CoCreatAR: Enhancing Authoring of Outdoor Augmented Reality Experiences Through Asymmetric Collaboration

Supplementary Materials

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1 Formative Study: Tools Summary

In this section, we present two plots summarizing the tools participants reported using in the formative survey to develop site-specific AR experiences. Fig. 1 illustrates that participants most frequently used Unity, Blender, and Figma in their design and development processes. Fig. 2 shows that Niantic SDK, ARFoundation, and ARCore were the most commonly used AR frameworks.

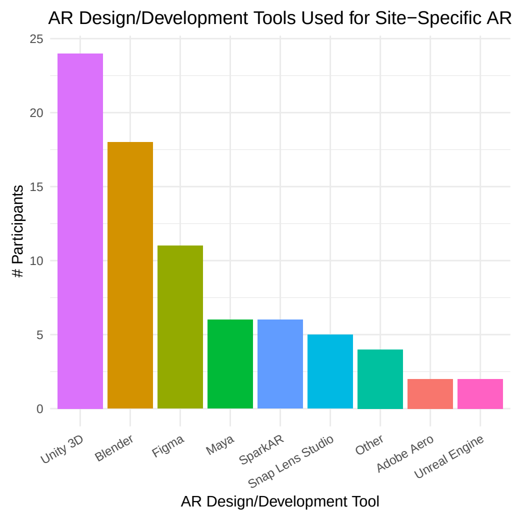

Fig. 1. The number of participants who reported using various AR development/design tools on the formative survey. Unity was the most-reported tool.

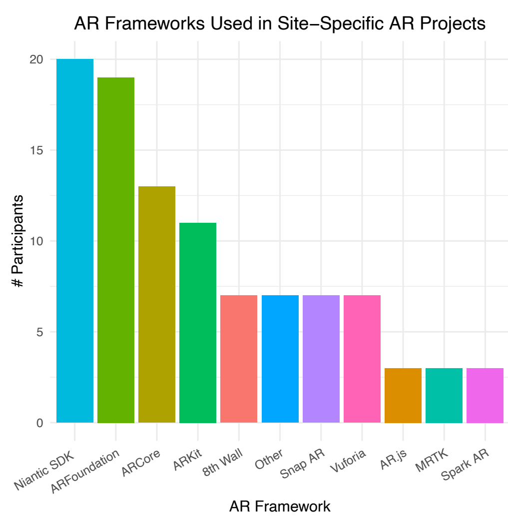

Fig. 2. The number of participants who reported using various AR frameworks on the formative survey. Niantic SDK was the most-reported AR framework.

2 System Walkthrough

In this scenario, a small AR agency is tasked with creating an AR tour for a university's open day. The lead developer initiates the project remotely using pre-captured spatial data and then collaborates in real time with an on-site client to ensure the AR experience accurately reflects the physical environment.

The developer begins by importing a pre-captured *location mesh* of the university campus from Niantic's Geospatial Browser into Unity. They place AR assets, such as interactive signs, narration points, and game elements, based on this mesh. Next, they initiate a collaborative session with the in-situ client. The client explores the AR tour on-site while the ex-situ developer monitors their progress remotely via a live stream of the client's screen within Unity. Early in the session, the developer notices a misalignment issue: a poster that was intended to be placed on a building wall appears embedded within the structure.

Using the **3D Cursor**, the ex-situ developer directs the in-situ client to the problematic poster. With **real-time synchronization**, the ex-situ developer adjusts the position and color of the poster, with the changes immediately reflected on the client's device, resolving the misalignment.

As the session continues, the developer observes—both from the *location mesh* and the client's streamed view—that certain elements are missing from the pre-captured mesh. Specifically, the entrance steps to a prominent building and some newly installed information stands are absent. To address these gaps, the developer asks the client to capture additional spatial data. The client uses **3D Coarse Mesh** capture to scan both the steps and the information stands, streaming the updated mesh in real time to the developer's Unity editor. The developer then integrates this new information, ensuring the AR content aligns with the physical space.

In another instance, the developer notices that the mesh lacks fine details of a nearby statue, including its face, hands, and the objects it holds. The ex-situ developer requests more detailed information, prompting the client to use **3D Snapshot** to capture a point cloud of the statue. This detailed point cloud is transmitted to the ex-situ developer, enabling them to refine the AR assets and ensure precise placement and detail.

Annotations are extensively used throughout the session to facilitate collaboration. At one point, the ex-situ developer asks the in-situ client to illustrate the expected flow of visitors during the open day. The client uses **Air Draw** to sketch visitor paths in the air, helping the developer visualize movement patterns and adjust the AR content accordingly.

Additionally, the client employs **Surface Draw** to propose specific locations for additional AR elements, such as interactive signs or objects. As they brainstorm together, the client sketches ideas on the ground and walls, while the developer provides input on which locations may be most engaging or logistically feasible. All annotations are synchronized and saved within the Unity scene, preserving spatial data and collaborative decisions for future iterations.

By the end of the session, the ex-situ developer has made significant real-time adjustments to the AR experience, incorporating both new spatial data and client feedback. Since the captures and annotations are saved for future use, they not only resolve immediate issues but also streamline later stages of the design process and reduce the need for further site visits.

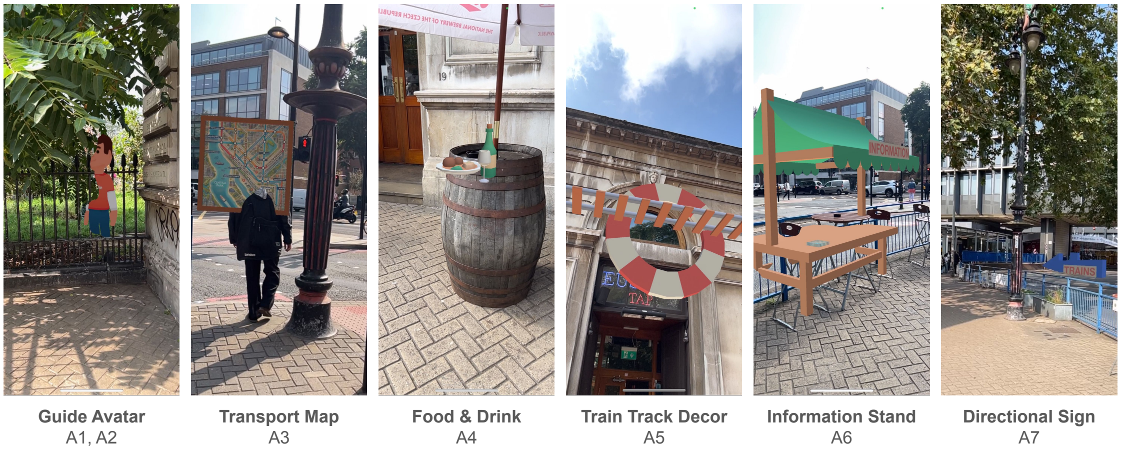

Fig. 3. The virtual objects in Prototype A, which are described in Section 3.1. The labels A1, A2, etc. refer to the issue types in Section 3.3.

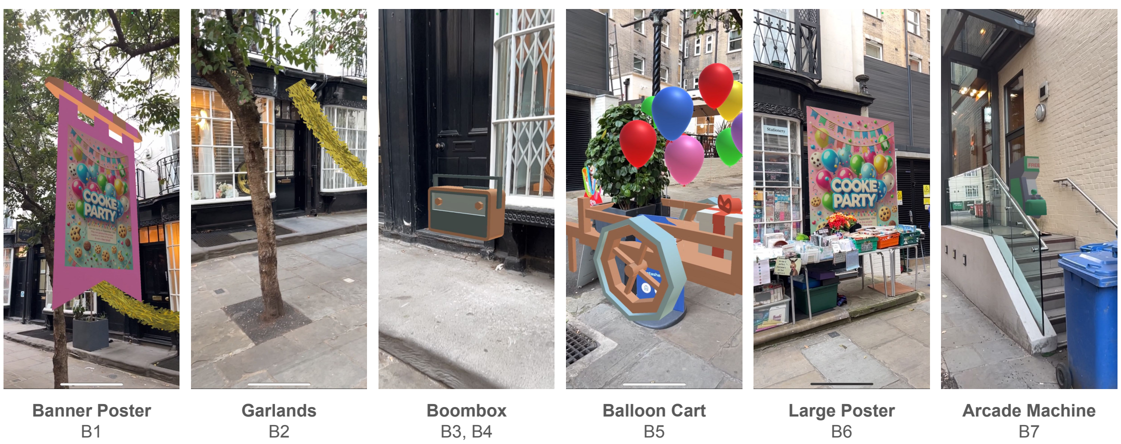

Fig. 4. The virtual objects in Prototype B, which are described in Section 3.2. The labels B1, B2, etc. refer to the issue types in Section 3.3.

3 Task Design: AR Prototypes in Two Locations

The user study involved two AR prototypes designed for distinct outdoor environments, each with a unique theme. The prototypes were developed based on the spatial characteristics of their respective sites by two authors of this work, primarily using information from the ***location mesh***, supplemented with data from Google Maps, Google Street View, and GPS to inform the placement of AR elements relative to the *location mesh*. The prototypes aimed to integrate interactive and decorative AR elements with the physical surroundings while emphasizing the local context of each location. Each prototype was tested on-site, and seven specific issues were identified and verified before the user study. These issues are shown in Fig. 3 and Fig. 4.

3.1 *Location* A: Welcoming Tourists to the City

Location A, situated near a major transit station, experienced high foot traffic, a nearby road, and elevated environmental noise. The AR experience at *Location* A followed the theme *"Welcoming Tourists to the City"*, reflecting its proximity to the transit hub and its intended function as a guide for visitors. Below, we describe the virtual objects in the prototype, referencing the identified issues (e.g., A1) detailed in Section 3.3.

- **Guide Avatar** (A1, A2): Positioned using the *location mesh*, the guide avatar was designed to interact with tourists upon arrival, providing location-specific audio information as they approached.
- **Public Transport Map** (A3): Positioned near a street lantern, the transport map was placed using the *location mesh* as a reference, supplemented by Google Street View data. It aimed to orient tourists and provide an overview of local transit options.
- **Food and Drink Items** (A4): These virtual elements were placed on a barrel table using the *location mesh* to complement the bar's physical setting.
- **Train Track Decoration** (A5): Positioned around the building's exterior using the *location mesh*, the train track emphasized the transportation-related theme of the location.
- **Information Stand** (A6): Located in an open space across from the bar, the information stand was placed using the *location mesh* and provided additional details for tourists.
- **Directional Sign** (A7): An arrow pointing toward the train station was placed using the *location mesh*, GPS, and Google Street View data. It was intended to help tourists navigate back to the station after exploring the AR experience.

3.2 *Location* B: Promoting and Celebrating the Upcoming Cookie Party

Location B was situated along a narrow street with a local cafe, characterized by significant foot and bicycle traffic and lower environmental noise compared to *Location* A. The AR experience at *Location* B followed the theme *"Promoting and Celebrating the Upcoming Cookie Party"*, aligning with the celebratory atmosphere of nearby restaurants and cafes. Below, we describe the virtual objects in the prototype, referencing the identified issues (e.g., B1) detailed in Section 3.3.

- **Banner Poster** (B1): Positioned using the *location mesh*, the banner poster was designed to hang from a tree and promote the upcoming cookie party to pedestrians below.
- **Garlands** (B2): Decorative garlands were placed between tree trunks and across streetlights, with their positioning determined by the *location mesh*.
- **Boombox** (B3, B4): Placed on a stool near the cafe using the *location mesh*, the boombox provided festive background music.
- **Balloon Cart** (B5): Positioned at the center of the street using the *location mesh*, this cart featured balloons, gifts, and cookies.
- **Large Poster with Event Information** (B6): Affixed to a nearby wall using the *location mesh*, this large poster provided details about the cookie party, including how to win a free ticket. It was designed to be clearly visible to pedestrians.
- **Arcade Machine** (B7): Placed further down the street near the event venue, the arcade machine was positioned using the *location mesh* as a reference, supplemented by GPS and Google Street View data. A purple arrow guided users toward the machine.

3.3 Task Components – Issues

After developing the AR prototypes for each location remotely, we identified at least seven issues per prototype during on-site testing before the user study. We intentionally left a specific set of seven issues at each location for participants to address, selecting them to ensure coverage of the issue types identified in our formative study. These issues are listed below and classified by type in Table 1.

To inform the design of the prototypes, we also drew inspiration from existing work on design patterns in AR [2]. As shown in Table 1, we classified each component based on the dimensions described in Section 5 of the main paper. These issues were used in the *refinement* segment of the user study task and are detailed below.

***Location* A: Welcoming Tourists to the City**

- A1. The guide avatar is difficult to find.
- A2. The guide avatar is hard to hear over the traffic noise.
- A3. The map is inconveniently placed and near (foot) traffic.
- A4. The drinks and food on the table appear to float in the air.
- A5. The train track decoration and striped ring do not look good from all perspectives and block the bar's logo.
- A6. The information stand is in an odd place.
- A7. The sign with the arrow pointing to the train station is hard to see from the information stand.

***Location* B: Promoting and Celebrating the Upcoming Cookie Party**

- B1. The banner poster is not attached to anything.
- B2. The garlands between the trees do not appear correctly placed.
- B3. The volume of the boombox with background music is too loud.
- B4. The boombox is floating.
- B5. The balloon cart is touching/inside another object.
- B6. The large poster is hard to see, and reading it requires caution due to bike traffic.
- B7. The Free Ticket Arcade machine is out of reach.

	Design Patterns						Referent Types					Alignment Type			Issue Types				
	Glyphs	Decal	Trajectories	Label	Ghost	Audio	Small object	Small plane/area	Large object	Large plane/area	Building structure	Overlap	Proximity	Surface	Physical constraints	User safety	Misalignment	User context	User flow
A1					✓					✓			✓	✓	✓		✓		✓
A2						✓				✓			✓					✓	
A3	✓	✓							✓					✓	✓	✓		✓	✓
A4					✓			✓						✓			✓		
A5			✓		✓						✓	✓					✓		✓
A6				✓	✓					✓				✓			✓		✓
A7	✓		✓	✓									✓	✓					✓
B1	✓	✓		✓					✓			✓					✓		
B2			✓						✓		✓						✓		
B3						✓							✓					✓	
B4					✓			✓											
B5										✓				✓	✓		✓		
B6		✓									✓			✓	✓	✓	✓		✓
B7	✓		✓	✓	✓			✓						✓	✓				

Table 1. Design patterns, referent types, alignment types, and issue types in AR element design.

4 Full Results of CoCreatAR User Study

This section presents the full findings from our user study. We employed linear mixed-effects models to analyze the data. Although we followed a Latin Square counterbalanced study design, we analyzed the data with consideration of a potential confounding factor, *location*. We also evaluated the data for any effect of participants' prior experience. Participant variability was modeled as a random effect, and all models converged successfully. Unless otherwise noted, the assumptions of the linear mixed-effects models were satisfied (including linearity, normality of residuals, homoscedasticity, and independence).

We separately examined the performance of *ex-situ* and *in-situ* participants, focusing on key metrics such as engagement and task load relevant to our hypotheses. As described in the main paper, Cronbach's alpha values indicated acceptable internal consistency for both engagement (0.740 for *in-situ*, and 0.764 for *ex-situ*) and task load items (0.812 for *in-situ*, and 0.772 for *ex-situ*).

4.1 Engagement

Engagement scores were analyzed using mixed-effects linear models, incorporating within-subject variability (participant as a random effect), location, and prior experience with smartphone-based AR (for *in-situ* users) or 3D editing tools (for *ex-situ* users).

4.1.1 Engagement by Condition. For *ex-situ* participants, we observed a significant effect of condition on engagement scores. The estimated coefficient for the Sync condition was 0.500 (SE = 0.140, $p < 0.001$, 95% CI [0.226, 0.774]), indicating that participants in the Sync condition reported significantly higher engagement compared to those in the Async condition. The intercept of 3.042 (SE = 0.306, $p < 0.001$, 95% CI [2.443, 3.641]) represents the baseline engagement score in the Async condition. Participant variability accounted for a variance of 0.145 in engagement scores.

Similarly, for *in-situ* participants, engagement was significantly higher in the Sync condition, with a coefficient of 0.340 (SE = 0.130, $p = 0.009$, 95% CI [0.085, 0.595]). The intercept of 3.118 (SE = 0.232, $p < 0.001$, 95% CI [2.663, 3.574]) reflects the average engagement score for the Async condition. Participant variability accounted for a variance of 0.092 in engagement scores for *in-situ* participants.

4.1.2 Effects of Location. We included location as a potential confounding variable. For *ex-situ* participants, no significant effect of location was detected, with a coefficient of −0.181 (SE = 0.140, $p = 0.196$, 95% CI [−0.454, 0.093]), indicating that location did not substantially influence engagement scores.

However, for *in-situ* participants, location had a significant effect on engagement. The coefficient for *Location* B was 0.299 (SE = 0.130, $p = 0.022$, 95% CI [0.044, 0.554]), suggesting that participants at *Location* B exhibited higher engagement compared to those at *Location* A.

4.1.3 Effects of Prior Experience. Prior experience with AR or 3D editing tools did not significantly affect engagement scores for either group. For *ex-situ* participants, experience with 3D editing tools had a coefficient of 0.091 (SE = 0.054, $p = 0.093$, 95% CI [−0.015, 0.197]), while for *in-situ* participants, experience with AR had a coefficient of 0.090 (SE = 0.075, $p = 0.231$, 95% CI [−0.058, 0.238]). Neither effect reached statistical significance, suggesting that prior experience did not substantially impact engagement.

4.2 Task Load

Task load scores were analyzed using mixed-effects linear models, with participant variability, location, and prior experience as factors.

4.2.1 Task Load by Condition. For *ex-situ* participants, condition did not significantly affect task load. The estimated coefficient for the Sync condition was 0.313 (SE = 0.309, $p = 0.312$, 95% CI [−0.294, 0.919]), indicating no significant difference in task load between the Sync and Async conditions. The intercept of 4.631 (SE = 0.724, $p < 0.001$, 95% CI [3.213, 6.049]) represents the baseline task load score in the Async condition. Participant variability accounted for a variance of 0.881 in task load.

Similarly, for *in-situ* participants, no significant effect of condition on task load was observed. The coefficient for the Sync condition was 0.213 (SE = 0.345, $p = 0.538$, 95% CI [−0.464, 0.889]), with an intercept of 4.205 (SE = 0.556, $p < 0.001$, 95% CI [3.116, 5.294]). Participant variability accounted for a variance of 0.396 in task load.

4.2.2 Effects of Location. Location did not significantly affect task load for *ex-situ* participants, with a coefficient of −0.250 (SE = 0.309, $p = 0.419$, 95% CI [−0.856, 0.356]). However, for *in-situ* participants, location showed a marginal effect on task load, with a coefficient of −0.637 (SE = 0.345, $p = 0.065$, 95% CI [−1.314, 0.039]), indicating a tendency for lower task load at *Location* B compared to *Location* A, though this effect did not reach statistical significance.

4.2.3 Effects of Prior Experience. Background experience did not significantly influence task load for either group. For *ex-situ* participants, experience with 3D editing tools had a coefficient of −0.181 (SE = 0.129, $p = 0.162$, 95% CI [−0.434, 0.073]), while for *in-situ* participants, experience with AR had a coefficient of −0.320 (SE = 0.176, $p = 0.070$, 95% CI

[−0.666, 0.026]). Neither effect was statistically significant, suggesting that prior experience did not substantially affect task load.

4.3 Confidence in Authored Result

To assess the impact of condition on participants' confidence in their authored results, we analyzed the number of issues participants reported to have confidently fixed. In this case, the dependent variable represents the number of issues participants indicated they "fixed and feel confident about." In addition, we analyzed the self-rated overall confidence score. This analysis included participant variability as a random effect, with location and prior experience with 3D editing tools as additional factors.

4.3.1 Confidence by Condition. The analysis revealed a significant effect of condition on the number of confidently fixed issues. The estimated coefficient for the Sync condition was 3.000 (SE = 0.373, $p < 0.001$, 95% CI [2.270, 3.730]), indicating that participants in the Sync condition fixed significantly more issues with confidence compared to those in the Async condition. The intercept of 0.578 (SE = 0.710, $p = 0.416$, 95% CI [−0.813, 1.969]) represents the average number of confidently fixed issues in the Async condition. Participant variability accounted for a variance of 0.425.

In addition, participants in the Sync condition reported significantly higher overall confidence scores to those in the Async condition (SE = 0.387, $p = 0.004$, 95% CI [0.367, 1.883]), with the coefficient for Sync being 1.125. Participant variability accounted for a variance of 0.258.

4.3.2 Effects of Location. We included location as a potential confounding variable. For *ex-situ* participants, there was a marginal effect of location on the number of confidently fixed issues. The coefficient for *Location* B was −0.667 (SE = 0.373, $p = 0.074$, 95% CI [−1.397, 0.064]), suggesting that participants at *Location* B tended to fix fewer issues with confidence compared to those at Location A, though this effect did not reach conventional statistical significance.

Similarly, location did not have a significant impact on overall confidence scores, with the coefficient for *Location* B being 0.125 (SE = 0.387, $p = 0.747$, 95% CI [−0.633, 0.883]).

4.3.3 Effects of Prior Experience. Prior experience with 3D editing tools did not significantly affect the number of confidently fixed issues, with a coefficient of 0.195 (SE = 0.117, $p = 0.096$, 95% CI [−0.034, 0.424]). While this effect was not statistically significant, it suggests a potential positive association between prior experience and confidence in fixing issues.

The analysis also revealed no significant effect of prior experience on overall confidence scores. The coefficient for prior experience was 0.078 (SE = 0.106, $p = 0.466$, 95% CI [−0.131, 0.286]).

4.4 Feature usage during the sessions

One author of this paper systematically coded the task recordings to document the usage frequency of each feature, along with qualitative observations on their application (e.g., using *Coarse 3D Mesh* to capture building geometry). The resulting distribution of feature usage counts is visualized in Fig. 5.

5 Survey and Semi-Structured Interview Questions

We outline the validated questionnaires, custom questions, and semi-structured interview questions in this section.

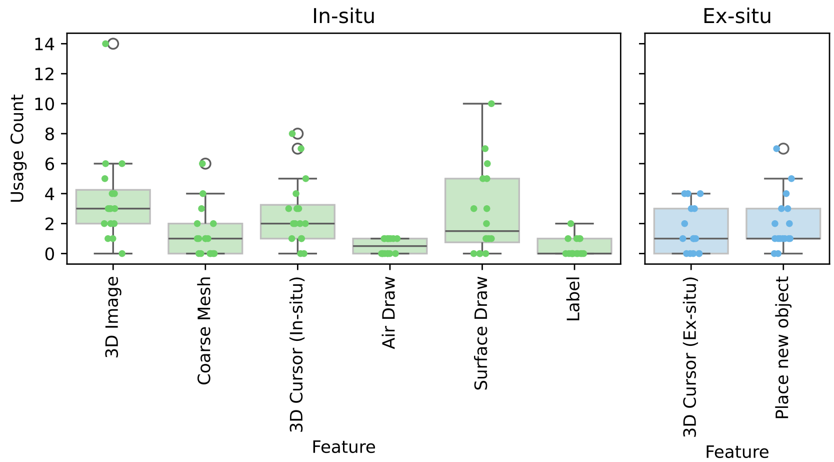

Fig. 5. Box plot representing the distributions of feature counts per group, with an additional visualization of individual data points. Green bars and points represent *in-situ* features, whereas blue represents *ex-situ* features.

5.1 Formative Study Questions

The formative study's survey and semi-structured interview questions are in Listing 1 and 2, respectively.

Listing 1. The formative study's survey questions.

```
1. Which of the following best describes your current occupation? Please select all that apply.
[Select multiple options, including Software Engineer, Technical Artist, UX Designer, ..., Other - Write In]

2. What best describes the type of organization you work for?
[Select one option, including Small Business, Agency, Enterprise, ..., Other - Write In]

3. How long have you been developing AR experiences?
[Select one option, including Less than a year, 1-2 years, 3-5 years, 6-10 years, Over 10 years]

4. How long have you been developing location-based AR experiences?
[Select one option, including Less than a year, 1-2 years, 3-5 years, 6-10 years, Over 10 years]

5. How would you describe the content you create? Please select all that apply.
[Select multiple options, including Long form (games, movies, other non-marketing experiences, etc), Short form (ads or
       marketing experiences, AR filters, product demos, etc)]

6. With brief bullet points, please describe 1-3 of your favorite location-based AR applications you have worked on.
      Feel free to add a link to your portfolio or projects.
[Long answer]

7. For what target group do you typically build location-based AR experiences? For example, 'adult grocery shoppers', '
      gamers aged 20-25' etc.
[Long answer]

8. How many other team members typically work with you on a location-based AR project?
[Number ___ team members, on average]
```

```
9. What are the roles of the other team members working on location-based AR projects with you? Please select all that
      apply.
[Select multiple options, including Software Engineer, Technical Artist, UX Designer, ..., Other - Write In]

10. Which AR frameworks have you utilized in location-based AR projects?
[Select multiple options, including ARFoundation, ARCore, ARKit, Snap AR]

11. What development/design suites or tools have you used in your location-based AR development process?
[Select multiple options, including Unity 3D, Unreal Engine, Adobe Aero, ..., Other - Write In]

12. Which of the following tools do you use to leverage real-world information in the development process of location-
      based AR experiences? Please select all that apply.
[Select multiple options, including Niantic Lightship VPS, Remote Authoring, Google Geospatial Creator (combined with
      Unity or Adobe Aero), Google Earth (or alternatives by Apple, Microsoft), ..., Other - Write In]

13. Approximately how much time do you spend testing your location-based AR experiences on-site (i.e. physically being
      at the location) vs off-site (e.g. virtually testing with a mesh or playback simulator)?
[___ % of time spent testing on-site (i.e., visiting the location in the real world)]
[___ % of time spent testing off-site in a simulation (e.g., in Unity/Adobe Aero using a mesh of the environment)]

14. Which of the following factors do you look to identify when testing your AR experience on-site (i.e. at the real-
      world location)?
[User context (e.g. lighting, weather, noise, crowdedness, distractions), Physical constraints (e.g. real-world
      obstacles that were not accounted for such as parked cars, temporary structures, closed gates), ..., Other -
      Write In]

15. How do you document or report bugs or improvements when testing a location-based AR experience on-site (i.e.
      physically being at the location)? For example, by writing a note on my phone in the moment, recording my screen,
       by remembering and writing it down later.
[Long answer]
```

Listing 2. The formative study's semi-structured interview questions.

```
1. When starting a new location-based AR project, what are the key elements of the physical location that you consider?
  (How do these elements influence your design decisions?)

2. How do you initially conceptualize the interaction between the user, the AR content, and the physical location?
(Could you share any specific tools or techniques you find essential during this phase?)

3. You mentioned you use tools such as [SURVEY RESPONSE] could you give an example of your workflow in developing a
      location-based AR experience?
  (At what point did you test the experience?)

--- Challenges and Solutions ---
4. You've mentioned in your survey response such as [SURVEY RESPONSE], what have been the most significant challenges
      in aligning the AR content with the physical world?
(How have you addressed these challenges?)

5. Can you share an example where you had to significantly modify or even discard a feature due to unforeseen real-
      world elements or constraints?
  (How did you navigate this setback?)

--- Testing and Refinement ---
6. Thinking about on-site vs off-site testing (e.g. Playback), [SURVEY RESPONSE]. What are the most essential factors
      that require you to test on-site?

7. How do you replicate physical conditions when testing off-site?
```

```
8. You mentioned you [SURVEY RESPONSE] to collect/integrate feedback from testing the experience. Could you elaborate
      on that a bit?

--- Collaboration and Workflow ---
9. How does your team collaborate on location-based AR projects, especially when dealing with complex, location-
      specific challenges?
  (Are there tools or practices that you use to facilitate effective teamwork?)
  (Do you ever engage in real-time collaboration through video calls or other tools?)

--- Vision for the Future and Wrap-up ---
10. What features or capabilities would your ideal toolset for developing location-based AR experiences include?
  (How would these tools address the current limitations you face?)

11. Is there anything not covered in this interview that you think is crucial for understanding the development and
      design of location-based AR experiences that you'd like to share?
```

5.2 User Study

The user study's surveys (Listings 3, 4, and 5) and semi-structured interview questions for ex-situ (Listing 6) and in-situ (Listing 7) participants are presented below. As described in the listings, the NASA-TLX [1] and UES-SF [3] questionnaires were used to measure sense of direction, task load, and engagement, respectively.

Listing 3. The pre-task survey questions.

```
--- Demographics ---
1. What is your age?
[Number greater than 17]

2. What is your gender?
[Select one option, including Woman, Man, Non-binary, Prefer not to say, Other - Write in]

3. What is your current occupation? If you are a student, please include your major.
[Short answer]

4. How often do you use the following? Please select the most appropriate option:
[Select one option for the following, including Several times a day, Once a day, ..., Never]
  a. Augmented Reality (smartphone)
  b. PC or Console Video Games

5. Have you ever used a 3D editor or game development platform, like Unity, Unreal Engine, Maya, Blender, etc.?
[Select either Yes or No]

[If yes...]
6. How often do you use 3D editors or game development platforms?
[Select one option, including Several times a day, Once a day, ..., Never]

7. Have you ever contributed to the design or development of a 3D game, movie or experience? (e.g. as a programmer,
      project manager, designer)
[Select either Yes or No]

[If yes...]
8. Have you ever contributed to the design or development of an augmented reality experience? (e.g. as a programmer,
      project manager, designer)
[Select either Yes or No]
```

```
[If yes...]
9. Have you ever contributed to the design or development of a location-based augmented reality experience? (e.g. as a
     programmer, project manager, designer)
[Small note:] Location-based augmented reality experiences are designed for specific physical locations, requiring
     users to be at that location to interact with the experience. These experiences often utilize a visual
     positioning system (VPS), such as the Niantic Lightship VPS or the Google ARCore Geospatial API, to function.
[Select either Yes or No]

10. Any other notes?
[Long answer]
```

Listing 4. The post-task survey questions for ex-situ participants.

```
1. For each statement, please use the following scale to indicate what is most true for you.
[Select one option from Strongly disagree to Strongly agree on a 5-point Likert scale for each of the following]
  a. I feel confident that the authored AR experience would function as I expect it to in the real world.
  b. I felt like I was able to accurately fix the issues with the initial AR experience.
  c. I felt like I was able to effectively extend the AR experience with the information given.

2. Why did you answer the ways you did in the previous questions? (Please write at least 1-2 sentences.)
[Long answer]

--- Task Load ---
[To measure Task Load, we used the Mental Demand, Temporal Demand, Performance, Effort, and Frustration questions from
     the NASA-TLX.]

--- Engagement ---
[To measure engagement, we used the UES-SF.]

--- Task-Specific Questions ---
1. Which location did you work on?
[Select one option, including Location A or Location B]

[If Location A:]
2. Please rate how you feel you performed on the different task items. [Select one option, including Fixed it and feel
     confident about the result, Fixed it but do not feel confident about the result, Did not fix it because I did not
      have enough time, Did not fix it because I did not have enough information, Other (write below)]
  a. The Guide avatar is difficult to find.
  b. The Guide avatar is hard to hear over the traffic noise.
  c. The map is inconveniently placed and near (foot) traffic.
  d. The drinks and food on the table appear to float in the air.
  e. The train track decoration and striped ring do not look good from all perspectives and block the bar's logo.
  f. The information stand is in an odd place.
  g. The sign with the arrow pointing to the train station is hard to see from the information stand.

[If Location B:]
3. Please rate how you feel you performed on the different task items. [Select one option, including Fixed it and feel
     confident about the result, Fixed it but do not feel confident about the result, Did not fix it because I did not
      have enough time, Did not fix it because I did not have enough information, Other (write below)]
  a. The banner poster is not attached to anything.
  b. The garlands between the trees do not appear correctly placed.
  c. The volume of the boom box with background music is too loud.
  d. The boom box is floating.
  e. The balloon cart is touching/inside another object.
  f. The large poster is hard to see, and reading it requires caution due to bike traffic.
  g. The Free Ticket Arcade machine is out of reach.
```

Listing 5. The post-task survey questions for in-situ participants.

```
--- Task Load ---
[To measure Task Load, we used the Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and
     Frustration questions from the NASA-TLX.]

--- Engagement ---
[To measure engagement, we used the UES-SF.]
```

Listing 6. The semi-structured interview questions for the ex-situ participant.

```
--- Location ---
1. Please draw as much of the location as you can remember in a simple top-down map without looking at Unity or any
     other maps/tools.
We know this might be tricky! No worries if you're not accurate, just be as detailed as you can in 5 minutes. Feel free
     to use the drawing tool or shapes.

2. Have you ever been to this location before?

--- System ---
3. Given that you had to develop a location-based AR experience, which method (async or sync) would you use? Why?

4. Which method did you enjoy using more? Why?

5. Which method did you feel more confident about the end result? Why?

6. What were some of the pros and cons of each method (async and sync)?
  a. Are there specific cases where you would use one method vs the other?

--- Future ---
7. Are there any features you can think of that you would want to add to the sync and/or async method, e.g. to address
     the cons?

8. How did you feel about the effectiveness of your communication between each method (sync vs. async)? Do you feel
     like the capturing, annotation features helped you in any way?

9. Anything else?
```

Listing 7. The semi-structured interview questions for the in-situ participant.

```
1. Given that you had to help test a location-based AR experience, which method (async or sync) would you use? Why?

2. Which method did you enjoy using more? Why?

3. What were some of the pros and cons of each method (async and sync)?
  a. Are there specific cases where you would use one method vs the other?

4. How did you feel about the effectiveness of your communication between each method (sync vs. async)?

5. How was your experience using the features for the synchronous condition (e.g. drawing on surface / in air, meshing,
     3D color image)? Did you use them? Why or why not?
  a. Are there any additional features you can think of that you would want to add to the sync and/or async method?

6. Anything else?
```

References

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