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Usability analysis of 3D Maps for Pedestrian Navigation among different demographic profiles

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Abstract: 3-Dimensional (3D) maps may provide the users with a more real-world like view in comparison with the 2-Dimensional (2D) maps. 3D maps offer more degree of freedom in movement to the users, a first-person perspective view and other dynamic details such as time of the day, weather could also be incorporated. This paper demonstrates the evaluation of the usability of 3D maps for navigation purposes, in several general aspects including recognising landmarks and using these visual cues for navigation among different representative user-groups. The 3D model was designed to replicate the High Street, Stratford, London, UK. The participants of the survey were required to explore the model, identify and memorise the landmarks and form a mental map. They were also asked to reproduce the route they took in a 2D paper map and answer a questionnaire on their perception of their own cognitive abilities and their response on the performance of the 3D model. The results confirmed that the usability can vary among users of different demographic profiles – age, gender and language and familiarity with 3D technologies. It also showed that with some improvements in level of details incorporated in the model and design, 3D maps could become a useful tool for navigation purposes.

Keywords: Navigation, landmark, 3D maps, usability, spatial cognition

1. Introduction

Wayfinding is a complex cognitive task fundamental to all human beings (Wolbers and Hegarty, 2017), and the level of complexity could be affected many factors. Two such factors are the cognitive ability of the person performing the task and the level of familiarity with environment the person is travelling (Farr et al., 2012). The process of wayfinding includes interaction with one's surroundings (Raubal and Winter, 2002), and landmarks could be used for positioning and orientation, since they are easily recognizable. The uniqueness of the landmarks is defined relative to the environment it is present and since pedestrians move at relatively slower speed, it allows them to notice these unique features/objects (landmarks) in the environment they are navigated through.

The use of various navigational aids such as street signs, paper-maps, mobile and desktop applications have made the users more independent and made the task time-efficient and economical (Amirian et al., 2016). The simplified projection of these 2D navigation apps could complicate the process of navigation in a 3D environment. 3D maps allow for more degree of freedom in movement, more interaction with the surroundings, easier self-positioning and self-orientation through a realistic portrayal of the outside world and first-person perspective view. The rapid improvement in technology and 3D modelling software enabled the creation of interactive and dynamic maps which could be implemented in the user's mobile devices without consuming a lot of data and storage space (Haeberling, 2002; Bandrova, 2005; Petrovic, 2003). 3D maps cater to a wide variety of users especially among the younger generation who are familiar with 3D technologies such as 3D games and movies. The realistic view offered by the 3D maps could be helpful for non-native people such as tourists since they don't have to follow the written and spoken instructions offered by 2D maps. In 3D maps, the viewpoint of the user can be set to the user's current view, so that the use can match the real world with the 3D components of the map. It is possible to overlay city information such as shops, bus-stops, hospitals, parking-spots on 3D maps (Maehara et al., 2002) and other features such as shadow and time of the day for realistic visualization. In this study, a model of a 3D urban setting was developed to analyse the usability of 3D maps. The 3D navigation application was developed to run on a stand-alone desktop computer. The next objective of the study was to measure the influence of demographic profile (age, gender and native language) and familiarity with 3D technologies on use of 3D maps. Another focus of the study was the influence of language in wayfinding and whether it could become a barrier for people who are non-native English speakers. This was accomplished with the help of a field survey and questionnaire. The analysis of the usability was done with the purpose of examining the general attitude and experience of the representative user group with 3D maps and was studied from the following aspects: 1. interacting with objects around them, 2. recognizing and memorizing the important features/objects, i.e. landmarks 3. creating a mental map so that the user revisiting the place can explore the place more independently, with less of spatial cognition and navigation challenges. In addition to this, the role of landmarks in a 3D environment and how users depend on landmarks as associative cues for forming a cognitive map is also studied. This paper focusses on an exploratory analysis of the usability of 3d maps among different representative user groups, and due to the relatively small sample size of the survey population, no definite hypothesis was formed on the performance of 3D maps.

This paper structured as follows; next section reviews literature to give an overview of the context, find the gap and explain the motivations of the paper. Then section 3 explains the experiments and section 4 discusses the results of the conducted survey. Finally, there is a conclusion and future work section.

2. Literature Review

Hart and Moore (1973) defined spatial cognition as 'the knowledge and internal representation of the structure, entities, and relations of space; in other words, the internalized reflection and reconstruction of space in thought'. Spatial cognition includes both retaining the visual images one has observed in the surroundings and reconstruction of these images (Kastens and Ishikawa, 2015) and these visual images can act as associative cues in forming the spatial information required to navigate in an environment (Werner et al.,1997). By making use of path integration, place recognition and continuous re-orientation in wayfinding, even in the absence of any visual cues or landmarks, one can develop a cognitive map by means of developing familiarity with the environment (Dijkstra et al., 2014). Route knowledge can be obtained by observing the decision points in the path of travel (Yang and Worboys, 2014). Pedestrians move with relatively slower speed allowing them to notice and recognize their surrounding environments. Mackaness et al. (2014) discuss the use of text-based and

landmark-based navigational instructions instead of maps for way-finding purposes. The text based and landmark-based navigation may allow the users to have more interactions with their surroundings and to focus on the sight-seeing or potentially other activities instead of spending time to read maps. The uniqueness of a landmark is relative to the surrounding environment (Basiri et al., 2016) and can be marked based on several properties such as visual attraction, semantic attraction, structural attraction and the location of the landmark (Raubal and Winter, 2002). The uniqueness of the landmarks makes them easy to memorize, remember, spot and recognize easily and help in forming a cognitive map relative to their position. Thus, landmarks can serve as the point of reference or the point of re-orientation (Michon and Denis, 1997). Their availability in both indoor and outdoor environment allow inclusion of landmarks in navigational instructions. Maehara et al. (2002) notes that most of the navigation services, such as Google maps, are built upon the 2-Dimensional (2D) maps. The simplified project of a 3D environment to a 2D flat map can confuse the pedestrians. 3D maps provide a more realistic representation of the environment allowing for higher level of details, and more interaction with the surrounding (Schobesberger and Patterson, 2007). 3D maps allow for easier re-orientation, self-positioning by giving a first-person perspective and higher flexibility. Representation of geometry of different features in the real world is more effectively done in 3D maps compared to 2D representations and this can potentially reduce the time spent on matching the map against the surrounding environment (Maehara et al, 2002). Thus, the purpose of this paper is to analyse the usability of a 3D navigation system, with landmarks serving as point of reference as well as point of re-orientation in unfamiliar environments. The demographic profiles, experience with similar services (Lu et al., 2016; Golledge, 2000) and environments, and even proficiency in the language (Schobesberger and Patterson, 2007), in which the navigational instructions are given, could affect the efficiency of a navigation system in way-finding, routing and self-orientation. Although the usability of 3D and 2D maps for navigation will be examined with respect to the general aspects, literature review suggests that the usability of 3D maps and 2D maps can differ among the users with different demographic profiles, e.g. age, gender, ethnicity. This research investigates the importance, impacts and roles of the demographic profiles (e.g. age and gender), former experiences with 3D technologies (such as video games), and proficiency in English as the default language of many services providing the navigational instructions. This is based on the potential easier self-positioning/orientation in 3D.

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3. Experiment

The overall aim of this paper is to:

- develop a 3D model in an urban setting
- examine the usability of this 3D model among representative user-group with different demographic profiles (age and gender) and their proficiency and level of familiarity with English, environment, and some other 3D environments such as gaming experiences by field testing and conducting a survey, and
- exploratory analysis of the responses to the survey

Thus, the initial stage of this study included the creation of a 3D model of a city running on standalone computer that will aid pedestrians in wayfinding. The next stage is the analysis of the usability of the 3D city model which included the following stages:

- preparation of questionnaire based on the research objectives,
- recruitment of the participants,
- field test of the 3D model in actual urban setting,
- exploratory analysis of the survey results.

3.1 Construction of 3D model

3.1.1 *Study area*

The study site used to build the 3D model is in High Street, Stratford, London, E15, the UK . Stratford is a part of the London Borough of Newham. Figure 1 illustrates the location map of the area selected for building the 3D model. The study site is popular among tourists as a cultural and leisure centre. This helped achieve one of the primary objectives of the study which is analysing the usability of the 3D navigations apps among non-English speakers or tourists.

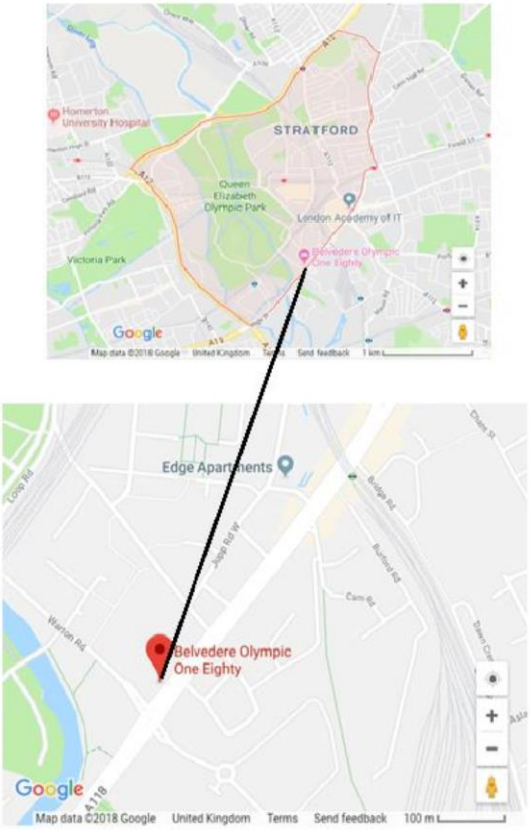

Figure 1: Location map of the study site (Google maps, 2019)

3.1.2 *Creating the 3D model*

The 3D model was created to replicate the study site including the terrain, buildings, streets etc. A user-controlled first-person character with attached camera was created so that the users could explore the streets. The primary applications used for constructing the model were SketchUp and Unity 3D. The model was created using basic shapes in Unity 3D to ensure minimum file size. Some models (for e.g. bus-stops) were imported from 3D warehouse in SketchUp. The textures for the geometry were obtained from Google street view, Google images and from photographs of the study site. Then the terrain (parts of roads and pavements) was baked to NavMesh to make sure that it is walkable. The classic skybox from Unity asset store were added to the scene. The model was exported as WebGL build.

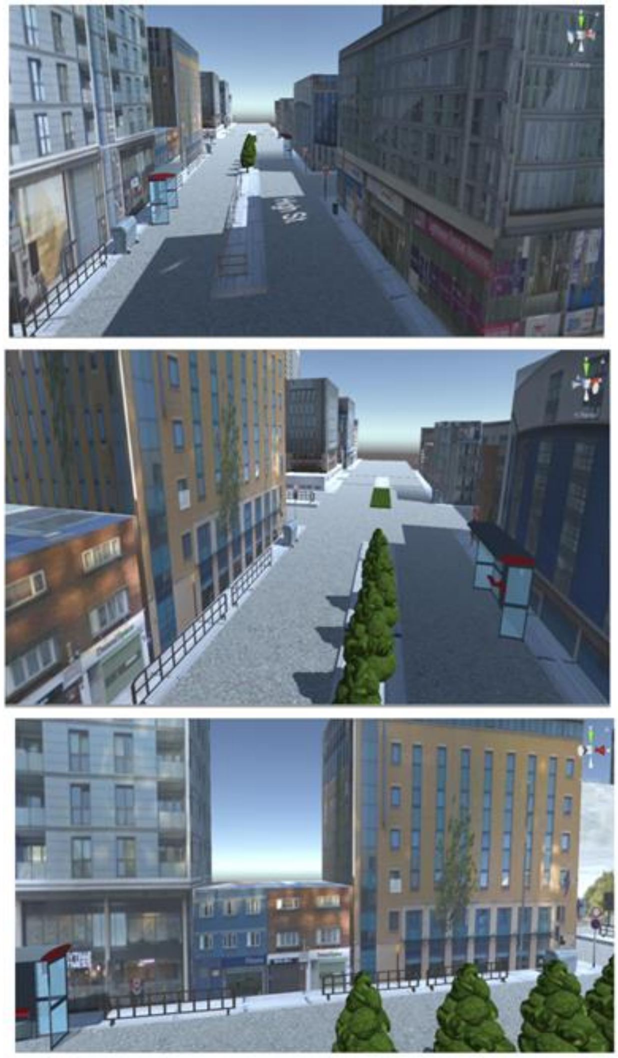

Figure 2: three instances of the location on the created 3D model

3.2 Survey

The rationale of the survey was to collect the responses of the participants, which in turn would reflect their views on the proposed 3D navigation system. The participants were recruited after making sure that they are unfamiliar with the study area. The participants were asked to explore the 3D model and were presented with a series of representative images. Few of these were images of buildings which were present in the model and others were images of buildings inserted at random. The participants were asked to pick the buildings that they can recognise from the model and on which side of the street it was located. They were also asked to make a drawing of the route they travelled in the model and was asked how long it would take to travel the distance. The participants were not required to use the 3D city model as a navigation app and explore the study site. Hence, the time spent on the tasks were not measured. There were required to answer a questionnaire to collect the following details.

- their demographic profile,

- familiarity with 2D and 3D navigational applications,
- their perception of their own cognitive abilities,
- the level of communication between the participants and the app,
- the level of details and interaction provided by the app, and
- the level of user satisfaction.

The responses were analysed to study the general trend in the representative user group. Closed short questions with Likert scale responses were created for collecting the responses of the participants. The analysis of the responses was done using R.

The 3D model developed in this paper, is a combination of various objects representing different features of the study site – including the terrain, buildings, infrastructure and other street properties. Figure 2 shows three instances of the 3D model of the location created using Unity 3D.

3.2.1 *Demographics of the survey population*

The size of sample population was 35 (N=35) and were chosen to represent the different user groups of navigation apps. Care was taken to not to under-represent any category of demography – age, gender and native-language. The demographic profile of the participants is given in Table 1.

Category		Number	%
Age	18 – 26	5	14.3
	27 – 35	9	25.7
	36 – 49	17	48.6
	Above 50	4	11.4
Gender	Male	16	45.7
	Female	18	51.4
	Prefer Not to say	1	2.9
Native Language	English	18	34.3
	Non-English	17	65.7

Table 1. Demographic Profile of the study population

The survey population were distributed among all the age groups with largest proportion in 36 – 49 years old (48.6%). There were no participants below the age of 18. The number of female participants out-numbered male participants by 51.4% to 45.7%. Only 1 participant (2.9%) among the total participants preferred not to reveal their gender. The percentage of English speakers to non-English speakers were almost considerably distributed (34.3% English speakers and 65.7% non-English speakers). None of the participants were familiar with the study site since they were tourists and didn't have any color-vision deficiencies.

Figures 3 and 4 show the bar-graph showing the CrossTable between age and gender, gender and language, and age and language.

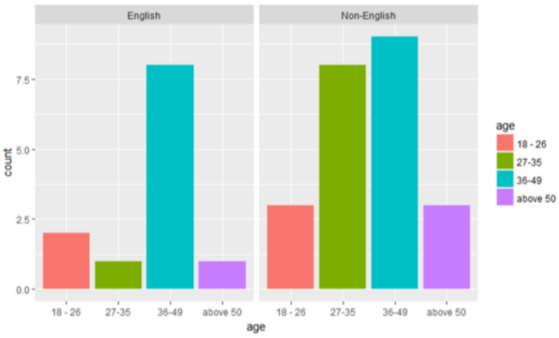

Figure 3: Bar-graph showing the CrossTable between age and language

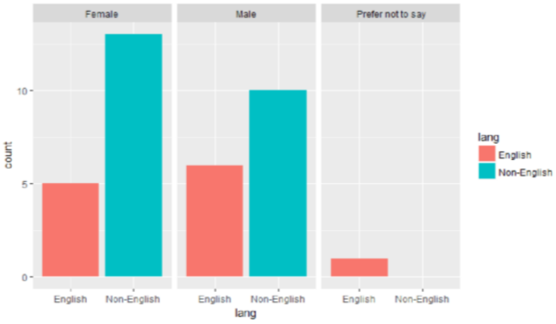

Figure 4: Bar-graph showing the CrossTable between native-language and gender

4. Results

4.1 Analysis of the survey

4.1.1 *Field Survey*

The 3D model was built so that the participants can travel from location A (Belvedere Olympic One Eighty, 180 High St, London, UK) to location B (Londis, London E15 2HR). Figure 5 shows the path on Google maps for pedestrians to travel from location A to location B.

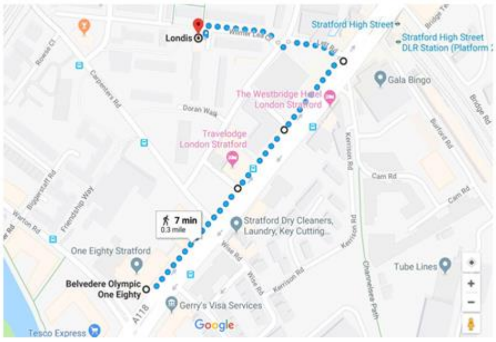

Figure 5: the path traversed by the participants using the 3D model as given in Google maps.

After using the 3D model, the participants were provided with a series of images which contained images of buildings which were present in the routes of travel and some images which were not in the route travel were also there. The location of the landmarks is marked in Google map and shown in Figure 6 and the images are given in Figure 7 separately.

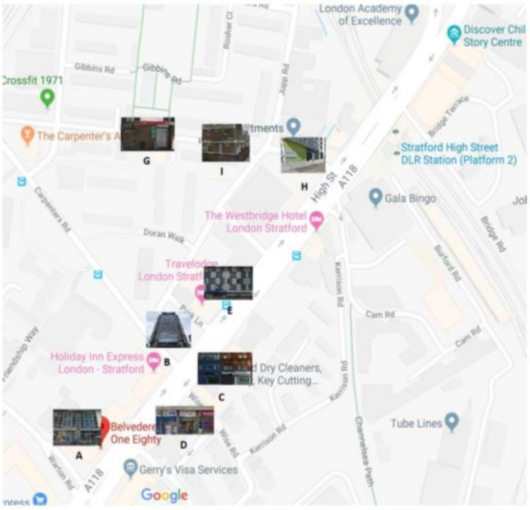

Figure 6: Location of the landmarks marked in Google map (Google maps, 2019; Google street view, 2019)

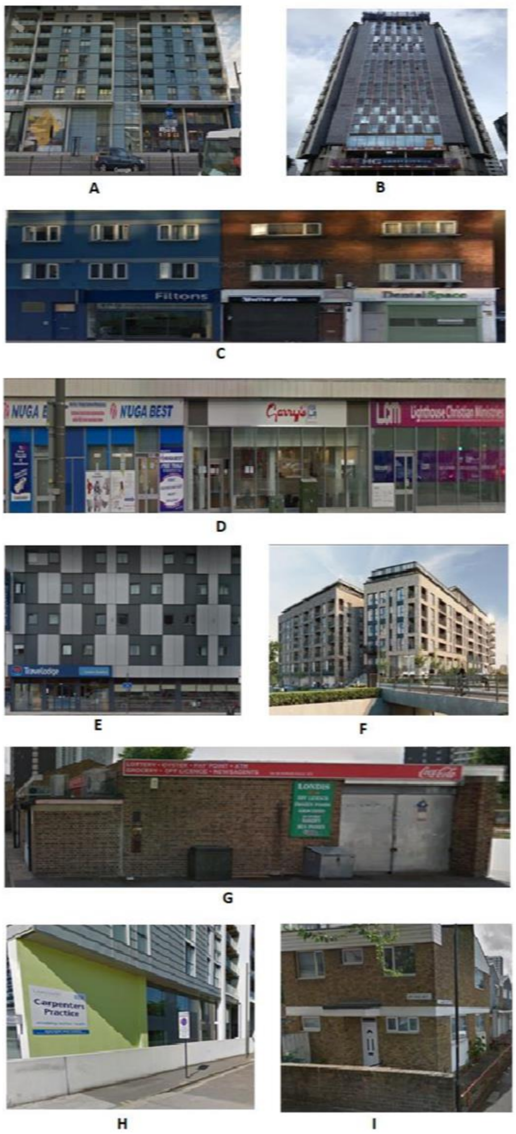

Figure 7: Images of the landmarks (Google street view, 2019)

Table 2 gives the count of number of times each landmark was identified by the participants and

Landmark A, D, E, H were most memorable to the participants. Landmark E is the image of a Travelodge situated in the path of travel and was identified by all the participants who took part in the survey. Participants commented that they were able to identify this landmark because of the familiarity in the texture and because of the huge sign board saying ‘Travelodge’ in the side view of the building. Landmark D was memorable due to the color and glass structure of the building. According to the participants who identified landmark A, the texture and structure of the building were noticeable factors. The color of the wall where it was written “Carpenter’s Practice” and location of the landmark in a decision point made Landmark H memorable. Even though, Landmark G was the destination of the travel, the texture of the building resembled the texture of most of the buildings in the neighbourhood and created confusion among most of the participants. As per the 3D model, Landmark B was under construction and the participants were given the image of the completed building. 14.29% of the participants were able to identify it from the board that said, “HG Constructions”. Landmark F was a building which was not situated in the path of travel and were identified by 11.42% of the participants. The building reminded them of some other building they had seen, and they were not able to tell if they were trying to recollect it from the model or not. Participants commented that it was difficult for them to identify Landmark C because of the shadow in the 3D model and only 8.57% of the participants were able to identify the building. Landmark I was a building situated on a decision point, but similar to all other residential plots in the area and hence the participants were not sure if they had seen the building. Compared to the male participants, it was observed that female participants were able to identify a greater number of landmarks. Also, most of the female participants were able to tell on which side of the street the landmarks were situated (50 % of male participants and 66.67% of female participants). Among the participants who identified the landmark incorrectly, majority were female participants (75%). When asked, they said they were sure that they have seen the building but were not sure if they remember it from the 3D model or from previous travel experience.100% of the participants who identified the landmark F were tourists. Since they were not familiar with London City, they seemed to have noticed and memorised the details of the buildings/landmarks to reach a specific destination and to find their way back. They found the uniqueness of several buildings situated in and around the study area, which was helpful for navigation, especially those situated in decision points.

Landmarks	Number of times	Percentage (%)
A	32	91.43
B	5	14.29
C	3	8.57
D	34	97.14
E	35	100
F	4	11.42
G	12	34.29
H	26	74.29
I	2	5.71

Table 2. Count of the number of times each landmark was identified

4.1.2 *Evaluation of the drawings created by the participants*

As it is shown in figure 8, the original path, travelling from location A to location B (1 – 2 – 3 – 4 – 5), has got four decision points (i.e. A, B, C, D). The participants were instructed to turn at point D to reach the destination and to avoid the points A, B, C and D. Majority of the participants (25 participants – 80%) were able to retrace their path of travel and among these, 56% were male participants (n=11) and 68.75% were female participants (n=14). Among the male participants who were able to retrace their path, only 27.27% participants (n=3) were able to reproduce their path of travel with minimum errors. On the other hand, among the female participants, the percentage was 35.7%. Here, the minimum error means, even though the participants did get confused with the decision points A, B and C with D, they were able to realize they took the wrong path and retrace the original path. Out of the 35 participants, only 2 participants (female) were able to identify the end point of the path, which is Londis, London. According to other participants who could not identify the location of the shop, the reason they gave was they missed to notice the distance they travelled from 4 – 5.

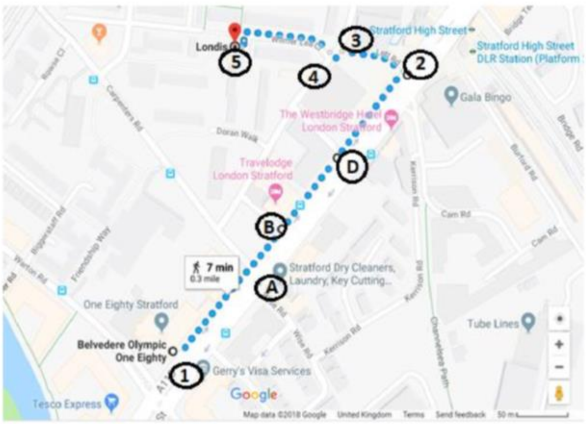

Figure 8: Path of travel and the decision points (Google maps, 2019)

Figure 9 shows the drawing made by one of the participants (Age-group: 36 – 49 years, Gender: Male, Language: Non-English). The participant was not able to retrace his path of travel. He identified the start point correctly – Belvedere Olympic One Eighty – which he marked as point 1. Instead of taking the turn at point D, he took the diversion from point C. But after reaching point D also, he got confused and was not able to find the end point. He was asked the name of the street where he started the journey, but he was not able to answer the question. When asked, he said he was overwhelmed by the details provided by the 3D model and also the fact that he is quite comfortable using Google maps for both pedestrian and vehicle navigation in 2D.

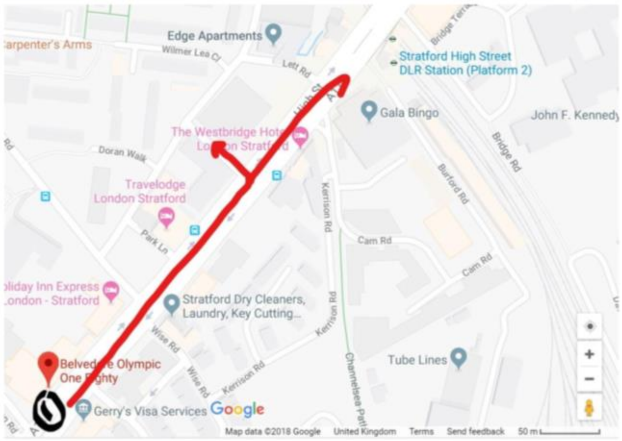

Figure 9: Drawing made by a participant who got lost once while taking the path (Google maps, 2019)

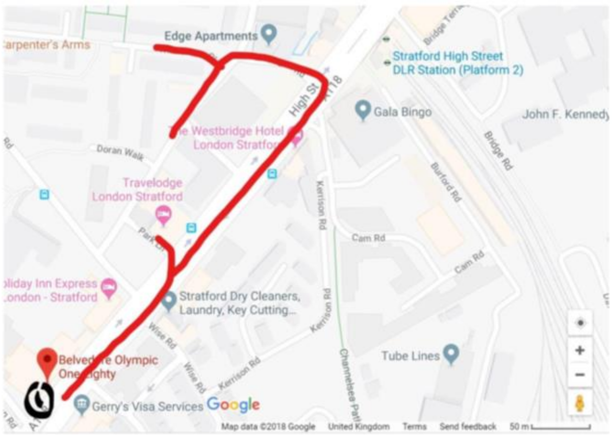

Figure 10: Drawing made by relatively better performing participant (Google maps, 2018)

Figure 10 shows the drawing made by Participant – 14 (Age-group: 27 – 35 years, Gender: Female, Language: Non-English). The participant was able to recollect all the decision points and retrace her path without any errors. She was also able to remember the name of the street, and she thought it would take around 10 – 15 minutes to travel from location A to location B.

4.2 Analysis of the responses to the survey questionnaire

Here, Likert scale items were used to collect responses on queries related to their own perception of spatial cognition and their opinion on the model. A score column was assigned containing numerical equivalent for the

Likert items to get a clearer idea about the distribution of the data (Not at all 1, Rarely = 2, Very often = 3, Always = 4) was also included.

4.2.1 *Analysis of the questionnaire based on age, gender and native language*

This sub-section discussed the responses for each questions of the survey for different age-groups, gender and native language.

- Question 1: How often do you use navigation apps e.g. Google maps?
- Majority of the participants responded that they depend on navigational aids even in familiar environments to keep track of direction, orientation and time. 28.571% of the participants depended on navigation apps very often, to find routes and to ensure that they are on the right track. 22.857% of the participants responded that they rarely depend on the navigation apps, only when they get lost during travel or when they are in an unfamiliar environment. It was observed that the percentage of female participants depended on Google maps were more compared to the male participants.
- Question 2: Are you familiar with desktop/mobile apps that make use of 3D/Virtual Reality (VR)?
- 40% of the participants were not familiar with 3D/VR applications and 31.43% of them rarely used any 3D/VR applications. Only a small percentage (8.57%) of participants used these apps quite often and were comfortable with the interfaces and controls provided in 3D/VR apps. Majority of the participants who were familiar with 3D/VR technologies were male participants and belonged to the age-group of 18 – 26 years.
- Question 3: Do you think you have a good sense of direction?
- Around 57.1% of the participants think they have a good sense of direction and can find their way effortlessly. They depend on navigation apps only to confirm their route to the destinations. 31.4% of the participants takes a lot of effort to find their directions in an unfamiliar environment, but they can manage with the help of navigational aids. 11.4% of the participants often get lost in an unfamiliar environment even with the assistance of navigational aids. It was observed that majority of the participants (75%) above age of 50 years think that they often get lost in an unfamiliar environment and must depend on navigational aids to track their position, direction and orientation. Also, majority of the male participants (68.75%) think that they have good sense of direction, compared to the female participants (50.00%).
- Question 4: When navigating in an unfamiliar environment, how often do you depend on navigation aids?
- 34.3% of the participants depended on navigational aids, while navigating in an unfamiliar environment and have the tendency to check the app frequently. 45.7% of the participants use navigational aids to find the route to the destination and they prefer to check the app occasionally, just to make sure they are on the right path. 20% of the participants do not prefer checking the app frequently. None of the participants preferred to ask people and look for street directions. Among the participants who rarely used navigational aids, male participants had a higher percentage (25%) compared to female participants (16.67%).
- Question 5: When navigating in an unfamiliar environment, do you often lose your way?
- 14.3% of the participants often lose their way, even with the help of navigational aids. 40% of the participants must depend on navigational aids constantly to keep track of their movement. 14.3% of the participants often lose their way in an environment with too many streets, junctions, and side roads. It was observed that majority of the participants in the age-groups 18 – 26 and 36 – 49 years lost their way in an unfamiliar environment. But, the participants in the age-groups 27 – 35 years and above 50 years said that they rarely lose their way in an unfamiliar environment.
- Question 6: Since you are a non-native English speaker, do you think find it easy to follow the navigational instructions offered by the apps?
- Among the non-English speakers, 73.91% of the participants were comfortable using the spoken instructions provided by the navigational apps. 26.09% of the non-English speaking participants were not comfortable following the spoken instructions provided by the navigational aids and they depend entirely the visual cues.
- Question 7: Were you able to recollect the route from the app effortlessly?
- 85.7% of the participants were able to relate the virtual world with the real-world scene and recollect the route they took in the 3D model. Only 5.7% of the participants were not able to relate the virtual world with the real-world scenes and recollect the route they previously took. Compared to the female participants the male participants were able to relate the 3D model with the real-world. There was no relationship between language and the ability to form a cognitive map. However, it was observed that the tourists tend to observe their surroundings more compared to the natives, since they found it easy to remember directions relative to landmarks.
- Question 8: Were you able to orient yourself without much effort in the unfamiliar environment?

- 68.6% of the total participants were able to orient themselves in that environment effortlessly. Only 22.9% of the participants did not think the app helped them orient themselves in the unfamiliar environment. 2.9% of participants thought that the app did not help them with orientation at all. Majority of the participants were able to locate the landmarks from the 3D model. Among the participants who couldn't remember the landmarks to orient themselves in the real-world, the highest percentage belonged to the age-groups of 36 – 49 years (25%).
- Question 9: How did you find the level of interaction with the app, satisfactory?
- 64.7% of the participants were happy with the level of interaction offered by the 3D model and were willing it try it in the future. 17.6% of the participants preferred a combination of 3D and 2D maps since they were familiar with the controls offered in 2D maps. Only 2.9% of the participants preferred to use 2D maps over 3D maps. Majority of the participants in all agegroup were content with the level of interaction offered by the 3D model. In the age-group of 18 – 26 years, 40% of the participants felt that a combination of 2D and 3D maps could be more useful. Majority of the female participants (>90%) were satisfied with the level of interaction provided by the 3D model, whereas 37.5% of the male participants still preferred 2D maps over 3D maps.
- Question 10: Do you think the app was able to convey you the real-world entities?
- 82.86% of the participants thought the 3D model was able to convey the real-world entities and that with some improvements, the model could be useful to them for wayfinding. 2.9% of participants were not happy with the 3D model and thought it requires further details.

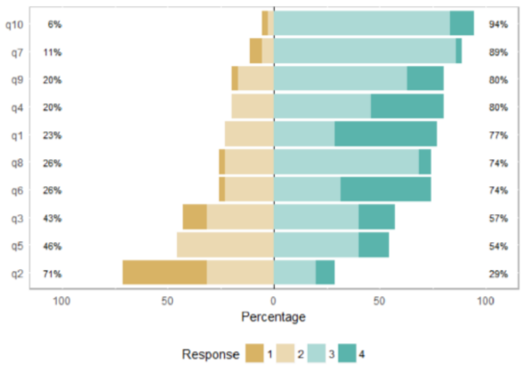

Figure 11: Diverging stacked bar chart for likert result

Figure 11 illustrates the diverging stacked bar chart used to visualize the likert scale data. The chart shows the responses of the participants to the questionnaire. Each participant has marked their responses on a four-point likert scale. Each bar in the bar chart are marked with the letter denoting the question and each bar represent 100%. The partition in the bar represents the percentage of participants in each level of agreement to the corresponding question. Here positive agreement is marked on the right side and negative agreement on the left side. The same data is visualized in the form of heat map in Figure 12. Here the values are replaced by colours and darker the colours, higher the percentage of participants who marked that specific level of agreement.

Figure 21: Heat map for the likert result

5. Conclusion

In this paper, we have discussed the usability of 3D maps for pedestrian navigation among users with different demographic profiles. Another focus of the study was to analyse the influence of landmarks in wayfinding in 3D maps and a field survey was set up to examine both these objectives. The informativeness provided by the objects present in a 3D map depends on the recognizability of these objects and can be used as landmarks. These landmarks could be used for positioning and orientation in a 3D map. Few participants were overwhelmed by the level of details provided in model and suggested they prefer only fewer details. One of the reasons was their over-familiarity with 2D maps, especially from car navigation. They thought the information provided by 2D maps in vehicle-navigation system was adequate since they did not have to remember the details. Compared to the male participants, the female participants seemed to have notice the surroundings and use the visual cues for wayfinding. Even though fewer female participants were familiar with 3D technology, they were open to the idea of using 3D maps in an unfamiliar environment. And that with improvements, 3D maps could become a useful tool for navigation. Age was another constraint in the performance of the 3D model. The younger generation, due to their familiarity with 3D technologies were comfortable relating the virtual world with the real-world and with the use of controls and interfaces provided. But the age-group of above 50 years, preferred the controls provided in 2D maps such as Google maps. Another focus of the study was whether language could become a barrier in wayfinding in an unfamiliar environment – for tourists visiting an unknown city. From the field survey, it was observed that the non-English speaking users prefer not to listen to the spoken instructions while travelling in an unfamiliar environment and they depend on the visual display provided by the Google maps throughout their journey. According to them, a 3D map if properly designed could help them with wayfinding. Pegg (2013) stated that a 3D map should be created to cater to the needs of the end-user and following a creative and artistic design can sometimes make it fail to deliver the information to the user. The feedback from the users confirmed this theory. Shadows were provided in one side of the 3D model to give a more realistic view of the world. But the users did not prefer this since it blocked their visibility and were not able to recognize the landmarks. Some users preferred details of pedestrian crossings and parking spots in the model to help them with the journey. In general, with more research on the end-user requirements along with some improvements in the design, 3D maps could become a useful tool in navigation across all demographic profiles.

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