Chapter 3 Methodology and Research Design

3.1 Methodology

In 2007, Peffers and others presented their "design science research methodology (DSRM) for the production and presentation of DS research in IS". (2007, p.46) Design science, as the authors explained, is not to explore the natural world, but build artefacts to serve human aspiration. They showed several practical employments of their framework into design research from different fields and demonstrated that those researches were successful conducted align with this methodology.

This methodology consists of six steps:

1. problem identification
2. objectives formulation
3. design and implementation
4. demonstration
5. evaluation
6. communication

3.2 Research Design

Based on the aforementioned methodology, we design our program into four phases, which may conduct iteratively. Figure 14 shows the structure of our research design.

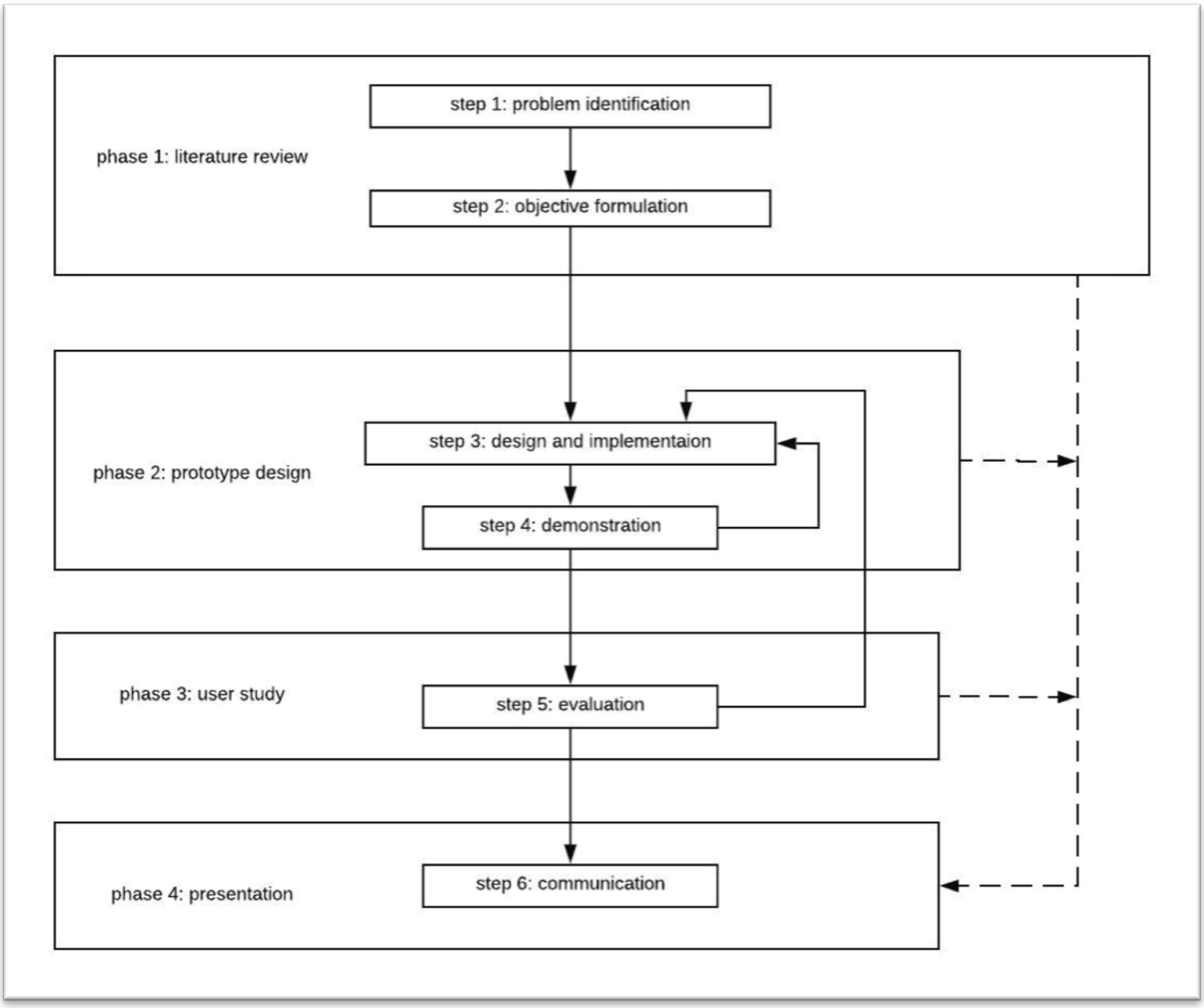

Figure 14 research design

Phase 1: Literature review

This phase related to DSRM step 1 *problem identification* and step 2 *objectives formulation*. First, we came up an idea that design an AR navigation system for our campus wayfinding. Look though a group of related literature, we have a research gap that user interface design, which is critical for system using efficiency, has not been discussed much in this filed. Then we articulated our main research question: ***How to design the user interface to make AR navigation systems more efficient?*** For solve this problem, we aim to find factors that affect AR wayfinding system performance by reading more relevant resources, and build an original guidelines for AR wayfinding user interface design, by designing and implementing prototypes and conducting experiment to test and analysis our prototypes. Although we name it as phase 1, but not as literally, this activity should continue throughout the whole research progress.

Phase 2: Prototype design

This phase reflects the above step 3 *design and implementation* and step 4 *demonstration*. In phase 2, we designed several AR guidance prototypes, which embody the realisation of different criteria from different dimensions. First, we gathered lots of AR navigational data representations from widely resource, then we observe and discuss their characters, and extracted features of different methods. Based on the features of guidance representations, we also added in our own ideas to create several models. After several rounds of exploration and continuous learning, we finally decided three prototypes which would be implemented for experiment.

The implementation process also iterated for several times. As the system updating continuously, we gradually reduced the errors that may be generated by users in the virtual environment, and gradually improve the interface design based on user feedback. In this phase, we get system design feedback mainly form experienced VR/AR system developer. Moreover, during the prototype design phase, we also got our ethic application approved.

Phase 3: User study

This phase corresponded to step 5 *evaluation* in DSRM. It includes running user study, recording users' performance, collecting user feedback, and analysis all data from the user studies.

After the experimental environment fully built, we conducted user studies, in compliance with ethical integrity. We invited students from different faculties in Monash University, explain wayfinding tasks and guide them familiar with motion and operations in a virtual reality environment. After user finished all tasks, they were encouraged to provide their feedback and innovated suggestions. From Figure 14we can see that phase 2 and phase 3 can be an iterated process. And actually, in practice, many problems were exposed during our first round of user study. For improve the quality of experiment data, we go back to phase 2 and redesigned our experiment again. The detailed information is demonstrated in next chapter.

Phase 4: Presentation

Phase 4 is related to DSRM step 6 communication. At the last stage, we presented our deliveries by a presentation and this final thesis.

Chapter 4 Prototype Design and Implementation

This chapter display the process of prototype design and go through the prototype implementation history.

4.1 Fundamental Analysis of Different AR Navigational Representations

Apart from AR wayfinding interface from literature, such as Figure 4, we also pay attention to commercial AR wayfinding products, in order to learn more about their user interface design. The following pictures display several navigational representations in different design.

Figure 15: Torch AR Wayfinding Prototype (2018)

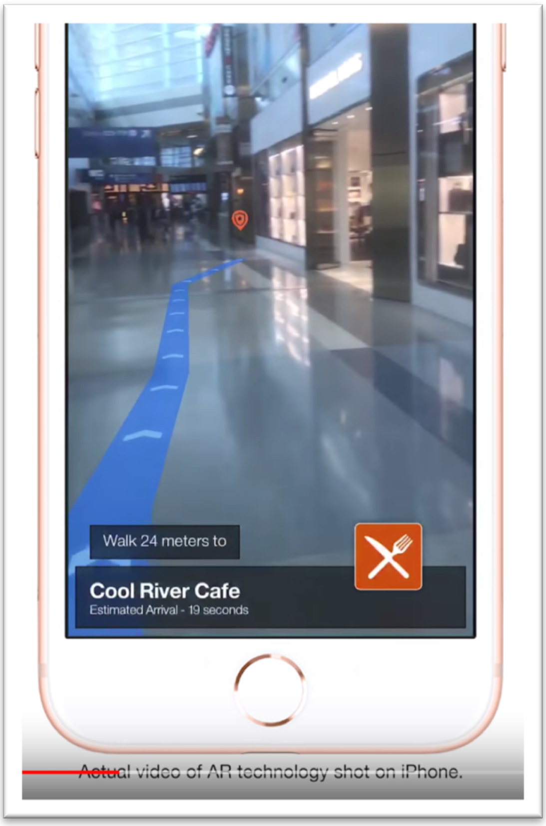

Figure 16: Prototype from Jones (2017)

- Figure 15 The guidance is a 3D robot. It moves in front of the user, and it will wait for users at every checkpoint till the user come and interact with the it. When the robot moves, it is pretty obvious to be seen, because the height of the robot moving track is at the centre of users' vision. However, the robot is easy to fuse in the background it goes far away. That is caused by its colour. The robot is mainly covered in two colours: grey and brick-red. The grey colour is similar to surrounded walls when the light degree is lower than normal. Then the brick-red colour is similar to the wooden door.

- Figure 16 The guidance is a blue line which fit on the ground. Within the solid blue line, there are light blue arrows shows the direction, and there is a red landmark wait at the destination. As the blue line statically seats on the ground, it covered some objects on the ground so that it may block users' vision.

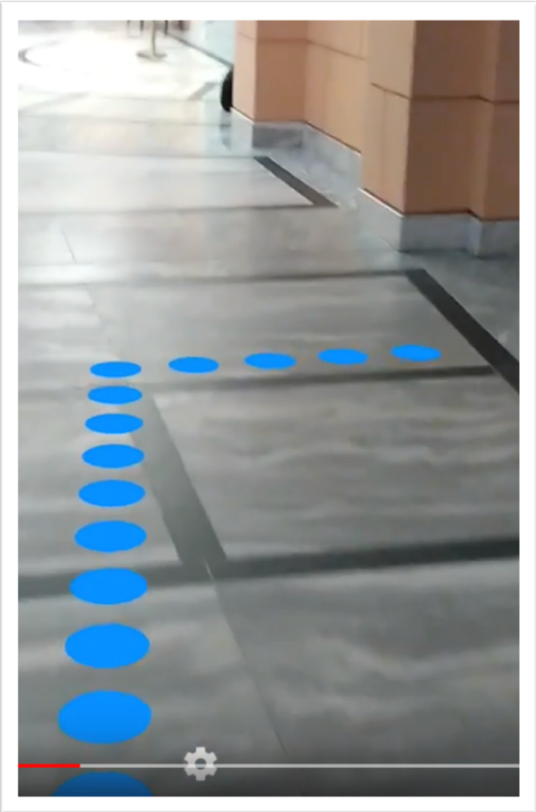

Figure 17: Find Your Way in a Museum (2017)

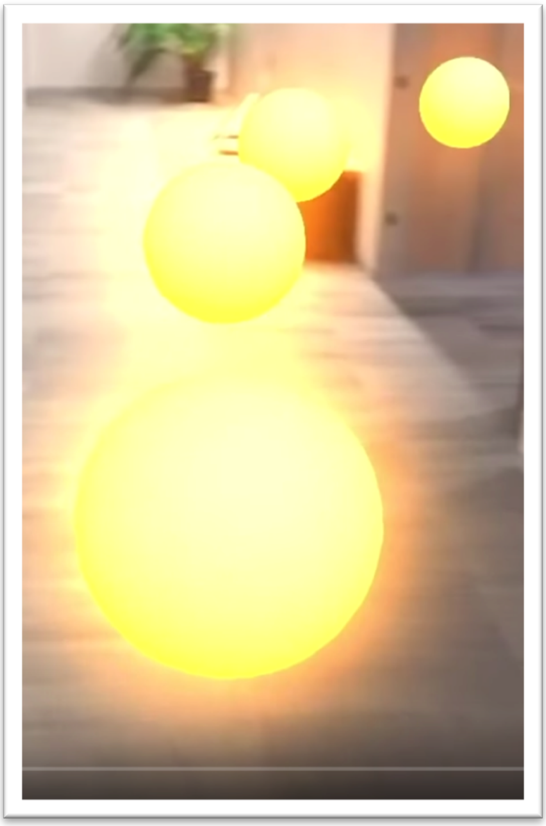

Figure 18: prototype from Hallberg (2018)

- Figure 17 The guidance is a dotted line which is consisted of many 2D blue circles. With user moving, new circles appear at the end of the dotted line. This method reduces the area of block parts covered by the guidance in two ways. Firstly, its label is relatively small. Secondly, before the user close to the last circle, other circles will not appear.

- Figure 18 This guidance is similar to Figure 17. But it uses larger 3D balls to replace 2D circles in Figure 16, and the yellow balls are placed in the air, rather than on the floor. With guidance of those yellow ball, users do not need to bow down their head all the time. Another feature of this representation method is that the navigational guidance is gleaming, which is really noticeable. However, the size of those yellow balls is much bigger than that of the blue circles in Figure 17, which may affect users observe surroundings.

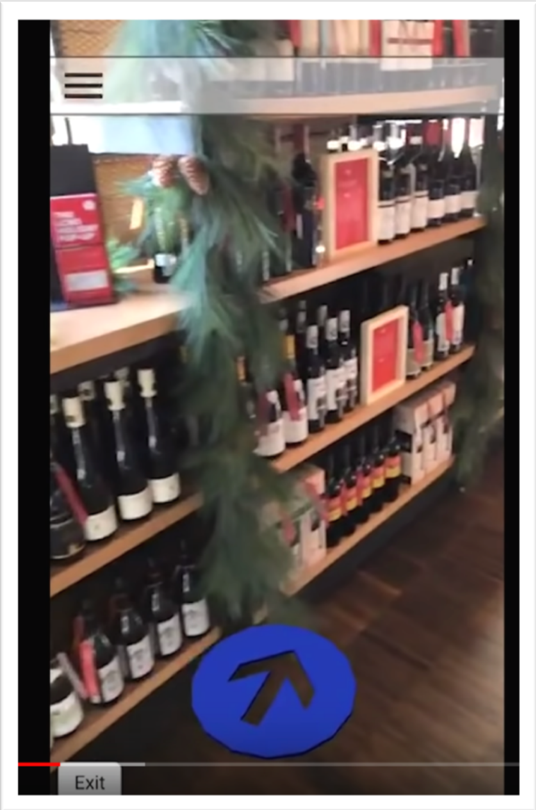

Figure 19: HeadUp prototype from Hallberg (2018)

Figure 20: AR wayfinding with a mini map (Technology news, 2019)

- Figure 19 The picture shows that there is an arrow in a circle. Actually, the location of the dark blue circle is relatively static to users. and the hollow arrow rotates to point out which direction the users need to walk along. We call this method as "head up", whose size and location are static, but shows navigational information by rotation within in a certain area. In the graph, this head up floats on the floor. It may not affect users' observation to the environment, but users need to bow their head frequently to read its instruction.

- Figure 20 Distinct from other methods, this method has a mini 2D map at the right-top corner. From the mini map, users can percept where their current position is in the whole task. There also is a long transparent curve on the ground, which display navigational instruction intuitively. This interface combines AR wayfinding with features of popular digital map. However, as the picture shows, this interface is applied in a navigation system for drivers. But our target users are pedestrian in campus. The distance of tasks of our users is way much shorter than that for drivers. Therefore, it needs more discussion if our users need to know the distance between their position and destination.

From a primary analysis, we summarised elements that can be used to present guidance in AR wayfinding systems. Table 2 shows the most basic methods that can be applied in AR wayfinding. The first column illustrates three primary categories: If the application shows their rate of process on the interface? If the guidance's position is relatively static to users? If the navigational object can move within the environment as users do? For each category, there are further distinct detailed representations. When developer design an AR wayfinding user interface, we can only choose a simple method to guide users, or we can achieve complex representations by combining a few simple models.

mini map	with map	
	without map	rate of process is invisible
		other data shows rate of process, such as figure or process bar
static method	lines	display whole lines at the beginning
		gradually appear as user get closer to it
	arrows (head up)	
moving object	moving speed changed according to user moving speed (always stay in users' visible range)	
	moving in constant speed (faster than users) and wait user at turning or checking points.	

Table 2: various methods for representing navigational guidance

4.2 Prototype selection

In the beginning, we designed four models that practice all the fundamental elements in Table 2. In Figure 21: original AR guidance models, model A applied a static line (in arrow shape) to show direction instruction, and help users realise where their position is between the starting point and the destination. Model B removed the mini map, but applied data, a more intuitive method to help users understand how far they are from their destination. Apart from that, the navigation guidance was changed to a head up arrow. Model C and D represented navigational data in a dynamic way. The Plane in model C moved to terminal point gradually, it kept its distance with the user by changing its speed according to the user's location. But the plane in model D kept going fast, its forward direction gave users a hint where they should go, and it stopped at turning points to make sure users can always receive its moving direction.

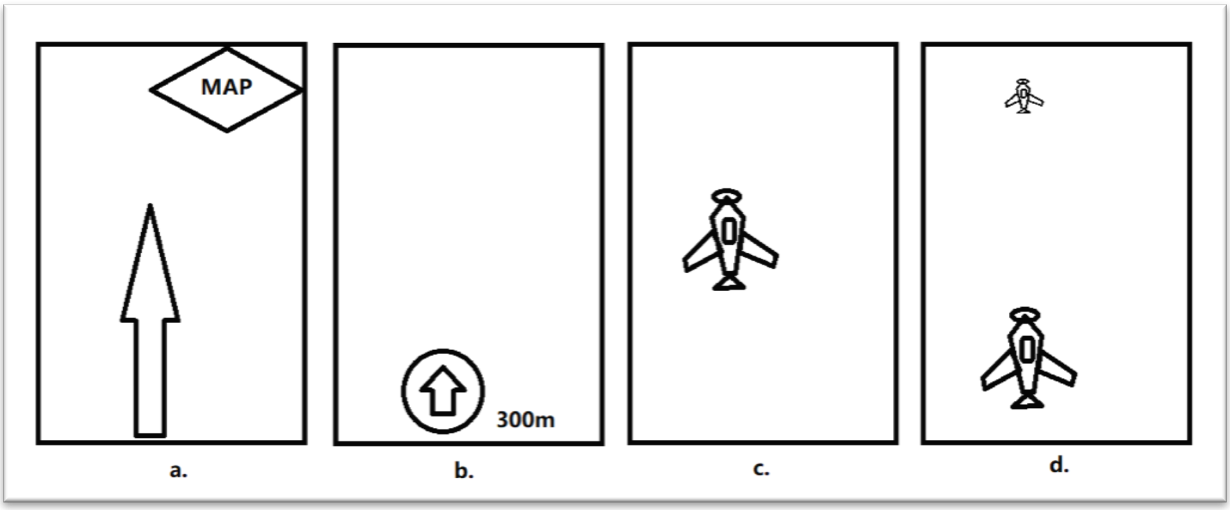

Figure 21: original AR guidance models

The first version of the models could fully reflect all basic forms of navigational data representation. But model A and model B provided more sense of control for user. To make the experiment clearer and more understandable, we revised the prototypes as Figure 22 shows.

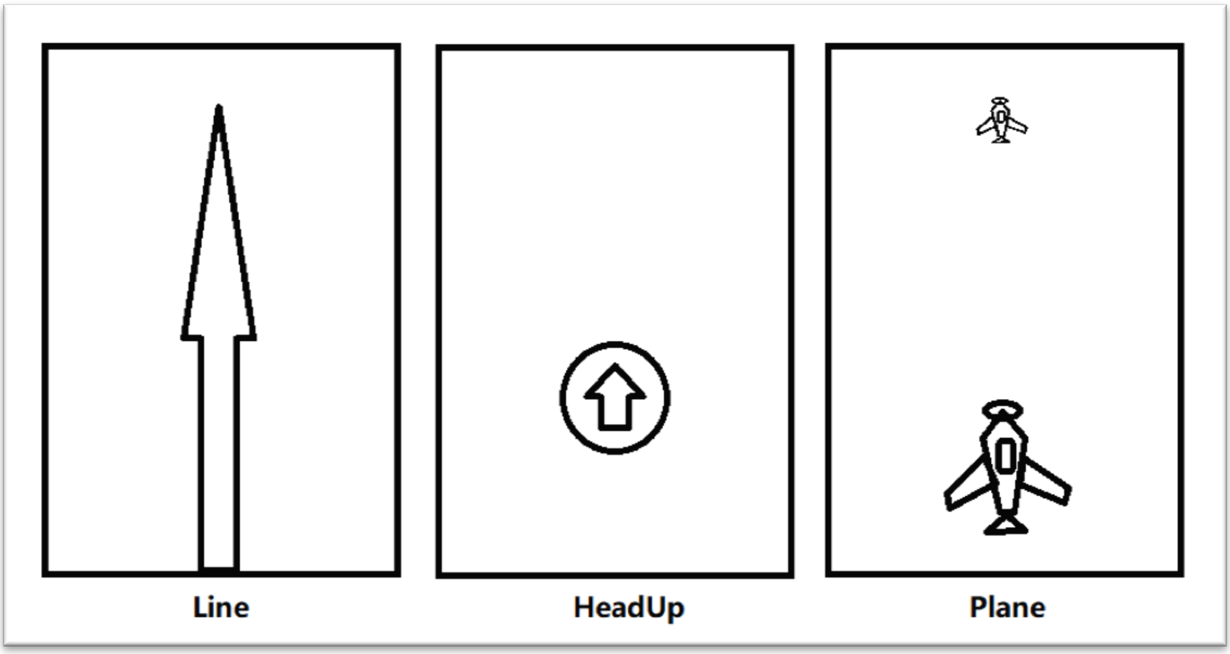

Figure 22: AR wayfinding navigational guidance prototypes

There are three methods in the revised prototypes. All of them just exhibit one basic feature from Table 2, and none of them reveals the rate of the process during the navigation tasks. So there is only one variable among the three prototypes, which is the representation of navigational information itself.

- Line. As we explained in section 2.3.1 Universal Design Elements, slanted lines provide users a trend of movement visually. The head of the arrow consists of two slanted lines which intersect at one point, that is why people mark direction by arrows naturally. A guidance line in arrow shape is easy to be understood. This line is fully generated since a new task starts, and static stick on the floor. Comparing with head up and plane, Line can present more information to users.

- Head up. head up also contains an arrow to demonstrate direction for users. Comparing with Line, its size is smaller, which may reduce the impact of navigation on the user's environment observation.

- Plane. The plane animation flies towards the destination and stops at every turning point. It starts to move again since it detects their user almost arrives turning point and close to it enough to catch its further moving direction. Due to its dynamic, the animation is more noticeable. Another distinct feature against Line and head up is that the Plane is hard to block users' vision. Because it keeps a distance from user location, and normally it is on the air.

4.3 Experiment Design

Due to time and permission limitation, we conducted our program in a virtual reality environment, which is displayed in Figure 23. Users need a headset (Samsung HMD Odyssey+) access to the VR context. Moreover, due to the limitation of space, users need to perform movement and interaction with the VR environment by controllers. In this building, we have defined 18 routes of similar length. Those routes start from the same place, and point to different destination.

Figure 23: an indoor environment in VR

We invited 12 students participated in our user study. Their task was moving along the 18 routes with the help of different navigational representation methods as soon as possible. Apart from time cost, we also paid attention to their observation of the environment. Therefore, we set waypoints and obstacles on the floor to test if users can realise the existing of waypoints and obstacles. Waypoints are common objects in indoor environment, including flags, flowers, and cola can (Figure 24), and obstacles are represented by small stones and big spiders (Figure 25).

Figure 24: waypoints in experimental environment

Figure 25: obstacles in experimental environment

We placed waypoints and obstacles evenly throughout the whole building. Basically, users would meet a similar number waypoints and obstacles in every task. Users were encouraged to get more waypoints and avoid meeting collisions with obstacles. During user study, we record time cost, the number of waypoint and the number of collision user met for every single task. The time cost is the main criterion to test navigation system efficiency, and setting of waypoints and obstacles is for understanding user observation of the environment. At the end of the experiment, users submitted a post-study questionnaire for us to understand their experience.

We split 18 routes into three groups. Every user finished all 18 tasks in the fixed order of paths, but they walked through different tasks with different guidance. For example, user A went through the first 6 routes by following a plane, but user B walked along them with the help of a head up. At the end, we gathered 216 wayfinding recorded, including 72 for each path group, and the proportions of the three methods in each path group were same. However, the first route in each path group was for training. They provided a practice space for users to familiar with new methods. Therefore, 1/6 from the 216 recorded are invalid, and we have collected 180 valid records from this experiment.

4.4 Implementation of Prototypes

We integrated those three prototypes(Figure 22) into the experimental environment(Figure 23) based on our guideline(Table 1).

4.4.1 Arrow Line

Table 3: Adaption for implement prototype 1 (line) shows the actions that how we adapt our guideline into implementation of prototype 1 (line).

Principle	Adaption
cooperate with information from the real world	A long solid line may affect user detect hurdles on the floor, as Figure 16 shows. We have mentioned Gestalt proximity las in section 2.3.2 Interactive System Design Principles human visual perception automatically treats a group of closely related objects as a whole, thus we changed the solid line to a dashed line.
compatible with the environment	We set the width of the line. It cannot broader than any width of entrance in the experimental environment.
fit with users' perception	As we explained in section 2.3.1 Universal Design Elements color is a vital component to make data distinct from background. For arrow line, we set it in red color be to noticeable. Then we have tired different levels of brightness and test them in the experimental context (Figure 26), after that we choose a suitable level of brightness for this method.
error prevention and correction	Arrow line is a static method that keep stick on ground. Whenever user miss it, they can find back correct track fast with the help of arrow line.
comfort and safety	Arrows in the line are transparent to avoid affecting users' inspection.
aesthetic and minimalist design	Simplify arrows by removing the lower part. Figure 27 shows in our application, the red arrows are simpler than it in original porotype (Figure 22) Between any two adjacent arrows there is an appropriate interval.
legibility	The individual arrows still contain the feature from a traditional arrow, which offer user a sense of movement.
visibility of progress status	
adaptive to body movements	The whole arrow line is fully established when new task start. User can see it at any time, so there is no need to make it adapt to user movement.
consistency and standards	Arrow line is a static guidance, it does not make any change when user move or turn-around.

Table 3: Adaption for implement prototype 1 (line)

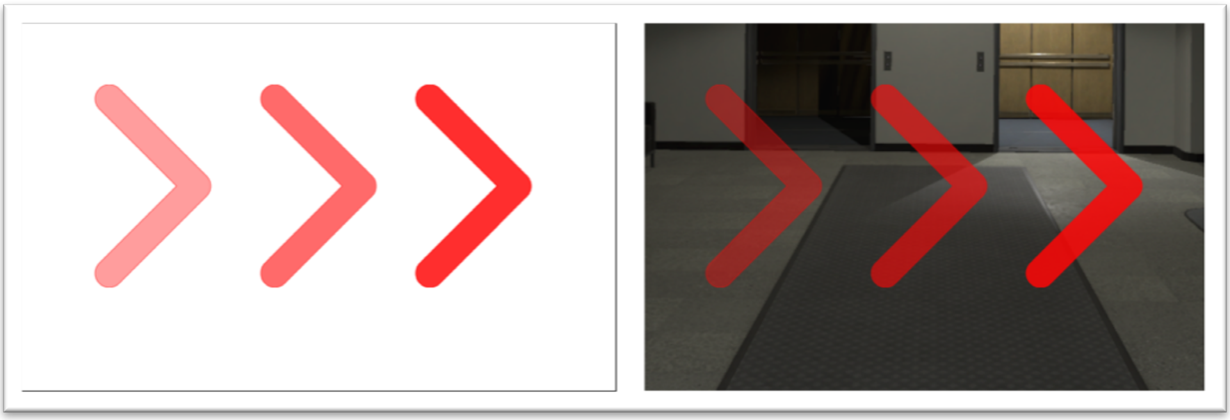

Figure 26: different brightness performance varies in different context

Figure 27: an instance of arrowLine in the experimental environment

4.4.2 Head Up

Table 4: Adaption for implement prototype 2 (head up) shows the changes we make implementation of prototype 2 (head up) according to the guideline.

Principle	Adaption
cooperate with information from the real world	The location of head up keeps relatively static to the headset, which means it moves with user rotation and movement. Therefore, it does not cover on something all the time.
compatible with the environment	We set a suitable diameter for the head up. It cannot larger than any width of entrance in the experimental environment.
fit with users' perception	The head up is always in front of the user one meter away.
error prevention and correction	
comfort and safety	The head up is transparent to avoid affecting users' inspection.
aesthetic and minimalist design	There is only one object represent navigational information. So computer generated data overlapping and clutter is impossible.

legibility	Head up use a traditional arrow (Figure 28) which show user direction information intuitively.
visibility of progress status	
adaptive to body movements	The head up points to next turning point when the user is closed to the current turning point. (in particular, we set 2.3m as a critical point.)
consistency and standards	The position of head up always changes with user movement and rotation to make sure user can see it at any time.

Table 4: Adaption for implement prototype 2 (head up)

Figure 28: an instance of head up in the experimental environment

4.4.3 Plane

Table 5: Adaption for implement prototype 3 (plane) demonstrates how we build prototype 3 (plane) align with our guideline.

Principle	Adaption
cooperate with information from the real world	The plane flies on the air (except its departure and landing), normally it does not affect user detect collision on the ground. And it moves faster and always waits user at turning points. So, it does not influence user observe surroundings as well.
compatible with the environment	We set a suitable size for the plane. It cannot larger than any entrance in the experimental environment.
fit with users' perception	From Figure 29 we can see that the plane is colourful. There is a tail follows the plane when it moves.
error prevention and correction	

comfort and safety	We controlled the moving speed of the plane, in order to avoid any uncomforting made by its movement. (in practice, we set the plane moving speed is 2.5m/s)
aesthetic and minimalist design	There is only one object represent navigational information. So, computer generated data overlapping and clutter is impossible.
legibility	Plane show the user navigational information by its moving track, which is straightforward.
visibility of progress status	
adaptive to body movements	The plane head to next turning point when the user is closed to the current turning point. (in particular, we set 2.3m as a critical point.)
consistency and standards	The plane moves in a constant speed.

Table 5: Adaption for implement prototype 3 (plane)

Figure 29: an instance of plane in the experimental environment

Chapter 5 User Study and Data Analysis

After our experimental environment was built completely, our research ethic application has been approved as well. Then we invited a group of students from Monash University to take part in our user study.

5.1 Pilot Study

According to the above plan showed in section 4.3 Experiment Design, 12 participants took part in the first round of user study, including 4 males and 8 females, and 8 out of the 12 are from have studied in IT. Figure 30 displays an overview of the time cost result from the first user study. There are many outliers in the graph and some of them are far away from maximum value. And an one-way ANOVA for time cost delivered the p-value > 25% ($F_{2,177}$ =1.35, p>0.26).

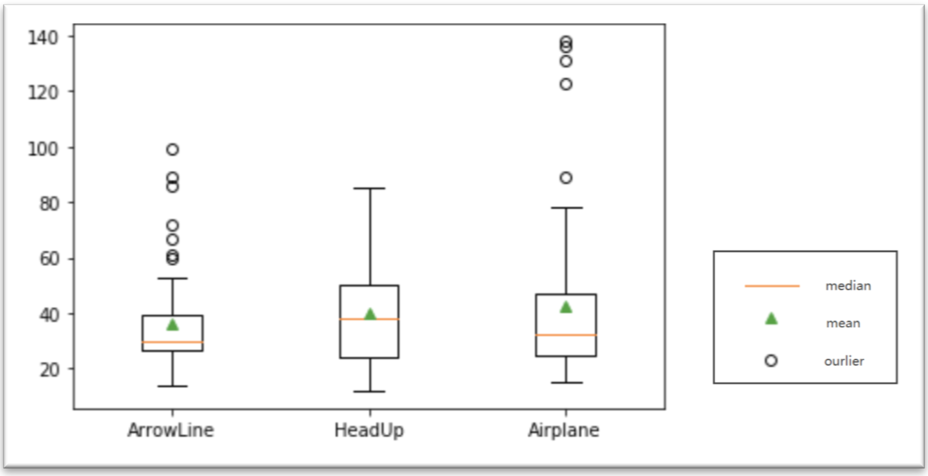

*Figure 30: boxplot of time cost form first user study. (min = Q1 - 1.5*IQR, max = Q3 +1.5*IQR)*

From the static analysis based on pilot study, we cannot obtain a significant difference among the three methods. Therefore, we consider the first round of user study as a pilot study. However, we have found some system problems during the user study.

1. As users learn more about the environment, a few of them try to get more waypoints which they won't go through during the specific task. And this activity serious affect timespan to get to the destination.
2. As they become more proficient in the operation, some users try to accelerate to by click on forward button in high speed, which caused that they moved at different speeds when doing different tasks.
3. In the virtual environment, there are some points which make users stuck in, which has an impact on the user's mood.
4. Most of users can finish their tasks in 25 min, and it may indicate that our task may be set too simple, which so it is not easy to reflect the difference in data.

For Improve those problem, we have re-designed our project. Comparing with the previous version, the changes are:

1. We set 3 different waypoints and 3 obstacles for each rout. User now can only see the 6 objects when they are doing a specific task. All the objects are placed

somewhere along the rout in this task. And we let users know that all object they must go through, so they no longer find extra waypoints by exploring the whole building.
2. The new version of the system strictly controls the user's forward speed. Frequently clicking (interval between two clicks < 0.5s) on the forward button is considered invalid.
3. Thoroughly detect the whole environment, mark places where anomalies may occur and avoiding place waypoints and obstacles around those places.
4. Increase the size of path group. In next round of user study, each path group contains eight routs. The first one is for training purpose, and other seven path is for testing user performance of wayfinding.

5.2 User Study

We run another round of user study after we revised our system. 12 participants (7 males and 5 females) took part in this experiment, 8 out 12 are from IT faculty. According to Figure 31, the number of outliers decreased, and the number of data is larger than the first user study, as a result, the data quality of the second user study is improved significantly.

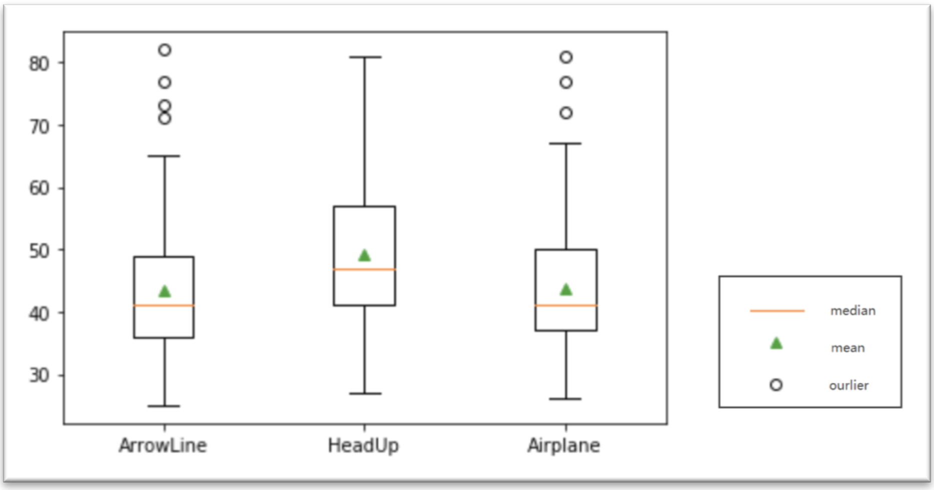

*Figure 31: boxplot of time cost form second user study. (min = Q1 - 1.5*IQR, max = Q3 +1.5*IQR)*

We do an ANOVA test (family-wise error rate is 0.05), the result shows ($F_{2,249} > 7.19$, $p < 0.001$). In addition, a post hoc test delivered that there is significant different between arrow line and head up ($p < 0.01$) and significant different Plane and head up ($p < 0.01$). However, the statistical analysis rejected a different between arrow line and Plane.

Except time costs, we also analysed score of waypoint and number of collisions from different methods. We did ANOVA for both two sets of data, but the statistical analysis did not show any significant difference. P-value for waypoint is 0.23, and that for collisions is 0.43. However, ostensibly, Figure 32 and Figure 33 show user observation towards environment may affected by different methods.

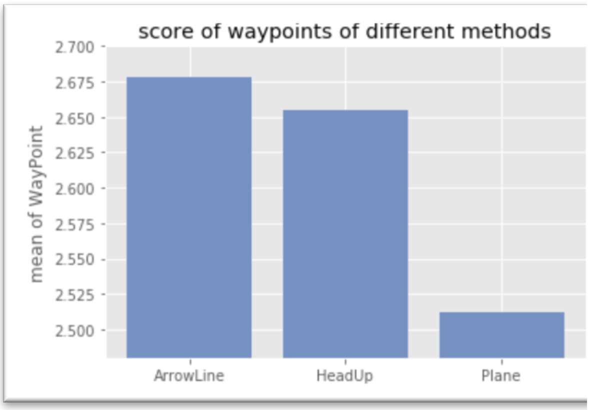

Figure 32: score of waypoints

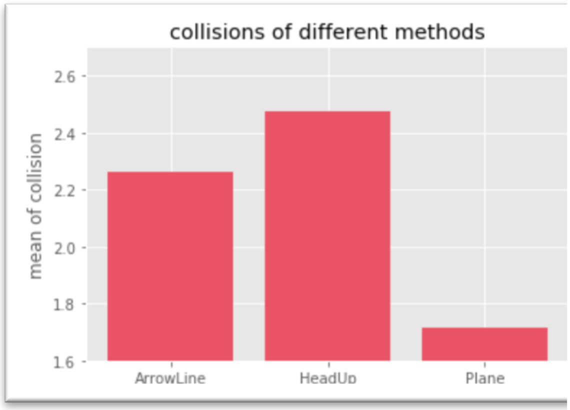

Figure 33: number of collisions

From statistical analysis and graphs, we summarised the following findings:

- User consume more time with the help of head up.
- User take less waypoint when they follow the Plane.
- User avoid more obstacles when they use Plane as guidance.

5.3 Prototype evaluation

Apart from the statistical analysis, our questionnaire also provided a huge amount of valuable knowledge. In the questionnaire, we asked users experiences about general satisfaction, visibility, legibility and collision situation about different methods respectively. Figure 34: overview of user feedback exhibits an overview of their answer. In the picture, user describe that they think arrow line performs best in every field. And generally, head up performs slight better than Plane.

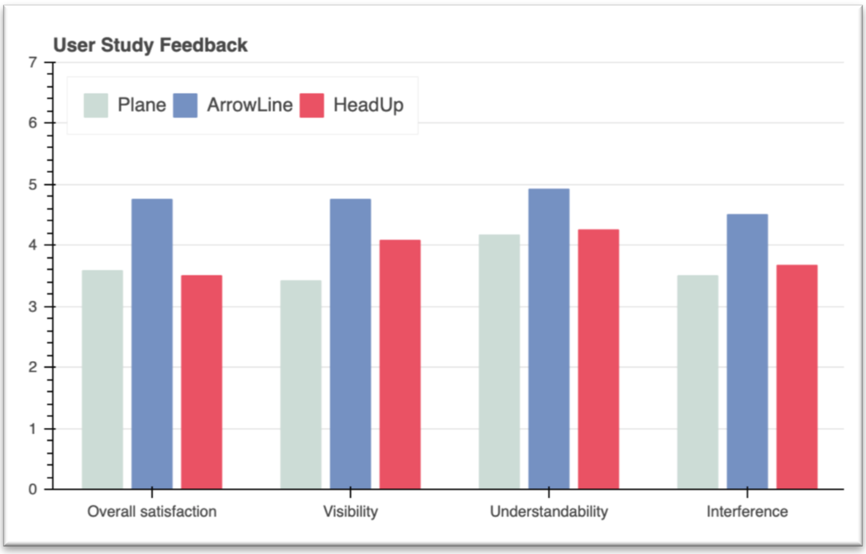

Figure 34: overview of user feedback

In addition, users present more feedback for open questions in the questionnaire. Table 6: summary of user feedback shows a summary of user feedback.

Method	Advantage	Disadvantage
Arrow Line	It helps users make earlier prediction about where and how they need to make a turn; It helps user avoid colliders on the ground; It is very easy to understand. Users are familiar with this method most because it is applied in many existing navigation systems.	Red arrows affect user observe road condition; It is not interactive because it is static.
Head Up	It is always visible; It gives user a sense of safety because they can find it easily.	Unless user is closed enough to a turning point, they do not know where they should make a turn, so they have to pay attention to the head up all the time; User need to bow their head down to get information from the head up, and it make user uncomfortable if the journey is too long; In the real word, user may bump against others if they always focus on the head up; It does not prompt notification when users are out of correct track; The head up sometimes clip into furniture in environment.
Plane	It does not affect user exploring new environment because it is far away and does not block anything; Its appearance looks best; Its movement is really noticeable; The landing process provide more information to user about where the destination is.	When it goes too far, it become invisible, and user feel they are lost; Its movement is too attractive which affect user observe environment; Even when it stops, user still need to focus on it to observe the direction for its next journey, otherwise user may miss instruction from it; It may start moving before user find where it stops at.

Table 6: summary of user feedback

From the user feedback, we found that:

- Conflict may exist between principles “fit with users’ perception” and “cooperate with information from the real world”. Increasing the size of virtual data can make it more noticeable. But with the size increasing, the virtual object may influence users’ observation to their context.
- Conflict may exist between principles “aesthetic and minimalist design” and “cooperate with information from the real world”. Some users prefer to use a plane (prototype 3) because its appearance is more beautiful, but they also admit that the plane is more attractive and may influence their observation to environment.
- Conflict may exist between principles “comfort and safety” and “cooperate with information from the real world”. For instance, the head up (prototype 2) was placed just above the floor to avoid it user observe environment, but users reflected that the observation to head up was tiring.
- Users expect animation in 3D environment. From users’ suggestions, we noticed that animation can contribute to AR wayfinding systems by two ways. First, it can improve legibility. Two users pointed that they hope arrows in arrow line can move forward as a stream. Second, animation can make instructions more noticeable. Some users indicated that

when the plane (prototype 3) stopped at somewhere far away, they did not notice it even when they were very closed to it. When the plane stays and waits for user, if it moves up and down, user may aware its position easily.

Chapter 6 Conclusion

This research identified a research gap of AR wayfinding efficiency in the field of user interface design, and it explained the importance of user interface design. Then, we proposed a user interface design guideline for AR wayfinding. The guideline refers to abundance of other research that related to navigation, general design principles and the application of augmented reality technique in wayfinding. After that, we constructed three prototypes that represent navigational information in different forms. Two experiments for verifying the navigation efficiency of those three prototypes was conduced later. The output of the experiments helps us evaluating the guideline we proposed before.

6.1 Outcomes and contributions

The main outcomes which contribute to our research question are:

- **A summary guideline.** We have learnt from a large amount of literature, thesis, and online videos to explore what aspects or factors in user interface design contribute to an AR wayfinding system efficiency and user experience, and how do they work. Then we filtered and grouped those factors together, and we summarised a set of principles which can be referred by other AR developers.

- **Prototypes design.** Apart from the detecting factors which influence AR wayfinding efficiency, we also paid attention to how to present navigational information. We studied from various existing AR wayfinding user interface, and we extracted elements that present guide instruction. Then we analysed and summarised basic forms of carrier of navigational information.

- **Prototype implementation.** They instantiation of prototypes exemplified the process that how to adapt the design guideline into a specific environment.

- **Experiment and its result.** Via a statistical analysis, the experiment proves that different user interface can lead to difference in efficiency of AR wayfinding systems. In addition, the experiment process itself introduced users how future navigation applications may look like. Moreover, participants provided more innovative suggestions about representations of navigational instruction.

6.2 Limitation and Future Work

There are a few limitations of this research. Some of them are in our plan, but after recalling the whole process, we have noticed other limitations that can be improved.

- We used a virtual environment to simulate the real world. The difference between the virtual world and the real world is inevitable. However, we run the experiments in an VR environment due to resource limitation. If we have more time and enough hardware support, we plan to run studies in the real world with augmented reality technique. Moreover, the user experience of AR system is affected by AR hardware. Users may have different need for different devices. Therefore, we may run experiment with multiple devices in the future.

- Our experiments were conducted in a single environment. Our experimental environment is spacious and tidy, but that in the real world may be very complex. In the future, we need to conduct more tests in various environment.

- There was only one context for user to do the task. The demands of navigation user interface vary from various aims, and the aim depends on context. The significance of the ten principles may vary in multiple context. For further study, we can design more contexts or background for users.

- Two principle were planned to be ignored for the first stage of experiment. The experiment we conducted is for testing the difference among navigational information carriers. We try to understand which instruction representation make users understand its information accurately and quickly. Hence in this experiment, we did not involve "error prevention and correction". Moreover, at the beginning, for controlling the number of variables and operability, we determined to ignore the work of mini map and other data representations which offer users the rate of process. This is a straightforward way to reflect "visibility of process status". However, according to the feedback from questionnaire, we realised that a sense of controlling is really important in navigation activities. In the next study, we will focus on exploring these two missing principles.

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