Supra-individual consistencies in navigator-driven landmark placement for spatial learning

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Abstract

Landmarks are an essential part of human navigation. In most situations, landmarks used for navigation are available in the environment. However, landmarks can also be set up deliberately to facilitate future orientation. The question how such navigator-driven and individual landmark placement affects spatial learning and what strategies are used has rarely been examined. We addressed this question with two experiments. Participants explored virtual environments and placed landmarks with the aim of developing a mental map of the environment (measured by sketch mapping, Study 1) or to facilitate wayfinding (Study 2). Their performance was compared to participants who did not place landmarks. Landmarks were detrimental to sketch mapping (Study 1), and provided no significant advantage for wayfinding (Study 2). However, we found strong supra-individual consistencies of landmark placement strategies in both studies, implying a "wisdom of the crowd" for critical landmark locations.

Keywords: virtual reality, landmarks, wayfinding, spatial learning strategies.

Landmarks in human spatial learning

Every sufficiently complex environment can turn into a confusing maze where one can easily get lost. This is especially true if the environment is visually sparse and lacks of visual elements -such as landmarks- that distinguish one location from another. Several ancient myths (e.g., Theseus and the Minotaur) and classic fairy-tales (e.g., Hansel and Gretel) tell us about such challenges and approaches to overcome them.

Research on spatial cognition has emphasized the role of landmarks as an essential aspect of human orientation and spatial learning. Golledge (1999) stated that "landmarks usually act as anchor points for organizing other spatial information into a layout." Despite their central role in human orientation, it has turned out to be surprisingly difficult to pinpoint the defining characteristics of a landmark. Several findings indicate that landmarks at decision points are more important for human navigation than landmarks at other locations (e.g., Michon & Denis, 2001), whereas other studies report rather contradictory findings (Schwering, Li, & Anacta, 2013). More formal frameworks attempt to characterize the importance of landmarks according to their visual, structural, and semantic salience and distinctiveness (Raubal & Winter, 2002). In the optimal case, this would allow the automatic assessment of the most relevant landmark in a given location. Orientation in built environments can also rely on a special form of landmarks: Signs are deliberately set up to reduce the cognitive demands of wayfinding in a building into a simple matching of pictograms (Hölscher, Büchner, Brösamle, Meilinger, & Strube, 2007). Signs can serve different purposes (see Passini, 1984). For example, they are (similar to landmarks) considered more relevant for orientation when positioned at decision points. However, signs may also suffer under a number of deficiencies such as poor positioning, which may affect their probability to be detected at all (Xie, Filippidis, Galea, Blackshields, & Lawrence, 2012). Thus, a sophisticated rationale for sign positioning is desirable.

These considerations concern landmarks already available in the environment. However, landmarks can also be set up by an individual in order to facilitate orientation. For example, hikers and scouts sometimes deliberately create landmarks to find their way back. But contrary to the popularity of Hansel and Gretel and their breadcrumb trace, there is almost no research that has investigated how people make use of such individually placed landmarks. Ruddle (2008) describes a computational method for generating trails, but not distinctive landmarks, in a virtual environment. Supportive evidence is reported by Cliburn, Winlock, Rilea, and Van Donsel (2007), who found that participants with individually or preplaced landmarks needed less navigation time and covered less distance in an artificial grid-like virtual environment than participants without landmarks. In a related research field, the placement of landmarks has been shown to foster the mapping abilities of robots (Beinhofer, Kretzschmar, & Burgard, 2013). Thus, there is some evidence that individually placed landmarks may help to mark previously visited places, disambiguate similar places and provide reference points for the integration of partial views. In other words, if such landmarks serve as anchor points for the organization of spatial information as claimed by Golledge (1999), we can expect an increase in spatial learning as compared to individuals who are not allowed to place landmarks. However, the development of a mental map of an environment is a cognitively demanding task, and requires the switch between egocentric and allocentric perspective (Shelton & McNamara, 2004). Thus, it is also possible that this cognitive effort limits potential advantages of individually placed landmarks for the development of survey knowledge. Moreover, the findings of Shelton and McNamara (2004) imply that a task involving landmarks may result in a landmark-centered orientation strategy. Thus, the facilitation of spatial learning by individually placed landmarks may be more pronounced in a setting that requires route knowledge.

Taken together, the present research addresses the following questions: First, does the placement of landmarks at individually chosen places in an environment support the development of a mental map of this environment (Study 1), respectively the ability to locate specific locations in a wayfinding task (Study 2)? Second, can we identify supra-individual strategies and patterns in the placement of landmarks in both scenarios?

Study 1

Study 1 examined whether individually placed landmarks support the development of a mental map of an environment. In order to avoid floor effects, we decided to use artificial but rather simple environments. One group of participants placed landmarks individually during the exploration, whereas another group of participants explored the environments without the help of landmarks. Similar to Cliburn and colleagues (2007), we included a third condition with preplaced landmarks. This allowed us to compare potential advantages of individually placed landmarks as compared to existing landmarks.

Method

Participants were 115 students (36 of them male; age: 19-33, $M = 23$, $SD = 3$).

Materials and Procedure. We created three environments based on simple geometric shapes ('Overlapping squares', 'Shifted stop sign', and 'Z in a box'), displayed in Figure 1. Participants were individually tested on three 24" monitors arranged in a semi-circle. Movement was controlled with a gamepad (left analogue stick: body movement; right analogue stick: head movement). Placement of landmarks was executed by pressing a button. Participants explored the first environment with the instruction to remain in the environment until they were sure to be able to draw a sketch of this environment, with a max time limit of eight minutes[1]. In the *individual landmarks* condition, participants were allowed to place up to four landmarks while they explored the environment. The landmarks were four differently colored balls hovering in space. In the *preplaced landmarks* condition, four landmarks were placed a priori in the way that from any point in the environment at least one landmark was visible. This was pointed out to participants before they explored the environment. In the *no landmarks* condition, participants explored the empty environment. After the exploration, participants from all conditions drew a sketch map of the environment without a time limit. This procedure was repeated for all environments.

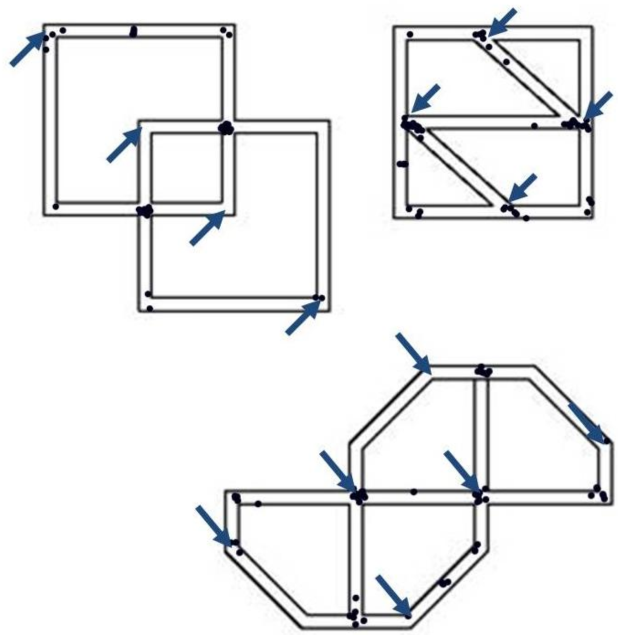

Figure 1: Layouts of the environments used in Study 1 (top left: Overlapping Squares; top right: Z in a Box; bottom: Shifted stop sign). Black dots indicate all landmarks placed in the individual landmarks condition. Blue arrows indicate landmark positions in the preplaced landmarks condition.

Design. The independent variables was landmark type (individual landmarks vs. preplaced landmarks vs. no landmarks), manipulated between subjects. The dependent variable were additional and missing segments in the sketch maps, as well as a rating of their overall quality.

Results

For all statistical analyses throughout this paper, the Type-I-error was set at $\alpha = .05$. As an indicator of effect

[1] Exploration time between the experimental groups was comparable for all environments, all $F < 1.50$, ns.

size, partial η^2 (η^2_p) is reported for statistically significant effects (Cohen, 1977).

Sketch map analysis. Two independent raters analyzed the sketch maps for number of additional segments (i.e., segments a participant sketched not existing in the original layout), number of missing segments (i.e., the number of connections between turns and intersections a participant did not sketch), as well as for their overall quality (1 = very good to 6 = very bad). Mean values were computed after a sufficient inter-rater correlation was confirmed, $r_t > .66$ for all measures and environments. All descriptive data are presented in Table 1.

First, we computed a (individual landmark**s** vs. preplaced landmarks vs. no landmarks**)** MANOVA for additional segments, $F(6,162) = 4.32$, $\eta^2_p = .14$, $p < .001$. There were significant differences for 'Overlapping squares', $F(2,82) = 10.96$, $\eta^2_p = .21$, $p < .001$, and 'Z in a box', $F(2,82) = 3.22$, $\eta^2_p = .07$, $p < .05$, but not for 'Shifted stop sign', $F = 2.18$, ns. Participants in the no landmarks condition draw fewer additional segments than the other experimental conditions, indicating a better comprehension of the environments' layouts.

Table 1: Mean number (and standard errors) of missing and additional segments in the sketch maps, as well as their overall quality ratings (ranging from 1 = very good to 6 = very bad), separately for all conditions and environments.

	Individual Landmarks	Preplaced landmarks	No landmarks
	Additional segments		
Overlapping squares	3.14 (.60)	3.86 (.50)	.95 (.36)
Shifted stop sign	1.08 (.70)	3.14 (.70)	1.92 (.43)
Z in a box	.64 (.27	.72 (.23)	.15 (.14)
	Missing segments		
Overlapping squares	1.47 (.26)	1.14 (.26)	.52 (.16)
Shifted stop sign	2.28 (.53)	1.67 (.53)	1.59 (.32)
Z in a box	.36 (.13)	.28 (.13)	.11 (.08)
	Overall grade		
Overlapping squares	3.53 (.34)	4.06 (.33)	1.97 (.21)
Shifted stop sign	3.41 (.36)	3.47 (.35)	3.04 (.22)
Z in a box	1.99 (.24)	2.13 (.24)	1.51 (.15)

A second MANOVA for missing segments missed significance, $F(6,162) = 2.06$, $p = .06$. However, a descriptive analysis of Table 1 implies that for 'Overlapping squares', participants in the no landmarks condition missed less segments than participants in the other conditions. This impression was confirmed by a significant univariate effect, $F(2,82) = 5.70$, $p < .01$. This effect did not extend to the other two environments, both $F < 1.71$, both $p < .18$, ns.

Third, we evaluated the overall quality ratings of the sketches. The MANOVA revealed a multivariate effect, $F(6,162) = 4.87$, $\eta^2_p = .15$, $p < .001$. Again, there were significant differences for the 'Overlapping squares', $F(2,82) = 17.45$, $\eta^2_p = .30$, $p < .001$, and 'Z in a box', $F(2,82) = 3.09$, $\eta^2_p = .07$, $p = .05$, but not for 'Shifted stop sign', $F < 1$, ns. The data depicted in Table 1 imply that the overall quality of the sketch maps drawn by participants in the no landmarks condition were higher as compared to sketch maps from participants in the two conditions with landmarks.

Discussion

The findings of Study 1 are quite clear: Landmark, even when placed at individually chosen locations, are rather detrimental to the development of a mental map, as indicated by sketch mapping (although this effect was less pronounced for the more complex 'Shifted stop sign' shape). It appears likely that the presence of landmarks primed participants towards a respective spatial orientation (Shelton & McNamara, 2004). Thus, individually placed landmarks may be more advantageous for a wayfinding task than for a mapping task. This assumption was tested in Study 2.

Although we found that the individual placement of landmarks did not facilitate sketch mapping, there was a remarkably high supra-individual conformity where participants placed their landmarks. This conformity is impressive, considering that participants had explored the environments from an egocentric perspective only. It appears that participants tended to place their landmarks at the most central and most visible locations within each environment. This finding will also be scrutinized more closely in Study 2.

Study 2

Study 2 examined the effects of individual landmark placement for wayfinding for a more complex environment as used by Cliburn and colleagues (2007). Thus, participants were required to explore a virtual model of the Tate Gallery in London (Conroy-Dalton, 2001) and find three goal locations in the otherwise visually sparse environment. One group placed non-directional landmarks (i.e., arrows pointing towards the ground). A second group placed directional landmarks (i.e., arrows pointing into a chosen direction), similar to signs indicating a direction. A control group was not allowed to place landmarks. Given the complexity of the environment, we did not include a condition with preplaced landmarks.

If placing landmarks for future wayfinding induces a landmark- and route-based orientation, it is more likely that placing landmarks is advantageous to spatial learning. Furthermore, directional landmarks should reduce more spatial ambiguity than non-directional landmarks and thus have additional benefits to wayfinding performance.

Method

Participants were 53 first-year students (about 50% of them male; age: 18-48, *M* = 25, *SD* = 5).

Materials. The apparatus was identical to Study 1.

A virtual model of the Tate Gallery consisted of no distinctive objects or textures but three goal locations marked with images on the wall ('Ball', 'Dog', and 'Mouse'). The only other exception was the entrance area (at the very bottom of Figure 2) with a blue texture. The general layout of the environment and the locations of these goal locations are displayed in Figure 2.

Landmarks were five 3D-arrows with a differently colored point each. In the directional landmarks condition, the arrows had a horizontal orientation, thus pointing into a direction chosen by the participant. In the non-directional landmarks condition, the same arrows had a vertical orientation, thus pointing towards the floor. Directional landmarks pointed into the direction of view during the moment of placement. In order to avoid unintentional and miss-oriented landmark placements, participants could retract a landmark for thirty seconds after the initial placing and place it again.

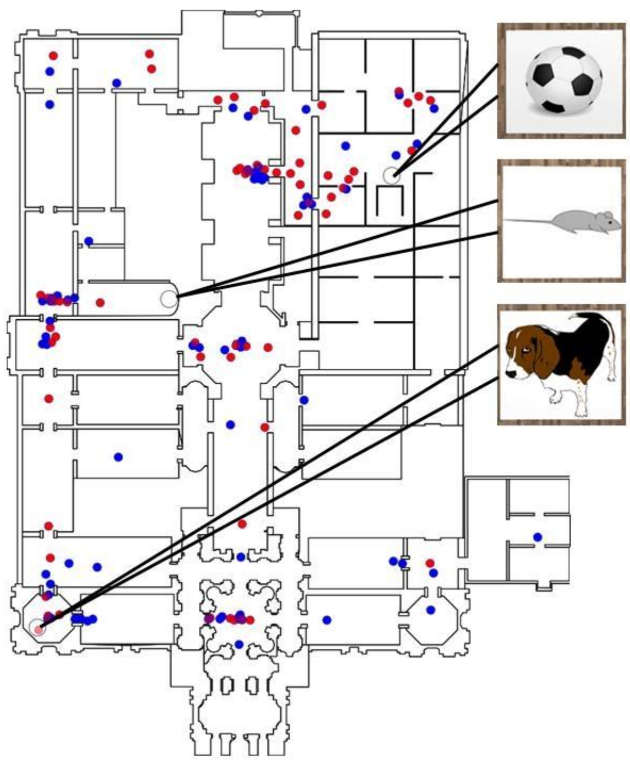

Figure 2: Layout of the Tate Gallery and goal locations. Dots represent landmarks placed by participants in the directional (red) and non-directional (blue) condition.

Procedure. In the *practice phase*, participants practiced movement with the gamepad for two minutes and the placement and retraction of landmarks for three minutes in a separated part of the environment. Participants in the no landmarks condition continued to practice movement. In the *exploration phase*, all participants started at the main entrance of the building, viewing into the direction of the main corridor. They were instructed to explore the building and locate the three goal location within 15 minutes. Participants in the two conditions with landmarks were also informed that they could place landmarks later in the experiment. In the subsequent *landmark placement phase*, participants in the directional and the non-directional landmark condition were instructed to place up to five landmarks within ten minutes, so that the landmarks would support the localization of the goal locations in the next experiment phase. Participants in the no landmarks condition continued to explore the building in this phase. In the *wayfinding phase*, all participants were positioned at a predefined location in the environment and instructed to find the goal location 'Mouse' within three minutes. Once the goal location or the time limit was reached, participants were automatically positioned at another predefined location, and the wayfinding task was, in this order, repeated for the goal locations 'Dog' and 'Ball'. Finally, self-reported sense of direction was conducted before participants were thanked and debriefed.

Design. The independent variable was landmark type (directional landmarks vs. non-directional landmarks vs. no landmarks) in a between subjects design. The dependent variables were time and distance in the wayfinding tasks.

Results

Wayfinding performance. The overall probability to find the goal location within the time limit was 67% for 'Mouse', 81% for 'Dog', and 73% for 'Ball', but these differences were not significant, $p > .15$. The maximal time of three minutes and the distance travelled up to that point of time, respectively, were used for analysis if participants had not found a goal location.

First, we analyzed the time participants needed to find the three goal locations in a 3 (landmark condition: directional landmarks vs. non-directional landmarks vs. no landmarks) x 3 (goal location: Mouse vs. Dog vs. Ball) ANOVA with repeated measures on the second factor (see Table 2). We found a main effect of goal location, $F(2,50) = 15.39$, $\eta^2_p = .24$, $p < .001$, indicating that participants required less time to find 'Mouse' than 'Dog' and 'Ball'. However, there was no difference between the experimental conditions and no interaction effect, both $F < 1.76$, ns. In other words, the placement of directional and non-directional landmarks did not enhance the participants' wayfinding performance as compared to participants in the no landmarks condition.

Table 2: Mean time in seconds (and standard error) in the wayfinding task, separately for all conditions and all goal locations (as well as the mean average for all locations).

	Directional Landmarks	Non-directional Landmarks	No Landmarks
Mouse	121s (8s)	136s (8s)	139s (9s)
Dog	84 (10s)	112s (7s)	105s (11s)
Ball	112s (9s)	117s (10s)	123s (11s)
Mean	106s (7s)	122s (7s)	122s (7s)

This result could be biased by participants who spend more time looking around in order to locate the next landmark, thus scoring a high time despite an efficient path choice. In order to account for this possibility, we analyzed the travelled distance in an equivalent ANOVA (see Table 3). The results corroborated the previous analysis with a main effect of goal location, $F(2,50) = 12.42$, $\eta^2_p = .20$, $p < .001$. Again, there was neither an effect of landmark condition nor an interaction effect, both $F < 1.52$, ns. Thus, there was also no positive effect of placing landmarks with regard to the travelled distance as compared to wayfinding without landmarks.

Table 3: Mean distance in the wayfinding task (and standard error), separately for all conditions and all goal locations (as well as the mean average for all locations).

	Directional Landmarks	Non-directional Landmarks	No Landmarks
Mouse	260 (15)	278 (15)	288 (14)
Dog	184 (20)	238 (22)	224 (19)
Ball	240 (18)	250 (19)	258 (17)
Mean	228 (13)	255 (13)	256 (12)

This findings imply that placing landmarks does not support wayfinding in a complex virtual building. To test this implication further, we will now turn to a more detailed analysis of the distribution of the deployed landmarks.

Distribution of landmark placements. As can be derived from Figure 2, there are several visible clusters where participants from both landmark conditions[2] preferred to place their landmarks. Some of these clusters are clearly related to a specific goal location (e.g., the clusters most closely located to the goal locations 'Mouse' and 'Dog' on the left side of the environment). However, other clusters are rather superfluous from a data processing point of view: they are located far from the next goal, and at central areas of the building that are already identifiable by their unique configurational layout (e.g., in the central part of the main corridor).

Considering that we found no significant wayfinding performance advantage of the conditions placing landmarks as compared to the no landmarks condition: Are the observed clusters meaningful and supportive in regard to wayfinding? In order to address this question, we used a k-means clustering algorithm (see MacKay, 2003), thus identifying the 'best' locations for deploying a landmark according to the 'wisdom of the crowd'. Next, we developed a formula to compute the mean distance of each participant's individually placed landmarks to the closest centroid (i.e., the central point of a landmark cluster), where let C be the set of centroids of the five largest clusters, and let D be the set of landmarks of one participant:

$$\frac{\sum_{l \in D} \min\left(\left\{\left|l - c\right| \mid c \in C\right\}\right)}{\left|D\right|}$$

[2] As there were no significant wayfinding performance differences between the two experimental conditions with landmarks, and since the visual inspection suggested highly similar placement patterns, all results reported in this paragraph are computed with data merged from both conditions.

Put differently, we computed how much an individual participant's landmarks deviated from the 'wisdom of the crowd'. This deviation correlated significantly with the wayfinding performance measures time ($r = .51$, $n = 33$, $p = < .01$) and distance ($r = .37$, $n = 33$, $p = < .04$): The closer individual participants placed their landmarks to the cluster centers derived from the placements of all participants, the better their wayfinding performance. Thus, although there was no benefit of landmark deployment for wayfinding performance per se, landmarks placed at the 'right' locations appear to be supportive in this regard. Furthermore, the deviation from the from the cluster centers also correlated with the self-reported sense of orientation ($r = -.45$, $p = < .01$): Participants with a good sense of orientation deployed their landmarks closer to the cluster centers. These correlations provide convincing evidence that the cluster centers represent indeed 'good' landmark locations for finding the given goal locations.

Discussion

The results of Study 2 suggest that wayfinding performance of participants who placed landmarks individually was not facilitated as compared to participants who did not place landmarks. This was observed for directional landmarks that pointed into a specific direction as well as for non-directional landmarks. Several reasons may have contributed to this rather unexpected finding. First, the Tate Gallery may have been too complex for the number of available landmarks or not complex enough to require the placement of landmarks for successful wayfinding. However, directional landmarks appeared to have a positive effect on wayfinding performance descriptively, as compared to both the non-directional and the no landmarks condition, but the effect was not strong enough to reach significance in our study. In this regard, it would be a challenging task to analyze how the directional landmarks were used in regard to the goal locations, although we were not able to identify obvious patterns in our study. Second, many rooms had -despite the absence of distinctive features or objects- a unique configurational layout that may have supported the self-localization of participants in the no landmarks condition (i.e., the pillars in the entrance hall make this area identifiable without any additional landmarks). Additionally, we assumed that participants would made use of all landmarks they had placed. However, it is possible that they actually did not detect relevant landmarks when searching a goal location (Xie et al., 2012). Third, participants may have placed landmarks at locations that were disadvantageous for wayfinding. The analysis of the landmark placement distribution speaks against this assumption: although the participants had neither seen a map of the environment nor an opportunity to discuss their strategies with other participants, there was a strong consistency in the placements. This consistency appears to represent a 'wisdom of the crowd', as participants who placed their landmarks in accordance with these cluster centers showed better wayfinding performance and indicated a better sense of orientation.

General Discussion

The research at hand is one of the first to examine the effects of navigator-driven placement of landmarks for different levels of spatial learning. Our findings imply that placing landmarks distracts from the development of a mental map of an environment as indicated by sketch mapping (Study 1). At the first glance, this result appears rather surprising, as landmarks should help to reduce ambiguity in the environment and enable the integration of partial views, similar to effects demonstrated in robotic environment mapping (Beinhofer et al., 2013). However, our findings are in line with previous research that implies that the focus on landmark placement induces a respective spatial orientation mode, thus inhibiting survey perspective taking (Shelton & McNamara, 2004). Future research should further address similarities and differences in robot and human use of landmark for enhancing an environmental representation.

In contrast to our hypothesis, we found no advantage of individual landmark placement for wayfinding performance, either, although the placing landmarks fits the spatial orientation required for wayfinding (Study 2). However, we do not claim that such an effect does not exist at all. Additional research on familiarity and complexity of the environment as well as on the number of available landmarks is required to draw this conclusion.

The most interesting finding of this research concerns the strong supra-natural consistencies in the placement of landmarks. Independently from each other, participants placed their landmarks at similar locations. Some of these clusters appeared to relate to the most central and visible areas in the environments (Study 1+2). Other clusters stand in clear relation to a specific goal location (Study 2). Strong correlations with wayfinding performance and self-reported sense of orientation suggest that on average, humans appear to have an intuitive understanding of configurational aspects of space, even when experienced from an egocentric perspective. We are currently aiming to relate our findings on the placement of landmarks to space syntax measures (Hillier, 2008). Space syntax has been found to be a strong predictor of pedestrian movement in the real as well as in a VR model of the Tate Gallery (Conroy-Dalton, 2001). Our findings could be a first step to establish how to use space syntax to understand and predict where humans require and expect wayfinding information, and thus develop a sophisticated rationale for good sign positioning in complex buildings.

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References

Beinhofer, M., Kretzschmar, H., & Burgard, W. (2013). Deploying artificial landmarks to foster data association in simultaneous localization and mapping. In *ICRA* (pp. 5235–5240). IEEE.

Cliburn, D., Winlock, T., Rilea, S., & Van Donsel, M. (2007). Dynamic landmark placement as a navigation aid in virtual worlds. In *Proceedings of the 2007 ACM symposium on Virtual reality software and technology* (pp. 211–214). ACM.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences* (Vol. Rev). Hillsdale, NJ: LawrenceErlbaumAssociates, Inc.

Conroy-Dalton, R. (2001). *Spatial Navigation in Immersive Virtual Environments*. University of London.

Golledge, R. G. (1999). *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. JHU Press.

Hillier, B. (2008). *The Social Logic of Space* (Reprint.). Cambridge University Press.

Hölscher, C., Büchner, S. J., Brösamle, M., Meilinger, T., & Strube, G. (2007). Signs and maps–Cognitive economy in the use of external aids for indoor navigation. In *Proceedings of the 29th annual cognitive science society* (pp. 377–382). Cognitive Science Society Austin, TX.

MacKay, D. J. C. (2003). *Information Theory, Inference and Learning Algorithms*. Cambridge University Press.

Michon, P.-E., & Denis, M. (2001). When and Why Are Visual Landmarks Used in Giving Directions? Spatial Information Theory. In D. Montello (Ed.), (pp. 292–305). Springer Berlin / Heidelberg.

Passini, R. (1984). *Wayfinding in architecture*. Van Nostrand Reinhold.

Raubal, M., & Winter, S. (2002). Enriching Wayfinding Instructions with Local Landmarks. In *Proceedings of the Second International Conference on Geographic Information Science* (pp. 243–259). London, UK, UK: Springer-Verlag.

Ruddle, R. A. (2008). Generating trails automatically, to aid navigation when you revisit an environment. *Presence: Teleoperators and Virtual Environments*, *17*(6), 562–574.

Schwering, A., Li, R., & Anacta, V. J. A. (2013). Orientation information in different forms of route instructions. In *Short Paper Proceedings of the 16th AGILE Conference on Geographic Information Science, Leuven, Belgium*.

Shelton, A. L., & McNamara, T. P. (2004). Orientation and perspective dependence in route and survey learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(1), 158–170.

Xie, H., Filippidis, L., Galea, E. R., Blackshields, D., & Lawrence, P. J. (2012). Experimental analysis of the effectiveness of emergency signage and its implementation in evacuation simulation. *Fire and Materials*, *36*(5-6), 367–382.