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USING QUICK RESPONSE (QR) CODES AS AN INDOOR WAYFINDING TOOL: BENEFITS AND LIMITATIONS (1)

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INTRODUCTION

Visitors of buildings with complex layouts, such as shopping malls, campus buildings, hospitals etc., may face difficulties in understanding, and remembering their interior configurations making wayfinding problematic (Li and Klippel, 2016; O'Neill, 1992). Typical solutions to this problem involve the use of wayfinding aids such as signage (O'Neill, 1991) and You-Are-Here (YAH) maps (Chen et al., 2009; Klippel et al., 2006; Levine, 1982) or help desks to provide directions. However, advancements in technology that led to the adoption of smartphones may reduce the need for such conventional tools and offer new wayfinding solutions based on mobile and smart devices (Bauer and Ludwig, 2019; Ishikawa et al., 2008).

Today, several indoor navigation systems enable visitors to view building maps on their phones. These systems rely on different technologies, such as Wireless Fidelity (Wi-Fi), Bluetooth, or Radio Frequency Identification (RFID), which require costly devices or cabling (Ciavarella and Paternò, 2004; Montanes et al., 2013). Unlike those, quick response (QR) codes provide a fast and cost-effective way to transmit information that a QR code scanner can reveal. With the development of specific software and hardware, smartphones have enabled users to take advantage of this tagging technology (Ashford, 2010; Sinkinson and Stoeckel, 2011). Moreover, there is more access to QR codes due to the growth of smartphone adoption. Although many fields now benefit from the advantages of QR codes (e.g., banking and tourism), there have been few attempts to use QR codes in wayfinding, especially for indoors where GPS technology is limited (Zheng and Ni, 2005).In the present study, we proposed a wayfinding tool based on QR codes, by which the participants were able to display an indoor map indicating not only their location but also their direction aligned with the setting. Further, this information could be updated after each scan. Below we present a brief literature review on wayfinding and explain why such a study may be beneficial.

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Wayfinding

Wayfinding is a spatial problem-solving activity that answers questions about one's location, destination, and the route that connects them (McAndrew, 1993). Responding to these questions necessitates the use of spatial cognition, which is central to the study of person-environment compatibility (Kaplan, 1983) and investigates how individuals acquire and use knowledge about their surroundings to determine where they are, how to obtain resources, and how to get to their destination (Waller and Nadel, 2013). These capabilities allow individuals to manage various levels of cognitive tasks in everyday life, such as wayfinding. To navigate through an environment, we need to acquire spatial knowledge, which is the spatial relationships of objects in an environment, as well as an understanding of how to move in that environment (Sorrentino et al., 2019). Spatial knowledge could be acquired by specific methods such as direct experience (Başkaya et al., 2004), maps (Abu-Obeid, 1998), photos (Herzog and Leverich, 2003), and videos and virtual navigation (Hunt, 1984).

In terms of spatial cognition, Siegel and White (1975) identify three types of spatial knowledge: landmark, route, and survey. Landmark knowledge refers to being able to identify distinct items without knowing the spatial relationships between them. Landmarks are points of reference external to the observer due to their visual, semantic, or structural attractiveness (Lynch, 1960). Route knowledge refers to following directions to get from one location to another without knowing our position in relation to the destination point (Rossano et al., 1999). This type of knowledge includes the location of landmarks and the routes that connect them. Survey knowledge refers to a holistic understanding of an environment's layout and the interrelationships of the spatial components available in the environment (Golledge, 1991). This type of knowledge could be obtained through maps or repeated exposure to the environment.

While perceiving an environment, people obtain, code, store, retrieve, and decode information about the relative location and attributes of the physical environment, called cognitive mapping (Tolman, 1932). Cognitive maps contain impressions about a place's structure or appearance, relative location, use, and values (Lang, 1987); they are guided by schemata (Neisser, 1977) and thus, are closely related to the individuals' experiences as well as the spatial environment (İmamoğlu, 2009). As a result, they vary from person to person and may include partial, schematized, topological, or distorted representations of the physical environment (Lang, 1987).

One's cognitive map could be improved by enhancing the legibility of the environment. Lynch (1960) defines five elements that people use to shape their cognitive maps and aid them in understanding complex environments. These are paths, edges, districts, nodes, and landmarks. Although these elements resemble the structural elements of a city, they are primarily based on the Gestalt laws of the visual organization (Lang, 1987). Because we perceive our surroundings in a similar way regardless of the type of built environment, these elements are also used to increase the legibility of buildings to aid people in wayfinding. Thereby, the structure of the built environment affects its legibility, the accuracy of the cognitive map, and thus our spatial behavior and wayfinding performance. Regarding the influence of gender, men seem to perform better in map reading (Lawton, 2010) and solving spatial problems (Chen et al., 2009; Lawton, 1994; Lawton et al., 1996), and feel less anxiety (Lawton, 1994;

Lawton and Kallai, 2002; Vieites et al., 2020) during wayfinding compared to women.

When there is insufficient environmental information or legibility, we may have difficulty acquiring spatial knowledge and wayfinding, especially indoors. Compared to the outdoors, indoor environments might have more complex layouts, zones similar to one another (McAndrew, 1993), and a narrower field of vision due to architectural elements such as walls and ceilings (Wang et al., 2019). Visitors who cannot estimate the overall configuration of settings encounter difficulties in wayfinding that may increase their stress levels and cause anxiety (Arthur and Passini, 1992; Carpman and Grant, 2002).

Environmental information is the architectural and graphic representation of information required to solve wayfinding problems (Passini et al., 1998). Therefore, navigation difficulties influenced by buildings with insufficient architectural information can be compensated to some extent by the use of signage such as graphic information aids. These tools have been developed in the form of orientation signs and directional signs (Arthur and Passini, 1992). The most widespread orientation signs are YAH maps, designed to ease one's understanding of the overall configuration of a setting by providing its simplified top view (Levine, 1982). Directional signs, on the other hand, guide people to a destination along with a designated or pre-selected route (Arthur and Passini, 1992). They are faster to process than orientation signs but require a new one at every decision point. However, to provide a better wayfinding experience, researchers and engineers have developed alternative indoor wayfinding solutions based on new technologies such as RFID (Xu et al., 2017), Wi-Fi (Han et al., 2016), Bluetooth (Ho and Chan, 2020), and computer-vision (Kunhoth et al., 2019). However, those technologies require costly electronic infrastructures (Mulloni et al., 2009). A possible solution that is inexpensive and simple to manufacture, install, and adopt (Ashford, 2010) is the use of QR codes described in detail below.

QR Codes

QR codes are a machine-readable data representation and a superior variant of barcodes (Ashford, 2010). They have the advantages of allowing data to be decoded at high speeds, being low-cost, scannable from all angles, and reusable with replaceable dynamic content (Chuang et al., 2010). If the content embedded in a QR code is a Uniform Resource Loader (URL), an internet connection via Wireless Local Area Network (WLAN) or cellular is required. Today, most smartphones can detect and decode a QR code.

In recent years, researchers have been exploring QR codes as a wayfinding tool in enclosed spaces. For example, two studies (Serra et al., 2010; Sushma and Ambareesh, 2017) employed a hybrid pedestrian navigation system for indoor environments based on the dead-reckoning system: their navigation system identifies the initial locations of the users by scanning a QR code. The users' movements are then calculated solely by the sensors embedded into their smartphones (compass and step counter). Ambareesh et al. (2017) introduced a similar approach in which QR codes identify the initial location. However, users need to update their current locations by scanning QR codes in buildings and see their positions on the auto-generated routes to their targets using a mobile application. Additionally, Torrado et al. (2016) proposed a wayfinding system called "AssisT-In" for cognitively impaired people. Their system relies on following a trail of clues that appear after scanning QR codes. Other research examined the use of existing barcodes in the environment rather than generating new ones. In one of these studies, library visitors were able to use the barcodes on books to see their location (Pearson et al., 2017). A second study utilized barcodes on products in a grocery store to aid visually impaired people (Nicholson et al., 2009); a third study (Mulloni et al., 2009) implemented QR codes on posters and banners in a congress center. However, the literature indicates that studies employing QR codes in wayfinding benefit from location-aware technologies, which require the use of electronic infrastructure, wiring, or specific devices with sensors for the users. Because of the extra expense, the use of these technologies is restricted to certain locales and limited in scale.

The Study

In the current study, we proposed a QR code-based indoor navigation tool that does not require such tools as smartphone sensors, emitters in the environment, or the use of a particular application. Therefore, the proposed model can operate solely with the users' smartphones, which makes it low-cost and easy to install. In line with Levine's (1982) recommendations, we also generated YAH maps and embedded them into dynamic QR codes, thereby allowing access to the maps via smartphones. To examine the performance of the proposed model, we conducted a study by comparing two conditions in which the participants performed similar wayfinding tasks, in a no-QR condition (N_QRC) and a QR condition (QRC). In N_QRC, we aimed to simulate an everyday wayfinding situation where maps are situated at the entrances of buildings. In QRC, however, we offered QR codes located near the decision points to view the maps on a smartphone. After completing the tasks in the conventional and the proposed condition, the participants expressed their responses to the conditions using a questionnaire. The research questions and the hypotheses we aimed to examine were as follows:

Research Questions and Hypotheses:

1. Are there any differences between wayfinding performance, perceived ease of task, and comfort level in N_QRC and QRC?

In terms of task completion time, considering that participants would be less familiar with QRC, we did not generate specific hypotheses involving the condition. As the influence of gender – men seem to have shorter task completion times (Chen et al., 2009; Lawton, 1994; Lawton et al., 1996) and feel more comfortable during wayfinding tasks (Lawton, 1994; Lawton and Kallai, 2002; Vieites et al., 2020) compared to women – is well established in the literature, we expected equivalent results in the present study.

2. How will the proposed QR Model be evaluated in terms of its usability and willingness to use it in the future?

In view of the flexibility provided in QRC, we expected that the proposed model would be evaluated positively in terms of its usability (usefulness, ease of use, ease of learning, and satisfaction; Hypothesis 2a) and in terms of participants' willingness to use it in the future (Hypothesis 2b).

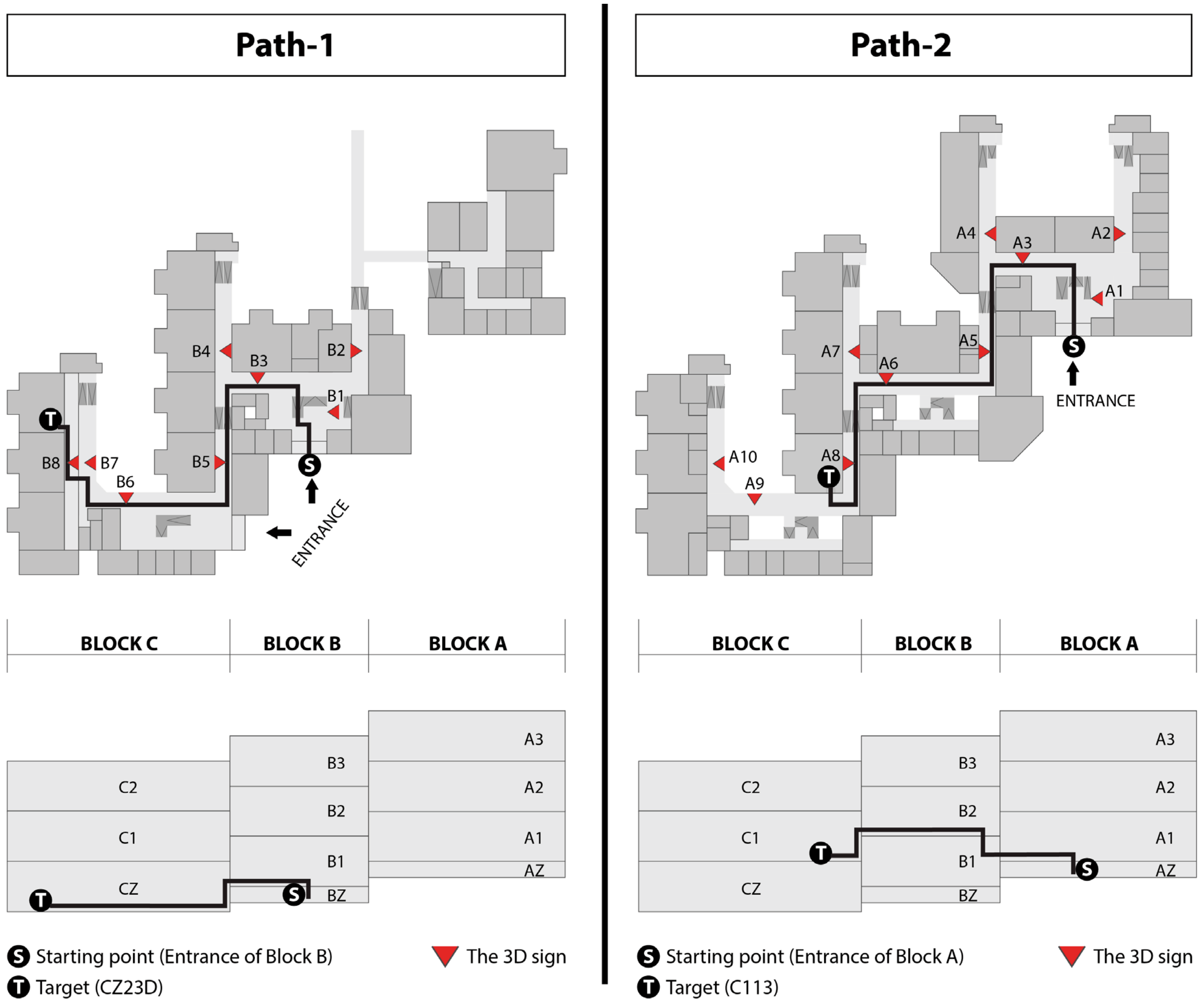
METHOD

The Setting and Participants

To attain similar layouts and signage systems in both wayfinding tasks, the study was conducted in a building at the main campus of a university. It was a large and complex multi-story building consisting of three blocks (**Figure 1**) that contained studios, classrooms, exhibition areas, and offices. The complexity of the building interiors was considered to increase the participants' cognitive load during wayfinding, which made it suitable to test the proposed model.

To avoid a learning effect, we did not use the same path in N_QRC and QRC; we chose two nonintersecting paths at different levels in the building. We determined the paths with the intention to have similar path lengths, number of turns, and level changes. The participants started from the entrance of block A to find room "C113" in path-1 and from the entrance of block B to find room "CZ23D" in path-2 (as can be seen in **Figure 1**). The study was limited to two floors.

Figure 1. Path-1 and path-2 indicated on the plans and sections of the building and QR code locations shown on the plans only



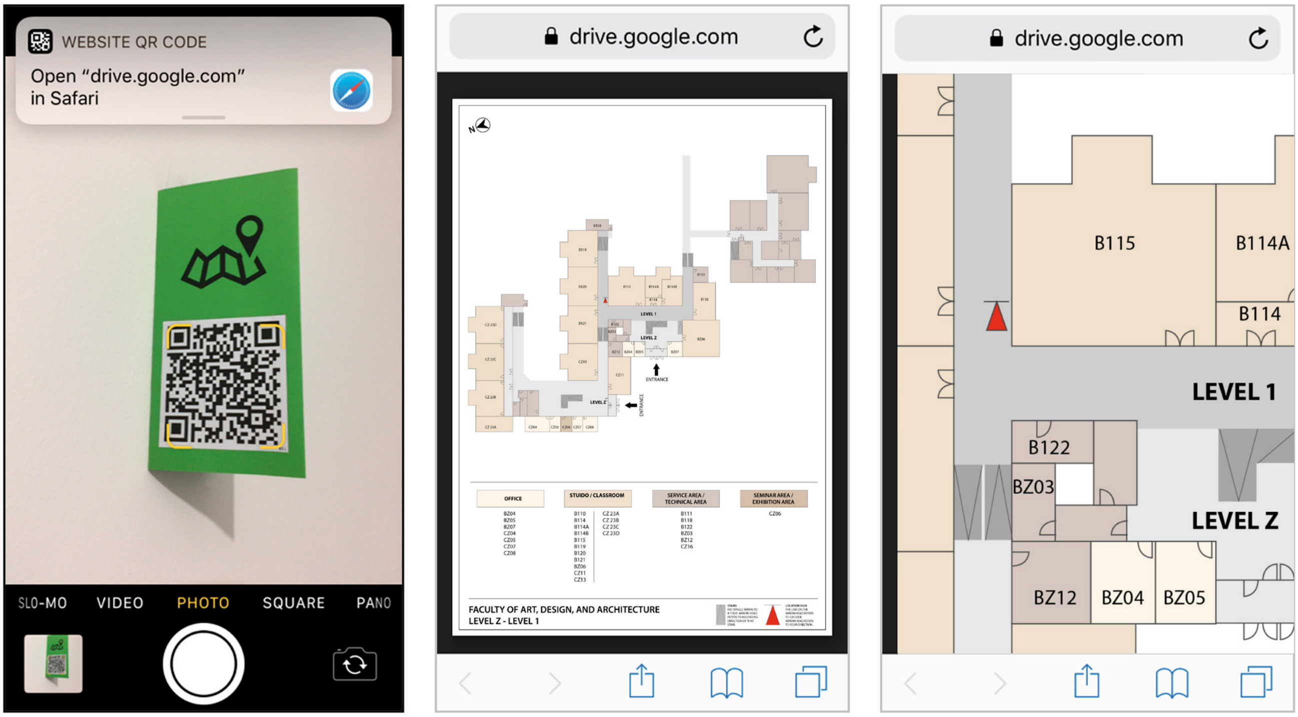
Thirty-eight undergraduate students (19 women, 19 men, after two extreme outliers were dropped) with a mean age of 23 years (range: 20-28 years) agreed to participate in the study. They were selected using quota sampling from the design and architecture departments of a different university than the one in which the study took place. Thus, all participants were unfamiliar with the building, and none had a prior wayfinding experience with QR codes.

Materials

Maps

We generated two maps with identical designs for use in the two conditions (**Figure 2**, middle). The physical maps were printed on A3-size papers and were only available on the glass panes of the entrance doors. Therefore, by looking at the physical map, the participants could see the building's general layout and their location at one of the entrances of the building. The digital maps, on the other hand, were accessible after scanning a QR code in the building and indicated a YAH icon (**Figure 2**, right), which was not available in the physical maps. Considering Levine's (1982) recommendations, we designed a YAH symbol that denoted two distinct terrain features: the QR code and the viewer. The short straight line indicated the location and the orientation of the QR code within the setting. The red arrow indicated both the viewer's location within the setting and on which side of the 3D sign (left or right) the viewer was standing. In other words, while the physical maps gave no clue as to the participants' position within the setting, the digital maps indicated the location of the participants and the direction they were facing in the building. We also adopted the "align the map with the terrain" recommendation by Levine (1982). To do so, the digital maps were rotated at specific angles to make sure that while scanning the QR codes, the participants' directions (indicated by a red arrow) always showed the front/forward on the digital

Figure 2. Screenshots of the QR code scan (left), the digital map (middle), and the zoomed digital map with YAH symbol (right)



maps. Thus, they did not need to make an effort to match the digital map with the layout of the setting.

Utilization of QR Codes in the Study

To display the digital maps in QRC, we utilized dynamic QR codes. Therefore, if there had been any changes in the layout of the map's setting or design, we had the opportunity to update the map while using the same QR code tag in the setting. Visibility was one of the main concerns in determining the location of the QR code tags on the walls. We designed a 3D sign in the form of a triangle by folding an A4-size paper with QR tags on the two sides providing angles making the codes visible from all sides (**Figure 2**, left). We used bright green for visibility and differentiation from other signage (Arthur and Passini, 1992).

Additionally, we devised an order to place the QR codes locating them at the decision points where two or more corridors intersected (Arthur and Passini, 1992), placing them near the end of corridors so that the digital maps could be viewed before arriving at decision points. Thus, a total of 18 pairs of signs were used in QR condition (20 and 16 QR codes on path-1 and path-2, respectively; **Figure 1**). As QR codes in the physical setting referred to YAH symbols on the digital map, a total of 36 digital maps were generated.

Smartphone

In the present study, we used an iPhone 6 in the study, based on its screen size and the native camera application with the QR code reading feature. The participants launched the default camera application to search for a QR code in the environment. When the smartphone recognized a QR code, a notification dropped down from the top of the screen with a preview of the link associated with the QR code (**Figure 2**, left). Tapping the notification triggered iPhone Operating System (iOS)'s native web browser (Safari) that displayed the digital maps with the YAH symbol (**Figure 2**, middle and right). Before the experiment, all the participants were trained on performing the required actions on the iPhone 6.

Procedure and Measures

Before starting the wayfinding tasks, the participants completed the Santa Barbara Sense of Direction (SBSOD) questionnaire (Hegarty et al., 2002) on a 7-point scale (1 = *strongly agree*, 7 = *strongly disagree*), which consisted of 15 items. While seven of the questions were stated positively (e.g., "I am very good at giving directions", "I am very good at reading maps"), eight of them were stated negatively (e.g., "I very easily get lost in a new city", "I have trouble understanding directions"). As a higher rating refers to a better sense of direction, the scores given to positively stated items were reversed. According to Hegarty et al. (2002), individuals with a good sense of direction are good at updating their position and orientation in an environment.

Later, we conducted a wayfinding study performed in the form of an experiment based on a 2 (gender) x 2 (condition: N_QRC, QRC) design with repeated measures on the last variable. We aimed to have an equal number of male and female participants in both conditions. In the first stage, while the participants in the first and the second group performed path-1 in N_QRC and QRC, respectively; the participants in the third and the fourth groups performed path-2 in N_QRC and QRC, respectively. In the second stage, we switched both the path and the condition for all the participants to control for order effects. After the wayfinding tasks, a questionnaire was administered to examine the participants' perceived ease of task and comfort level in both conditions and their reactions to the proposed model.

Each participant attended the study individually after signing the consent form. Before the task, the researcher guided them to the starting point of each route outside the building according to their task type. The participants were then informed on the number of maps, their distribution in the building, and how the maps worked. Additionally, before the QRC task, the researcher instructed the participants on scanning the QR codes in the building using the provided smartphone. They were asked not talk to anyone during the experiment. The participants started to perform the tasks after they indicated that they understood the rules and how to use the QR codes.

While performing in N_QRC, the participants were allowed to use the physical maps only, located on the glass panes of the entrance doors of blocks A and B. They were allowed to go back to the building entrance if they needed to look at the physical maps while performing in N_QRC. On the other hand, in QRC, the participants did not have access to the physical maps at the entrances. Instead, they were expected to scan the QR codes within the setting at least once to access the digital maps on the smartphone. During the task, the researcher followed the participants from a distance and did not interfere unless they tried to go beyond the designated floors.

The task completion times were recorded using a timer, and there was no time limit for any of the tasks. We started measuring as they began to read the physical map on the glass pane in N_QRC and as they entered the building in QRC. We stopped measuring as they reached the target. We traced their routes on paper and marked the QR codes they used. Their travel speed (m/s) was obtained by dividing the travel distance by the time spent. We also measured the number of times the maps were accessed. If the participants went back to the building entrance to look at the physical maps in N_QRC or followed a series of actions in QRC such as opening the camera application, scanning a QR code, and waiting for the map to load, it was referred to as map access.

After completing the two tasks, we asked the participants to indicate their responses to an online questionnaire using a tablet computer. The questionnaire consisted of three sections: In the first section, the participants responded to two items for each condition to rate their perceived ease of task ("I easily found my way") and comfort levels ("I felt comfortable during wayfinding") using 7-point scales (1 = *strongly disagree*, 7 = *strongly agree*). In the second section, the participants assessed the usability of the proposed model on the USE test (Lund, 2001; 7-point scale), which consisted of 30 items divided into four categories: (a) Usefulness, which consisted of 8 items; e.g., "It is useful", "It meets my needs"; (b) Ease of Use, which consisted of 11 items; e.g., "It is easy to use", "Using it is effortless"; (c) Ease of Learning, which consisted of 4 items; e.g., "I learned to use it quickly", "I quickly became skillful with it", and (d) Satisfaction, which consisted of 7 items; e.g., "I am satisfied with it", "I feel I need to have it". Reliability tests showed that Cronbach's alpha values for each categories' items were .94, .92, .90, and .93, respectively. Finally, the third section, involving willingness to use QR codes for indoor wayfinding in the future, was included to explore the degree to which participating in the present study motivated people to use QR codes for indoor wayfinding. Accordingly, the participants responded to one item to rate their intentions to possibly use the proposed model in the future, again on a 7-point scale: "If available, I would prefer to use QR code-based wayfinding tools inside buildings."

RESULTS

Data were analyzed using separate 2 (gender) X 2 (condition: N_QRC, QRC) analyses of variance (ANOVAs) for factorial designs with repeated measures on the last variable. Below, we present the results involving the dependent variables of sense of direction, wayfinding performance, perceived ease of the task, comfort level, usability of the proposed model, and willingness to use the proposed model in the future. In addition, QR code usage based on their locations and correlations between the variables were examined.

Sense of Direction

The participants' mean score of sense of direction was 4.3 points out of seven (SD = 0.94). The results of independent samples t-test revealed that there was a significant difference between the sense of direction scores of men (M = 4.8, SD = 0.9) and women (M = 3.8, SD = 0.6), $t(36) = 4.30$, $p < .001$.

Wayfinding Performance

According to ANOVA results involving task completion time, the condition main effect indicated that the participants completed the wayfinding tasks in N_QRC (M = 188.2, SD = 94.1) in less time compared to QRC (M = 267, SD = 125.6), $F(1, 36) = 9.58$, $p = .004$, $\eta2 = .21$ (**Table 1**). Gender main effect showed that men (M = 200, SD = 64.6) spent less time completing the given task compared to women (M = 255.3, SD = 84), $F(1, 36) = 5.19$, $p = .03$, $\eta2 = .13$. Follow-up Bonferroni post hoc test revealed that women spent significantly more time in QRC (M = 302.6, SD = 143.1) compared to N_QRC (M = 207.9, SD = 95), $p = .03$.

According to the ANOVA results pertaining to walking distance, the condition main effect revealed that there was no significant difference between the participants' walking distances in both conditions. The

Table 1. ANOVA results involving condition main effects and post hoc comparisons

Variable	N	N_QRC Mean (SD)	QRC Mean (SD)	F statistics	Significance	Effect Size
Task completion time (in sec.)	38	188.2 (94.1)	267.0 (125.6)	$F(1, 36) = 9.58$	$p = .004$**	$\eta2 = .21$
Men	19	168.4 (91.4)	231.5 (96.2)		$p = .06$	
Women	19	207.9 (95.0)	302.6 (143.2)		$p = .03$*	
Travel distance (in meters)	38	156.3 (78.3)	148.7 (68.8)	$F(1, 36) = 0.24$	$p = .63$	$\eta2 = .01$
Men	19	139.8 (56.0)	138.7 (46.8)		$p = .94$	
Women	19	172.9 (94.2)	158.6 (80.6)		$p = .62$	
Walking speed (m/s)	38	0.9 (0.2)	0.6 (0.2)	$F(1, 36) = 39.72$	$p < .001$**	$\eta2 = .78$
Men	19	0.9 (0.2)	0.6 (0.2)		$p = .002$**	
Women	19	0.8 (0.2)	0.6 (0.1)		$p < .001$**	
Number of map access	38	1.1 (0.3)	2.6 (1.3)	$F(1, 36) = 38.04$	$p < .001$**	$\eta2 = .51$
Men	19	1.0 (0.2)	2.2 (1.3)		$p = .001$**	
Women	19	1.2 (0.4)	2.9 (1.2)		$p < .001$**	

Note. N = sample size; N_QRC = no-QR condition; QRC = QR condition; SD = standard deviation; **$p < .01$; *$p < .05$.

participants' walking speed, however, indicated a significance between N_QRC (M = 0.9, SD = 0.2) and QRC (M = 0.6, SD = 0.2), $F(1, 36) = 39.72$, $p < .001$, $\eta 2 = .78$. According to the follow-up Bonferroni post hoc test, the data showed that both men (N_QRC: M = 0.9, SD = 0.2; QRC: M = 0.6, SD = 0.2; p = .002) and women (N_QRC: M = 0.8, SD = 0.2; QRC: M = 0.6, SD = 0.1; $p < .001$) walked slower during QRC compared to N_QRC.

We also examined the time spent by the participants to access the physical maps in N_QRC and the digital maps in QRC. During the wayfinding tasks, the participants used the physical maps 1.1 times (SD = 0.3) in N_QRC and the digital maps 2.6 times (SD = 1.3) in QRC. In N_QRC, since the participants started the tasks at the entrances of the blocks, where the maps were located, the first look at the physical maps did not require an extra effort to reach the map. For this reason, in calculating the time spent to access the physical maps, we considered only the second attempt of the participants, if any. The results showed that only five participants (one man, four women) went back to the building entrance to look at the maps for a second time and spent 88 seconds on average (SD = 36.8). In QRC, the participants accessed the camera application, scanned the QR code, and waited for the map to load to achieve a digital map, all taking an average of 21 seconds (SD = 11.2). Furthermore, the participants spent 52.3 seconds (SD = 46.2) in total to reach the digital maps while performing the task in QRC.

To measure the degree to which time spent to reach the maps affected wayfinding performance, we compared the total travel time (including the time spent for accessing the maps) with the active travel time (excluding the time spent for accessing the maps) (**Table 2**). However, it should be noted that active travel time includes the time spent for examining the maps. According to ANOVA results, the time spent to access the maps affected the total travel time significantly both in N_QRC (total travel time: M = 188.2, SD = 94.1; active travel time: M = 176.6, SD = 70.6; $F(1, 36) = 4.76$, p = .036, $\eta 2 = .12$) and QRC (total travel time: M = 267, SD = 125.6; active travel time: M = 214.8, SD = 105.7; $F(1, 36) = 51.20$, $p < .001$, $\eta 2 = .59$). In QRC, accessing the map led to a significant difference between the total travel time (M = 267, SD = 125.6) and the active travel time (M = 214.8, SD = 105.7), $F(1, 36) = 51.20$, $p < .001$, $\eta 2 = .59$. As we compared the active travel time of the participants in both conditions, ANOVA results revealed that there was a significant difference between N_QRC (M = 176.6, SD = 70.6) and QRC (M = 214.8, SD = 105.7), $F(1, 36) = 4.23$, p = .047, $\eta 2 = .11$.

Perceived Ease of Task and Comfort Level

Differences did not reach significance in terms of ease of task and comfort level except for a trend suggesting participants may feel more comfortable in QRC compared to N_QRC (see **Table 3**). ANOVA results involving

Table 2. ANOVA results involving the total and active travel time

Variable	N	Total Travel Time Mean (SD)	Active Travel Time Mean (SD)	F statistics	Significance	Effect Size
N_QRC	38	188.2 (94.1)	176.6 (70.6)	$F(1, 36) = 4.76$	$p = .04$*	$\eta 2 = .12$
Men	19	168.4 (91.4)	169.5 (69.0)		$p = .33$	
Women	19	207.9 (95.0)	192.6 (70.3)		$p = .045$*	
QRC	38	267.0 (125.6)	214.8 (105.7)	$F(1, 36) = 51.20$	$p < .001$**	$\eta 2 = .59$
Men	19	231.5 (96.2)	191.6 (82.9)		$p < .001$**	
Women	19	302.6 (143.2)	237.9 (122.3)		$p < .001$**	

Note. N = sample size; N_QRC = no-QR condition; QRC = QR condition; SD = standard deviation; ** $p < .01$; * $p < .05$.

Variable	*N*	N_QRC Mean (*SD*)	QRC Mean (*SD*)	*F* statistics	Significance	Effect Size
Perceived ease of task	38	5.6 (1.4)	5.6 (1.6)	$F(1, 36) = 0.40$	$p = .85$	$\eta 2 = .001$
Men	19	5.8 (1.4)	6.0 (1.5)		$p = .76$	
Women	19	5.4 (1.4)	5.2 (1.6)		$p = .65$	
Comfort level	38	5.1 (1.8)	5.7 (1.5)	$F(1, 36) = 3.73$	$p = .06^{\#}$	$\eta 2 = .09$
Men	19	4.7 (1.9)	6.1 (1.2)		$p = .003$**	
Women	19	5.4 (1.7)	5.3 (1.6)		$p = .84$	

Table 3. ANOVA results involving condition main effects and post hoc comparisons

Note. *N* = sample size; N_QRC = no-QR condition; QRC = QR condition; *SD* = standard deviation; N.S. = not significant; **$p < .01$; *$p < .05$; $^{\#}$p = .06.

the reported comfort levels of the participants showed that there was a significant interaction between gender and condition, $F(1, 36) = 5.08$, $p = .03$, $\eta 2 = .13$. Post-hoc paired comparisons revealed a significance for men, who had a higher comfort level in QRC ($M = 6.1$, $SD = 1.2$) compared to N_QRC ($M = 4.7$, $SD = 1.9$), $p = .003$.

Evaluations of the Proposed Model

Participants rated the USE test with a mean of 6.3 ($SD = 1.2$) points out of seven. In other words, our proposed model reached a usability score of 89.9%, which stands for "excellent usability" in similar tests (Bangor et al., 2009; Brooke, 1996). The proposed tool was rated positively in terms of usefulness ($M = 5.9$, $SD = 1.4$), ease of use ($M = 6.3$, $SD = 1.2$), ease of learning ($M = 6.8$ $SD = 0.5$), and satisfaction ($M = 6.5$, $SD = 1.1$). In the last section of the questionnaire, the participants rated their willingness to use QR codes for indoor wayfinding in the future with a score of 6.4 points ($SD = 1.2$).

Correlations

This section presents the results involving the Pearson correlation coefficients (r values) between the variables in QRC (**Table 4**). The data revealed that the participants who spent longer time tended to perceive the task easier. The ones who traveled longer distances tended to spend more time, access more maps, perceive the task easier, and feel more comfortable. As they had more attempts to access the maps, they were disposed to walk longer distances and spend more time. The participants who perceived the task easier and felt more comfortable tended to describe the proposed model as more usable. In addition, those who had a higher comfort were likely to use the model in the future. The ones who had a better sense of direction tended to spend less time, travel shorter distances, access fewer maps, and perceive the task easier.

DISCUSSION

Wayfinding Performance

The results indicated that the participants spent more time in QRC compared to N_QRC. The difference might be due to a higher number of accesses to the maps in QRC than in N_QRC, which was also supported by the positive correlations between the number of map access and time spent. In QRC, the participants performed a series of actions that required additional time to access a map, such as launching the camera application, capturing a photo of a QR code tag, and waiting for the digital map to be loaded. Therefore, as the map access in QRC increased, so did the time spent in QRC, increasing the time difference between the two conditions.

		1	2	3	4	5	6	7	8
N_QRC									
1.	Sense of direction								
2.	The time spent	−.42**							
3.	Travel distance	−.37*	.87**						
4.	Travel speed	.18	−.29	.17					
5.	Number of map access	−.27	.78**	.71**	−.14				
6.	Perceived ease of task	.45**	−.59**	−.50**	.15	−.52*			
7.	Comfort level	.17	−.25	−.21	.10	−.05	.42*		
QRC									
1.	Sense of direction								
2.	The time spent	−.36*							
3.	Travel distance	−.37*	.81**						
4.	Travel speed	.10	.48**	.05					
5.	Number of map access	−.37*	.78**	.54**	−.54**				
6.	Perceived ease of task	.42**	−.42**	−.49**	.13	−.45**			
7.	Comfort level	.28	−.18	−.36*	−.16	−.31	.66*		
8.	Usability (USE) score	.14	−.06	−.30	−.41*	−.04	.36*	.58**	
9.	Willingness for future use	.15	.11	−.10	−.36*	−.01	.15	.55**	.74**

Table 4. Correlations between the measures in N_QRC and QRC

Note. ***p* < .01; **p* < .05.

In addition to looking at the maps immediately after map access, the participants had the flexibility to walk with, look at, zoom in/out, rotate, and pan the maps as they wanted in QRC as opposed to the N_QRC in which this was not possible. Thus, the alternative way to look at the maps in QRC might have increased the total travel time in that condition. Regarding the possible effect of gender, we found a difference between the two conditions for women only. In line with the literature (Chen et al., 2009; Lawton, 1994; Lawton et al., 1996), our results indicated that men completed both tasks in less time compared to women in both conditions. Similarly, we found male participants to have a better sense of direction compared to female participants, as expected (Chen et al., 2009; Garling et al., 1985; Lawton, 1994).

According to correlation results, travel distance was positively correlated with the number of times maps were accessed. In N_QRC, since access to the physical maps required traveling, the travel distance might have increased. However, in QRC, because the QR code tags were on each corridor, accessing the digital maps did not require extra effort.

Perceived Ease of Task and Comfort Level

No significant differences were observed in terms of perceived ease of task between the conditions. However, in both conditions, perceived ease of task was positively correlated with the sense of direction. In light of this result, we may refer that the participants with a lower sense of direction may perceive the wayfinding tasks as more difficult regardless of what the navigational aids offer.

On the other hand, a nonsignificant trend was observed for the comfort level to be higher in QRC compared to N_QRC, which may be related to the flexibility provided by the proposed model. In N_QRC, the participants initially looked at a physical map and then tried to remember the route, destination, number of turns, or landmarks (Arthur and Passini, 1992). However, in QRC, the participants were aware that they could use more than one QR code (as needed) in the wayfinding process. In other words, updating their current location by scanning a QR code and carrying the map with them might have diminished the cognitive load associated with N_QRC.

Evaluation of the Model

The usability score was essential to understand whether the proposed model worked as intended. The responses to the USE test indicated that the proposed model was rated to be very useful. In other words, the participants' ratings confirm that the proposed model worked well and fulfilled its purpose. Correlations revealed that the participants' perceived comfort and ease of task in QRC were associated with their usability scores. Therefore, the development of these factors and their associated factors might play a key role in increasing the usefulness of the proposed model.

The results indicated that the participants had quite positive reactions to using the proposed model as an indoor wayfinding tool and that QR codes could be quickly adopted when used for a purpose that meets visitors' needs. In our study, the participants' comfort level was higher in QRC compared to N_QRC, implying that QRC was less stressful and might have met the wayfinding needs of the participants.

Strengths, Limitations, and Suggestions for Future Research

Most studies focusing on QR code-based indoor wayfinding rely on location-aware technologies requiring a high budget and effort to apply. Therefore, their use in practice is minimal. However, to increase their adoption, we proposed an indoor wayfinding tool for this study that is lightweight, depends solely on the tools we use every day and could be easily replaced with the YAH maps, which are currently one of the most commonly used wayfinding aids. Based on the comparisons of our model with the current use of YAH maps, we could state that the proposed model may reduce visitors' wayfinding stress and contribute to satisfaction with public buildings; this, in turn, may lead to repeat visitors.

One of the limitations of the present study is the uneven distribution of QR codes and YAH maps in the two conditions. To compare the QR code-based wayfinding method to what happens in everyday environments, we considered YAH maps, usually located at the entrance of buildings, as the current situation, and taking advantage of the compact size of QR codes, we placed them in each corridor. If we had placed the QR codes only at the building entrances, the conditions would have been more similar, but we opted for arguably the more realistic condition that took advantage of the technology.

Among the more particular limitations, one issue was that when a QR code was scanned, although the digital map displayed the related floor level, it provided only a partial understanding of the building's overall configuration. Future research may utilize digital maps that show all floor levels separately and highlight the specific floor level on which the QR code was scanned. This adjustment may contribute to a better understanding of the utilized maps. The other constraint could be that we conducted the experiment in a physical environment, and we did not record the behaviors of participants to be unobtrusive. For that reason, we could not analyze the time spent to look at the maps in both conditions. Another limitation of the study is that our sample consisted of university students with an age range from 20 to 28. Younger people's involvement with technology could give them an advantage over older ones, so future studies may benefit from including more diverse age ranges. Similarly, because the participants were students from the design and architecture departments, their background involving design education may be an influence (Groat, 1982; Nasar and Purcell, 1990; Purcell et al., 1998). While navigating, people from different fields of education may employ different wayfinding strategies. Thus, future studies may consider possible differences between architects and non-architects and include participants from a variety of fields.

As we consider the constant increase in smartphone ownership and internet connection availability, the proposed model may likely be used in buildings with complex layouts, such as campus buildings, hospitals, terminals, shopping malls, as well as their parking garages. According to their preferences, institutions could easily and economically adopt QR codes for indoor wayfinding and manage the tool independently from top to bottom as they are independent of location-based hardware and software. Replacing physical maps that cover large areas with compact QR codes may contribute to the environments being perceived as more spacious and aesthetically pleasing. Also, the assurance of displaying and updating the current location within a setting might reduce visitors' stress levels and increase their satisfaction due to wayfinding. Since people would spend more time in an environment they are satisfied with, the institutions benefiting from this technology may attract more visitors/customers and increase their image and popularity.

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Anahtar Sözcükler: Karekodlar; yön bulma; haritalar; kapalı mekanlar; karmaşık binalar.

KAREKODLARIN İÇ MEKANDA YÖN BULMA ARACI OLARAK KULLANIMI: FAYDALARI VE SINIRLAMALARI

Karekod (QR) teknolojisi, yön bulma da dahil olmak üzere hayatımızın birçok yönünde fayda sağlayabilir. Ancak, karekodlara dayalı iç mekan navigasyon araçları özel donanım ve yazılım gerektirdiğinden pratikteki uygulamaları sınırlıdır. Bu doğrultuda, bu çalışmada, iç mekan ortamları için oluşturulmuş düşük maliyetli, uyarlaması kolay ve konum algılama teknolojilerinden bağımsız karekod tabanlı bir yön bulma aracı önerilmekte ve aracın olası performansı araştırılmaktadır. Bunun için karmaşık bir üniversite kampüs binasında 38 katılımcı ile karekodlu ve karekodsuz olmak üzere iki koşulda deneysel bir yön bulma çalışması gerçekleştirdik. Katılımcıların yön bulma performansını, algılanan görev zorluğunu, rahatlık düzeylerini ölçtük ve çalışmayla ilgili değerlendirmelerini inceledik. Değişkenler arasındaki ilişkileri ve koşullar arasındaki farklılıkları ortaya çıkarmak için Pearson korelasyon katsayısı testi ve tekrarlanan ANOVA ölçümü kullandık. Bulgularımız, katılımcıların karekod koşulunda yön bulma görevlerini uygulamanın olmadığı duruma göre daha düşük hızda ve daha uzun sürede tamamlamalarına rağmen değerlendirmelerinin genel olarak daha olumlu olduğunu ortaya koydu. Karekodların karmaşık binalarda yön bulma amaçlı kullanımı kullanıcı kaygısını azaltma potansiyeli ile halihazırda yaygın olarak kullanılan 'Şu an buradasınız' haritalarına kullanışlı ve düşük maliyetli bir alternatif olabilir.

USING QUICK RESPONSE (QR) CODES AS AN INDOOR WAYFINDING TOOL: BENEFITS AND LIMITATIONS (1)

Quick Response (QR) code technology can improve many aspects of our lives, including wayfinding. However, since the indoor navigation tools based on QR codes require specific hardware and software, their practical application is limited. To examine this issue, this research aimed to propose and investigate the performance of a lightweight QR code-based wayfinding tool for indoor environments that is low-cost, easy to adapt, and free of location-aware technologies. To do so, we conducted an experimental wayfinding study in a complex university campus building with 38 participants under two conditions: with and without QR codes. We measured wayfinding performance, perceived ease of task, comfort level of the participants, and collected their assessments of the study. To reveal the relationships between the variables and differences between conditions, we conducted the Pearson correlation coefficient test and repeated measure ANOVA. Our findings showed that although the participants completed the wayfinding tasks in the QR code condition at a lower speed and in a longer duration than the no-QR condition, their evaluations were generally more positive. Using QR codes inside complex buildings for indoor wayfinding may prove to be a lightweight and low-cost alternative to You-Are-Here maps, with potential to decrease user anxiety.

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