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Exploring Sign System Design for a Medical Facility: A Virtual Environment Study on Wayfinding Behaviors

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Abstract: The National Taiwan University Hospital (NTUH) is a significant institution in modern medicine in Taiwan. Its West Campus, the oldest medical center in the country, has been recognized as a municipal historic site due to its architectural and historical importance. However, visitors have faced navigation difficulties for a long time. To address this issue, a study was conducted to find navigation solutions within the constraints of architectural structure, hardware, and busy crowds. Blender and Unity were used to recreate the environment, and interactive virtual wayfinding experiments were conducted with 64 participants divided into two groups. Each group completed 12 tasks in two scenarios, and their task performance, wayfinding behavior, and questionnaire responses were collected to evaluate the overall environment. The pretest helped identify problems in the existing signage system and weak areas, leading to redesigning of a new signage system. The main objective of the posttest was to evaluate the new design's effectiveness. Our research contributes to future signage system layout design references, enhancing readability and information coherence while recommending locations within medical facilities. We set specific design standards to facilitate wayfinding signage systems in complex environments.

Keywords: wayfinding; sign system design; virtual environment; medical facility; indoor navigation; signage design

Citation: Wang, C.-Y.; Chen, C.-I.; Zheng, M.-C. Exploring Sign System Design for a Medical Facility: A Virtual Environment Study on Wayfinding Behaviors. *Buildings* **2023**, *13*, 1366. https://doi.org/10.3390/buildings13061366

Academic Editors: Oleg Kapliński, Agata Bonenberg, Jan Słyk and Wojciech Bonenberg

Received: 3 May 2023
Revised: 17 May 2023
Accepted: 20 May 2023
Published: 23 May 2023

1. Introduction

Finding one's way in a building is a prerequisite for successfully achieving goals [1]. However, locating a destination in a medical institution is also one of the first steps for a patient to seek treatment. Wayfinding problems can lead to confusion, frustration, anger, stress, increased blood pressure, headaches, and fatigue [2,3]. Staff also constantly interrupt work to provide directions, wasting staff time and reducing concentration [4]. Therefore, improving the indoor wayfinding system is crucial to promote the user's wayfinding experience and spatial awareness.

National Taiwan University Hospital (NTUH) is the core institution of modern medicine in Taiwan. The NTUH Original Building, also known as West Campus, is the oldest medical center in Taiwan and has been registered as a municipal monument due to its architectural and historical significance. The existing interior layout is configured with a central corridor throughout the building. Still, the West Campus is steeped in complexity and sign systems due to its long history, new services, and surrounding expansion. Visitors quickly get lost in the hospital, which leads to the need for some volunteers to help guide the way. However, as the West Campus is a municipality-designated monument, its historical value must be retained, so it is difficult to arbitrarily change its space and interior decoration. So, the sign system is more critical as environmental information can be added additionally and is less expensive to change.

In summary, providing a clear and effective sign system for visitors to find their way into medical institutions is essential. Still, since NTUH West Campus is a monument, the optimization of the signage system is compared to changing the structure of the building or interior design easier to achieve. Our study considered the busyness of the medical environment and employed experiments in virtual environments.

1.1. Wayfinding

Wayfinding is an indispensable behavior in daily life, a concrete socialization activity that occurs almost daily in our lives [5]. The term wayfinding was first coined by Kevin Lynch [6] in his book *The Image of the City*, in which he defined it as one of the elements of urban intentions as "the process of using spatial and environmental information to navigate to a destination". The term was not widely used until the 1970s, when it largely replaced the term "spatial orientation" used in academic writing [7]. Allen [8] believes that wayfinding is a motivated, purposeful process. He divides wayfinding tasks into three categories according to functional goals, the most challenging of which is that when people move in unfamiliar environments, they are more likely to have a low level of awareness of the environment and cause a temporary loss of the situation [9–12].

Down and Stea [13] also define the wayfinding process as the following four stages: positioning orientation, path decision-making, path monitoring, and target confirmation. The most crucial factor in Down and Stea's definition is that the third stage measures the repeated recursive behavior of all decisions based on continuous environmental cognition. So, Conroy-Dalton [14] has a new definition of wayfinding: wayfinding refers to reaching a destination through a constantly recursive route selection process while assessing spatial decisions before the continuous perception of the environment.

1.2. Sign Systems in Indoor Space

Wayfinding is challenging for many, especially in complex buildings such as hospitals, airports, and office buildings [7]. Many environmental factors affect wayfinding behavior in indoor spaces. The layout configuration of buildings, the degree of difference between areas, visibility, and signs are essential factors in predicting wayfinding behavior [1]. Jamshidi et al. [15], based on the four factors proposed by Weisman [1] and Lynch's [6] study of the outdoor environment, proposed several environmental factors: area, edge, path, node, landmark, plan configuration, sign, map, etc. This paper mainly focuses on the research results of wayfinding related to medical institutions, which are divided into three aspects: layout configuration, regional differences, and signs and landmarks.

A study pointed out that the layout's complexity negatively impacts the wayfinding behavior, and a space with high integrity can improve wayfinding efficiency [16]. In addition to layout configuration, support for regional differences is required. Some studies found that in polyclinics, symmetrical building structures and path differences are less repetitive and monotonic, which makes it easier for more people to feel lost, and more people need the uniqueness of the area to help find their way [17–20]. However, the actual outpatient space cannot be changed arbitrarily, so it is even more important to add additional environmental information that can be added and is less expensive to change, such as signs and landmarks. If signs are appropriately set and positioned, they can help reduce wayfinding difficulties, while the presence of landmarks can also reduce cognitive workload and promote higher wayfinding success rates [21].

The sign system represents clear information in the overall configuration and structure of the environment. As the [14] functionality of the medical facility increases, the expansion leads to an increasingly complex building layout, and the user's wayfinding in the building is also negatively affected [3,17]. When people are unfamiliar with the environment or the environment is too complex for people to fully familiarize themselves, the demand for signs also increases [19,22–25]. Each site in a medical institution has information that must be conveyed to users. The information may be too complex and invalidate the signage if not integrated and managed. So, providing clear and unambiguous signs in medical institutions is vital to help users quickly obtain the correct information and arrive at their destination without a burden [26,27].

Color coding is also a consideration for studies that process complex information quickly. Making the most of color-coded communication helps readers decipher the encoded data and maximizes the effectiveness of our communication [28–31]. Some studies show that color coding plays a role in classifying complex information [32–34] and even helps achieve better performance in mazes [34].

1.3. Wayfinding Research in the Virtual Environment

Since NTUH West Campus is a municipal monument, its historical value must be preserved, and it is difficult to modify or change it arbitrarily regarding space and interior decoration. The sign system is relatively easy to implement at a low cost and can be added and changed in the building. However, among the facilities of established medical institutions, it is difficult to make a rigorous comparison through any form of wayfinding function research. We created virtual environments to mirror the physical world as a "digital twin" for physical assets, processes, or systems—the term derived from Michael Grieves' concept [35], creating "cheap information bits" that virtualize "expensive physical atoms" to improve the performance benefits of design and testing [36]. Advances in the technology of "digital twins" (DTs) have allowed us to understand the nature of reality and its virtual forms better [37]. This concept has also been tested in practice [38]. The diversity of DTs in different application scenarios, such as cultural heritage and medical treatment, shows that the DT concept has been widely accepted by academia and industry [39].

In recent years, the rapid development of virtual environment technology, from computer desktops to fully immersive virtual environment settings, has provided new experimental methods for studying wayfinding behavior and spatial knowledge acquisition [14,20,40–44]. More and more of the fielding of wayfinding research is carried out in a virtual environment. With this technology, all changes in the experimental setting can be accomplished with a lower financial cost and less time [45,46]. Many researchers have also compared the wayfinding cognitive process and spatial knowledge acquisition of the virtual environment with prototypes of their natural world. They found that the way people find their way in the virtual environment and the natural world is similar, and there is no noticeable difference [14,47].

Therefore, many scholars have begun using the virtual environment as an experimental method to explore the influence of different signs and internal design conditions on hospital wayfinding behavior. Saleh Kalantari et al. [48] built a virtual reality test platform to evaluate the impact of signage and hospital internal design conditions on wayfinding tasks. Al-Sharaa et al. [49] also investigated the existing wayfinding system in Malaysian public hospitals through two virtual environment experiments, conducted the experiment again with a new proposal, and cross-compared the two results. The results show that the time spent by participants in the task in the new proposal is reduced, and the walking distance is shortened, which proves that the new proposal can effectively improve the wayfinding efficiency. These studies demonstrate that virtual environments can be an effective tool for participatory and evidence-based design, avoiding the need for costly changes after physical construction.

Based on the previous background and motivation, the aim of this study was to use the virtual environment to discover the design of sign systems in NTUH West Campus. We wanted to observe participants' wayfinding behavior in medical institutions and their ways of viewing signs through experiments. We also wanted to summarize the problems and areas for improvement in the existing sign system. The basic design principles of the signage system are formulated, a new design proposal is proposed, and then the same experimental process is used to verify whether the new design proposal can effectively improve the wayfinding performance of the participants. Finally, the design focus and suggestions for the future logo system are further summarized. We also propose the advantages and disadvantages of using a virtual environment for research.

2. Method

The advantage of this study is that the experimental process did not affect the hospital's operation, and it can control the variation and scope of the experimental field and save a lot of time and physical strength for testing. Participants conducted the task in the first-person view, giving researchers a clearer idea of what they were looking at. However, there are still some limitations in this experimental method, that is, the influence of the "crowd" on feelings and wayfinding behavior.

2.1. Situation Investigation and Material Design

2.1.1. Field Exploration

We visited the location and recorded each sign in NTUH West Campus. Wall signs are used as a spatial identification system in addition to the hanging type sign system of the circulation corridor (Figure 1) at the entrance hall, around the corner, around the elevator and the stairs, and outside each clinic or examination room (Figure 2). We can find how different indications are distributed in the figure.

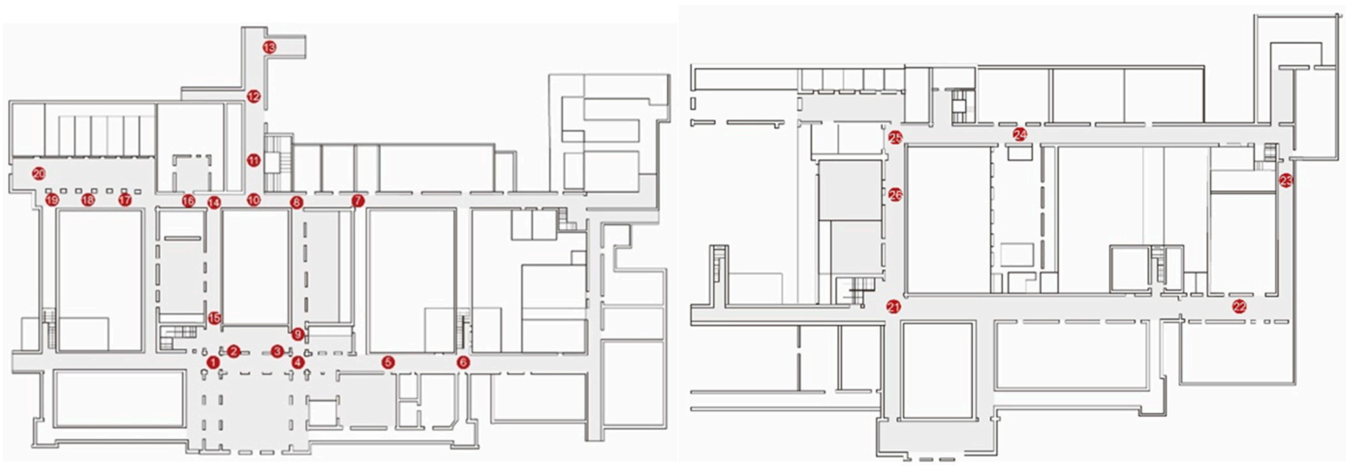

Figure 1. Locations and distribution of the walkway's hanging-style sign. The left graph is the first floor; the right is the second floor. (The numbers in the picture are for researchers' records only).

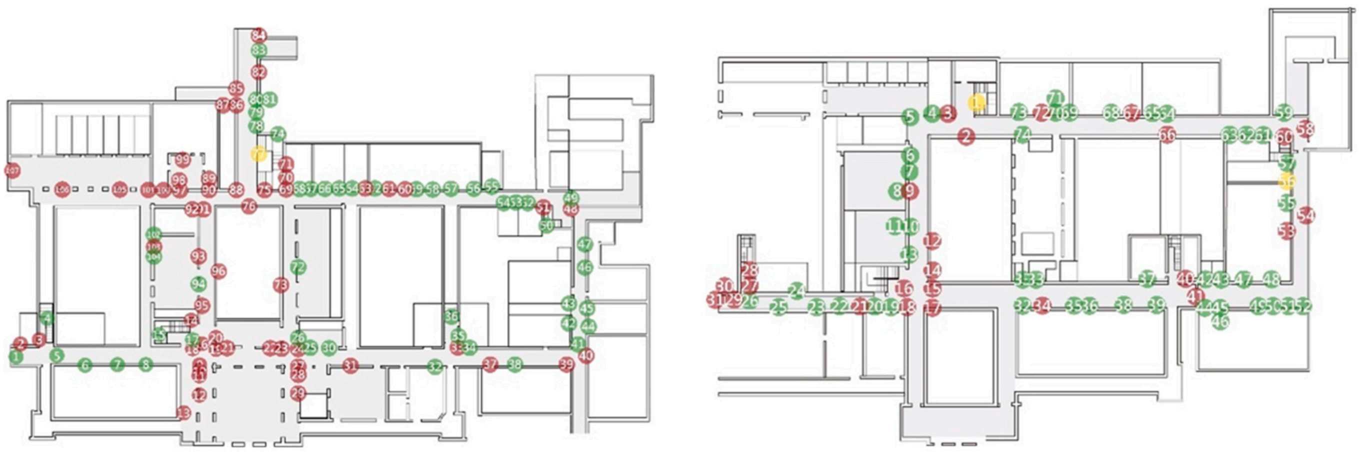

Figure 2. The location of the walkway's wall signs (the left graphic is the first floor; the right is the second floor). (The numbers in the picture are for researchers' records only).

We also found that some signs were pasted to add or remove information, resulting in a visual crowding of layout information (Figure 3). The various wall signs also have inconsistencies in visual design (Figure 4).

Figure 3. The presentation of information on existing hanging-style signs; the picture above is a photo from the scene, and the figure below is a graph drawn on an as-is basis for use in a virtual environment. (Please refer to Appendix A. Figure A1 for the English content of the signs).

Figure 4. The presentation of information on existing wall signs; the pictures above are photos from the scene, and the figure below is a graph drawn on an as-is basis for use in a virtual environment. (Please refer to Appendix A. Figure A2 for the English content of the signs).

2.1.2. Material Design

According to the current situation, we drew the sign system, size, font, typeface, typography, etc., and built a virtual environment. Two models were built using the 3D modeling software "Blender" (Figure 5). One was a practice room model, to familiarize participants with the operation of the entire experiment before the formal test. Another model was for the West Campus, which contained a virtual model of the circulation corridor on the two floors of the entrance area and the main outpatient area. It covered all signs except temporarily posted signs and illuminated all environments evenly. After that, we imported the models into Unity 3D to simulate a scene that allows participants to move freely around the building at an equal speed (Figure 6). Participants watched the computer display screen, proceeded with the keyboard's arrow keys, and used the mouse to rotate the perspective.

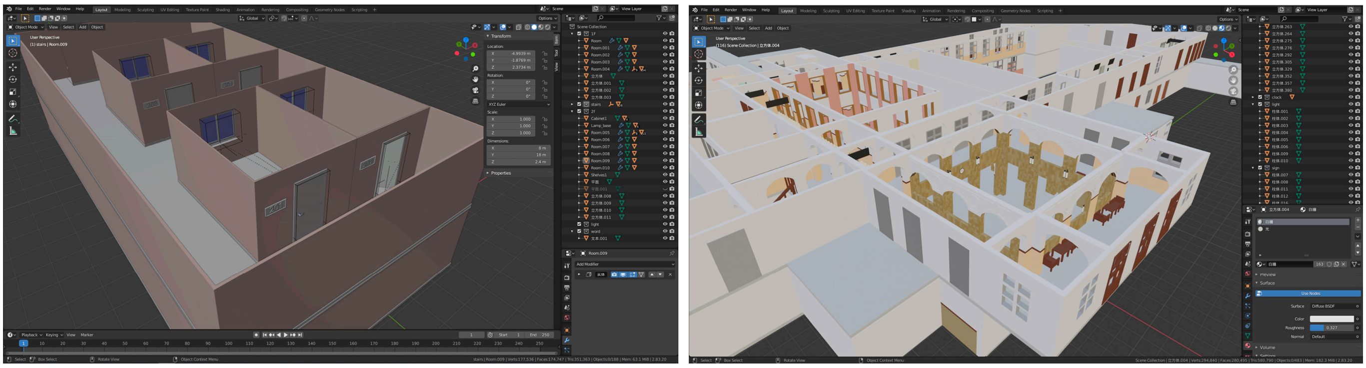

Figure 5. Screenshot of the 3D modeling software Blender (the left picture is the practice room model, and the right is the NTUH West Campus model).

Figure 6. The screen displayed while walking.

In Unity, we added a way to set the character as a Rigibody of the physics engine and bind the camera to simulate a scene. It allowed the test to move freely inside the building at a consistent speed from a first-person view (FPV). After finishing the work, we uploaded this file to the Unity Play website to make an online game. It is convenient for all test participants to click on the URL to conduct virtual environment experiments.

2.2. Participants

In the pilot test, we found that participants aged 40–60 who were unfamiliar with the relevant operations in the past had more difficulty in control and were more likely to feel intense dizziness during the process. Therefore, formal experiments limited this study's age group to 20–39. Participants must not have been to the National Taiwan University Hospital Original Building, and participants were required to have no experience with "visually induced motion sickness" (VIMS) [50–52] but be familiar with computer operation.

We recruited 64 participants, with 32 people in the pretest and 32 people in the posttest. There was no significant difference in the analysis after age and wayfinding performance.

2.3. Experiment Design

The experimental design of this study was to use the "existing sign system" for wayfinding, to understand the wayfinding performance and behavior of visitors under NTUH's existing sign system, and to unify the problem points. After the design conditions, we proposed an optimized version of the sign system. In the posttest, the same procedures were conducted to test the newly designed sign system. In addition, "color coding" was added to this primary sign as a variable, and two virtual environments were set up. One is the conventional format, and the other is the color-coded format; participants were randomized into two groups for the experiment. Under the same virtual experimental scene, experimental process, and situational tasks as the pretest, we compared the pre- and posttests in terms of evaluation of task performance, wayfinding behavior, anxiety, and readability of experimental participants. On the other hand, we wanted to know if the color coding on the sign system influenced the users' wayfinding behavior (Figure 7).

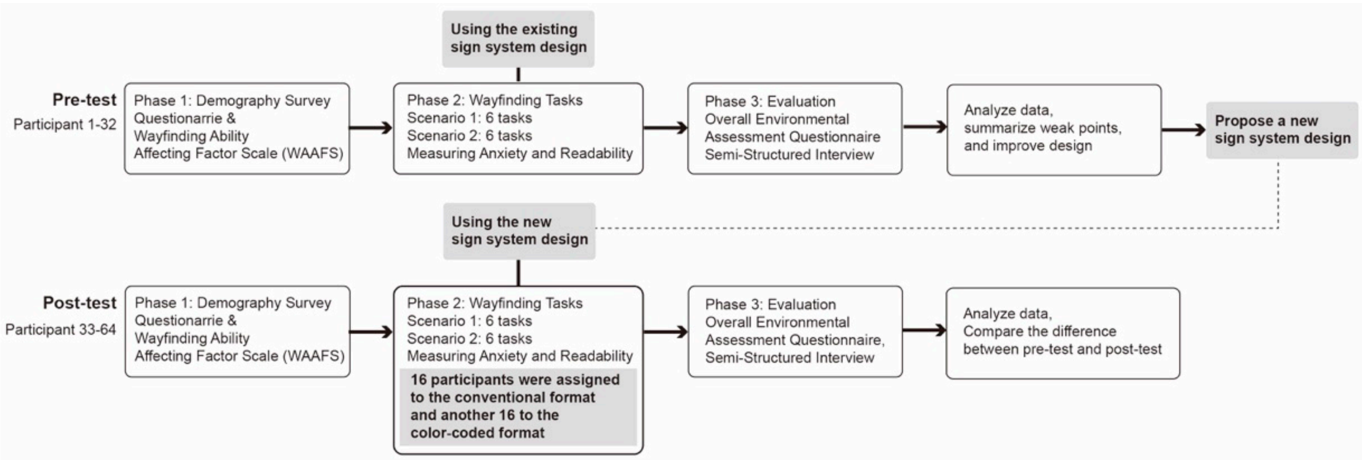

Figure 7. Experiment flowchart.

The experimental processes of the pretest and posttest were the same. Each experimental process was divided into three stages: (1) Participants were asked to complete the pretest questionnaire, including basic information and experience playing 3D games. The Wayfinding Ability Affecting Factors Scale (WAAFS) [53] was used to understand participants' essential wayfinding ability and confidence. (2) A simulated situational task wayfinding experiment was conducted; it began in the practice room to let participants learn how to move in the virtual space, and then two sets of scenarios with twelve wayfinding tasks were carried out. Each set of scenarios began with a different entrance and provided a text scenario description that asked participants to imagine hurried wayfinding in a healthcare facility. Each group's six tasks required upper and lower floors (Figure 8) and a return to the original entrance in the last task. In this process, in addition to recording the task completion time, we also counted the number of signs participants saw in the task and determined whether the signs they saw provided target information to calculate the efficiency of viewing the signs. We asked them to think aloud at the same time during the task. In addition, participants answered two questions after each task to report their anxiety level and the mark evaluation of the route. (3) At the end of all tasks, we asked participants to complete the overall environmental assessment questionnaire, which included an evaluation of the overall spatial layout and signage. A semi-structured interview was conducted to assess the participants' wayfinding behavior and the perception of signs. For the execution of the experiment, please refer to the environment and operation described in Section 2.1.2.

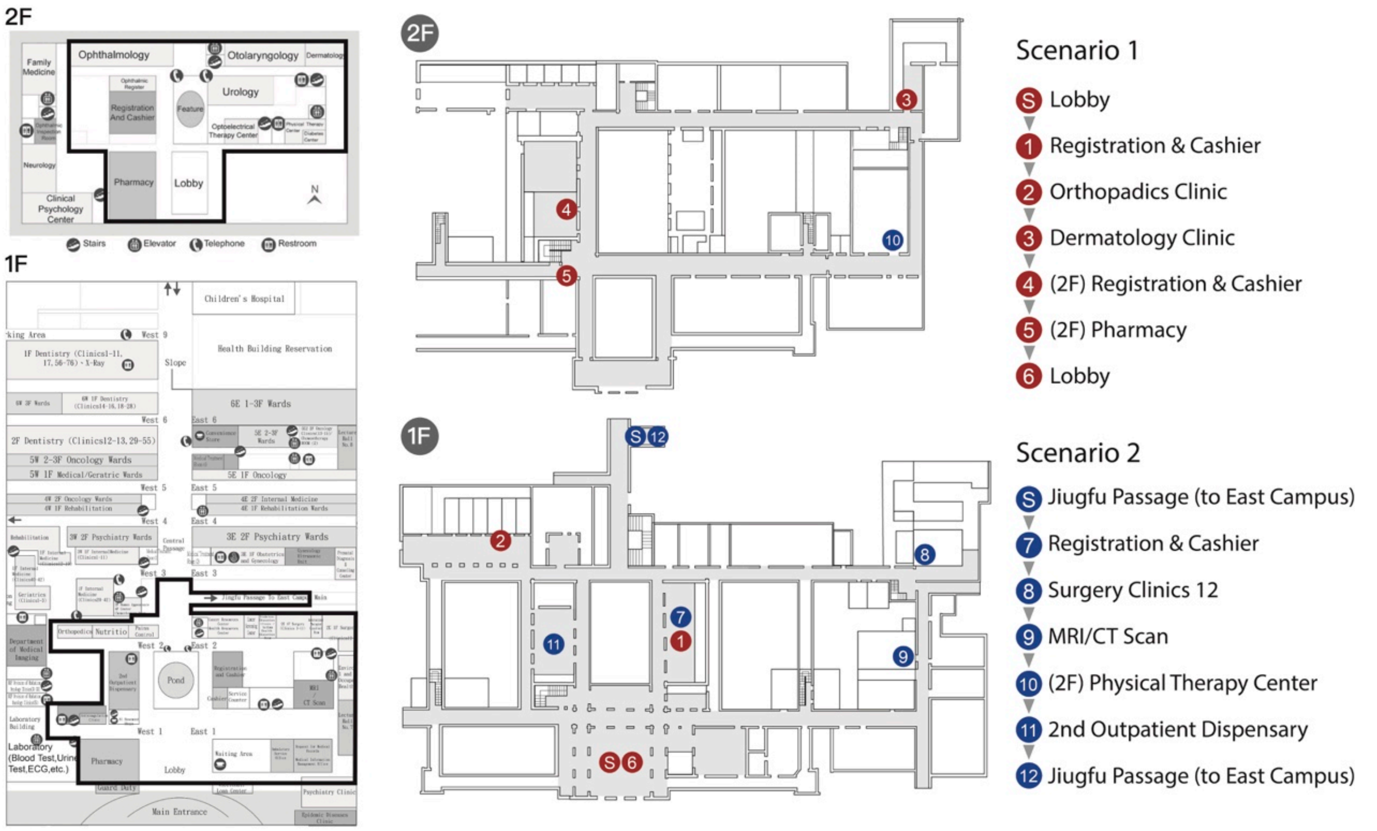

Figure 8. The left map is an original map from NTUH (https://www.ntuh.gov.tw/ntuh/Fpage.action?muid=3484&fid=3257 (accessed on 4 February 2021). The gray part of the middle floor plan is the area where participants can walk in the virtual environment. The number marked above is the task number in the scenario description, and S is the starting point of the task. After that, the task numbers are referred to simply as T1 through T12.

The overall environmental assessment questionnaire questions are shown in Table 1, designed with a four-point Likert scale, from 1 to 4 points representing strong disagreement to strong agreement.

Table 1. Contents of the overall environmental assessment questionnaire.

Overall, I think the spatial layout of this hospital can be well-oriented.
Overall, I think the hospital sign system is helpful for wayfinding.
Overall, I think the hospital sign system is easy to understand.
Overall, I think the hospital's hanging-style sign system from the ceiling is straightforward to understand.
Overall, I think the hospital's hanging-style sign system from the ceiling has helped me a lot.
Overall, I think the signs on this hospital's walls are straightforward to understand.
Overall, I think the wall signs of this hospital have helped me a lot.

2.4. New Sign System Design

Through the forward test experiment, we summarized the participants' problem points and interview results in the wayfinding process and derived their design conditions. This resulted in a reformulation of the design specifications for the new marking system and the readjustment of all signs for subsequent verification using this rule. The optimization content is as follows.

2.4.1. Hanging-Style Sign System

The hanging-style signs were uniformly changed to more recognizable white text on a black background (Figure 9), the leading guide for visitors to find their way to the hospital. In the central corridor, complete information was presented, including all the hospital's critical administrative services and outpatient departments. The services' functions were divided into outpatient, medical, laboratory, and ward. We focused on information consistency and the principle of legibility. Services in the same building were prioritized in order.

Figure 9. Comparison of hanging-style signs (The image above is the existing sign, and the lower image is the redesigned sign. Please refer to Appendix A. Figure A3 for the English content of the signs).

2.4.2. Wall Sign System

First, we removed any duplicate information signs on the wall, set up a corridor code and direction guide in each corridor, and added floor space information signs to the stairs and elevators. In addition, the auxiliary signs initially posted on the lower position on the wall in the hospital were changed to uniform white characters on a gray background. Although it was distinguished from other signs in the background color, it maintained the same form as the overall sign system in the font and directional arrows. All wall signs followed the specifications of the comprehensive sign system (Figures 10 and 11).

Figure 10. New design for wall sign system (The left is the sign of the corridor passage on the left, and the right is the sign near the stairs on the right. Please refer to Appendix A. Figure A4 for the English content of the signs).

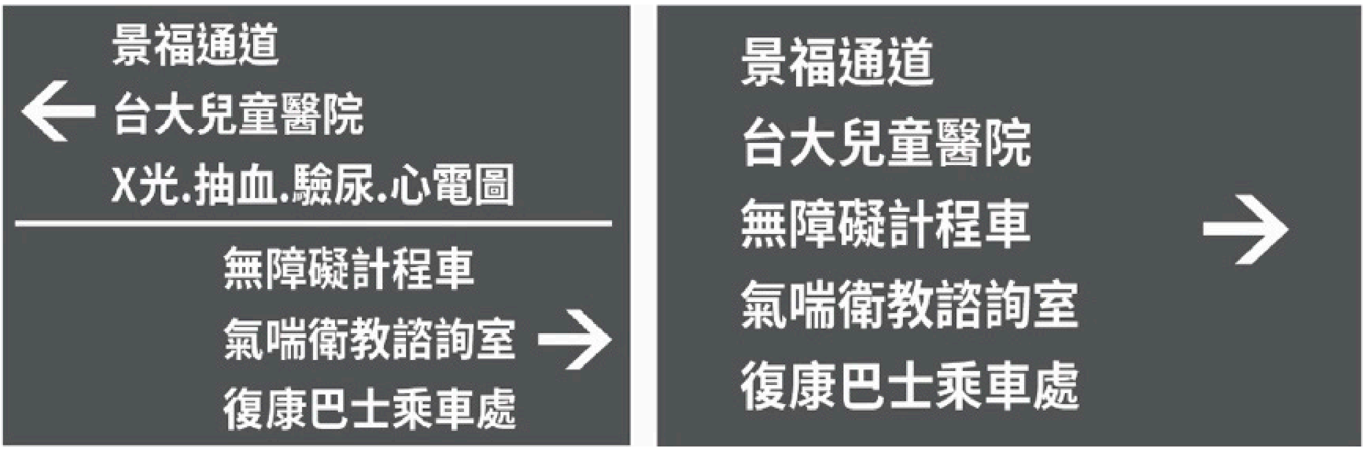

Figure 11. Auxiliary wall signs in the new sign system (Please refer to Appendix A. Figure A5 for the English content of the signs).

2.4.3. Color-Coded Design Proposals

Since the hospital provides many services, the amount of information presented on the sign is still hefty, so we hoped to add other ways to help viewers quickly filter information. Many participants also mentioned in interviews that adding color coding to the sign system is recommended to help find the way. So, based on the above design, color coding was added to the second version of the design proposal (Figures 12–14), which adopted a unified background color and text color. We used the presentation of the color bar on the elevator sign of the existing sign system as a form of color coding. We integrated it into all signs except auxiliary signs. The color selection was divided into four colors according to the active type of service provided, red for outpatient services, blue for laboratory services, green for forward services, and yellow for other medical administrative services. The color block preceded all sign information in the sign system except for auxiliary signs.

Figure 12. Color-coded format hanging-style sign system (Please refer to the appendix for the English content of the signs; the content is the same as Figure 9).

Figure 13. Color-coded format wall sign system (on the left is the corridor passage sign, and on the right is the staircase sign).

Figure 14. Spatial identification signs (on the left is the conventional format, and on the right is the color-coded format).

3. Results

3.1. Wayfinding Performance

Wayfinding performance is judged on two metrics; one is the time spent on the task, and the other is the valid rate of the signs.

3.1.1. Task Completion Time

For calculating task time spent, except for the starting point to T1 in Scenario 1 and the starting point to T7 in Scenario 2, observers told participants before the experiment to say "I found it" upon arrival at each task location. This speaking time point was used to calculate their time to the next task until all tasks were over. After comparing the task performance of the pretest experiment and the posttest, we found that the posttest is almost always better than the pretest experiment in task performance. Eleven tasks are shorter than the pretest in the average task completion time, and nine of the independent sample T-tests are significant (Table 2).

Table 2. Descriptive analysis of task completion time for pretest and posttest.

		M	SD	*t*-Value	*p*-Value
T1	pretest	51.00	36.11	2.506 ***	0.000
	posttest	30.56	28.73		
T2	pretest	42.97	20.23	1.439	0.078
	posttest	36.53	15.21		
T3	pretest	143.53	69.65	1.279	0.103
	posttest	122.72	60.19		
T4	pretest	50.97	25.67	2.508 **	0.008
	posttest	37.19	17.53		
T5	pretest	29.69	38.80	2.476 **	0.009
	posttest	12.22	9.35		
T6	pretest	69.06	47.10	3.371 ***	0.000
	posttest	36.50	27.71		
T7	pretest	62.19	31.86	3.536 ***	0.000
	posttest	36.50	25.95		
T8	pretest	56.47	47.57	2.481 **	0.009
	posttest	34.84	12.97		
T9	pretest	71.72	46.77	3.43 ***	0.000
	posttest	40.69	20.79		
T10	pretest	259.16	85.29	13.696 ***	0.000
	posttest	45.75	22.24		
T11	pretest	74.50	33.62	−0.135	0.447
	posttest	75.47	22.87		
T12	pretest	160.06	116.05	3.648 ***	0.000
	posttest	73.94	66.10		

Note: There were 32 participants each in the pretest and posttest; ** $p < 0.01$, *** $p < 0.001$.

Analysis of T3 and T10 in the pretest

The results of the forward test show that the average time spent on all tasks is 89.3 s. The tasks that took the longest in both groups were T3 (to find the first consultation with Dermatology) and T10 (to find the Physical Therapy Center). Both tasks needed to be found from the stairs on the first floor to the second floor. In T3, there were a total of six signs on the first floor, with information from the Dermatology Clinics on the second floor, placed in the lobby, the central corridor, and near the stairs and elevators (Figure 15). So, although participants looked back and forth on the first floor, they still were able to find these specific signs and successfully go upstairs. However, in T10, there were only two signs with information about the Physical Therapy Center on the second floor, a sign next to the elevator with all floor information and a sign next to the staircase nearby. As a result, participants spent a lot of time searching for the Physical Therapy Center on the first floor, and some did not even find the sign before going upstairs. We found from the think-aloud log that some participants in these two tasks could not find clear information on the sign. They began speculating that it was classified under other relevant departments and went to those departments to look for it. This leads to further deviations from the target location. For example, in Task 3, the majority of people speculated that the Dermatology Clinics were affiliated with Surgery Clinics. In T10, most people assumed that the Physical Therapy Center was affiliated with Rehabilitation Clinics.

Figure 15. T3-related signs in the pretest. The numbers on the floor plan correspond to the five pictures.

Analysis of T3 and T11 in the posttest

The posttest results show that the average time spent on all tasks is 48.6 s. The tasks that took the longest to complete in both groups of situations were T3 (look for the first diagnosis of Dermatology) and T11 (look for the second Outpatient Dispensary). In the posttest, the newly designed sign system in T3 placed the relevant signs of floor guidance next to the stairs and elevators (Figure 16), which differed from the existing sign system that mixed information on the wall and the hanging-style signs. While the information is presented more consistently, we also observed that this change causes participants to go through stairs or near elevators to perceive this information, which is why T3 took longer to perform than other tasks. However, the same task to go upstairs for which the longest average completion time was found for the pretest participants was T11 (look for the Physical Therapy Center). Since participants noticed signs next to the stairs and looked for them after leaving the previous task location, their task performance was significant even if they did not go through the elevator. This also indirectly caused almost all participants to be guided up and down the stairs farthest from the second Outpatient Dispensary, so T11 (look for second Outpatient Dispensary) also has a longer average time to complete.

Figure 16. Schematic diagram of signs and locations related to T3 in the posttest. The numbers on the floor plan map to the five pictures. The positions of No. 11 and No. 22 in the floor plan correspond to the signs on the right figure.

3.1.2. Valid Rate of Signs

By counting the number of signs viewed by participants in the task and whether the signs they considered provided task target information divided into valid and invalid signs, we can know the effective rate of the signs viewed by participants in each task. The average viewing efficiency of the posttest was higher than that of the pretest in nine tasks, of which seven were significant (Table 3). We found from the participants' movement trajectory that the participants' movement path in the posttest is more uniform. Posttest experiments also exhibited significantly reduced behaviors such as losses, reentries, or misses that would have occurred in the task.

Table 3. Descriptive analysis of valid rate for pre- and posttest.

		M	SD	*t*-Value	*p*-Value
T1	pretest	0.63	0.31	−3.170 **	0.001
	posttest	0.85	0.24		
T2	pretest	0.84	0.21	−6.35	0.264
	posttest	0.87	0.17		
T3	pretest	0.36	0.17	2.160 *	0.018
	posttest	0.28	0.11		
T4	pretest	0.84	0.19	0.514	0.305
	posttest	0.82	0.17		
T5	pretest	0.63	0.36	−4.159 ***	0.000
	posttest	0.92	0.32		

Table 3. *Cont.*

		M	SD	*t*-Value	*p*-Value
T6	pretest	0.30	0.33	0.099	0.461
	posttest	0.29	0.32		
T7	pretest	0.49	0.13	−8.003 ***	0.000
	posttest	0.73	0.11		
T8	pretest	0.84	0.22	1.225	0.113
	posttest	0.78	0.15		
T9	pretest	0.56	0.22	−2.777 **	0.004
	posttest	0.70	0.17		
T10	pretest	0.17	0.07	−23.270 ***	0.000
	posttest	0.89	0.16		
T11	pretest	0.61	0.27	−2.270 **	0.014
	posttest	0.74	0.18		
T12	pretest	0.12	0.13	−7.208 ***	0.000
	posttest	0.42	0.19		

Note: There were 32 participants each in the pretest and posttest; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The results show that the new sign system can play a higher guiding role for users who are finding their way in hospitals, and visitors can make correct wayfinding decisions through the guidance of the signs. It helped to find the target faster, rather than wandering around the corridor to find the target department. In addition, during the pretest, some users began to question the name of the task location on the sign system after not finding the target information on the sign many times and speculated about going to the department that is considered to find it, thus completely deviating from the target direction. This phenomenon does not appear again in the posttest experiment.

Analysis of T6 and T12 in the pretest

In the forward test results, the tasks with the lowest average efficiency in the two sets of scenarios were T6 (look for the entrance of the lobby; valid rate = 0.30) and T12 (look for the entrance of Jingfu Passage; valid rate = 0.12). Both T6 and T12 require participants to retrieve the entry task at the beginning of the situational task. Since there are few signs in hospitals that provide information about the location of exits, but the lobby is a space with high ceilings and is quite different from other areas, most people in T6 can find the hall without relying on signs. However, in T12, most participants had to go back and forth on the ground floor to find information about various corridors and signs, and only a very few remembered the location of the Jingfu Passage. There were only three signs about Jingfu Passage in the hospital, scattered and incoherent guidance, which also led to participants being unable to find Jingfu Passage through a single sign even if they noticed the sign information.

Analysis of T6 and T12 in the posttest

The tasks with the lowest valid rates of the average viewing markers in the posttest are still T6 (look for Dermatology Clinic) and T12 (look for Jingfu Passage). However, in the new sign system, the information on the Jingfu Passage was changed to an auxiliary sign placed lower on the wall and placed at the turning point of the central corridor (Figure 17). Compared with the results of the pretest, the performance of this task has increased significantly in terms of completion time and valid rate. However, due to the low position of the auxiliary sign, it was more difficult for participants to notice the sign the first time, which also led to a lower valid rate of viewing the sign than other tasks. Refer to the movement track diagram of T12 (Figure 18).

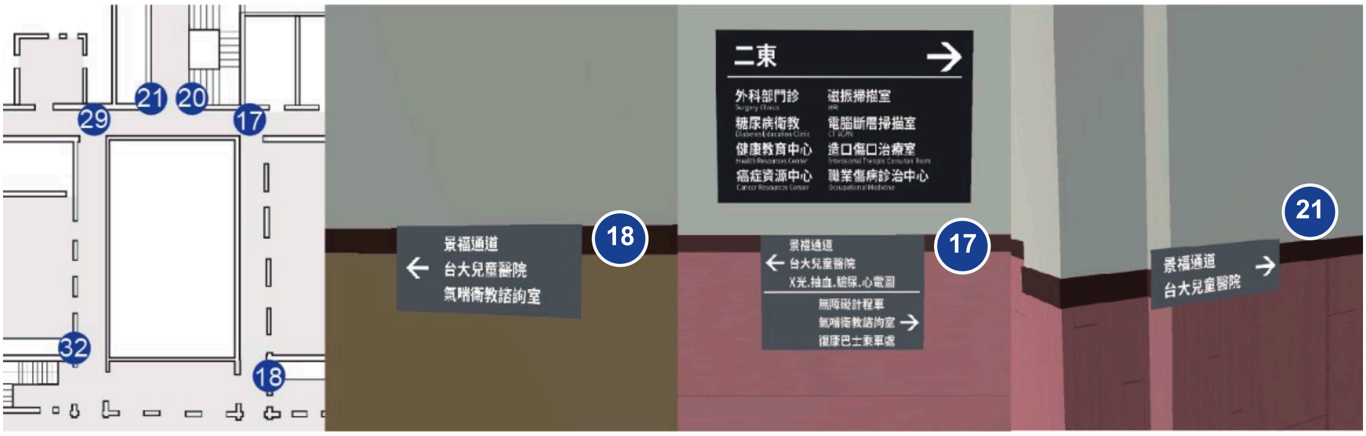

Figure 17. Schematic diagram of the relevant signs and locations of T12 in the posttest. The positions of No. 17, No. 18, and No. 21 in the floor plan correspond to the signs on the right figure.

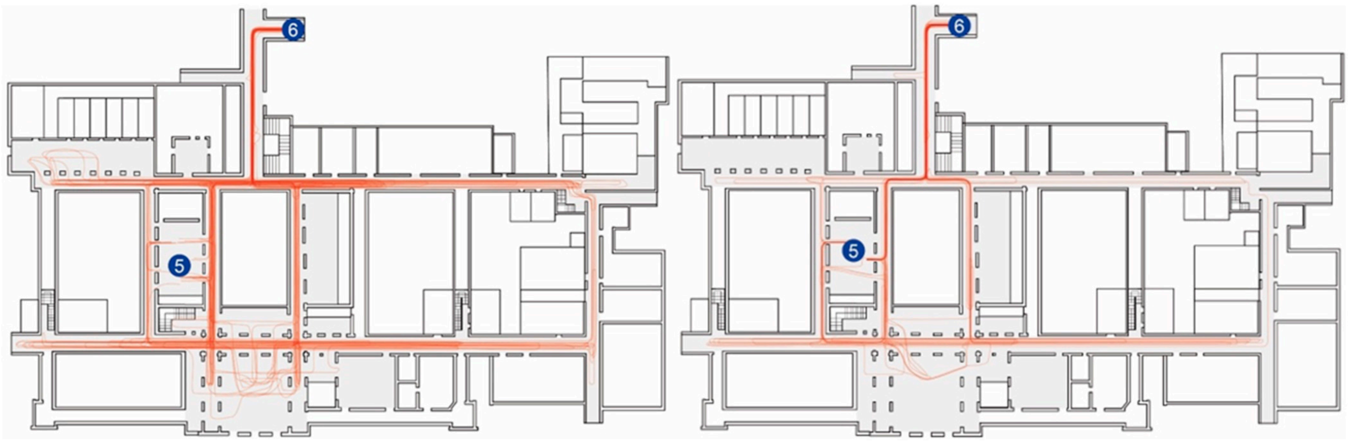

Figure 18. The movement track diagram of T12 (the left is the pretest, and the right is the posttest).

3.2. Participant Feedback

After each task in the pretest and posttest, participants answered two questions. One recorded their anxiety level (this task makes me feel very anxious). The other was the readability evaluation of signs on the task route (the sign setting in this task is easy to understand). Both questions were answered on a five-point Likert scale.

Participants in the posttest reported less anxiety in each task than in the pretest, and seven tasks were significant (Table 4). All scores were also higher than those in the pretest on task scoring, and 11 items were significant (Table 5). The result shows that the new sign system can significantly reduce the negative emotions generated during wayfinding while improving the efficiency of wayfinding in the hospital. Whether the participants gave the readability score of the route in each task or the overall sign system after the test, the score of the new sign system was higher than that of the existing sign system in the hospital.

The results showed that participants reported lower readability in T3 (readability: M = 2.72; anxiety value: M = 3.00) and T10 (readability: M = 1.69; anxiety value: M = 3.84) and felt more significant anxiety (overall task readability M = 2.94; anxiety: M = 2.5). These two tasks also took the longest to complete, which showed that participants experienced increased anxiety due to delays in finding related signs. The Physical Therapy Center in the first-floor sign system had fewer signs than the Dermatology Clinic, so participants felt higher anxiety levels. This also lowered the evaluation score for readability in this route.

Table 4. Descriptive statistics of anxiety values for each task in the pre- and posttests.

		M	SD	*t*-Value	*p*-Value
T1	pretest	2.44	1.29	2.662	0.050
	posttest	1.69	0.93		
T2	pretest	1.94	0.95	1.603	0.057
	posttest	1.59	0.76		
T3	pretest	3.00	1.46	0.582	0.282
	posttest	2.81	1.09		
T4	pretest	1.91	0.96	1.659	0.051
	posttest	1.53	0.84		
T5	pretest	1.69	0.96	3.001 **	0.002
	posttest	1.53	0.84		
T6	pretest	2.59	1.48	2.818 **	0.004
	posttest	1.69	1.06		
T7	pretest	2.50	1.34	3.083 **	0.002
	posttest	1.59	0.98		
T8	pretest	2.06	0.98	1.865 *	0.034
	posttest	1.66	0.75		
T9	pretest	2.50	1.19	2.502 **	0.008
	posttest	1.84	0.88		
T10	pretest	3.84	1.30	6.253 ***	0.000
	posttest	1.97	1.09		
T11	pretest	2.28	1.17	0.316	0.377
	posttest	2.19	1.20		
T12	pretest	3.28	1.49	2.984 **	0.002
	posttest	2.25	1.27		

Note: There were 32 participants each in the pretest and posttest; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 5. Descriptive statistics of readability for each task in the pre- and posttests.

		M	SD	*t*-Value	*p*-Value
T1	pretest	3.00	1.37	−3.878 ***	0.000
	posttest	4.13	0.91		
T2	pretest	3.56	1.19	−3.518 ***	0.000
	posttest	4.47	0.84		
T3	pretest	2.72	1.33	−1.545	0.064
	posttest	3.19	1.09		
T4	pretest	3.56	1.08	−3.031 **	0.002
	posttest	4.31	0.90		
T5	pretest	3.53	1.08	−5.107 ***	0.000
	posttest	4.69	0.69		
T6	pretest	2.78	1.16	−3.898 ***	0.000
	posttest	3.84	1.02		

Table 5. *Cont.*

		M	SD	*t*-Value	*p*-Value
T7	pretest	3.22	1.04	−3.597 ***	0.000
	posttest	4.13	0.98		
T8	pretest	3.53	1.16	−2.763 **	0.004
	posttest	4.22	0.79		
T9	pretest	3.00	1.27	−3.177 **	0.001
	posttest	3.91	1.00		
T10	pretest	1.69	1.03	−8.833 ***	0.000
	posttest	4.03	1.09		
T11	pretest	2.72	1.20	−3.084 **	0.002
	posttest	3.66	1.23		
T12	pretest	1.91	1.00	−5.412 ***	0.000
	posttest	3.47	1.30		

Note: There were 32 participants each in the pretest and posttest; ** $p < 0.01$, *** $p < 0.001$.

3.2.1. Overall Environmental Assessment

From the evaluation results, we found that the tasks in which participants felt the most anxious and had the lowest average readability evaluation scores in the two scenarios; these tasks were T3 (look for Dermatology Clinic; readability: M = 3.19, anxiety value: M = 2.81) and T12 (look for Jingfu Passage; readability: M = 3.47, anxiety value: M = 2.25). These two tasks were also given a lower valid rate by participants in the two scenarios (all tasks readability: M = 4.00, anxiety value: M = 1.83). Even if they looked at many signs, participants in this task may not have been able to find information on the direction to the target. This illustrates that when participants cannot find the information they need on the sign for the first time, it will increase anxiety and result in a low evaluation of the medical facility’s signs.

The results of the overall environmental assessment questionnaire after the test (Table 6) showed that the average score of the participants for the new sign system was much higher than that for the original sign system, and the readability of the spatial layout was also improved. They rated the entire hospital as medium or above, agreeing that the new sign system could help with wayfinding and easy understanding. In addition, as in the pretest, the participants gave the hanging-style sign a higher score than the wall sign, indicating that users thought hanging style from the ceiling was more helpful in finding a department in the hospital.

The results of the overall environmental assessment questionnaire filled out after all tasks in the pretest showed that from the first three questions, the participants did not have a high average evaluation of the spatial layout and signs of the overall hospital. However, they still agreed that the signs were helpful for wayfinding. In addition, based on the results of the last four questions, we found that after the pre- and posttest, participants gave higher scores to signs hanging from the ceiling than signs posted on the wall after experiencing the sign system. This illustrates that they believe the signs hanging from the hospital ceiling are more straightforward and easier to understand and help them find their way.

Table 6. Descriptive analysis of the pre- and posttest overall environmental assessment questionnaires.

OVERALL, I THINK . . .		M	SD	*t*-Value	*p*-Value
the spatial layout of this hospital can be well-oriented.	pretest	2.53	1.05	−3.574 ***	0.0005
	posttest	3.59	1.32		
the hospital sign system is helpful for wayfinding.	pretest	3.56	1.01	−4.506 ***	0.000
	posttest	4.53	0.67		
the hospital sign system is easy to understand.	pretest	2.75	1.02	−6.307 ***	0.000
	posttest	4.28	0.92		
the hospital's hanging-style sign system from the ceiling is straightforward to understand.	pretest	3.00	1.22	−4.981 ***	0.000
	posttest	4.31	0.86		
the hospital's hanging-style sign system from the ceiling has helped me a lot.	pretest	3.75	0.80	−3.735 ***	0.000
	posttest	4.50	0.80		
the signs on this hospital's walls are straightforward to understand.	pretest	2.81	0.97	−5.424 ***	0.000
	posttest	4.19	1.06		
the wall signs of this hospital have helped me a lot.	pretest	2.66	1.00	−4.481 ***	0.000
	posttest	3.94	1.27		

Note: There were 32 participants each in the pretest and posttest; *** $p < 0.001$.

3.2.2. Results of Semi-Structured Interviews

In the pretest interviews, most participants indicated that they would prioritize looking at the signs hanging from the ceiling to find directions during the wayfinding process, citing the belief that the hanging-style signs would provide complete information. Since the hanging-style signs seemed more important from a height place, the information provided by the signs posted on the wall seemed more fragmented, and those only served as auxiliary signs in the wayfinding process. Participants suggested that the hospital signs provided too much information, and the typography and interspersed icons would distract the reading order. As a result, they struggle to find the information they need and miss it. The current way of classifying information in wards and clinics is very misleading, so a more clearly categorized and easier-to-read layout is desired. The arrows diagonally above the direction indicators are confusing by sometimes indicating going upstairs and sometimes indicating going straight to turn. Participants were troubled by the frequent incoherence of information between signs, and if the target was to go straight and turn left, they expected the next sign to tell them whether to continue straight or turn left, and if they did not have this message, they may turn back to look at it (Figure 19).

Figure 19. The information classification method of existing hanging-style signs.

Most participants in the posttest still said in interviews that they would preferentially rely on hanging signs to find directions. For suggestions that the verification sign system could be improved, they mentioned adding more information or signs, such as instructions on stairs, exits, or parking lots. In interviews with color coding, only 7 of the 16 people in the color-coded group said they used color coding to assist in wayfinding. After understanding the differences between the two versions, 22 people in the two groups had a higher preference for a color-coded sign system, and the rest indicated no preference. The rationale for preferring color coding is that there is an additional way to help identify and classify information.

3.3. Individual Differences in Participants

We took the participants' basic wayfinding ability and game experience as individual differences and analyzed whether both affect task performance. Through the WAAFS filled in by the participants before the test, the participants were divided into high, medium, and low abilities according to the three aspects of wayfinding anxiety, direction perception ability, and path memory ability, and then analyzed with one-way ANOVA with task performance. No relevant significance was found in the aspect of path memory ability. Participants with low wayfinding anxiety or high directional awareness in a particular task were more likely to reach mission objectives faster. Highly directionally aware people may also have less anxiety during tasks. In addition, all participants move at an equal rate during the simulated wayfinding. However, in some cases, it will still take more time for those without game experience to reach the mission site than those with game experience. The result is similar to the findings of the pretest, that even though all participants moved freely in the environment at an equal rate, participants without gaming experience still need to spend more time reaching the target location in certain situations and might be more likely to feel anxious. The reason is that they were less familiar with this type of operation and therefore found it more challenging to navigate in a virtual environment.

3.4. The Effect of Color Coding on Wayfinding Performance

The results show that compared with the existing sign system in the pretest, the difference between the conventional and color-coded formats is less noticeable. Regarding task performance, eight tasks had a lower average completion time in the color-coded format group than in the conventional format group. However, no significant result was found. However, two tasks are significant in the T-test: T7, which is to find the first floor of Registration and Cashier ($p = 0.046 < 0.05$), and T12, which is to look for Jingfu Passage ($p = 0.042 < 0.05$). However, we observed the movement tracks and wayfinding behaviors of T3 and found the cause of the difference is that the participants of the conventional format group arrived at Registration and Cashier almost without any problems. Some "color-coded" group members missed certain signs and returned to the lobby.

However, this condition does not seem to be related to the color-coded variation on the logo. Color coding is not provided on the auxiliary logo identifying Jingfu Passage in T12. Overall, no color-coded variation on the signs has been found to lead to significant task performance change. In the interview, it was also found that only 44% (seven people) of the participants in the color-coded group used color coding to assist in wayfinding. In addition, very few participants could clearly articulate the meaning of the color coding (distinguished by service function). Therefore, the main factors that affected the wayfinding performance were the position adjustment, information presentation, and the typesetting method of the overall signs.

On the other hand, from the results of the anxiety and readability assessments, 10 of the tasks scored slightly higher than the conventional format. The same results were found in the overall environmental assessment questionnaire (Table 7), especially in the hanging-style sign for wayfinding ($p = 0.015 < 0.05$). Most participants who learned about the differences between the two formats in the interview had a higher preference for a sign system with a color-coded format. Therefore, although classifying information by color coding could not directly affect participants' wayfinding performance in this study, it still improved visitors' impressions.

Table 7. Overall environmental assessment questionnaire with different color-coded descriptive analyses.

OVERALL, I THINK . . .		M	SD	t-Value	p-Value
the spatial layout of this hospital can be well-oriented.	Conventional format	3.56	1.15	−0.132	0.448
	Color-coded format	3.63	1.50		
the hospital sign system is helpful for wayfinding.	Conventional format	4.38	0.72	−1.333	0.097
	Color-coded format	4.69	0.60		
the hospital sign system is easy to understand.	Conventional format	4.19	0.98	−0.568	0.288
	Color-coded format	4.81	0.40		
the hospital's hanging-style sign system from the ceiling is straightforward to understand.	Conventional format	4.19	0.91	−0.819	0.210
	Color-coded format	4.44	0.81		
the hospital's hanging-style sign system from the ceiling has helped me a lot.	Conventional format	4.19	0.98	−2.357 *	0.015
	Color-coded format	4.81	0.40		
the signs on this hospital's walls are straightforward to understand.	Conventional format	3.94	1.24	−1.351	0.094
	Color-coded format	4.44	0.81		
the wall signs of this hospital have helped me a lot.	Conventional format	3.94	1.24	0.000	1.000
	Color-coded format	3.94	1.34		

Note: N = 32; * $p < 0.05$.

4. Discussion

This study explored the influence of the sign systems in medical institutions on wayfinding behavior using the virtual environment as an experimental method. NTUH West Campus was used as the research site. For this purpose, we conducted a field study of NTUH, a pretest, and a posttest. We discussed the results of the two tests and further proposed medical facility sign system design methods and follow-up research.

4.1. Wayfinding for Moving between Floors

In past studies, wayfinding between different floors was a common challenge for visitors [18,19,54]. From the experimental results, we found that most participants would preferentially rely on hanging-style signs on the ceiling to find directions and search for and read more informative signs. It was more difficult to find tasks that needed to move between floors. There needed to be a clear sign informing the target of the location of the floor. Otherwise, visitors would not easily go upstairs to find it. During the wayfinding process, if the target information was not seen on the sign, the participant would wander the corridor repeatedly or return to the lobby. Some participants might reason independently to look for other related subjects, resulting in a complete deviation from the correct route. Therefore, the hanging signs in the lobby and the central corridor should play the main role of guiding visitors. The signs on the walls could complement and compensate for the shortcomings of the hanging signs. Participants looked at the sign and expected the next sign with the information they needed, and incoherent information led to confusion or return.

Due to the hospital's lack of signs for floor instructions, participants generally found it challenging to go from the first to the second floor to find the target. Unless the sign with the target location was on the second floor, they did not quickly go upstairs but repeatedly wandered on the first floor to search, increasing their negative emotions when finding the way.

4.2. Weak Points in Information Architecture

The main purpose of information architecture is findability [55]. However, the term is designed with its origins in the rise of the Internet and extended to the user experience. However, it largely corresponds to the paths, edges, districts, nodes, and landmarks in

Kevin Lynch's *The Image of the City* [6]. Since the NTUH West Campus is a Baroque building and a completely symmetrical structure, the concept of "landmark" is not applicable in this indoor environment. However, the lobby is very different from the rest of the building, and most visitors can find it without relying on signs. However, the number of signs with information about the location of other exits in the hospital is small, such as the Jingfu Passage linking the West Campus to the East Campus, which is not easy to find. However, to exit to the East Campus, most participants must go back and forth to find various corridors and signs for information. Therefore, the sign system in the hospital still needs to add signs and smaller specific exits to assist with wayfinding.

Currently, the classification method of information on the hanging-style sign is difficult for unfamiliar visitors to understand. They were even misled by the two classification titles of ward and outpatient. This is not in line with the "labeling system" in the information architecture that should consider viewers' manner or mental model [55]. The auxiliary icon was interspersed with text information without rules, which interfered with the user's reading flow. It is necessary to arrange the information content neatly and regularly; otherwise, it is easy to ignore the information. The meanings of directional arrows must also be unified to avoid misunderstandings. Currently, the walls of the circulation corridor of the hospital are full of signs of various styles and sizes and too many kinds of presentation methods. Too much repetitive information and the lack of consistency will make the visitors question and be confused about finding their way, reducing trust in this sign system [56]. Therefore, it is necessary to unify the design specifications to make and decide the location of the installation.

4.3. The Impact of Basic Wayfinding with/without 3D Gaming Experience on Wayfinding Performance in a Virtual Environment

The experimental results show that the essential wayfinding ability of the participants in the pretest affected the task performance in some tasks. High-ability people are more likely to reach task goals faster and may generate less anxiety during the task. Still, similar results were not found in the posttest. We speculate that this may be due to the optimization of the sign system so that people of both high and low ability can better reach their destination in the hospital. In terms of experience with FPV 3D games, it was found in both experiments that although all participants moved at an equal rate during the simulated wayfinding, in some cases, those with no game experience still took more time to reach the task targets than those with game experience. Therefore, in a virtual environment, the participant's "experience with/without 3D games" is more likely to impact experimental performance than "essential wayfinding ability".

4.4. Pros and Cons of Virtual Environments for Wayfinding Research in Medical Facilities

The advantage of this study is that the experimental process did not affect the hospital's operation, and it can control the variation and scope of the experimental field and save a lot of time and physical strength for testing. Participants conducted the task in the first-person view, giving researchers a clearer idea of what they were looking at. However, there are still some limitations in this experimental method, that is, the influence of the "crowd" on feelings and wayfinding behavior. In addition, this study was conducted on a desktop screen display, which is relatively narrow compared to walking in the real field, and it is easy to ignore the scenery on both sides; in particular, the corridor of NTUH West Campus has many pillars and arches, which easily cause blind spots. In addition, due to the long experimental time during the pilot test, a small number of people reported dizziness during the process of going up and down the stairs, and the way of climbing the stairs was changed to touching the specified icon and then being teleported upstairs so that the number of participants who reported dizziness was greatly reduced. If participants are inexperienced with 3D games, they can reduce the mouse sensitivity beforehand to avoid dizziness caused by uncomfortable operations. Although there are many parts to pay attention to when using a virtual environment as an experimental method, it still has many advantages for related wayfinding research in medical institutions because it can easily change the environment and verify the design effectiveness without affecting the hospital's operation. This presents the benefit of the "digital twin" concept [35,36,38].

4.5. Design Priorities and Recommendations for Future Sign Systems

Based on the pretest results, this study formulates the basic sign system design principles. We readjust the information presentation, classification, and layout of all hanging-style signs and various types of wall signs in the experimental environment and propose a new sign system. The information on the hanging sign is changed to outpatient, medical, laboratory, and ward services according to the type of function provided. Based on the Gestalt principles [57] and synthesizing the study results, we make three recommendations: (1) Important hospital administrative services and outpatient departments must be presented. (2) The information on the sign is processed consistently to avoid interruptions in reading, and the layout is based on the principle of not affecting the columnar format. (3) Services on the same floor should be prioritized in order.

Repetitive information is removed from the wall, and each corridor is marked with its corridor code and directions. Stairs and elevators are also equipped with a sign system with columnar format floor space information, which follows the exact specifications of the overall sign system. At the same time, adding a color classification system to the above design can positively impact the wayfinding behavior of visitors.

The results of the posttest show that the new sign system is better than the existing sign system in the performance of many tasks, which shows that the basic design principles set are conducive to visitors finding destination information in the hospital sign system. People can make correct wayfinding decisions through the guidance of the sign, which helps to find the target faster and significantly reduces the negative emotions generated during wayfinding. In addition, we have also found that when there is perfect sign guidance in a medical facility, people of high or low ability can smoothly follow the sign guidance in the hospital to reach their destination, so the wayfinding behavior tends to be consistent.

Through the design verification of the posttest, the following design points and suggestions are summarized in this study for reference in future medical institution marking systems:

Hanging-style sign design

The information on the signs on important circulation corridors should include essential administrative services and outpatient departments in the hospital. The information between the signs should be presented consistently, and the direction arrows should be used uniformly and standardized because of visual consistency; the viewer's accessibility in reading information will be improved [58,59]. The diagonal upper arrows can be emphasized by adding floor or staircase icons if they mean upper and lower floors. In addition, in the posttest, we also found that some participants could not find their direction for a while after going upstairs, so a hanging sign could be added to indicate the staircase on the second floor. The auxiliary icons on the sign should not be interspersed with principal text information, and stairs, exits, or parking lots can be added as needed to assist visitors in finding their way.

How information is arranged

Information can be classified according to the type of function provided, such as outpatient, medical, laboratory, and ward services. According to proximity and common region in Gestalt principles [57], the same type of information can be placed in the same block, and the order is not affected by the principle of column reading. The layout of the sign system is uniformly arranged in this order for easy access so that the user can quickly find the target information.

Wall sign design

For the wall, the use of many repetitive signs should be avoided, and all signs should be designed with the exact specifications of the overall sign system. Each staircase and elevator should provide complete and precise floor information regarding floor guidance. In the posttest, the task performance of going upstairs to find the Dermatology Clinic and the Jingfu Passage is still low. So, the wall near the entrance can be modified to contain the floor map and spatial system information of the entire hospital to improve the wayfinding efficiency of visitors.

Other recommendations

Since medical facilities will gradually add new services and facilities over time, or the location of departments will be adjusted, it is possible to pay more attention to the use of types that can be easily changed in the sign system so that flexible adjustments can be made at any time. In addition, an overall wayfinding sign and a color-coded four-color description were added at the lobby entrance and used in conjunction with the West Campus map colors. Madson and Goodwin's [60] research has demonstrated that color coding systems positively impact wayfinding, which can amplify the impact of color coding and improve wayfinding performance.

5. Conclusions

In this study, we conducted a field study and created a virtual environment that could map the physical NTUH West Campus to address the difficulties of conducting experiments in a physical environment. We conducted the study using task-oriented controlled experiments in which we identified current marker system issues from task performance, participant evaluation, and interview feedback. The design solution was then proposed, and the posttest assessed the same tasks to validate the design. We observed people's behavior and habits when observing indicator wayfinding and pointed out weaknesses in the current indicator system by analyzing task performance. In addition, the impact of basic wayfinding with/without 3D gaming experience on wayfinding performance in virtual environments was explored through the questionnaire results. Further, we proposed the pros and cons of using virtual medical facilities for wayfinding research. Posttest experiments verified that the signage system outperforms existing signage systems in multiple tasks, showing that the basic design principles are beneficial for visitors to find destination information in hospital signs. People can use signs to guide them to make the right wayfinding decisions, help them find their goals faster, and significantly reduce the negative emotions generated during the wayfinding process.

Study Limitations and Recommendations for Follow-Up Studies

The experimental site was the virtual model of the NTUH West Campus. However, when the experimental conditions change, there may be different findings. Because of the severe global COVID-19 epidemic during the study period, to avoid congregation, the experimental process of this study was conducted online, and the participants were requested to share their screen pictures in the online conference room. The different sizes of computer screens used by each participant may also affect the speed at which signs can be viewed during wayfinding. In the future, it is suggested that the test subjects be invited to a unified computer device to conduct experiments to reduce the variables that affect the performance of the task. In the experimental field, due to the very large scope of the entire NTUH West Campus, this study only built a virtual environment model of part of the NTUH West Campus for wayfinding experiments, and there is still insufficient understanding of how visitors will find their way between departments over longer distances or between each building. Therefore, we suggest that the scope of the virtual environment can be expanded for further research.

In addition, the visitors of NTUH are diverse, but the experimental participants in this study ranged in age from 20 to 39 years old and were mainly young people skilled in various computer operations. For the insufficient sample of older adults, the individual differences of other age groups and different groups should be explored to expand the understanding of wayfinding behavior in medical institutions.

Author Contributions: Conceptualization, software, formal analysis, investigation, writing—original draft preparation, C.-Y.W.; methodology, C.-Y.W. and M.-C.Z.; validation, resources, supervision, project administration, M.-C.Z.; data curation, writing—review and editing, visualization, C.-I.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Due to confidentiality agreements, supporting data can only be made available to bona fide researchers subject to a non-disclosure agreement. Details of the data and how to request access are available from Meng-Cong Zheng (zmcdesign@gmail.com) at the National Taipei University of Technology.

Acknowledgments: The authors are grateful for the helpful comments of Kiminobu Sato, Design Research Institute, Environmental Design, Chiba University, whose advice was invaluable. The authors would like to thank all the anonymous reviewers and editors who contributed their time and knowledge to this study.

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

Appendix A

Figure A1. It's the English translation of Figure 3.

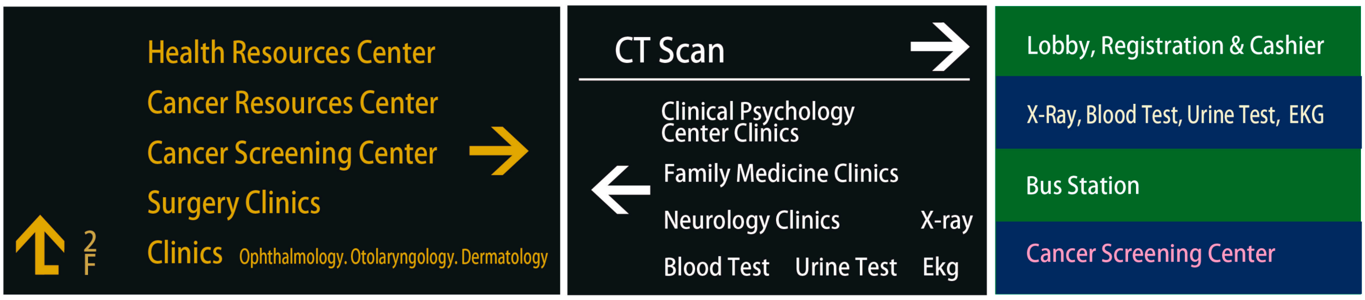

Figure A2. It's the English translation of Figure 4.

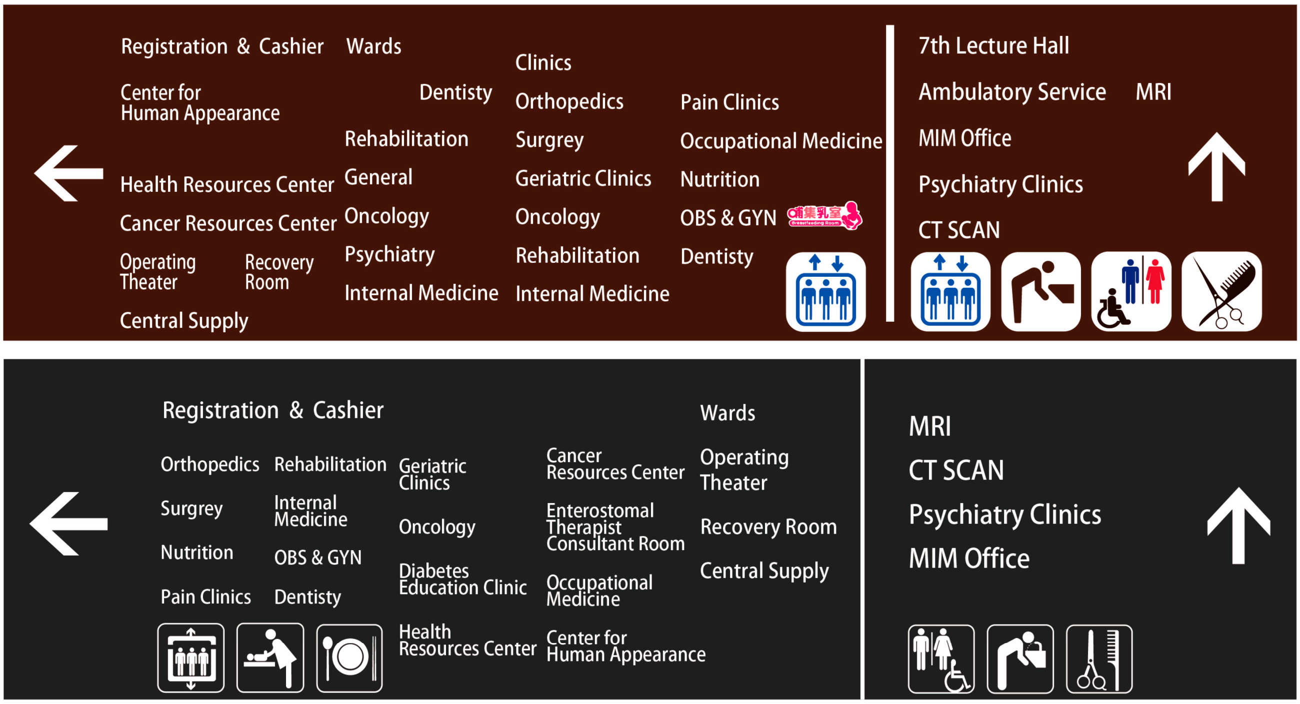

Figure A3. It's the English translation of Figure 9.

Figure A4. It's the English translation of Figure 10.

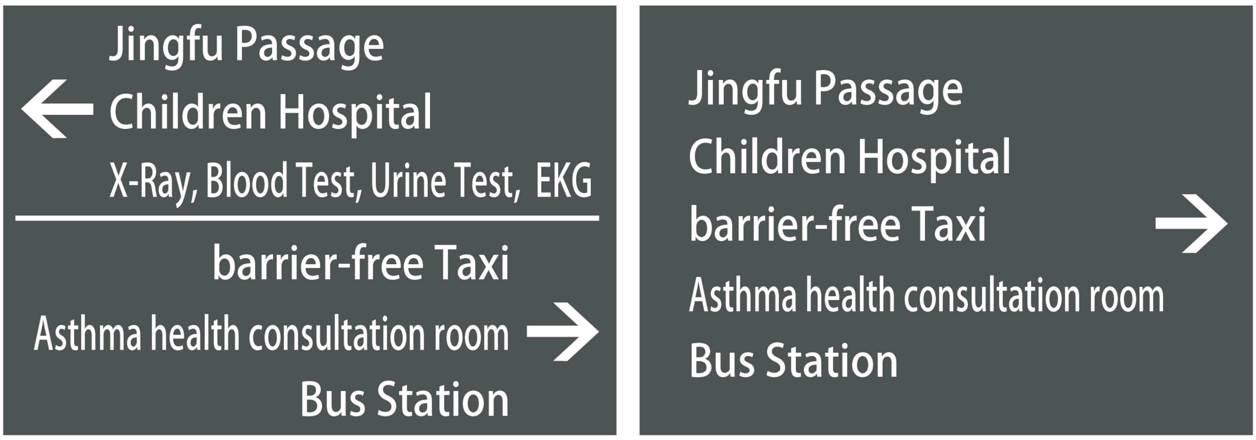

Figure A5. It's the English translation of Figure 11.

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