User Preference for Navigation Instructions in Mixed Reality

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Abstract

Current solutions for providing navigation instructions to users who are walking are mostly limited to 2D maps on smartphones and voice-based instructions. Mixed Reality (MR) holds the promise of integrating navigation instructions directly in users' visual field, potentially making them less obtrusive and more expressive. Current MR navigation systems, however, largely focus on using conventional designs such as arrows, and do not fully leverage the technological possibilities. While MR could present users with more sophisticated navigation visualizations, such as in-situ virtual signage, or visually modifying the physical world to highlight a target, it is unclear how such interventions would be perceived by users. We conducted two experiments to evaluate a set of navigation instructions and the impact of different contexts such as environment or task. In a remote survey (n = 50), we collected preference data with ten different designs in twelve different scenarios. Results indicate that while familiar designs such as arrows are well-rated, methods such as avatars or desaturation of non-target areas are viable alternatives. We confirmed and expanded our findings in an in-person virtual reality (VR) study (n = 16), comparing the highest-ranked designs from the initial study. Our findings serve as guidelines for MR content creators, and future MR navigation systems that can automatically choose the most appropriate navigation visualization based on users' contexts.

Index Terms: H.5.1 [Information Interfaces and Presentation (e.g., HCI)]: Multimedia Information Systems—Artificial, augmented, and virtual realities;

1 Introduction

Most navigation solutions for pedestrians rely on 2D map overviews and voice-based feedback delivered through mobile devices such as smartphones. While smartphone-based 2D map interfaces provide users with a good overview of next steps and future directions, the disconnect between their surroundings and display can be distracting to users, and increases the likelihood of not noticing their surroundings [15]. Voice-based interaction minimizes this problem, but does not provide users with continuous instructions, which may be detrimental to the overall user experience, in particular for indoor navigation in locations where instructions should be frequent (e. g. a museum).

Mixed Reality (MR) can deliver navigation instructions that are directly integrated in users' visual field, thus their environment, in particular when using always-on devices such as head-mounted displays (HMDs) and heads-up displays (HUDs) [9]. By blending the virtual elements with the physical world, such MR instructions have the potential to be unobtrusive yet continuously available to users, and only capture users' attention when needed. Current approach to MR navigation instructions focus mostly on directly transferring well-known interaction paradigms from 2D to 3D, such as displaying arrows on the ground in front of users (e. g. [30, 31]). While these types of visualizations have the benefit of familiarity, they might capture too much attention and are not always suitable. For example, to users who are rushing to reach a departure gate at a busy airport, virtual arrows displayed on the ground may be a distraction, as they interfere with motions of other pedestrians. Additionally, in situations where users are strolling towards a restaurant without a time constraint, they may want to view and explore their surroundings; therefore, constantly displaying directions through view-anchored items (e. g. text displayed as head-up display items) may be perceived as unnecessarily obtrusive. While arrows work well in some scenarios, they may be worse than other navigation designs in different situations, and this is likely true for all other navigation visualizations as well. We therefore argue that the context users are in should be treated as a main deciding factor for which visualization is most suitable in a particular scenario.

In this work, we aim to explore which MR navigation instructions are preferred by users when presented alongside various navigation scenarios. Our goal is to evaluate classical MR navigation techniques and visualizations (e. g. arrows, callouts), as well as other approaches that provide a tighter integration with the physical environment, such as desaturation of non-targets or virtual replicas of physical objects as guidance, and visualizations that are situated between those two types such as virtual glowing paths. To achieve this, we placed these visualizations in distinct scenarios with different combinations of contexts. By comparing the effectiveness of each design across diverse situations, we aim to establish a set of guidelines to help content creators choose the most effective visualization for a particular context, and set the foundations for computational approaches that automatically decide which visualization is most appropriate.

To achieve this goal, we performed two evaluations. First, in an online evaluation, we presented 50 users with different navigation scenarios consisted of different contexts (e. g. environment, time pressure, task), and images of different MR navigation instructions, shown in Figure 1. They were asked to rank their top three visualizations and provide reasoning for their choices. Results indicate that participants preferred arrows, callouts, avatar, and desaturation of target-irrelevant parts of the environment. Participants' choices were highly dependent on time constraints (e. g. desaturation was most preferred in a rushed scenario), task (e. g. arrows significantly less preferred for browsing tasks), and, to a limited extent, by the environment (e. g. no difference between arrows, callouts and avatar for large outdoor environments).

Secondly, in an in-person study (n = 16), evaluated the design preference of participants when performing a navigation task in 3D. Participants completed a series of navigation tasks in virtual reality (VR), comparing arrows as baseline, with the three best scoring alternatives from the first study: avatar, callouts, and desaturation. The arrows technique was chosen as the baseline as it is not only the favorite navigation design amongst participants of the first study, but also a frequently employed design amongst current navigation systems. Results indicate that arrows and avatar were the most preferred, and that aspects such as efficiency, clarity and the size

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of the environment play major roles for participants when deciding which navigation design is more effective. We believe that our results serve as extended guidelines for content creators, and open doors to more research with a goal of discovering and evaluating MR navigation visualizations beyond simple arrows.

In summary, we make the following contributions:

- An online study (n = 50) comparing a series of MR navigation instructions, shown as images, for a variety of contexts. Results reveal general preferences of participants towards arrows, avatar, callouts and desaturation, and context-specific considerations such as task and time constraints.
- An in-person VR study (n = 16) evaluating the most preferred techniques from the initial study. This assessment confirms and expands on the initial results, and provides further insights into when to use specific MR navigation designs.
- A set of guidelines that can be used by MR content creators, as well as for future computational approaches that automatically decide which navigation design is the best in a specific scenario.

2 RELATED WORK

In this section, we review the most relevant related works on conventional and MR navigation interfaces.

2.1 Conventional navigation interfaces

Do et al. [10] analyzed 77 participants' phone usage data over nine months. They found that a majority used a map application (e. g. Google Maps) at least once, while roughly 80% used it more than ten times. This indicates that navigation is one of primary use cases of mobile devices today. To understand which navigation applications people most often utilize, Ceci et al. [5] analyzed the download data of mapping applications from the Google Play Store and the Apple App Store. Results indicate that Google Maps and Waze [2] are by far the most commonly used navigation applications today. Both applications are similar in that they present information through some combination of 2D map interfaces and voice outputs. For instance, when a user searches for directions to a restaurant, conventional navigation applications will display arrows and colored lines on a digital map, while providing spoken directions near turns. Such design is simple and intelligible, but prior research suggests that it may also be unsafe in certain scenarios.

In order to use a conventional navigation system, users have to look at its graphical user interface, which forces them to shift their attention away from the real world. To drivers, this can become hazardous as their reaction time to sudden events can increase whenever they are not focused on the road ahead [37]. This is also true for pedestrians, as they can become less aware of their surroundings, including obstacles, cars, and other pedestrians, when using their phones and walking simultaneously [15]. These challenges within navigation occur due to inattentional blindness, amongst other factors, a phenomenon where people overlook even the most conspicuous events when not paying attention [4]. To address this problem, researchers began to look into embedding guidance into the physical world so that users can concurrently view both the directional information and the real world. Knierim et al. [22], for example, used a projector mounted onto a quadcopter to display in-situ navigation instructions, which enabled users to better observe real-world points of interest. In our work, we employ conventional 2D map-based navigation and other visualizations such as arrows and paths on the ground as inspiration for the designs in our first study, and for the application scenarios of both studies.

2.2 Mixed Reality navigation

Mixed Reality has been proposed as a viable solution for displaying safe in-situ instructions for navigation (cf. Cipresso et al. [7], Dey et al. [9]). MR is advantageous in that it can overlay virtual cues on the real world [9], meaning users do not have to look away from the path ahead. Conventional MR navigation systems include the Live View feature of Google Maps [12] and the 3D View feature of Apple Map [13], both of which superimpose arrows and text onto the real world for users to follow while enabling them to simultaneously observe the surrounding scenery. These techniques can be applied to both pedestrian and driving navigation, for example.

The automotive user interface community has been interested in shifting away from traditional navigation systems to instead using MR technologies to display navigation instructions in the driver's field of view. This is because although current personal navigation devices (PNDs), which present information through a combination of visual indicators and sound, are less distracting than paper directions (e. g. physical map), their graphical displays take attention away from their user's main task of driving [23]. To investigate the effectiveness of MR PNDs in addressing this issue, Kun et al. [23] compared the effects of different PNDs on drivers' attention. Results indicate that MR navigation systems have less negative impact on drivers' visual attention on the road than traditional PNDs [29, 36]. Additionally, researchers studied the benefits of displaying navigation information directly onto the vehicle's windshield using MR. Similar to before, users were less distracted when navigation instructions were superimposed on their field of view [21].

Besides visual navigation instructions, 3D spatial sounds are being used to aid blind or visually impaired (BVI) individuals in navigation tasks. For instance, when such a navigation system vocalizes "Turn Left," a BVI user wearing a stereo headset will hear this instruction from their left. Such feature is included in several products such as Microsoft Soundscape [1]. In this work, we focus on visual modalities. Our insights into the importance of context (differences between casual and targeted navigation, for example) make us believe that it is beneficial to investigate alternative presentations of instructions such as sound.

In terms of navigation instructions for pedestrians, prior studies suggest that MR navigation systems for pedestrians could serve a variety of purposes, such as guiding users in museums [24, 32] and aquariums [20], helping shoppers find items in malls [14], and providing tourism in unfamiliar locations [8]. We use these scenarios as applications for our evaluations. However, for such a system to be successful, there is a need to investigate how navigation instructions should be designed for MR [9]; thus, to address this concern, we compared multiple viable visualization techniques to understand which designs work best in different scenarios.

One commonly used, and arguably the most frequently used, MR navigation visualization technique are arrows. Although this design can look similar across various MR navigation systems, it often differs in the number of arrows used (e. g. one large arrow vs. a continuous set of arrows) and their placement (e. g. ground vs. mid-air). For instance, Google Map's Live View feature [12] uses three consecutive mid-air arrows, while Apple's 3D View feature [13] uses one large mid-air arrow when communicating directions with their users. In addition, MR navigation prototypes from prior research often relied on a single grounded arrow to display navigation instructions [30, 31, 35]. Due to its recurrent use across across numerous products and research, we included arrows in the list of designs in our first evaluation, and used it as a baseline in the second study. Our goal was to explore whether designs beyond arrows work better in some scenarios, and which factors contribute to users' preferences.

3 EXPERIMENT 1 - NAVIGATION INSTRUCTIONS IN 2D

The goal of the first study was to compare a wide variety of navigation instruction designs under different contexts. In an online study, users were asked to rank their preferred designs for each presented scenario. The choice of design was informed by previous work on MR navigation [9,30,31], commercial systems (e. g. [12,13]), as well

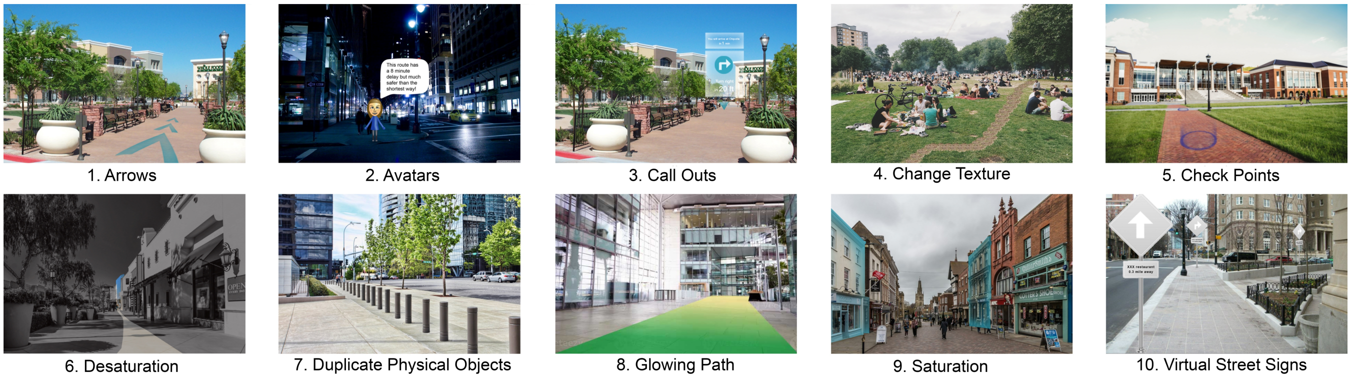

Figure 1: Navigation instructions used in study 1.

as work that modifies the environment to communicate with users (e. g. Zhao et al. [38], Jones et al. [18, 19], Lindlbauer et al. [26, 27]). The scenarios were chosen to cover a broad range of different environments and tasks.

3.1 Method

We presented participants with twelve scenarios. For each scenario, they were asked to pick their top three designs, out of ten possible choices. The study was conducted online, with designs being presented as images.

3.1.1 Scenarios

We presented users with twelve common navigation scenarios of users walking, considering three different factors of varying levels: (1) *environment* (outdoor, large indoor, small indoor), (2) *time* (not rushed, rushed), and (3) *task* (targeted, browsing). We chose these factors to cover a wide range of contexts, each of which could trigger different user considerations. As an example, we anticipated users' preferences to be different for small indoor scenarios in which they were navigating a crowded space (e. g. Scenario 2, Table 1), compared to walking in a large outdoor location such as a city sidewalk (e. g. Scenario 1, Table 1).

The specific *environments* mentioned in the scenarios included sidewalks and parks (outdoor), museums and aquariums (large indoor), and grocery stores and libraries (small indoors). *Time* refers to how much time a person has until when they must reach their destination, i. e. rushed or not rushed. We anticipated that the resulting level of urgency might influence participants' preferences. For instance, an individual who is in a hurry may prefer a continuous set of arrows over a slowly moving avatar. *Task* was defined as whether the scenario had a clearly-defined destination, i. e. targeted or browsing. The combination of the three factors resulted in a total of twelve scenarios (3 environments x 2 times x 2 tasks). Each scenario contained some unique combination of contexts. For example scenario 1 is as follows: "You have a reservation at a popular local restaurant. You began walking towards the restaurant with plenty of time left until the reserved time." This scenario takes place in an outdoor environment, the individual is not in a hurry, and is performing a targeted task. By presenting participants with the twelve scenarios, we aim to understand if contexts influence participants' preferences towards each navigation design. All scenarios were presented as a combination of a textual description and an image. The textual descriptions can be found in the Appendix, Table 1. The images that were used to showcase the navigation designs somewhat reflected these scenarios, although we did not present each design in each scenario individually. All images and designs used in study 1 can be found in the Appendix, Figure 5.

3.1.2 Navigation designs

We used 10 different navigation designs, shown in Figure 1. We include summaries of each design below.

- **Arrows**: An array of consecutive arrows on the ground.
- **Avatar**: A humanoid figure resembling a tour guide.
- **Callouts**: Information displays consisting of directions and distances to intermediate goals.
- **Change Texture**: A path on the floor with a material that is distinct from the environment.
- **Checkpoints**: Series of glowing circles on the ground.
- **Desaturation**: Applying a grayscale filter to remove color from the world, except for the path and destination.
- **Duplicate Physical Objects**: Duplicating key contextual elements to passively indicate a path.
- **Glowing Path** A simulated glowing path situated either above the horizontal view angle (i. e. ceiling) or below (i. e. ground).
- **Saturation**: Use an oversaturated frame to highlight the target.
- **Virtual Street Signs**: Simulated street signs that display various information relevant to intermediate goals.

3.2 Participants & Apparatus

The experiment was designed to support remote participation to enlarge and diversify the pool of participants. Participants were asked to complete an online survey with multiple pages, each containing one scenario and one representative image that illustrates the text. Below this scenario description, participants were presented with ten sets of images, one per navigation design, each containing an original image and its modified version containing one navigation design. These images did not necessarily relate to the presented scenario, but matched its environment to assist participants with imagining how navigation designs would look in the given scenario. These images can be found in Figure 5 (Appendix).

The survey was distributed through XRDRN, a crowd-sourcing platform for conducting remote extended reality (XR) studies [16], as well as advertised at a local university. Participation was limited to US-based participants to allow for compensation ($10 per participant). We collected responses from 50 participants over a one week period. The participants were between 18 and 40 years of age ($M = 29.52$ years, $SD = 0.54$ years), with 56% being male, 42% being female, and 2% preferring not to say. When asked to rate their previous experience with AR and VR (1 none, 5 expert), they rated themselves as $M = 3.18$ ($SD = 1.29$) and $M = 3.12$ ($SD = 1.38$) respectively.

3.3 Procedure

Participants first completed a consent form and completed a brief demographic survey. They then read the twelve scenarios and reported their top three visualizations per scenario, as well as reasons behind their choices as free-form text. We did not specify which contexts users should consider, but only to rank their top three designs to prevent confounding the results.

Upon completion of all ranking tasks, participants were given a post-study questionnaire consisting of questions regarding the overall favorite and least-liked designs, a 7-point Likert-like scale (1 low, 7 high) asking how much "appearance," "obtrusiveness," "integration in physical world," and "including information about navigation target" played a role in deciding their favorite designs, combinations of designs that may work well, and any contexts they considered when making their decisions.

3.4 Quantitative results

Each chosen design was assigned points according to rank (3 points for first rank, 2 points for second rank, and 1 point for third rank). Average ratings for all conditions for visualization type, environment, time, and task are illustrated in Figure 2. The data was analyzed using a 3 *Environment* × 2 *Task* × 2 *Time* × 10 *Visualization Type* repeated measures ANOVA ($\alpha = 0.05$) with Greenhouse-Geiser adjustment when sphericity was violated according to Mauchly's test, and Bonferroni-adjusted post hoc tests for pair-wise comparison when the results indicated a main effect, as suggested by Norman [33]. The statistical analysis was performed using JASP 0.16 [17].

Navigation designs. Results revealed a main effect for visualization type, $F(4.64, 232.06) = 9.172, p < 0.001$, Greenhouse-Geiser correction for violated sphericity. The top four choices were arrows, avatar, callouts and desaturation, all statistically different to the lower ranked designs. In detail, post hoc tests revealed the following preferences (all $p < 0.05$):

- Arrows were preferred over change texture, checkpoints, duplicate physical objects, glowing path, saturation, and virtual street signs.
- Avatar was preferred over duplicate physical objects, saturation, and virtual street signs.
- Callouts were preferred over checkpoints, duplicate physical objects, saturation, and virtual street signs.
- Change Texture was preferred over duplicate physical objects.
- Desaturation was preferred over duplicate physical objects, saturation, and virtual street signs.

Environment. No main effect for environment was present. Results indicate an interaction effect between environment and navigation designs, $F(11.93, 596.42) = 2.876, p < 0.001$, Greenhouse-Geiser correction for violated sphericity. Post-hoc comparisons with Bonferroni adjustment revealed that avatar was rated lower for small indoor than outdoor environments ($p < 0.05$), and callouts were rated lower for large indoor than outdoor environments ($p = 0.05$). No other navigation designs were significantly influenced by this variable. Note that the navigation designs and environments varied across pictures, which might have influenced the results. Based on the qualitative feedback, however, we still believe that the findings are valid. As an example, participants were concerned that the size of indoor environments may negatively influence the usage of the avatar design, which goes in line with the quantitative findings.

Time. No main effect for time was present. Results indicate an interaction effect between time and navigation designs, $F(5.92, 296.00) = 3.591, p < 0.01$, Greenhouse-Geiser correction for violated sphericity. Bonferroni-adjusted pairwise comparisons showed that Desaturation performed better in rush scenarios (rush vs. no rush $p = 0.002$), effectively becoming the most preferred design, together with arrows and callouts. We believe that this shows that participants could imagine removing highlights from non-target areas as a viable alternative, and that alteration of the physical environment was well received.

Task. No main effect for task was present. Results indicate an interaction effect between task and navigation designs, $F(4.72, 235.94) = 4.301, p < 0.01$, Greenhouse-Geiser correction for violated sphericity. Bonferroni-adjusted pairwise comparisons indicate the influence of task on the arrows design, as it was rated higher in targeted tasks compared to browsing tasks ($p < 0.01$). We believe that this shows that for casual navigation without a clear target or destination, alternative designs might be preferred over classical arrows.

3.5 Qualitative results

We used thematic analysis and affinity diagramming [28] to distill the qualitative feedback provided by participants. In this section, we provide a per-design analysis, to enable content creators to choose based on the strengths and weaknesses of the individual designs.

Arrows, Callouts, and Checkpoints Participants liked these three designs for related reasons. They were perceived as non-invasive, straightforward, and familiar. This notion was summarized by P2 as "...they appear the least distracting/invasive, the least ambiguous, and the most similar to the navigation systems I am used to." In addition, participants especially appreciated these designs in a targeted and/or rush scenarios because they just show the necessary path in the most straightforward manner. Advantages aside, participants expressed concerns towards the positioning of the arrows design (on the ground), which might take away attention from the real world, which might lead to people bumping into obstacles or overlooking hazards. Callouts was positively highlighted for providing additional information beyond just directions. However, P3 and P5 also noted that due to the vertical length and overall large size of callouts compared to other designs, it can be distracting or may not be visible in bustling environments such as an airport. Finally, participants were concerned about the discrete nature of checkpoints, i. e. not providing continuous directions such as arrows and ultimately being harder to follow.

Avatar Participants liked the avatar design because of its humanoid nature and its ability to (1) act as a guide, (2) display additional information (e. g. speech bubble), and (3) promote a sense of companionship and safety. This opinion is best described by the following two quotes: "Having an avatar in this situation would be like having your own personal tour guide, which could be very helpful and even a little comforting if you are alone in a country where you don't know anyone," (P4) and "The avatar could make you feel better about being in an unfamiliar place where you don't speak the language and could also provide you with info about the landmarks" (P7). P8 further commented that the dynamic nature of this design can display additional human-, and even AI-generated information more seamlessly than a static design such as arrows. Participants rated the avatar design favorably with it being especially effective for browsing tasks (e. g. exploring a museum), but raised concerns when viewing this design in crowded indoor environments (e. g. mall), as it can quickly blend into the crowd and become difficult to keep track of due to its humanoid nature.

Change Texture Participants liked the straight-forward nature of this design, and its ability to display a clear navigation path. However, participants were concerned that this design can be overlooked. As P2 commented, "I could imagine just thinking this to be a part of the environment and not relevant to my task of navigation." Although this design is more subtle, it carries a risk of becoming ambiguous.

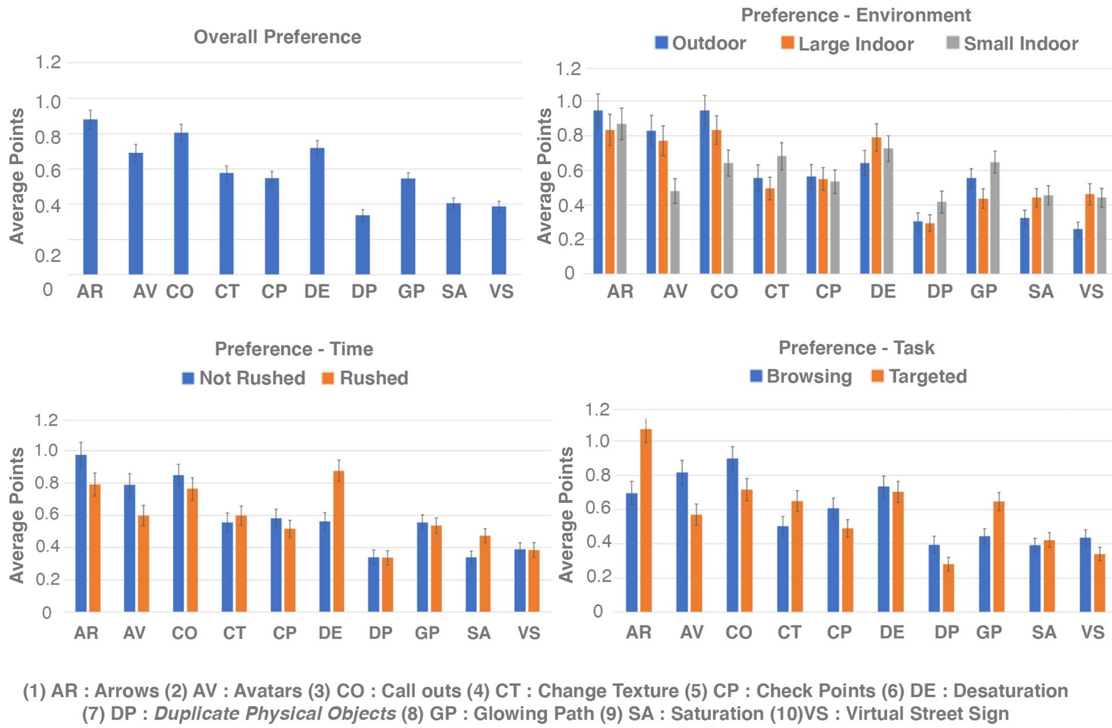

Figure 2: Mean preference values for the independent variables in study 1, calculated by assigning points to the ranked design (first: 3 points, second: 2 points, third: 1 point). Error bars indicate standard error.

Desaturation Participants appreciated desaturation as it allowed them to quickly locate their targets by drawing attention to it. P4 noted that "I chose desaturation first because this would keep you focused on your goal and make it easy to locate what you are looking for." In addition, P1 noted that desaturation might be better suited for crowded scenarios than designs that appear on the ground such as arrows, since it does not add additional elements to an already cluttered environment. Participants, however, were concerned that removing color from most of the environment can lead to losing too much real world information.

Duplicate Physical Objects Participants were concerned that this design might not always be easily applicable, and that they might not be able to differentiate the design from real world elements, as commented by P2: "I could imagine just thinking this to be a part of the environment and not relevant to my task of navigation." These concerns might be due to the nature of our study apparatus, with images showing exact replicas of the objects, rather than slightly altered version as would be expected for MR examples.

Glowing Path Glowing paths were perceived as straightforward, familiar, and to work well in rush scenarios. In addition, its higher saliency compared to arrows was appreciated. Furthermore, participants liked how the glowing path could be positioned on the ceiling to prevent further cluttering of the floor. As noted by P2 and P5, however, the design was perceived as more invasive and distracting than arrows. P3 and P4 further expressed concerns that, because this design covers a large area of the floor, it could hide potential tripping hazards.

Saturation Similar to the desaturation design, the saturation design allowed its users to quickly locate their targets. However, P2 and P13 both commented that saturation is the most invasive design, thus they prefer it less.

Virtual Street Signs Virtual street signs were perceived to work well in browsing scenarios due to their ability to provide a large quantity of information. For instance, as P4 noted, people will be able to find out where all of the exhibits are located and plan a path to visit their favorite historical artifacts. Because virtual street signs also exist in the physical world, however, participants were concerned that they might not be able to distinguish them from "real" street signs. In addition, similar to callouts, this design may not work as well in a crowded environment because of its vertical and slim nature.

3.5.1 Combinations

As part of the post-experiment questionnaire, we asked participants which combinations of navigation designs they think would work well. Both P4 and P7 agreed that arrows and desaturation might work well for the following reason: "Desaturation and arrows would be helpful so you always know where you are going without being distracted by additional objects" (P7). In addition, both P5 and P7 agreed that arrows and callouts might work well for the following reason: "The arrows and the callouts seem like they could combine nicely to give a good visual but also provide a bit more information" (P7). No other combinations were reported as a potentially effective design by two or more participants. It is evident that participants often chose two designs that can best cancel out the challenges of each other, which future experiments should exploit.

4 Experiment 2 - Navigation instructions in 3D

The goal of the second study was to investigate if the findings from the formative online survey can be confirmed in a 3D environment. Furthermore, we aimed to expand on the findings and probe participants for feedback on preferences among the top ranked designs from study 1.

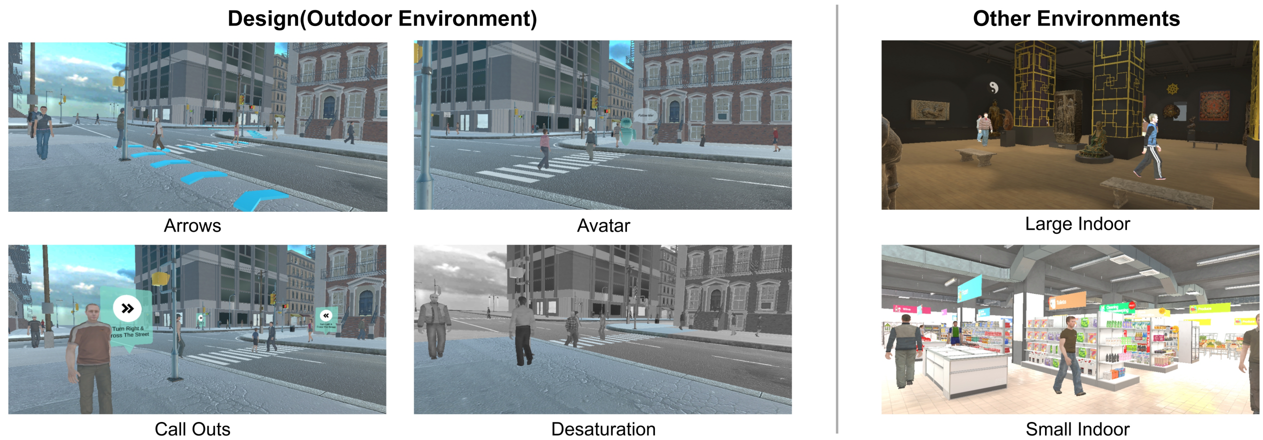

Figure 3: Navigation designs and environments employed in study 2.

4.1 Design

The experimental design included two independent variables, specifically *Environment* (outdoor, large indoor, small indoor) and *Navigation design* (avatar, callouts, desaturation). Avatar, callouts, and desaturation were each tested with one environment, resulting in three conditions. Additionally, we considered arrows as a baseline method; thus, for each environment, participants completed two navigation tasks, one with arrows and one with one of the three other designs. We chose the arrows technique as the baseline design, as it was not only the highest ranked design from study 1, but also a frequently used design across research and products. We used different paths for each condition per environment to avoid learning effects. The order of environments was counterbalanced using a Latin Square; the order of navigation designs per environment was randomized. We devised this study design to balance the length of the study, learning effects, and to ensure that each design was presented at least once.

4.1.1 Navigation designs

We designed each navigation visualization such that it closely resembles its design from the prior study. The designs used for study 2 can be found in Figure 3. The arrows design consists of consecutive blue arrows on the ground, which users can follow. The avatar design consists of a robot-like avatar with some human-like characteristics that moves at a steady pace and waits for its user to catch up after traveling some distance. We created an avatar that is familiar but new, and that is not a humanoid to avoid uncanny valley. The call out design consists of semi-transparent panels with both the direction and distance to the next intermediate goal. Finally, the desaturation design applies a grayscale filter to the world, except for the path and destination a person needs to follow.

4.1.2 Environments

We used three environments, shown in Figure 3: a metropolitan city with tall buildings including restaurants, and busy crosswalks as the outdoor environment; a museum containing various historical artifacts as the large indoor environment; and a grocery store as the small indoor environment. Additionally, each environment contains multiple autonomous humanoids (120 humanoids in the outdoor environment, 80 humanoids in the large indoor environment, 40 humanoids in the small indoor environment) to simulate a busy environment. Each environment consisted of two distinct pre-defined paths of similar lengths (2 - 3 blocks or 4 - 5 straight paths in the outdoor environment, 2 exhibits in the large indoor environment, 5 - 6 aisles in the smaller indoor environment) for users to navigate. Users could navigate through the environments using standard VR teleportation locomotion. Users were only able to teleport a set distance (10 m in the outdoor environment, 7 m in the large indoor environment, 4 m in the small indoor environment) at a time to simulate a more realistic walking scenario and avoid participants travelling large distances at once.

4.2 Apparatus & participants

The experimental software was programmed using Unity 2020. Participants were wearing an Oculus Quest 2 headset connected to a commodity gaming PC (Dell XPS desktop, Intel Core i7-11700, NVIDIA GeForce RTX 3060 Ti 8GB GDDR6, 16GB Ram). The experiment was conducted in a quiet experimental room. We used existing assets as environments, specifically Modern Supermarket for small indoor[1], Museum VR Complete Edition for large indoor[2], and the Module Based City Pack for outdoor[3]. For crowd simulation, we used the Citizens Pro 2019 Unity package[4].

We recruited 16 paid participants (10 male, 6 female) from a local university, aged between 20 and 26 years ($M = 23.13$, $SD = 1.89$). Participants rated their AR experience as $M = 2.94$ ($SD = 1.00$) and VR experience as $M = 2.88$ ($SD = 1.26$) on a scale from 1 (none) to 5 (expert). No participant exhibited elevated motion sickness susceptibility, as assessed with the MSSQ-short questionnaire [11].

4.3 Procedure

Participants first completed a demographic questionnaire and received a short introduction to the VR headset and the necessary controls. Participants then followed navigation instructions to reach pre-set destinations for each environment, resulting in a total of six navigation tasks.

After completing the two navigation tasks per environment, participants filled out a post-condition questionnaire, consisting of questions regarding preference between arrows and one of three other designs, as well as strengths and weaknesses of both designs.

[1] Modern Supermarket, `https://assetstore.unity.com/packages/3d/environments/modern-supermarket-186122`, retrieved Nov. 5 2021

[2] Museum VR Complete Edition `https://assetstore.unity.com/packages/3d/environments/museum-vr-complete-edition-89652`, retrieved Nov. 5 2021

[3] Module Based City Pack, `https://assetstore.unity.com/packages/3d/environments/urban/module-based-city-pack-154302`, retrieved Nov. 5 2021

[4] Citizens Pro 2019, `https://assetstore.unity.com/packages/3d/characters/citizens-pro-2019-143604`, retrieved Nov. 5 2021

After completing all six navigation tasks, participants filled out a post-study questionnaire, including rating the effectiveness of the four navigation designs using a 7-point Likert-type scale, assessing how much "appearance," "obtrusiveness," "integration in physical world," and "including information about navigation target" played a role in deciding their favorite designs, and answer two free-form response questions asking for combinations of designs that may work well and any contexts besides environment that they could think of that may affect the effectiveness of navigation designs.

4.4 Quantitative results

Results are shown in Figure 4. We performed a series of individual repeated measures ANOVAs ($\alpha = 0.05$) on the factors navigation design with four levels, environment with three levels, and environment order with three levels. Mauchly's test of sphericity indicated that sphericity was not violated for any of the tests. We applied Bonferroni correction for post hoc pairwise comparisons to account for multiple comparisons. Note that participants only rated the individual designs at the end of the experiment, with one rating for each design, and navigation in each environment was only performed using arrows and one of the three other navigation designs. We therefore cannot perform a full-factorial analysis and are limited to individual comparisons.

Results indicate a main effect for navigation design, $F(3,45) = 6.693, p < 0.001$. Post-hoc comparisons revealed that arrows yielded a higher preference than desaturation ($p < 0.001$). The difference between arrows and callouts ($p = 0.051$) and arrows and avatars ($p = 0.738$) was not statistically significant. No other statistically significant differences were observed. Results did not indicate a main effect for environment, $F(2,30) = 3.212, p = 0.054$, (outdoor $M = 5.19$, $SD = 1.33$; small indoor $M = 4.625$, $SD = 1.46$; large indoor $M = 3.88$, $SD = 1.63$) or presentation order ($p = 0.505$).

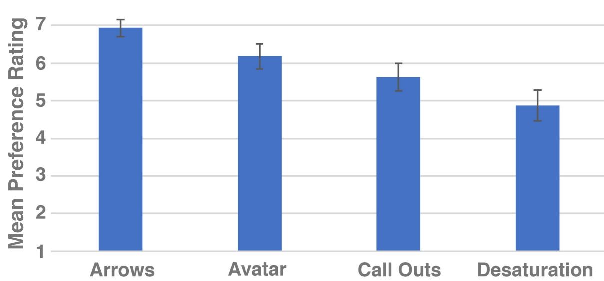

Figure 4: Mean preference values for the navigation designs in study 2. Error bars indicate standard error.

4.5 Qualitative results

We again analyzed participants' comments using thematic analysis and affinity diagramming [28].

Arrows Participants commented positively on the simplicity of this navigation design and its ability to simply and precisely convey directional information. They also appreciated how this design allowed them to retain awareness of their surroundings, in particular in the outdoor environment, since the arrows were static and in a predictable location. However, participants mentioned that arrows required more effort to track in the small indoor environment (P5), that they might be occluded in all environments, and that they interrupted the browsing experience in the large indoor environment. Additionally, participants noted that they would have liked to see additional information such as distance or general direction, packaged in a more subtle design.

Avatar Participants appreciated the playful and interactive nature of this approach and that it was more personal than the other designs. This was expressed in various comments, such as "The avatar creates a sense of personalization for my navigation experience" (P13), "It was 'friendly' seemingly. It was the same scale as the human figures so it felt like asking a grocery store worker for assistance" (P12), "experience is more lively, like having a tour" (P16), and "more enjoyable since there is a buddy who is guiding me through an unknown environment" (P5). Additionally, the avatar gave participants a sense of accomplishment after finishing the navigation task, as noted by P13 who said "Also once I reach the destination, I think the avatar provides stronger feedback and sense of achievement". As challenges, participants stated that the avatar did not adapt to their moving speed ("I have to wait for the avatar.", P10) and occasionally disappeared behind corners. In fact, some participants even felt stressed by this approach: "I have to keep eyes on the avatar to follow the avatar, and the avatar is fast and crosses at a red light. I felt more rushed to follow this avatar than other designs." (P8).

Callouts The Callouts design was appreciated for its simplicity, that it tended to blend well into the environment, and that it was not visually dominant while still providing additional information. One participant stated that "Callouts served as checkpoints for me to reach. It made me more curious about what happens in the next step." (P5). However, participants commented that they did not like that the design intruded the physical space ("It would be slightly better if the callout signs become more transparent as I approach them.", P15), and were concerned about not being able to read the information from acute angles, or in a crowded space.

Desaturation Participants appreciated the clear instructions of this design, as noted by P6 ("Desaturation was extremely easy to see where you're supposed to go") and P12 ("It reduced the attention of the surrounding information and so I focused on the task at hand a bit more"). However, some disliked how parts of the environment not relevant to the navigation task turned gray ("everything else was desaturated, so it looks unfinished/unrealistic.", P5), especially in the museum environment ("It does not feel like you are in a museum but just completing a navigation task.", P8). Participants further commented that an additional information source would have been helpful, reflected in comments such as "if I was to follow this navigation for a longer time in a new environment, I can easily imagine myself getting lost at one point, forgetting which direction I came from and to where I should head." (P8).

4.5.1 Combinations

As part of the post-experiment questionnaire, we asked participants which combinations of navigation designs they think would work well. All but one participants indicated that the combination of arrows and callouts would be useful if the size of both were slightly reduced. This opinion is best summarized by P7 ("Making the callouts smaller on the upper side and having arrows on the bottom might be a good combination.") and P12 ("...there would be too much signage and then it would dominate the environment."). Participants reasoned that they appreciate the combination of additional information that callouts provide and clear guidance of arrows.

Half of the participants indicated that the combination of arrows and avatar would work well, although they raised concerns that this might become too visually dominant. Participants appreciated the engaging nature of the avatar design and considered this combination to be beneficial for similar reasons as P5, who said "Since it is likely that the user will get lost of where the avatar is, arrows could serve as hints when that happens, and the user could spend more time looking around". This also goes in line with P11's idea that "the avatar can leave some foot step on the ground.", further hinting at the complementary nature of the two designs.

Participants considered the combination of arrows and desaturation as redundant ("The functionality and visual signals are repetitive. Seeing either should provide me sufficient feed-forward on what I should do and what might happen next.", P12). One participant expressed the desire to toggle between the two designs, further strengthening our previous finding that the scenario and task play a significant role in the choice of appropriate design.

5 Discussion

In this work, we presented two studies to gain insights into user preferences for navigation instructions in Mixed Reality. Overall, results indicate that while participants have a preference towards a familiar arrows visualization, alternatives such as a moving avatar, callouts, and visual alterations of the physical environment are viable alternatives and useful additions to the toolbox of MR content creators.

5.1 Preference and context

Both the qualitative and quantitative data indicate that the arrows design was perceived as the most versatile and preferred visualization. We believe that this is due to multiple factors. For one, this design is simple and easy to understand, which was repeatedly mentioned by participants. In addition, we believe that participants' familiarity with the arrows design positively influenced this result. This result is similar to other studies on MR interfaces where legacy bias plays a large role in participants' preference [6]. This makes arrows a universal design that fits many situations. Participants' ratings of the other designs were more variable under the influence of different contexts. While avatar was ranked positively, this particular design was perceived as too bulky for small indoor environments. Conversely, avatar and callouts were the highest ranked designs for browsing tasks. Lastly, desaturation was the highest ranked design for rush scenarios in the first study, but less preferred in the entirety of the second VR experiment. We believe that while participants could imagine this to be useful, its implementation details need to be carefully considered. A simple grayscale design of non-target areas was perceived negatively. Nevertheless, we believe that our results indicate that the space of possible navigation designs that are positively perceived goes beyond the simple arrows design.

5.1.1 Combinations

Most participants considered the combination of arrows with one of the other three navigation techniques used in study 2, rather than all combinations. We believe that this is at least partially due to the fact that we used arrows as baseline, meaning participants used this design more often than others during the study. Future experiments should explore the full combination, in particular the combination of avatar or callouts with designs that alter the environment such as desaturation.

5.2 Design Recommendations

Based on the results from above, we distill a set of design recommendations that can be used by content creators and in the development of future approaches that automatically decide on which navigation design to use.

- **Arrows are universal.** Arrows are a universally accepted design based on both of our studies. This confirms that familiarity, simplicity and clarity are key factors when designing successful navigation visualizations.
- **Companionship is desired for browsing tasks.** Participants appreciate the engaging and accompanying nature of avatars for browsing tasks such as in a museum. Additionally, they see potential in callouts to serve as checkpoints during browsing tasks. These designs, paired with specific contexts, are not required to display clear directions, which gives greater autonomy to viewers and flexibility to content creators.
- **Include additional information.** Participants requested additional relevant information (e. g. distance, task progress), even when viewing designs that are intended to communicate directions in a simple and clear manner (e. g. arrows).
- **Rush affords drastic changes.** Participants were open to drastic alterations of the environment if it helped them efficiently reach their target during rush scenarios.
- **Too drastic alterations are less likely to be accepted.** Participants commented that drastic alterations, even if they enhance navigation performance, need to be designed carefully. Future versions of desaturation, for example, should retain more color information rather than rendering all non-target areas as grayscale.

5.3 Limitations and Future Works

While we aim to create generalizable guidelines for MR navigation, our current studies were constrained to 2D images (study 1) and fully immersive environments (study 2). While using VR to test interaction techniques for see-through MR is common (e. g. [6, 25]), differences in user behavior can still occur. Running study 2 in VR facilitated testing of some navigation designs such as desaturation, which are very challenging to achieve with current optical AR HMDs. The findings from the first study were largely confirmed in the second study, which we believe demonstrates their validity. We aim to expand our study with optical see-through devices in the future. Additionally, we aim to expand our evaluation to users performing a series of tasks in a wide array of contexts, rather than completing one casual navigation scenario per environment. In addition to time, task, and crowdedness, which were varied in study 1 but not in study 2, there are various other contexts to consider. For instance, several prior works (e. g. Alghofaili et al. [3], Pfeuffer et al. [34]) have used visual attention to generate gaze-adaptive interfaces. By expanding our study with optical see-through devices and additional contexts, we will be able to further confirm our findings and discover other contexts that may influence user preference. The focus of our work was on visual navigation. Many current navigation systems, however, rely on voice-based instructions, or a combination of multiple modalities. We aim to expand our research to modalities other than visuals in the future.

We believe that apart from serving as guidelines for content creators of MR navigation systems, our insights will be useful for future automated systems. Because context continues to change (e. g. crowdedness can vary based on location and time), any MR navigation system has to constantly adapt its appearance and placement of elements (cf. [6, 25]). As an example, an automated approach could change the employed navigation design based on users' ongoing tasks from arrows (e. g. locating a store) to callouts (e. g. browsing through a store).

6 Conclusions

In this work, we aimed to provide general guidelines and insights into user preferences for MR navigation instructions. We conducted two studies to find out which navigation instructions are preferred, and why. Results from the first online survey (N = 50) indicated a clear preference for arrows, avatar, callouts and desaturation, largely due to their simplicity, clarity, saliency, and informativeness. Participants' preferences were strongly influenced by the scenarios and their contexts. Rush scenarios, for example, yielded a stronger preference for desaturation of non-relevant areas. In the second study, we confirmed and expanded those findings in an in-person VR study. Results indicated that while arrows were preferred, alternatives such as avatar and callouts were also well received, in particular for casual browsing scenarios, due to their ability to display additional information beyond just directions. Our findings inform the design of MR navigation instructions in general, and help researchers develop automated approaches for context-aware MR navigation systems.

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A Appendix

Scenario	Environment	Time	Task
You have a reservation at a popular local restaurant. You began walking towards the restaurant with plenty of time left until the reserved time.	Outdoor	Not Rushed	Targeted
Christmas is tomorrow, but you are still missing a few gifts for some members of your family. You are still not sure what to get, so you begin to walk around the shopping mall hoping an idea will spark. The mall is crowded with last minute Christmas shoppers, so items are running out fast!	Large Indoor	Rushed	Browsing
You are done crossing off your grocery list and now searching for the self check out line. There is no rush because the store will be open for another three hours. However, you do not want to buy unnecessary items.	Small Indoor	Not Rushed	Targeted
As you chat with your friends, it became 6 PM. You and your friends want to get dinner, but have no idea where to go. You and your friends begin to walk down the street looking for a place to eat. The street is full of other people also looking for a place to eat. One of your friend has another place to go to in an hour, and so you need to find a place quick!	Outdoor	Rushed	Browsing
Your flight at the Midway airport in Chicago is at 2:00pm. You arrived at 12pm. After getting through the security gates, you still have an hour left until your flight. It is lunch time, and so you are looking for a place to eat. You heard that the most popular food place is Gold Coast Dogs (a hot dog place), which you would like to try.	Large Indoor	Not Rushed	Targeted
You are in a clothing store (such as H&M) looking for a new shirt. You have not picked out a shirt yet, but the store clerk announced that the store is closing in 30 minutes.	Small Indoor	Rushed	Browsing
Despite the fact that you have a reservation at a popular local restaurant, you were not keeping track of the time because you were watching a movie. The reservation is at 6 PM, and you left the house at 5:50 PM. You began to walk quickly to the restaurant.	Outdoor	Rushed	Targeted
You are at the American Museum of Natural History in order to see dinosaur fossils. You plan to check out as many exhibits as possible. There is plenty of time to check out all of the exhibits.	Large Indoor	Not Rushed	Browsing
You are done crossing off your grocery list and now searching for the self check out line. You have a few frozen items, so you need to leave the store and get home quickly.	Small Indoor	Rushed	Targeted
You traveled to a foreign country for the first time where you do not speak their language. You would like to walk around historical landmarks and learn more about the country's history.	Outdoor	Not Rushed	Browsing
Your flight at the Midway airport in Chicago is at 2:00pm. However, because of traffic, you arrived at 1:00pm. After getting through the security gates, you have 10 minutes to get to your gate. Because it is lunch time, you start craving hot dogs, but likely cannot go to Gold Coast Dogs because there is a long line.	Large Indoor	Rushed	Targeted
You are browsing though a clothing store (such as H&M). You do not have anything specific in mind, but would like to look at the new arrivals. You have plenty of time to look at all of the clothes in the store.	Small Indoor	Not Rushed	Browsing

Table 1: Scenarios used in the first study.

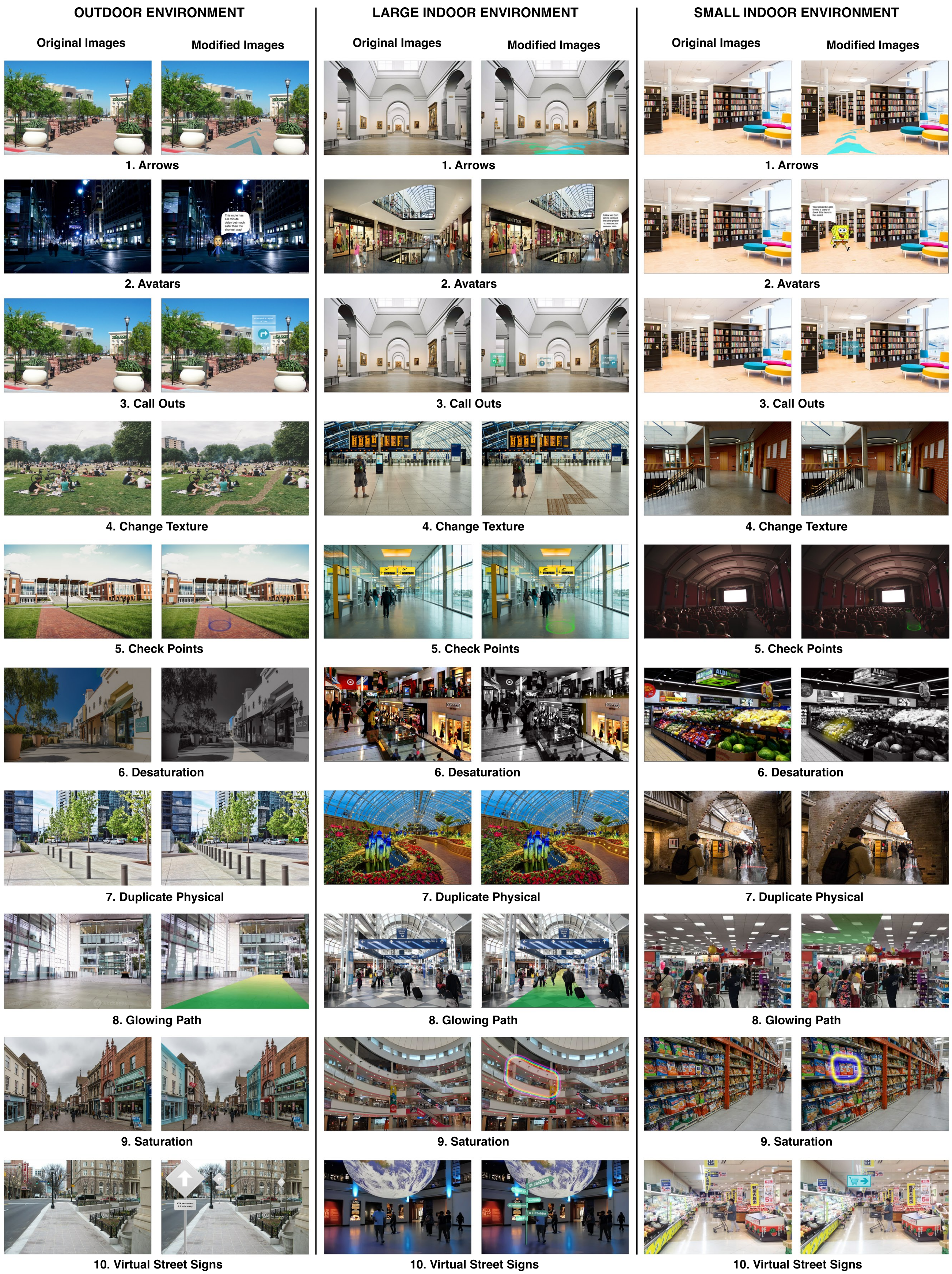

Figure 5: Thumbnails of all navigation designs per environment used in study 1.