli can increase attention, but in the long term, adapting to a preferred environment can lead to positive outcomes in work performance.

The foremost emotion in a decision-making space is a pleasure-related emotion. Understandably, these emotions also affect task performance enormously. However, as shown by the results, there is a limit to the positive impact on work. When short-term work is conducted in a space, experiencing positive emotions such as pleasure and relaxation has a measurable effect, but it does not necessarily lead to good work performance. However, in the context of personal decision-making, working memory performance is higher than in other spaces. As a result, feeling pleased or contented has a positive impact and increases the work performance in the decision-making space. However, it is important to consider the emotion of feeling important in addition to other emotions in personal decision-making spaces. Feeling important is distinct from other emotions, but it has a negative impact on work performance. Therefore, it is important to recognize that a space designed for individual decision-making may not always have a purely positive effect. Whereasan environment that encourages individual decision-making can promote personal recovery and peace, its impact on work performance is limited. Therefore, it is important to design interior spaces based on how people feel during work to optimize work performance.

5. Conclusions

This study aimed to analyze the difference in human emotional responses and work efficiency due to changes in interior space design as telecommuting and indoor space personalization increase. Recent technological advancements have enabled real-time visual modifications to spatial design, allowing customization to individual preferences. To assess the impact of indoor space design on emotions and work efficiency, a total of 30 participants were subjected to a mixed-reality environment where indoor design was changed in real time. Human emotions were measured through the PAD test, and work efficiency was compared and analyzed through four cognitive tests.

The experiment, conducted in a systematic manner, revealed that non-preferred spaces tended to elicit feelings of suppression and control in individuals, while personal decision-making spaces were associated with positive emotions such as happiness and a sense of autonomy. On the other hand, in terms of task efficiency, it was found that non-preferred spaces had higher levels of execution ability and attention, while personal decision-making spaces had higher levels of working memory. Through regression analysis, it was found that as individuals felt more controlled and dominated in non-preferred spaces, their attention and execution ability increased. Therefore, in the current environment of increased remote work due to COVID-19, it is not necessarily advantageous to establish personal preferred spaces, and spaces that induce uncomfortable emotions may actually lead to an improvement in work efficiency.

The study's reliance on a brief test in a virtual environment (mixed reality) and obtaining certification from an ethics committee limited its ability to ensure normality. However, it is noteworthy for identifying emotions induced by spatial design and determining their impact on work efficiency. The study proposes a spatial design approach based on individual work preferences during the process of increasing telecommuting and setting up a home office. Interestingly, the study found that negative emotions can enhance concentration and execution ability. To further validate the study's findings, future activities, such as practical execution studies that modify room designs on a real scale and conduct actual work, are necessary. Furthermore, work efficiency can vary depending on the type and purpose of the tasks, and as it is defined in diverse ways, future research should analyze it in more detail, considering the participants' occupations or expertise. This will enhance the integrity of the research topic and expand its scope. In addition, expanding the study's scope would involve the use of psychophysiological measures such as heart rate variability and electrocardiography to practically understand how the human body reacts to different spaces [2,39].

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editing, J.-H.K.; visualization, C.-H.P.; supervision, J.-H.K.; project administration, K.-T.L.; funding acquisition, J.-H.K. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Hanyang University, and the protocol was approved by the Ethics Committee of Hanyang University (HYUIRB-2022202-005).

Data Availability Statement: Data available on request due to restrictions, e.g., privacy or ethical. The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Short Portable Mental Status Questionnaire (SPMSQ)

1. What are the date, month, and year?
2. What is the day of the week?
3. What is the name of this place?
4. What is your phone number?
5. How old are you?
6. When were you born?
7. Who is the current president?
8. Who was the president before him?
9. What was your mother's maiden name?
10. Can you count backward from 20 by 3's?

Appendix B. PAD Test to Identify the Emotion in Each Experimental Place

<7-point Likert Scale—Options>
1—Strongly disagree, 2—Disagree, 3—Somewhat Disagree, 4—Neutral, 5—Somewhat agree, 6—Agree, 7—Strongly Agree

<Pleasure>

1. Do you feel **happy** in the experimental space?
2. Do you feel **pleasure** in the experimental space?
3. Do you feel **satisfied** in the experimental space?
4. Do you feel **contented** in the experimental space?
5. Do you feel **hopeful** in the experimental space?
6. Do you feel **surprised** in the experimental space?

<Arousal>

1. Do you feel **stimulated** in the experimental space?
2. Do you feel **sluggish** in the experimental space?
3. Do you feel **awake** in the experimental space?
4. Do you feel **excited** in the experimental space?
5. Do you feel **jittery** in the experimental space?
6. Do you feel **aroused** in the experimental space?

<Dominance>

1. Do you feel **controlling** in the experimental space?
2. Do you feel **crowded** in the experimental space?
3. Do you feel **dominant** in the experimental space?
4. Do you feel **influential** in the experimental space?

5. Do you feel **important** in the experimental space?
6. Do you feel **free** in the experimental space?

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