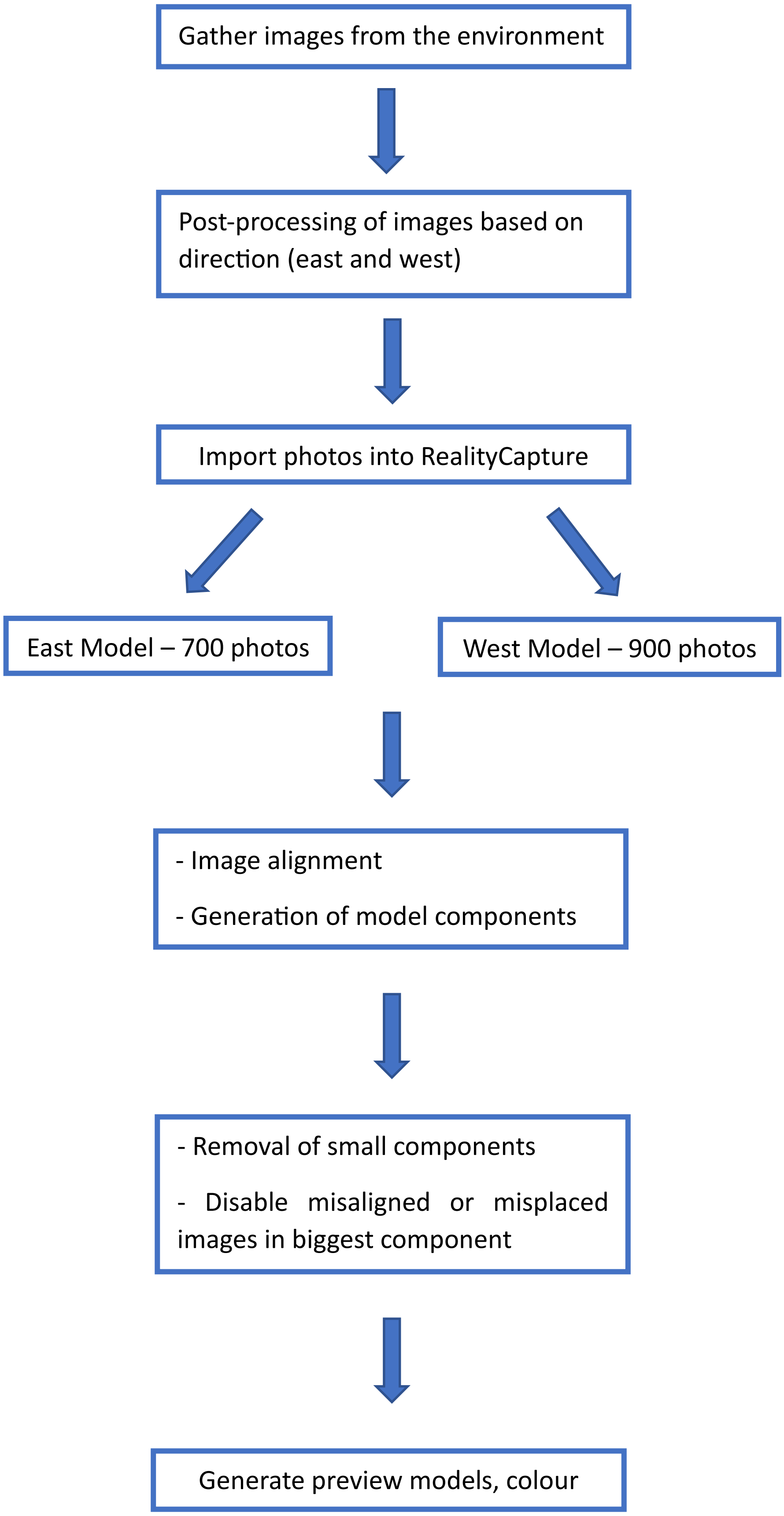
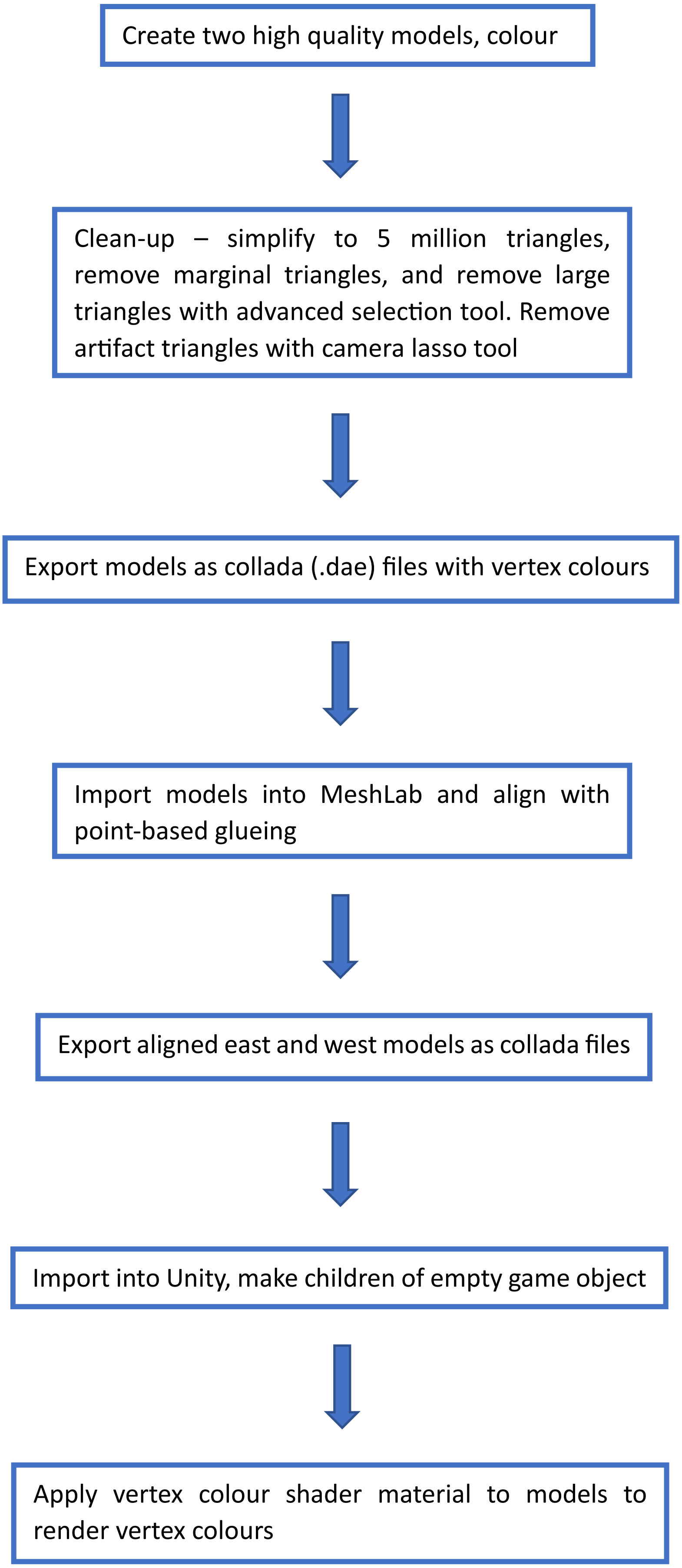
Appendix A: Model Workflow for Virtual Environment Generation




Create two high quality models, colour
Clean-up – simplify to 5 million triangles, remove marginal triangles, and remove large triangles with advanced selection tool. Remove artifact triangles with camera lasso tool
Export models as collada (.dae) files with vertex colours
Import models into MeshLab and align with point-based glueing
Export aligned east and west models as collada files
Import into Unity, make children of empty game object
Apply vertex colour shader material to models to render vertex colours

Appendix B: Experiment Questionnaire

Questions

Question Part A: General Information

1. What is your age?

2. Select your gender with a tick in the corresponding box

☐ Male ☐ Female ☐ Gender diverse ☐ Prefer not to say

3. If you are a university student, select your field of study with a tick in the corresponding box. Note: Geospatial Science corresponds to Surveying or GIScience related fields. If you are a member of the public, go to question 4.

☐ Geospatial Science ☐ Psychology ☐ Geography ☐ Information Science ☐ Computer Science ☐ Other

4. In your own words, please share your understanding of what spatial cognition is?

5. In your own words, how would you describe spatial intelligence?

For question parts B – D, consider the statements before circling the number you think best applies to them.

Question Part B: Assessment of Technological Familiarity

1. I am familiar with digital devices and how they function.
   Strongly disagree 1 2 3 4 5 Strongly agree

2. I frequently play video games.
   Strongly disagree 1 2 3 4 5 Strongly agree

3. I am familiar with virtual reality devices and how they function.
   Strongly disagree 1 2 3 4 5 Strongly agree

4. I would consider myself a technologically competent person.
   Strongly disagree 1 2 3 4 5 Strongly agree

5. I can usually solve technology related problems without external help.
   Strongly disagree 1 2 3 4 5 Strongly agree

Question Part C: Assessment of Spatial Ability

1. I have a good sense of direction.
   Strongly disagree 1 2 3 4 5 Strongly agree

2. It doesn't take me long to learn the general layout of an unfamiliar place.
   Strongly disagree 1 2 3 4 5 Strongly agree

3. I feel comfortable navigating without Google Maps.
   Strongly disagree 1 2 3 4 5 Strongly agree

4. I feel comfortable navigating with a paper map.
   Strongly disagree 1 2 3 4 5 Strongly agree

5. When I am lost I struggle to find my way back to a familiar place
   Strongly disagree 1 2 3 4 5 Strongly agree

6. I can visualise routes in my mind and use them to navigate.

Strongly disagree 1 2 3 4 5 Strongly agree

7. I can imagine looking at places from a perspective that is different to my own.
   Strongly disagree 1 2 3 4 5 Strongly agree

Question Part D: Virtual Environmental Experience

1. I enjoyed navigating through the virtual environment.
   Strongly disagree 1 2 3 4 5 Strongly agree

2. It was easy to navigate through the virtual environment.
   Strongly disagree 1 2 3 4 5 Strongly agree

3. The virtual environment experience was exciting.
   Strongly disagree 1 2 3 4 5 Strongly agree

4. I felt a sense of mystery in the virtual environment.
   Strongly disagree 1 2 3 4 5 Strongly agree

5. The virtual environment seemed glitchy.
   Strongly disagree 1 2 3 4 5 Strongly agree

6. I noticed a sudden change in my cognition *before* the choice point.
   Strongly disagree 1 2 3 4 5 Strongly agree

7. It was difficult to decide which path to take to get to the object.
   Strongly disagree 1 2 3 4 5 Strongly agree

8. I noticed a sudden change in my cognition at the path junction before choosing my path.
   Strongly disagree 1 2 3 4 5 Strongly agree

9. I had a sudden moment of realisation at the decision point.
   Strongly disagree 1 2 3 4 5 Strongly agree

10. I felt like I suddenly remembered something at the choice point.

Strongly disagree 1 2 3 4 5 Strongly agree

11. I felt a déjà vu like experience at the path junction.

Strongly disagree 1 2 3 4 5 Strongly agree

12. I felt confident that the object would be along the path I chose.

Strongly disagree 1 2 3 4 5 Strongly agree

13. I felt attracted to one path over the other.

Strongly disagree 1 2 3 4 5 Strongly agree

14. I felt like I learned something about the environment.

Strongly disagree 1 2 3 4 5 Strongly agree

15. I had a moment of insight that influenced my path decision.

Strongly disagree 1 2 3 4 5 Strongly agree

16. My spatial cognition improved in the virtual environment.

Strongly disagree 1 2 3 4 5 Strongly agree

17. Describe your experience of the virtual navigation task. What were you thinking about as you were moving through the environment? Elaborate on this.

18. Did you notice any changes in your way of thinking about or perceiving the environment during and after the experiment? If so, elaborate on this; where (or when) did these changes occur?

19. What (if anything) made you decide to choose the path that you did to find the object?

20. Did you find the Object? Describe your experience of finding (or not finding) the object in your own words. What were you thinking about immediately before, during, and after the appearance (or absence) of the object?

Appendix C: Derivation of Chance Performance and Participant Blink Distributions

For deriving the chance performance distribution of participants during the 2AFC decision making task and their expected blink distribution during the visualisation window, the combinatorics formula without order [1] was applied.

$$C(n, r) = \frac{n!}{r!(n-r)!} \quad [1]$$

Where n is the number of trials and r is the number of correct path decisions or blinks.

Substituting the experimental parameters into [1] (n = 8 trials, r = 1 - 8 correct path decisions or blinks) gives the following number of combinations (Table 1).

r	0	1	2	3	4	5	6	7	8
Combinations	1	8	28	56	70	56	28	8	1

Table 1: *Number of combinations for x correct path choices or blinks in an experimental session of eight trials*

To determine the probability distribution of x correct path decisions or blinks in n trials as a sample percentage, a modified binomial formula [2] is used.

$$P_x = Cp^x q^{n-x} * 100 \quad [2]$$

Where C is the number of combinations for r correct path decisions or blinks (Table 1), p is the probability of a correct path decision or blink, and q is the probability that an incorrect path decision or that the participant will not blink.

Taking p and q as chance probabilities (I.e. p = q = 50%) and substituting these values into [2] gives the following probability distribution (Table 2).

Correct (x)	0	1	2	3	4	5	6	7	8
Sample %	0.4	3.1	10.9	21.9	27.3	21.9	10.9	3.1	0.4

Table 2: *Probability distribution of x correct path decisions in an experimental session per participant.*

Recent research on blink rates in VR head-mounted displays has shown that average blink rates are reduced to around ten blinks per minute (Kim et al., 2018, 2022). For this model, a blink rate of twelve blinks per minute (one every five seconds) is used, which is consistent with research on average blink rates and their interblink durations (Fatt & Weissman, 1992; Kwon et al., 2013; Tsubota et al., 1996). Consequently, the values for p and q are taken as 20% and 80% per second respectively. Substituting these values into [2] gives the following probability distribution (Table 3).

Blinks (x)	0	1	2	3	4	5	6	7	8
Sample %	16.8	33.6	29.4	14.7	4.6	0.9	0.1	~0	~0

Table 3: *Probability distribution of x blinks in an experimental session per participant.*

Appendix D: Derivation of Visual Loss Contributions

In addition to a visual loss of 20% caused by blinking (see Appendix C above), research on subliminal reorientation and repositioning in virtual reality suggests that additional opportunities for visual loss may come from the perspective shift occurring during saccades, which occur every 300 – 400ms (Bolte & Lappe, 2015) and last between 30 – 100ms (Ramat et al., 2007). This defines the problem of saccade contingent updating, where visual information in a scene is updated at the same time as a saccade, impairing the visual system due to image blur while the eye is in motion (Triesch et al., 2002). When combined with blinking, this would create multiple windows for visual loss, where participants would either completely miss the precue, or only be exposed to the precue for a shorter duration than the shift time. It is therefore expected that for an experimental session, 20% of the visualisations will be unnoticed due to blinking, and a further 33% will be unnoticed due to saccades occurring during the perspective shift (taking the duration of a saccade as lasting for one third of a second). Consequently, it is expected that the combined visual loss of the interface is 53%. This is consistent with participant interview responses, as no participants claimed to see any teleportation-based mental imagery more than half of the time.

References

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