3D Indoor Map for Pedestrian Navigation in a Multi-level Complex Building

Seonghyeok Park
KAIST
Daejeon, Korea
Seonghyeok@kaist.ac.kr

Yiling Jin
KAIST
Daejeon, Korea
yiling.jin@kaist.ac.kr

Jie Bian
KAIST
Daejeon, Korea
cheop.byeon@kaist.ac.kr

ABSTRACT
This study addresses the possibility of the 3D Map in a complex indoor navigation environment. Unlike the current indoor navigation method, we define a LOD4 3D Map to better visualize semantic and geometric details. Experiment results show that users prefer to use the LOD4 3D Map in a complex indoor environment, LOD4 3D Map decreases the time of finding landmarks and deciding paths compared with the traditional 2D Map. The positive relationship of spatial memory for the landmarks and the performance is obvious from the conducted experiment. As a result, 3D Maps were suggested in indoor navigation, which requires a better understanding of the environment.

Author Keywords
3D Map; Pedestrian navigation; Indoor navigation; Complex Building; Spatial Memory; VR; Spatial decision making.

INTRODUCTION
Most of us get help from outdoor navigation when we travel in unfamiliar places. However, we have been lost and have trouble finding our way to specific spots more often in an indoor environment, such as a shopping mall, department store, subway station, library or factory. It is due to the lack of effective navigation offered in an indoor environment. The buildings have much more complex structures compared to the outdoors.

2D map is insufficient in providing comprehensive and vivid navigation due to the lack of stereo and motion parallax [3]. 2D maps could not offer information about the connection between each floor which is more critical than distances, angles and coordinates, and also weakened the role of landmarks in the map, which should be flexible due to the visual block.

3D navigation has obvious advantages compared to a traditional 2D map in an indoor environment since its representation improves space awareness by offering rich mapping of the buildings including rooms, corridors, intersections and stairs [10, 11]. It is ideal for simulation rich indoor contents and building assets for capturing the reality.

Therefore, we proposed a 2D [12] and 3D Map for indoor navigation based on the comparisons above. Through designing a scenario factory and VR device, we simulate the wayfinding process. Considering features, geometric complexity, internal items and dimensionality, we developed a 3D Map that will visualize the whole multi-level building all at once, especially strengthening the connection between each floor and highlight the important internal landmarks.

LOD4 3D Map Design
The definition of LOD4 3D Map was based on basis CityGML 2.0 LODs standards [6,7]. A comparison between various maps is shown in Table. 1. The designed LOD4 3D Map progressively adds both semantic and geometric details, especially in the interior and connection between each floor.

Features	Indoor Map		
	2D	Traditional 3D	LOD4 3D
Individual buildings	●	●	●
Large building parts (>4m, 10 ㎡)	●	●	●
Small building parts (>2m, 2 ㎡)			●
Top surfaces		●	
Internal items (e.g., mechanical equipment>2m, 2 ㎡)			●
Landmarks (e.g., fire extinguisher)			●
Connections between floors (e.g., stairs, elevator)			●

Table 1. Specification of the refined features of detail fitting the various indoor maps.

METHODS

Experimental Design

We set the two map modes to be independent variables: traditional 2D map and full(use LOD4) 3D Map.

The dependent variables were recorded the participants' performance including travel distance, travel time, travel break time and travel break ratio. After repeating 3 blocks, our participants are asked to do a usability survey after the 1st and 3rd block with a 7 point Likert scale survey for 10 questions. Finally, we asked them to evaluate their workload by Nasa-TLX for overall and sub-scales.

Preliminary Study

A preliminary study was conducted to find the most suitable scenario for a 3D Map. First, a subway scenario was implemented and found it difficult to give the subway station

with a complex interior decoration under no reference. Thus when the implementing structure is relatively less complicated, 2D and 3D Maps may conduct a similar performance in such a simple indoor environment. Second, a more complicated maze scenario suffered from visual blocking in the 3D Map, and also too far apart from a real environment. Consequently, it is necessary to rethink the applicable scene of the 3D Map and consider the practical significance of the scenario.

Participants

Total 8 participants, consisting of 4 females and 4 males, were assigned to 2D and 3D Maps, respectively. Therefore, group A has 2 males and 2 females using traditional 2D Map, group B has 2 males and 2 females for LOD4 3D Map. They didn't have significant differences in wayfinding performance indoor and VR experience based on a 7-point Likert scale self-reporting survey. All participants are from the KAIST campus.

Experimental Settings

We use the immersive VR environment to control the nuisance factors of the real environment and designed a virtual environment to simulate the scenes of a factory to be representative, complex and meaningful. For the virtual environment implementation, Oculus Quest 2 and Oculus Link with Unity 2019.4.15 editor were used. The simulated factory is shown in figure 1.

Figure 1. The left figure shows a simulated virtual factory in VR. The right figure shows the first view of the LOD4 3D Map in a virtual environment

Experiment Procedure

Before the experiments, participants were given a brief introduction about the experiment's goal and task. They did a survey related to their wayfinding and VR experience by 7-point Likert scale before tutorial and task perform

Participants conducted a learning session for our participants to get to know the virtual environment settings, such as what kind of constructions they are located and how they can use the VR handler to control their movement. They got a tutorial session by pseudo scenes and assigned map mode. Then explained their main tasks in the specific building. In these experiments, they are supposed to find all 6 fire extinguishers located in the multi-level scene, a plant factory.

The main task consisted of 2 parts; wayfinding tasks using a given map and travel tasks on the virtual environment without a map. In the first part, the participants were given 30 seconds to learn the construction or building's inner structures through reading the map. They should try to recognize the landmarks and the between-level structures to plan an efficient way for their paths for the task and try to memorize the fire extinguishers' locations and the route passing by all of them.

Sequensely, they were asked to start to visit and find those fire extinguishers in a sequent manner without a map. A half transparent blue bar and green bar is used for the timer once they pass by. We also recorded their wayfinding process.

The task repeated the process for 3 blocks of path finding and travel tasks. After the 1st and 3rd experiment, participants did surveys for usability evaluation with scores 1-7. Nasa-TLX was done for the wayfinding tasks experience after three blocks.

Data Analysis

The participants' coordinates on the virtual environments were recorded by UNITY software automatically with a 9-10Hz sample ratio. The wayfinding performance (travel distance, travel time, travel break time, travel break time ratio) were calculated by that time serial data. Two-way ANOVA (2 map mode x 3 blocks) was selected to test the wayfinding performance variables. The two-sample t-test tested the usability survey and Nasa-TLX by each question and subscales.

RESULTS

Wayfinding Performance

The map mode had significant effect ($p = 0.048$) and the block had boundary significant effect ($p = 0.054$), but there was no interaction effect. Shorter break time ratio means participants were easy to find landmarks while they stop and make a decision. In other words, a 3D Map may help decrease decision making time. As they train multiple times, they need shorter decision making time. The trends were shown in Figure 2.

The travel distance, time, break time were only affected by blocks ($p < 0.001$; $p=0.001$; $p=0.010$, respectively) and no significant effect of map mode and interaction.

Usability Survey

There are significant and close to significant questions by map mode, as shown in Figure 3. Consequently, 3D Maps help to remember landmarks and are preferred by our participants.

Nasa-TLX

There are close to significant questions by map mode. 3D Map needs a poor performance and higher effort subscales. Therefore, 3D Map wayfinding tasks made a higher workload than 2D Map, as revealed in Figure 4.

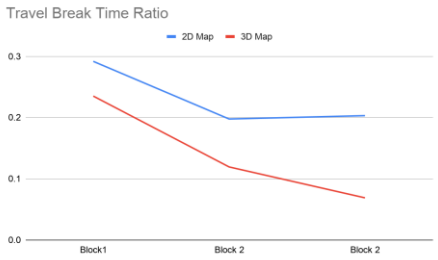

Figure 2. travel break time ratio by map mode.

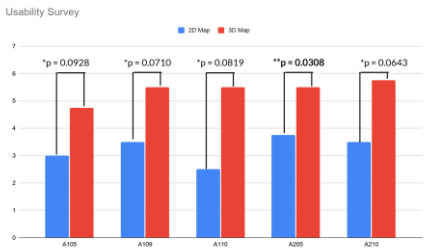

Figure 3. Significant usability survey questions. A105, 205 are "The map is easy to remember landmark", A109 is "The contents are well organized". A110, 210 are "I prefer to use the map". * means p<0.1, ** means p<0.05

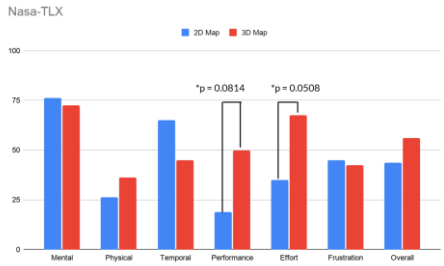

Figure 4. Nasa-TLX results of overall and subscales. * means p<0.1

DISCUSSION

LOD4 3D Map is arguably a case of a potential solution to indoor navigation map design. Most people who have used the map believe it could be a valuable tool for indoor navigation, especially under complex environments. The numerical analysis also prove that LOD4 3D Map decreases the time of finding landmarks and deciding paths. The positive relationship of spatial memory for the landmarks and the performance is obvious from the conducted experiment.

Perhaps not surprisingly, more detailed map information requires a higher workload to perform pathfinding tasks which are reflected in performance and effort on sub-dimensions from the NASA-TLX survey. From the preliminary study result, applicable indoor environments of this kind of map, there is a clear trend. An environment that is straightforward will not highlight the advantages of the LOD4 3D Map, and an environment that is too complex may cause serious occlusion.

Therefore, LOD4 3D Map should be carefully recommended for the indoor pedestrian map to increase spatial learnability and the designers who want to use the map have to evaluate the implemented environment and know the possibility of increasing the workload of users.

The study shows the possibility of LOD4 modeling for indoor navigation map and proved some potential applications as follows: LOD4 3D Map itself may overcome 2D maps limitations in complex indoor environments; Surface interfaces such as a kiosk or digital board OR virtual environment; Combining the ubiquitous computing and sensor technology, support 'Here-You-Are' Map on personal smart devices such as smartphone or tablet PC; and Giving understand of to future map designer on practical application step

LIMITATIONS & FUTURE WORK

Due to the small sample size and experiment design, between subjects might be a problem of validity and small statistical power. From the participant's perspective, the learning procedure might be conducted during a travel task. Meanwhile, participants' individual characteristic differences for spatial ability might be affected even though there is no statistical difference in our background survey. For the last VR device problem, the different field of view (VR:95`, Human vision limit: 200`) causes limitation and also a popular reason for VR sickness [4,5]. Some participants claim that they got serious motion sickness for walking on stairs and object finding tasks which might affect performance.

From the preliminary study, we found that it is necessary to study the suitable implementation environment for LOD4 3D Map due to the suitability of map design is highly related to the object and environment construction. We suggest that in future studies, precise specifications of suitable indoor environments are defined. Finally, we designed some interaction features for the map which need improvement in GUI or VR perspectives in the future.

CONCLUSION

In this paper, we presented a thorough evaluation of the LOD4 3D Map by specifically defining and conducting experiments to prove the strengths. 3D Maps are suitable for indoor pedestrian navigation and the map designer should consider both the superiority of the 3D Map and the workload it requires from the users.

REFERENCES

1. Aditya, T., D. Laksono, H. Sutanta, N. Izzahudin and F. Susanta. "A USABILITY EVALUATION OF A 3D Map DISPLAY FOR PEDESTRIAN NAVIGATION." ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 6210 (2018): 3-10.
2. Biljecki, F., H. Ledoux and J. Stoter. "An improved LOD specification for 3D building models." Comput. Environ. Urban Syst. 59 (2016): 25-37.
3. M. Tavanti and M. Lind, "2D vs 3D, implications on spatial memory," IEEE Symposium on Information Visualization, 2001. INFOVIS 2001., San Diego, Ca, USA, 2001, pp. 139-145, doi: 10.1109/INFVIS.2001.963291.
4. Jung, J. Y., Cho, K. S., Choi, J., & Choi, J. (2017). Causes of cyber sickness of VR contents: an experimental study on the viewpoint and movement. The Journal of the Korea Contents Association, 17(4), 200-208.
5. Nooij, S. A., Pretto, P., Oberfeld, D., Hecht, H., & Bülthoff, H. H. (2017). Vection is the main contributor to motion sickness induced by visual yaw rotation: Implications for conflict and eye movement theories. PloS one, 12(4), e0175305.
6. Chen, J.. "DEFINING SEMANTIC LEVELS OF DETAIL FOR INDOOR MAPS." SDSC 2018 (2018).
7. Biljecki, F., H. Ledoux and J. Stoter. "An improved LOD specification for 3D building models." Comput. Environ. Urban Syst. 59 (2016): 25-37.
8. Pei-Ying Li, Haruo Hibino, Shinichi Koyama, Meng-Cong Zheng, Tailoring Map Design Based on Map-Reading and Way-Finding Behaviour in Subway Stations, Procedia - Social and Behavioral Sciences, Volume 42, 2012, Pages 466-476, ISSN 1877-0428, https://doi.org/10.1016/j.sbspro.2012.04.212.
9. Rantakari, Juho, et al. "Exploring the design of stereoscopic 3D for multi-level maps." Proceedings of the 6th ACM International Symposium on Pervasive Displays. 2017.
10. Kuliga, S.F., Nelligan, B., Dalton, R.C., Marchette, S., Shelton, A.L., Carlson, L., Hölscher, C., 2019. Exploring Individual Differences and Building Complexity in Wayfinding: The Case of the Seattle Central Library. Environ. Behav. 51, 622–665. https://doi.org/10.1177/0013916519836149
11. Luo, Z., Luo, W., 2013. Spatial representation of a multi level building: Bias, complexity and the role of a 3D Map. Int. J. Comput. Res. 20, 25–52.
12. Lee, P.U., Klippel, A., Tappe, H., 2003. The effect of motion in graphical user interfaces. Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics) 2733, 12–21. https://doi.org/10.1007/3-540-37620-8_2