

# Development Framework for Multi-User Cross-Device AR Applications

Master's thesis defense

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**1) Problem**

**2) Solution**

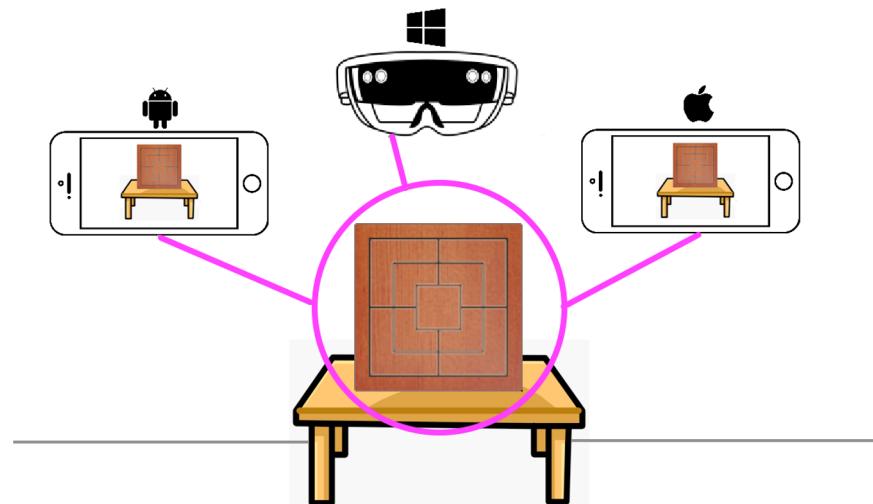
**3) Evaluation**

**4) Conclusion and Future Work**

# 1) Problem

## Motivation:

- Multiple applications available providing co-located multi-user AR with:
  - Consistent AR views
  - multi-user interactivity
- Problem:
  - high effort to develop
  - reusable basic features required



## Research question:

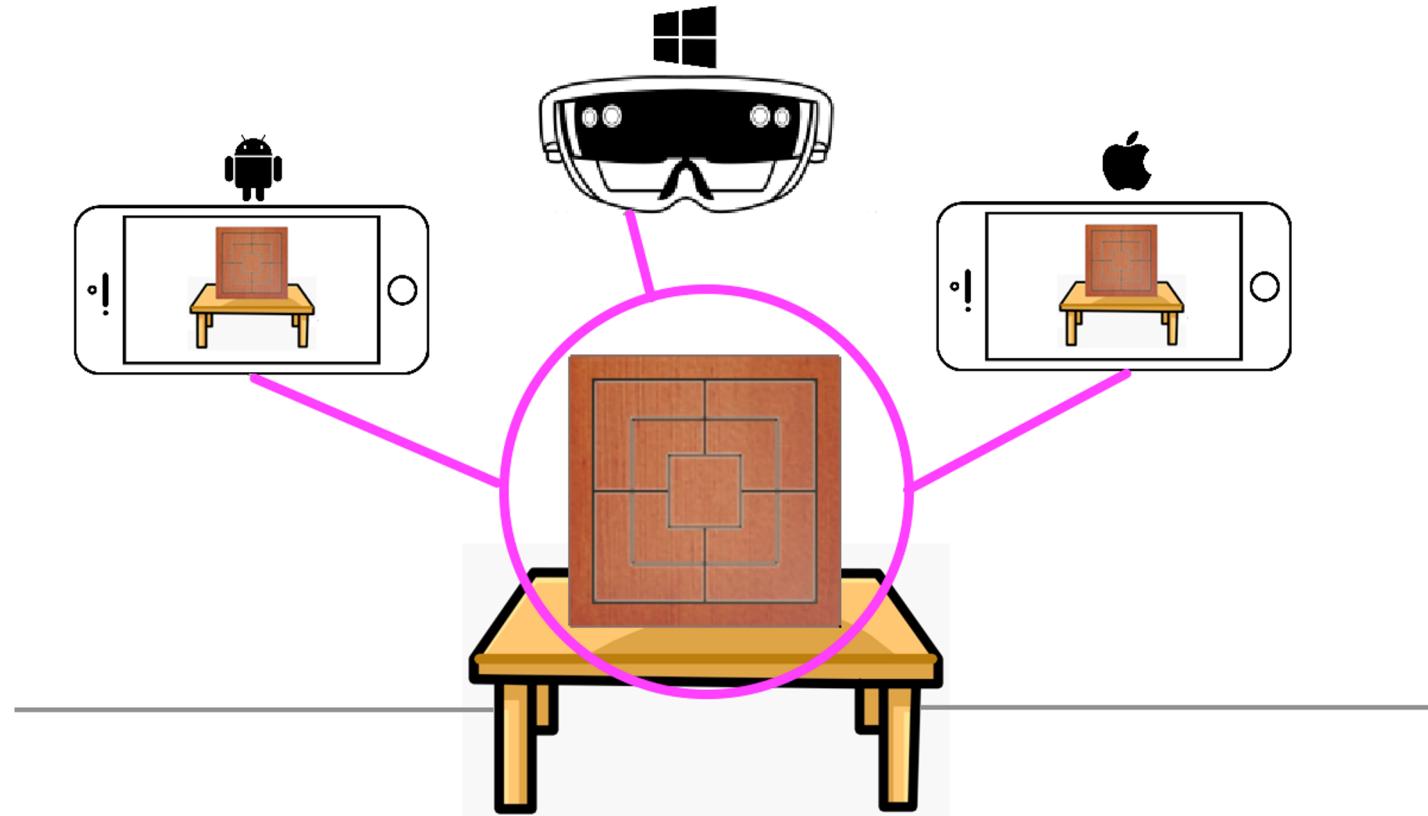
How to develop a multi-user AR framework, that can be used for sample applications, which support collaboration and usability.

## 1.2) Requirements

R1: Support multi-device sessions

R2: Cross-platform range

R3: Supported device types

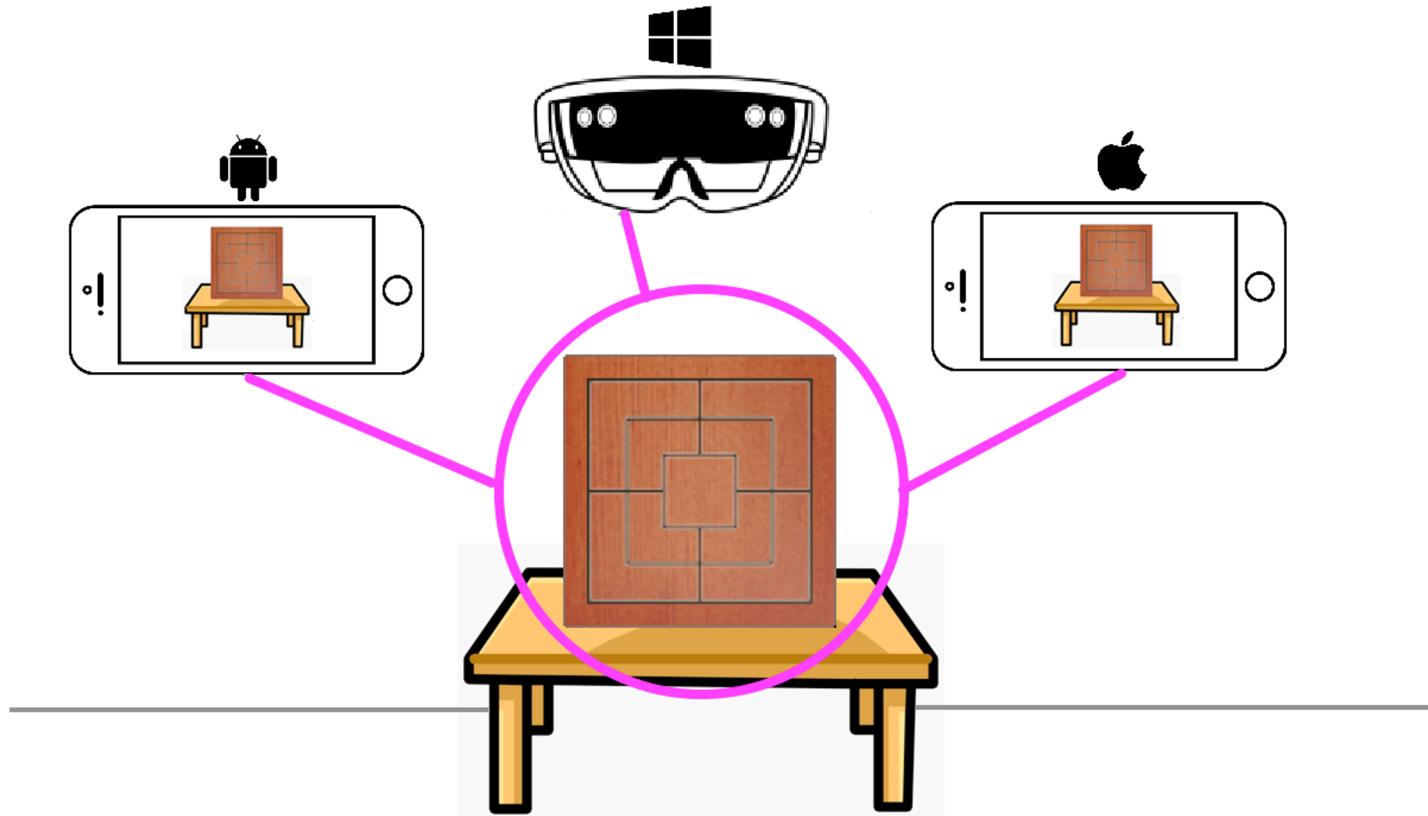


## 1.2) Requirements

R4: Consistent AR view

R5: Co-located AR

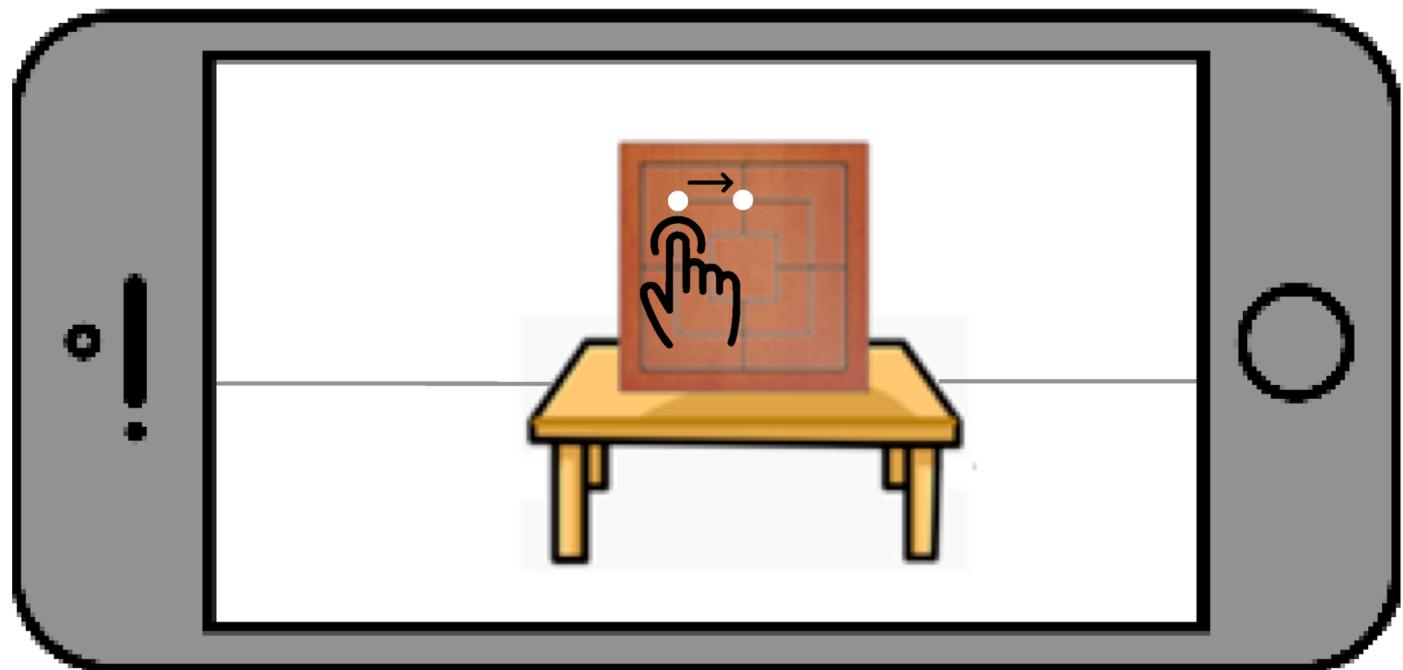
R6: Markerless AR



## 1.2) Requirements

R7: Interactivity for multiple users

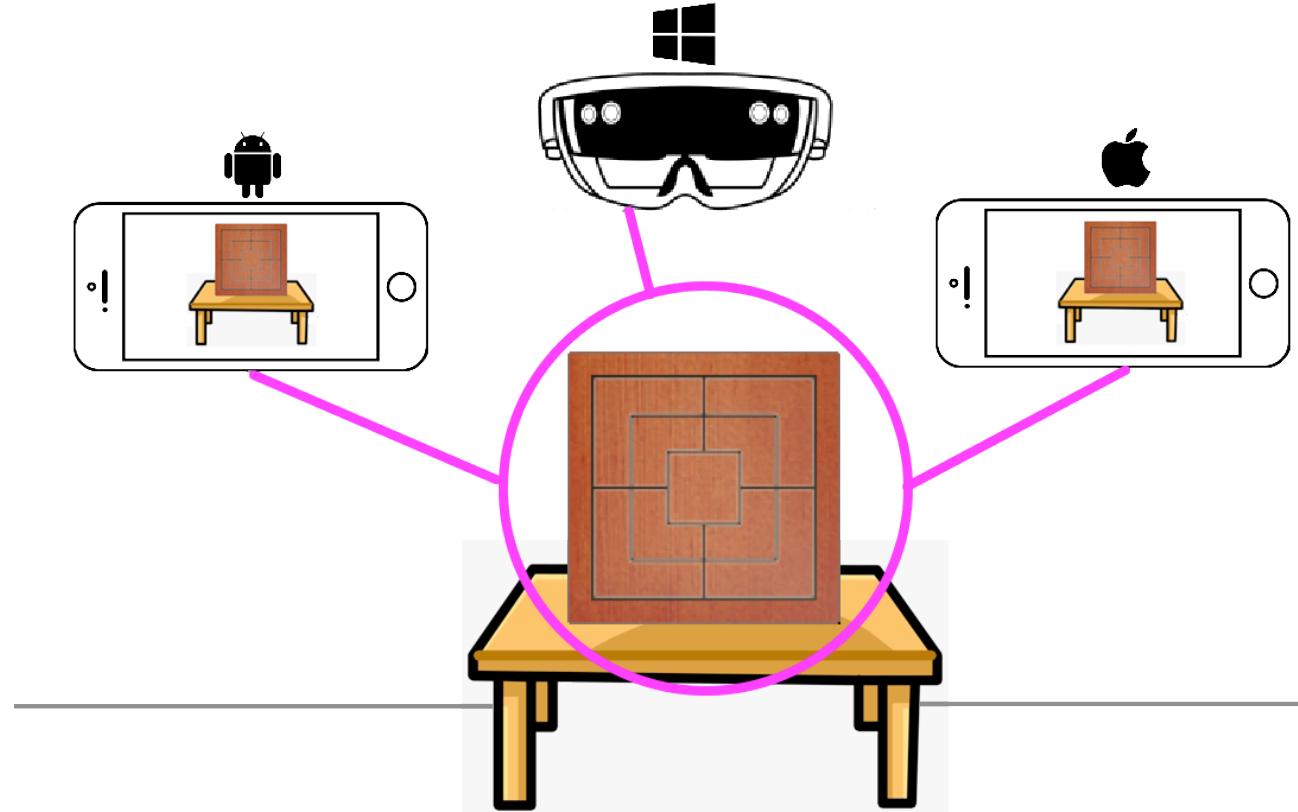
R8: Framework character



## 2) Solution

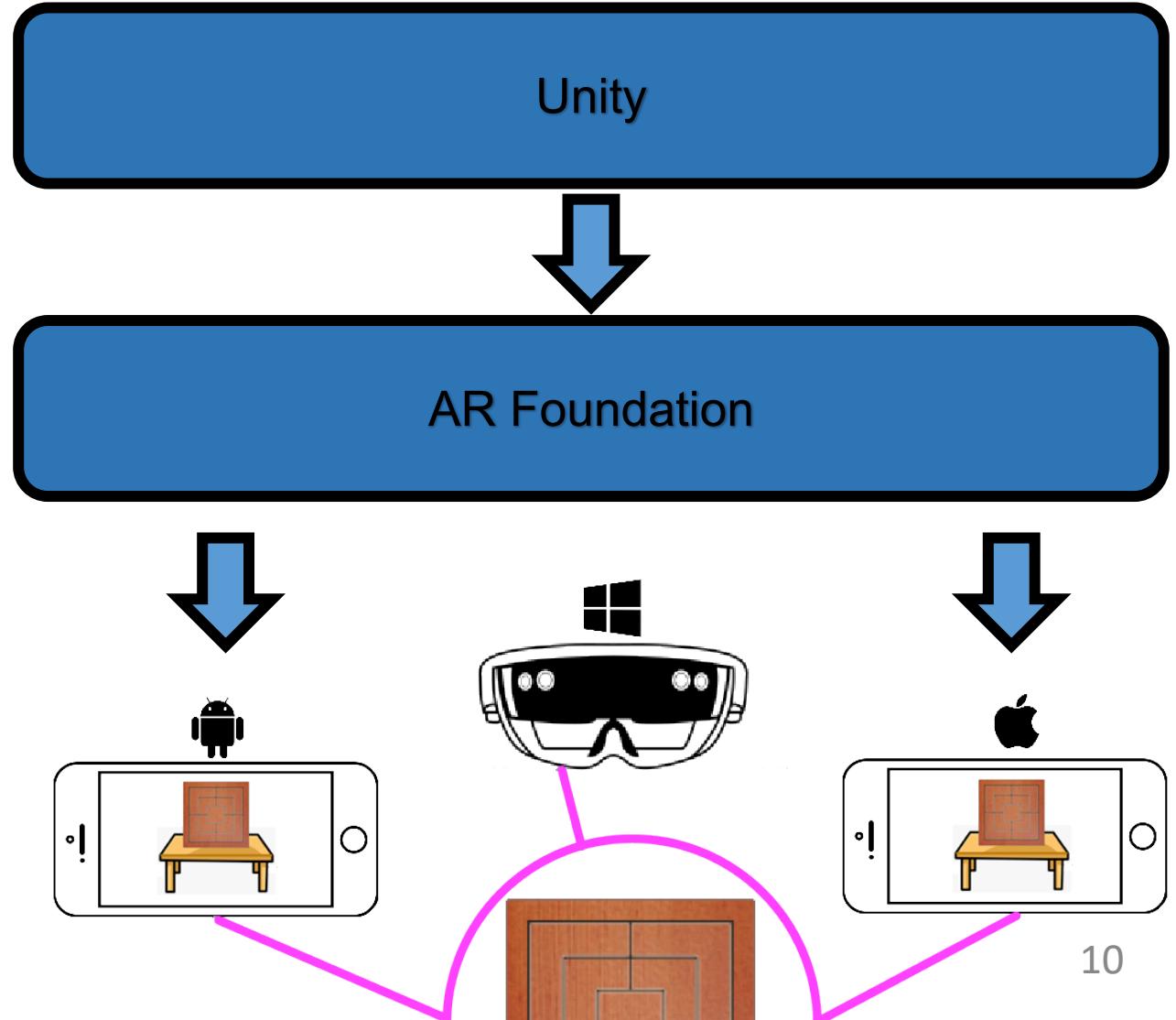
## 2) Solution

**Scenario:**  
**Co-located multi-user AR**



**3D engine and IDE: Unity**

**AR framework: AR Foundation**

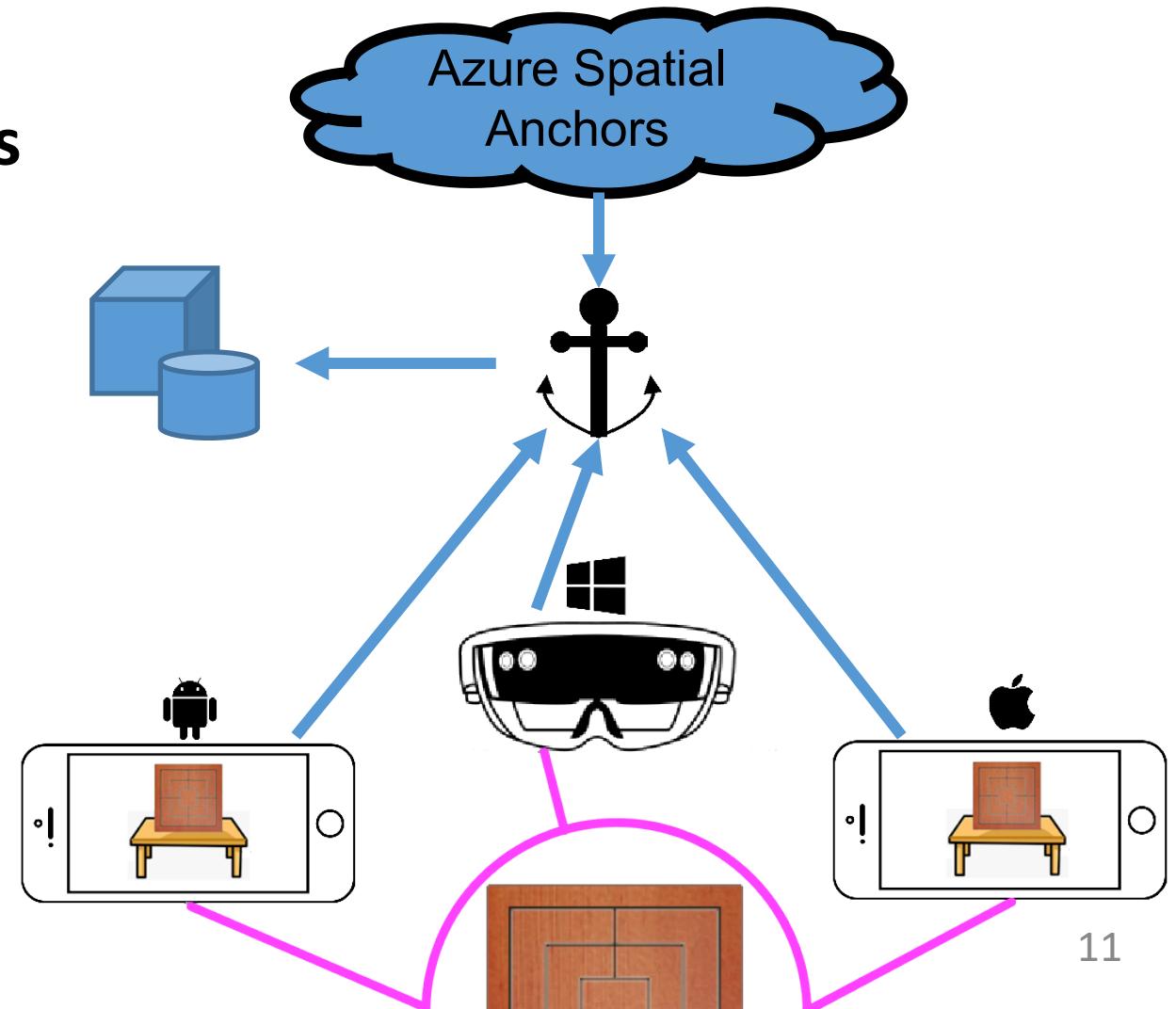


### Shared Anchors: Microsoft Azure Spatial Anchors

**Coordination:** virtual objects' coordinates in relation to anchor

**Surface Detection:** anchor set and located on detected surface

**Cloud Computing:** environment scanning information shared via external servers

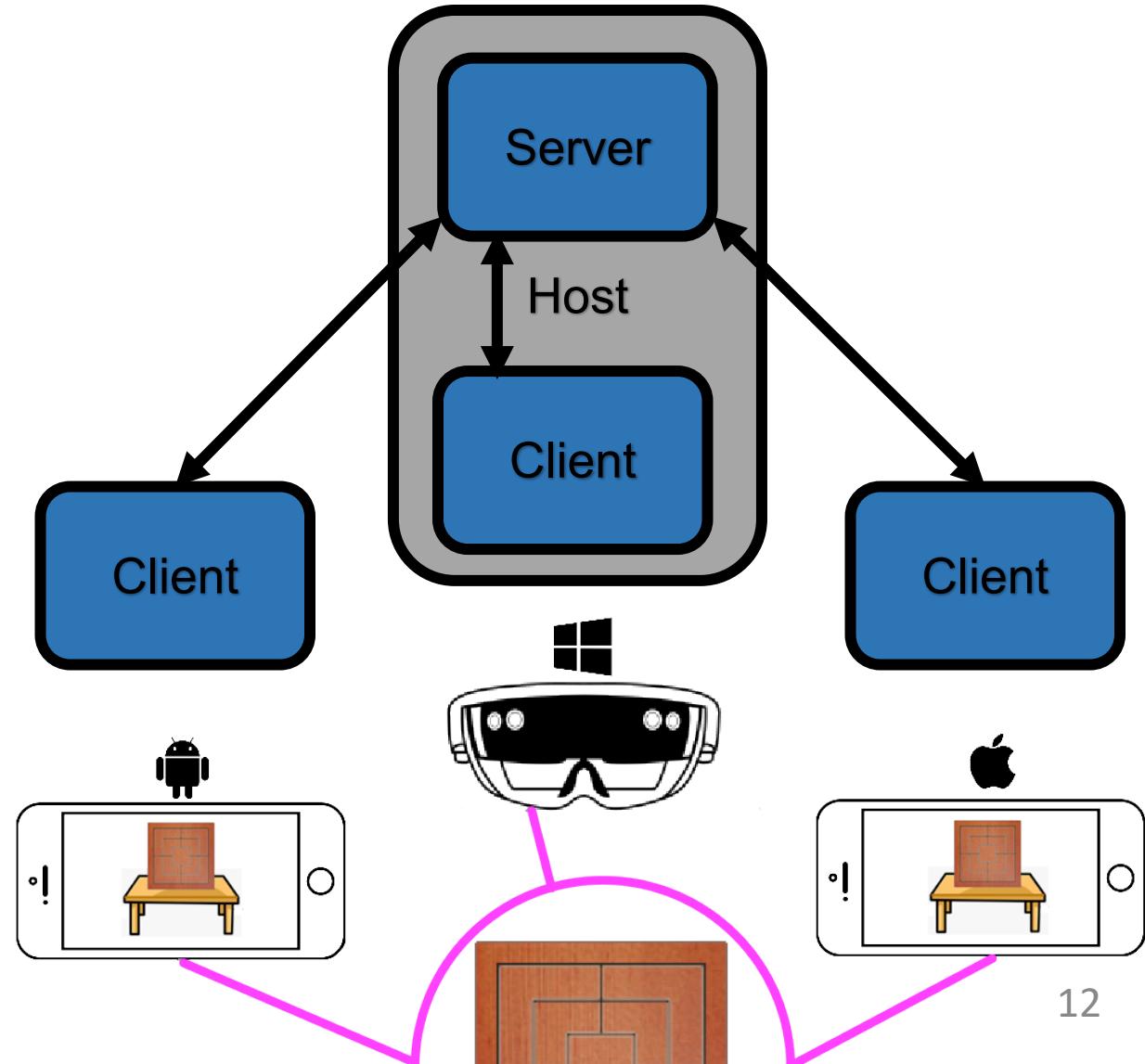


### Network communication: Mirror Networking

**Architecture:** Self-hosted client-server architecture

**Data Manipulation:** server-side

**Server Commands:** from clients



### Standard Interactions:

Create

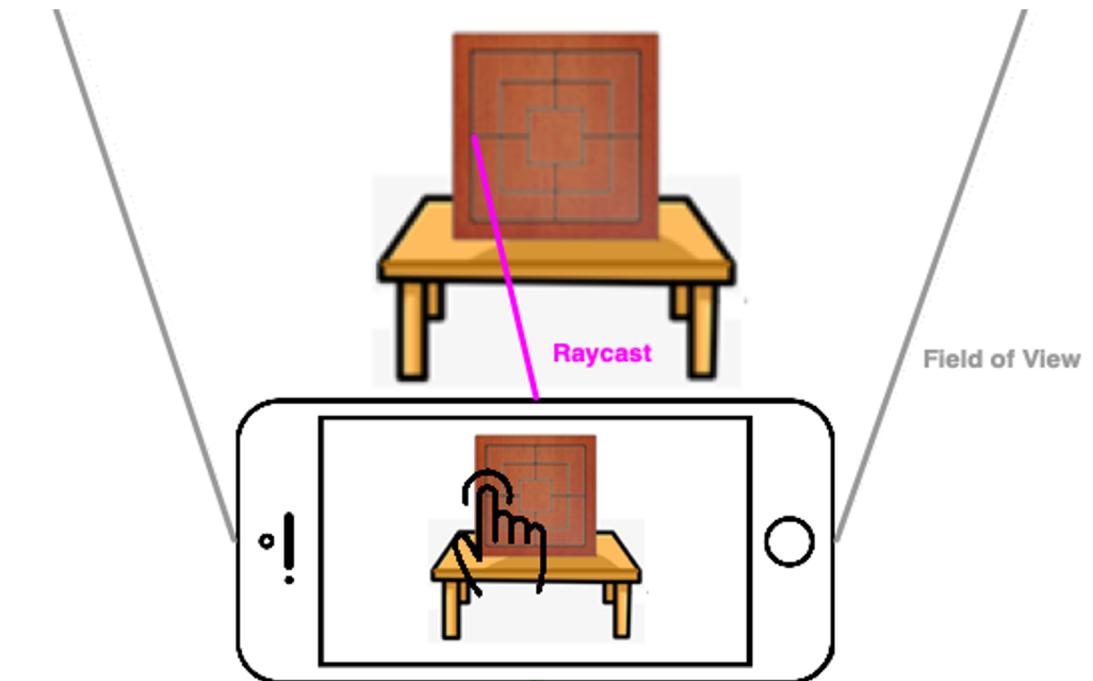
Delete

Select

Move

Scale

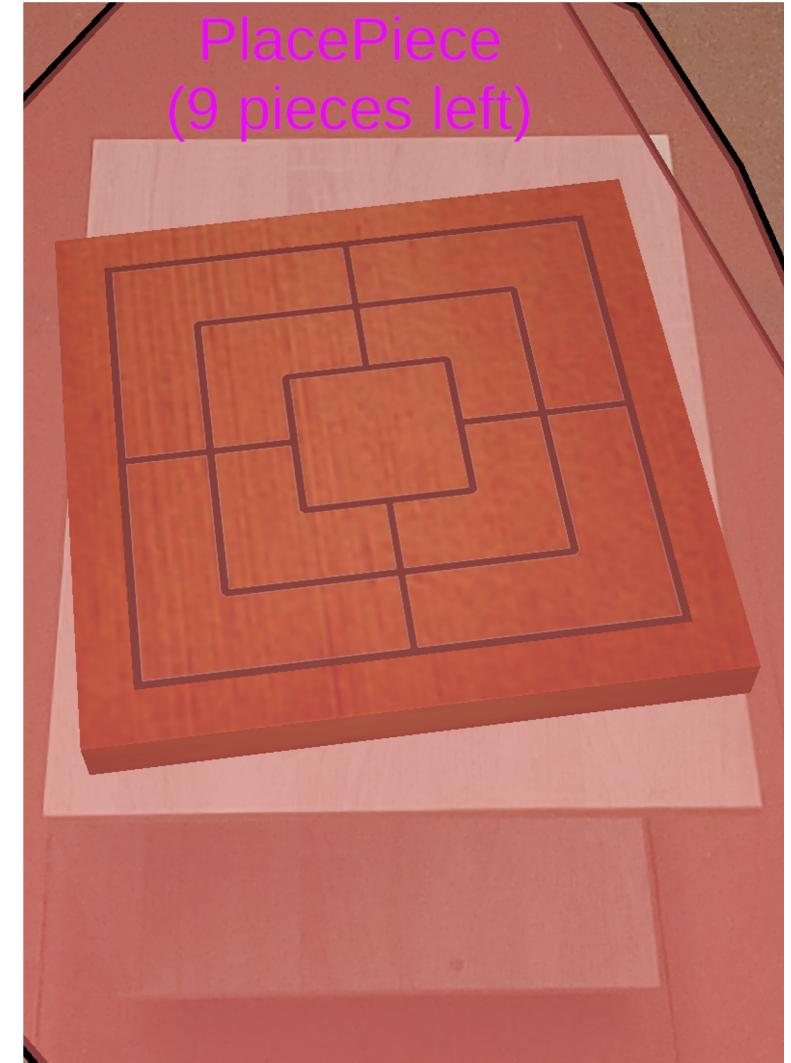
Rotate



# 3) Evaluation

#### Example app: Mill game

- Based on framework
- Two players
- Synchronized board visualization
- Synchronized game state
- Server-side game logic
- Generic input modalities for game piece interaction
  - Set stone
  - Move stone
  - Remove stone



## 3.2) Demo Video

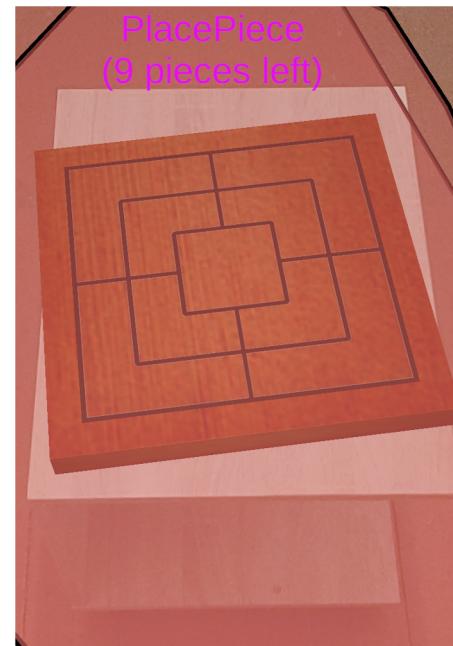
<https://www.youtube.com/watch?v=Ryiirr0M-g4>

#### Setup:

- **8 teams of each 2 participants**
  - 6 female, 10 male participants
  - 6 teams tested in university, two in living rooms
- **Room requirements:**
  - Bright room
  - Wifi with permission to connect devices
  - Rectangular table with sharp edges
- **Used tools and devices:**
  - Motorola moto g8 power
  - Samsung Galaxy A7
  - Analogue mill game

## 3.4) Tasks

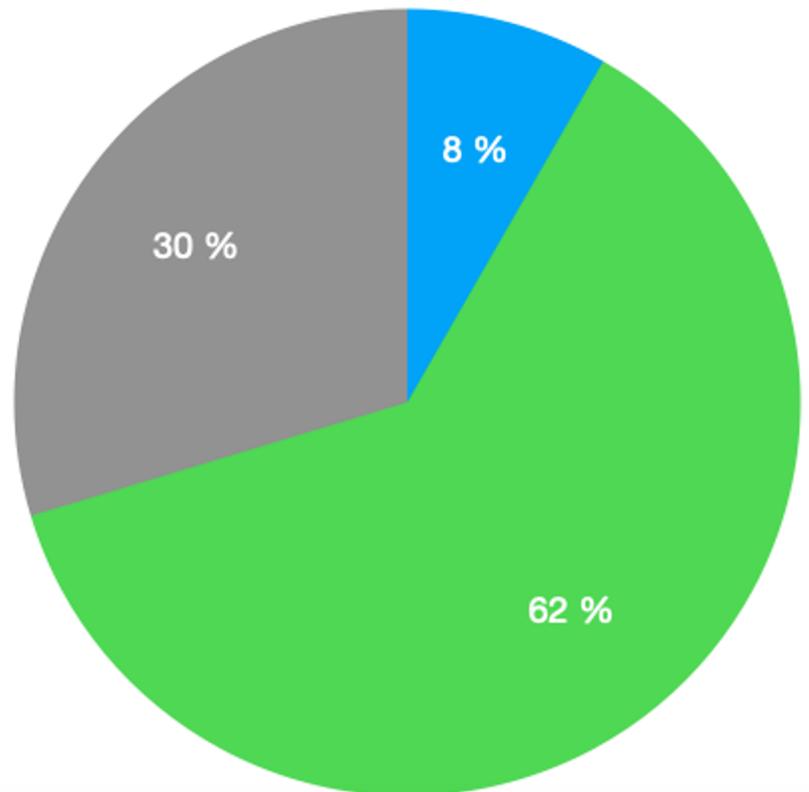
- **Variant 1: Analogue mill game**
  - Task 1: Build up game
  - Task 2: Play game for 5 minutes
- **Variant 2: Multi-user AR mill game**
  - Task 1: Connect devices
  - Task 2: Set and share Spatial Anchor
  - Task 3: Locate Spatial Anchor
  - Task 4: Play AR game for 5 minutes
- **Evaluation Metrics:**
  - Effectivity
  - Efficiency
  - User satisfaction



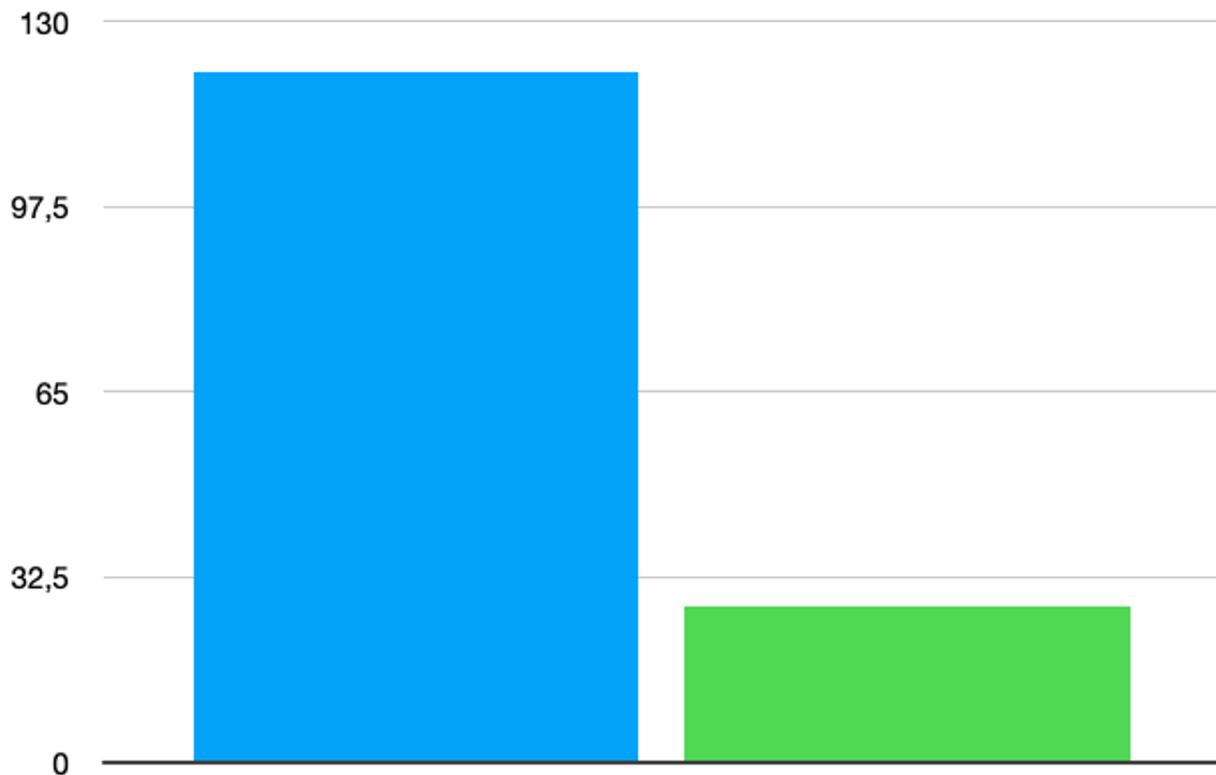
- All preparations worked successfully
- All types of game interaction were executed successfully by all participants
- Found problems with application:
  - Surface detection failed once after >5 minutes
  - Only rectangular tables found as surfaces
  - Low light made scanning harder
  - Several teams did not get to stone moving within 5 minutes of playing

### 3.6) Efficiency

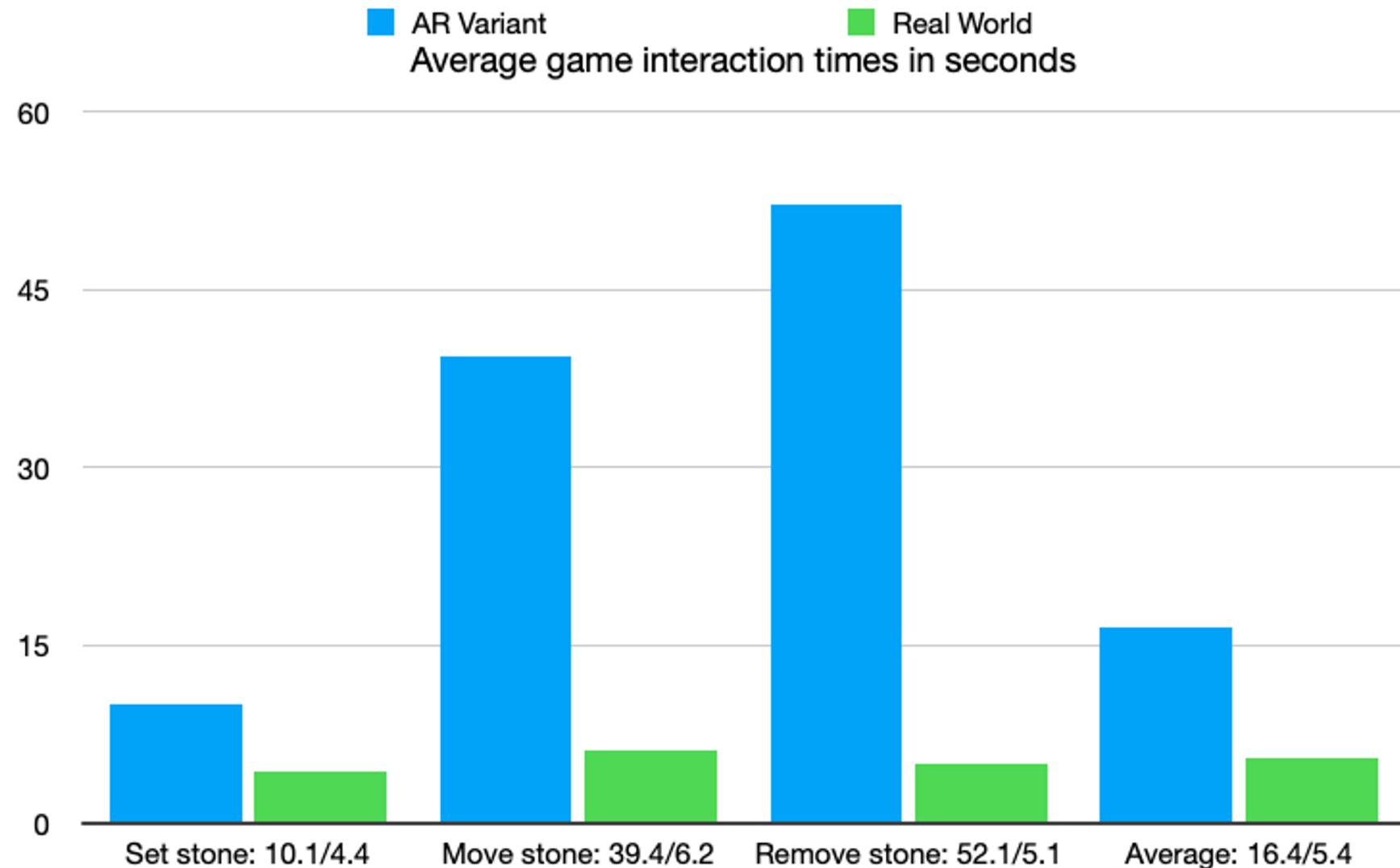
- Network Connection: 10.1
  - Set Anchor: 75.2
  - Find Anchor: 36
- Average time for preparation of AR session: 121 seconds



AR Variant: 121 seconds      Real World: 27 seconds  
Average complete preparation times



### 3.6) Efficiency



## Survey: System Usability Scale

Real World Variant	SUS-Score	AR Variant	SUS-Score
A1-A10	88.3	A1-A10	59.7
A11-A17	85.1	A11-A17	69.1

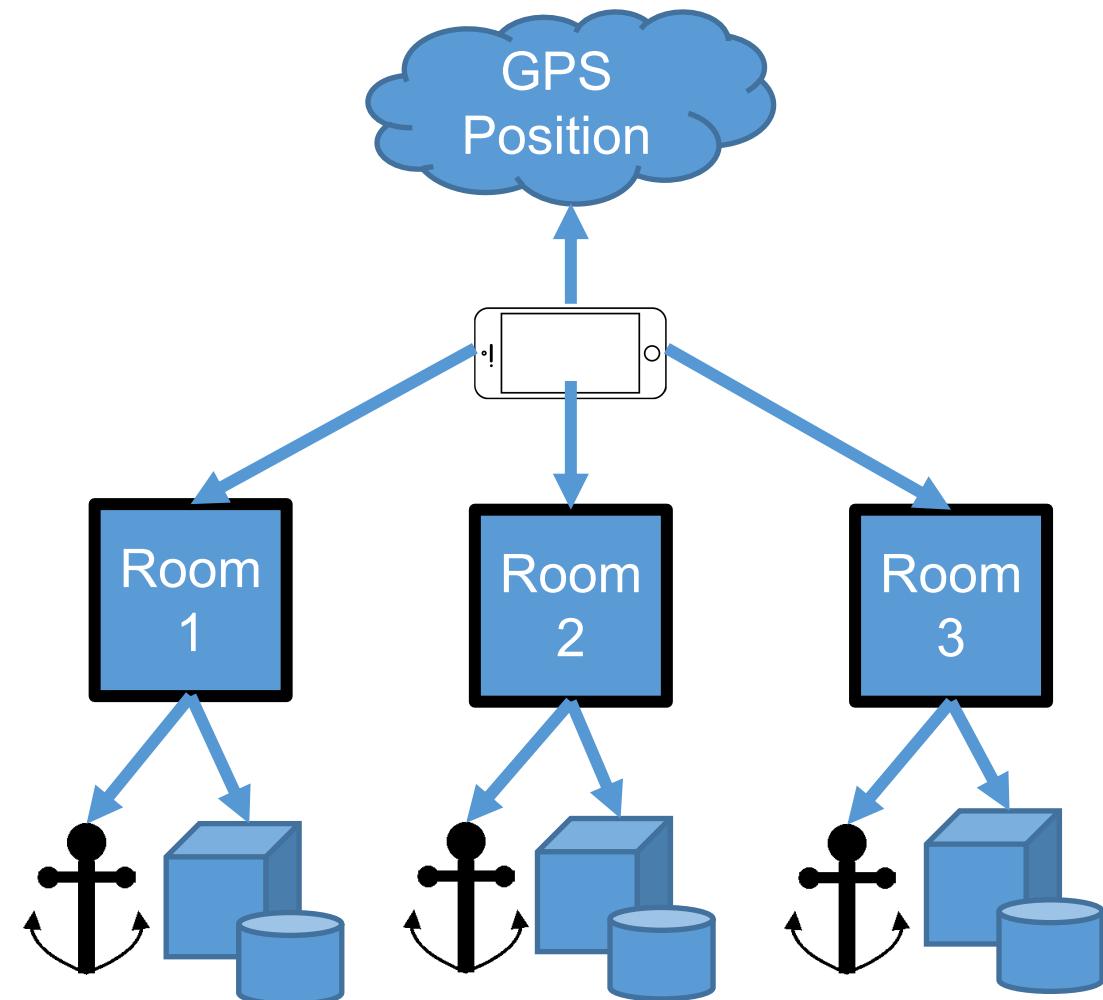
## 4) Conclusion and Future Work

### Requirements:

- **R1:** Support multi-device sessions 
- **R2:** Cross-platform support 
- **R3:** Supported device types: Handhelds 
- **R4:** Consistent AR view 
- **R5:** Co-located AR 
- **R6:** Markerless AR 
- **R7:** Interactivity for multiple users 
- **R8:** Framework character 

## 4.2) Future Work

- Implement HMD interactions
- Test HoloLens support
- Provide using multiple anchors
- Increase duration of persistency
- Integrate GPS location



Thank you for your attention

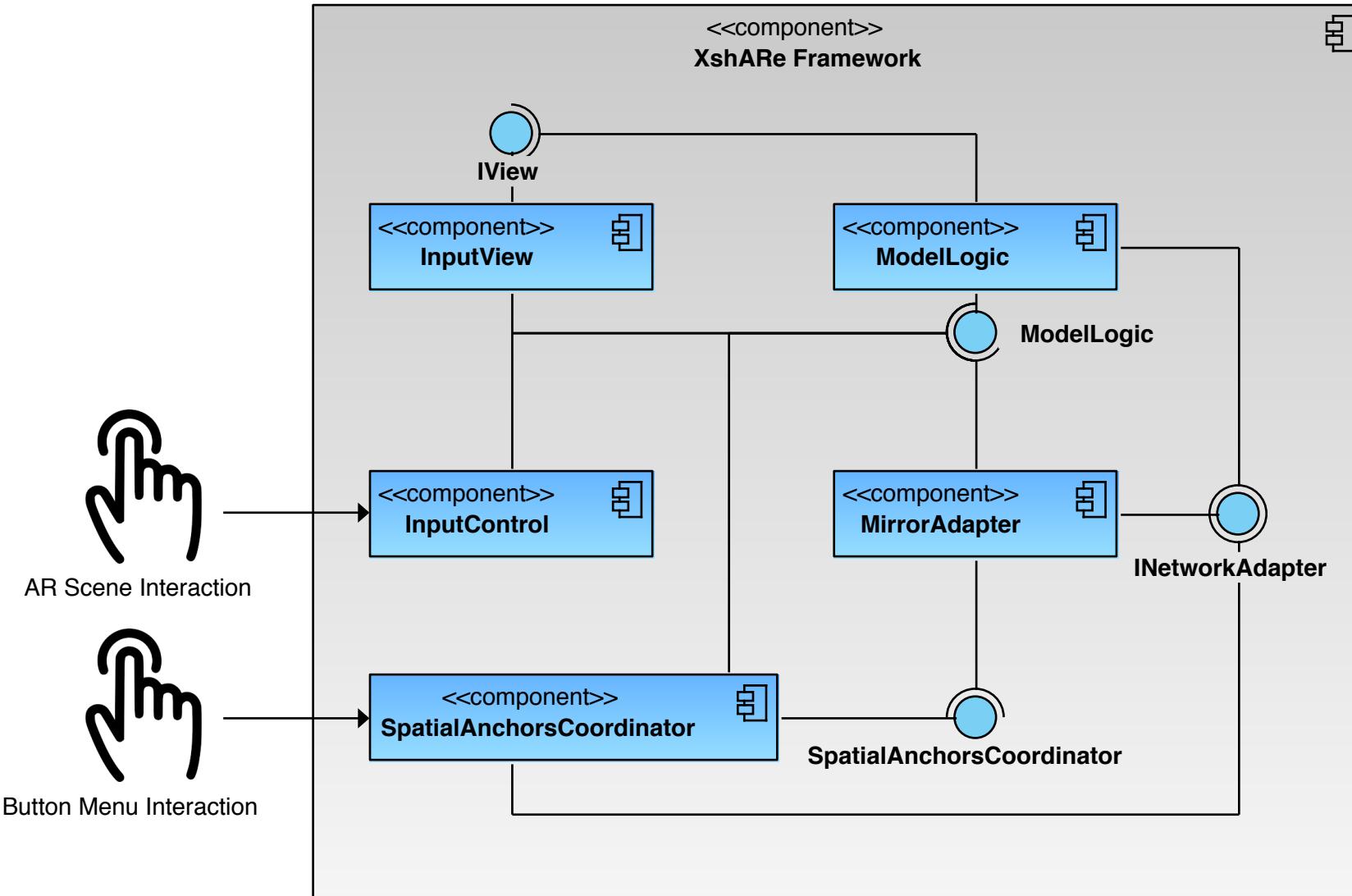
**Reverse engineering on Spatial Anchors**

**Providing interchangeability for external components**

**Network component features have massive influence on the architecture**

**Comparing coordinate systems**

# Components



### Research:

Research on related work

Research on available technologies

*AR engines*

*shared anchors*

*network communication*

### Framework development:

Concept design

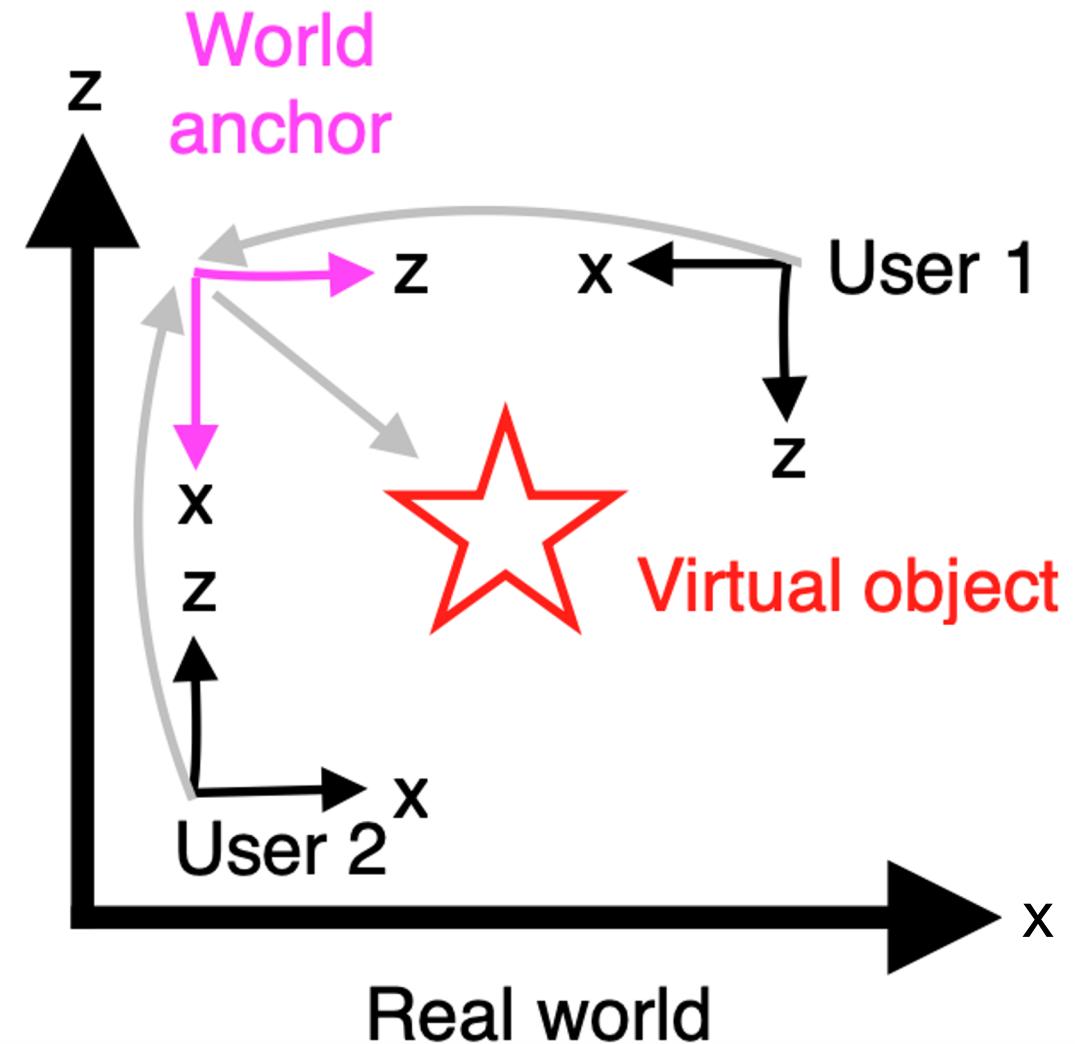
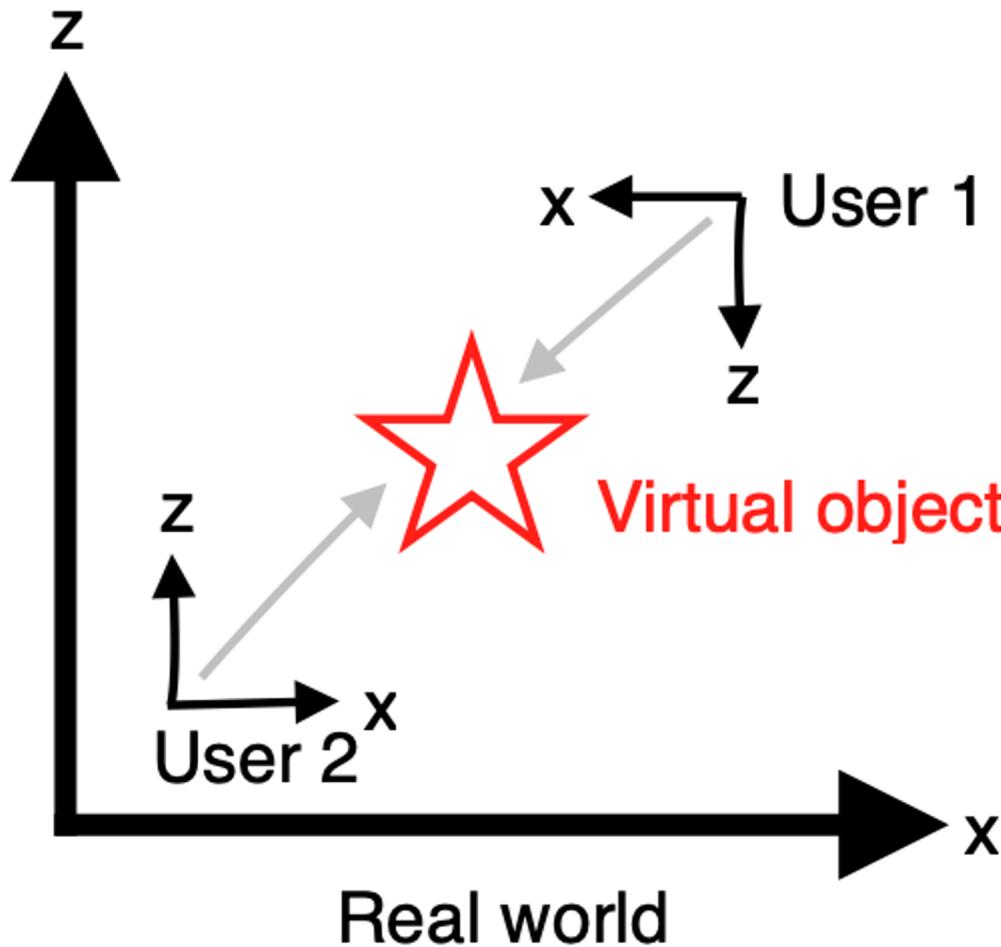
Framework implementation

### Evaluation

two example applications as case studies

Evaluation on usability

## 2) Solution

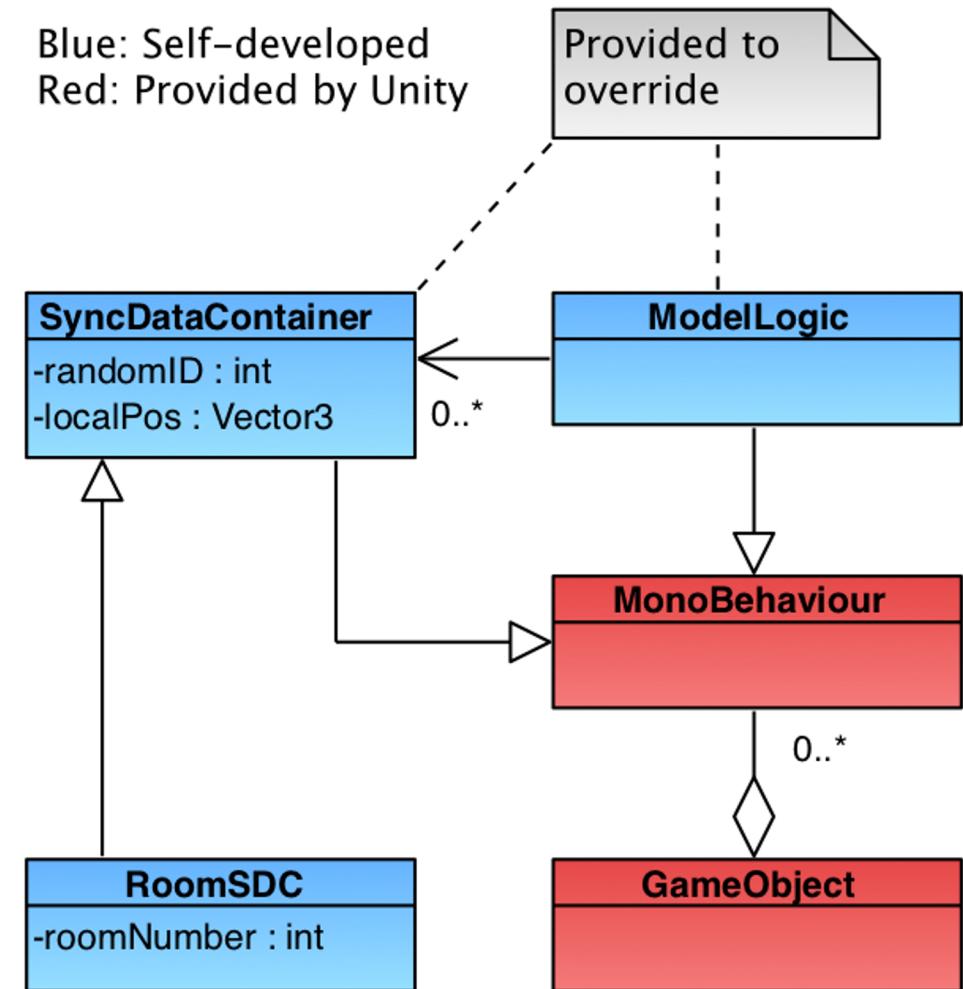


### Business Logic and Model Data:

ModelLogic: write your own specific class for transformation rules

SyncDataContainer: attach metadata to GameObjects

Blue: Self-developed  
Red: Provided by Unity



## Example app: Furniture placement

- Based on framework
- Multiple users
- Synchronized furniture visualization
- Generic input modalities for furniture interaction
- Creatable Furnitures:
  - Table
  - Chair
  - Shelf



### Metrics:

- **Effectiveness:**
  - Did all sessions work to the end?
  - Could all users complete all tasks?
  - Which technical issues appeared
- **Efficiency - Measured times:**
  - Preparation
    - Real World: Build up
    - AR: Connect, Set Anchor, Find Anchor
  - Game interactions: Set, Move, Remove
- **User satisfaction: Extended System Usability Scale**

## 2) Description of evaluation approach

### Hypothesis:

Using collaborative AR applications is helpful to increase collaboration.

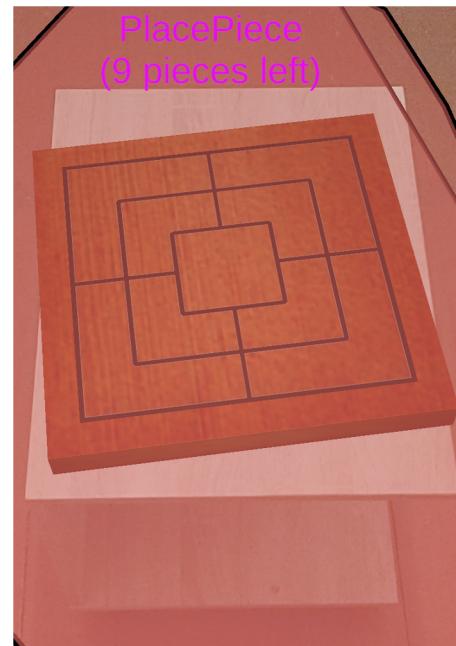
**Suggestion:** Using multi-user AR applications is practicable to enable collaboration.

### Setup:

- **8 teams of each 2 participants**
  - 6 female, 10 male participants
  - 6 teams tested in university, two in living rooms
- **Room requirements:**
  - Bright room
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  - Analogue mill game

## 2.2) Tasks

- **Variant 1: Analogue mill game**
  - Task 1: Build up game
  - Task 2: Play game for 5 minutes
- **Variant 2: Multi-user AR mill game**
  - Task 1: Connect devices
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  - Task 3: Locate Spatial Anchor
  - Task 4: Play AR game for 5 minutes



### User satisfaction: Survey

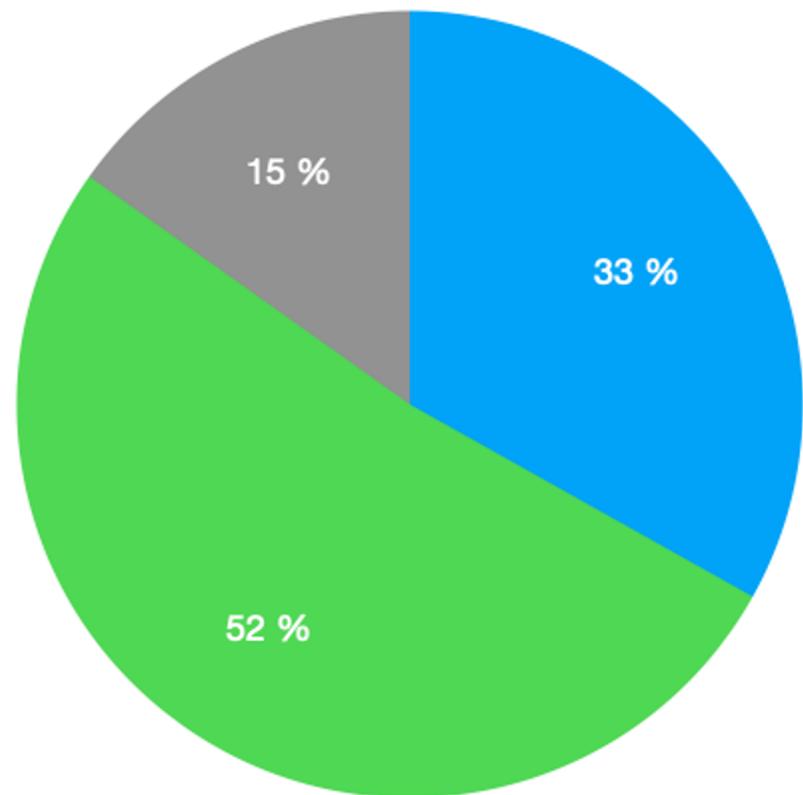
- Questions 1-10: From System usability scale
- Questions 11-17: Derived from requirements

- 11) I found working with my device more or less attractive than with my partner's device (C1: Platform independence)
- 12) I had a common feeling of virtual objects' positioning with my partner (C2: Shared coordinates)
- 13) I found interaction with game elements comfortable and intuitive (C3: Interaction modalities)
- 14) I had the feeling to see exactly the same as my partner (C4: Varying end-user experience)
- 15) I found preparing and set-up for the game quick, comfortable and easy to understand (C5: Easy set-up)
- 16) I had an overview about my partner's assets and game situation (C6: Information-enriched augmented users)
- 17) I found it easy to follow the rules and play the game as intended (C7: Shared session information and assets)

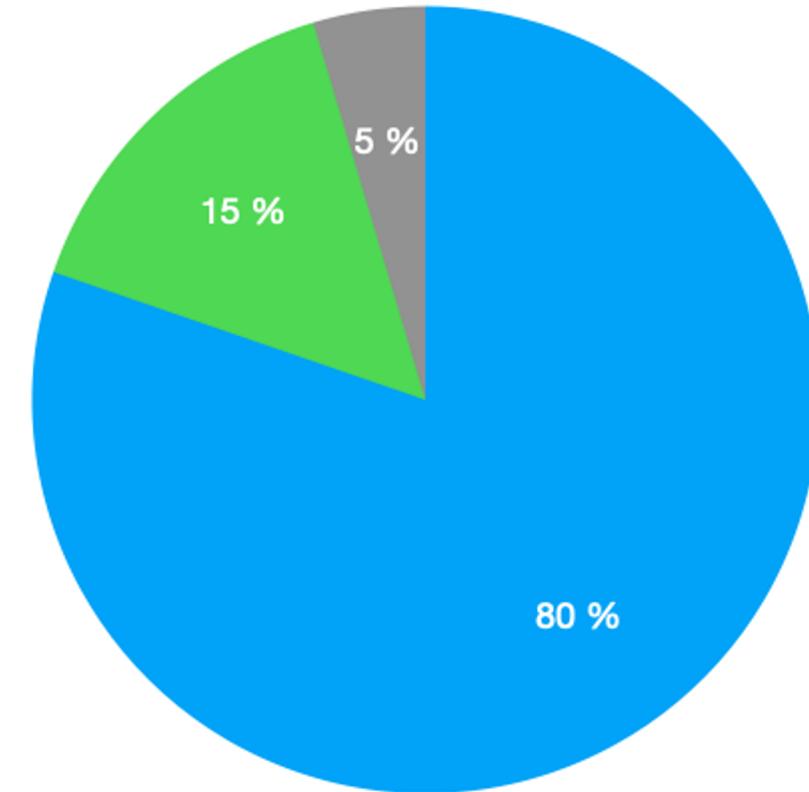
# 3) Results

## 3.2) Efficiency - Data overview

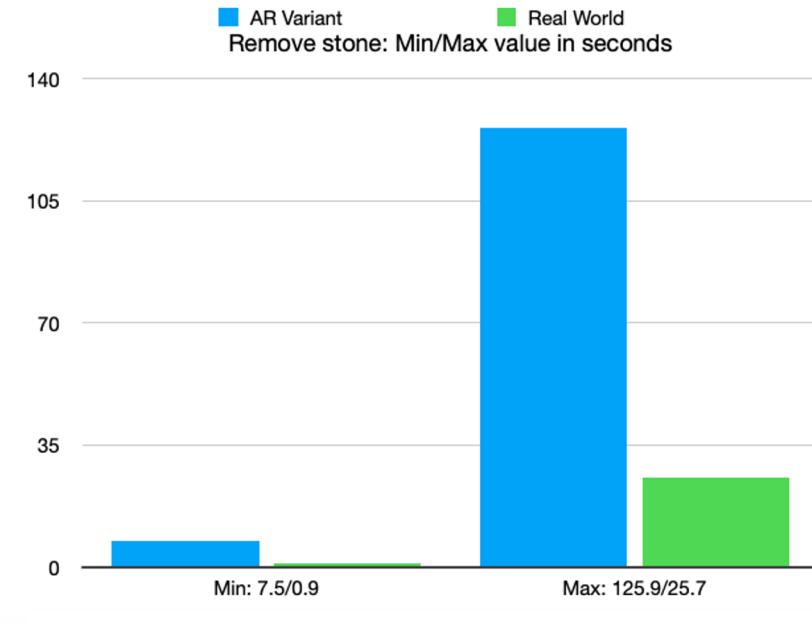
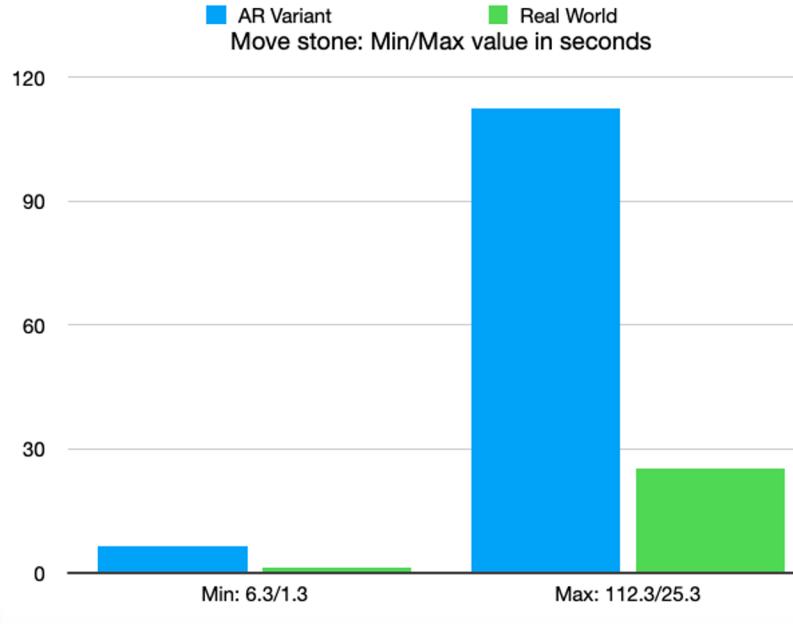
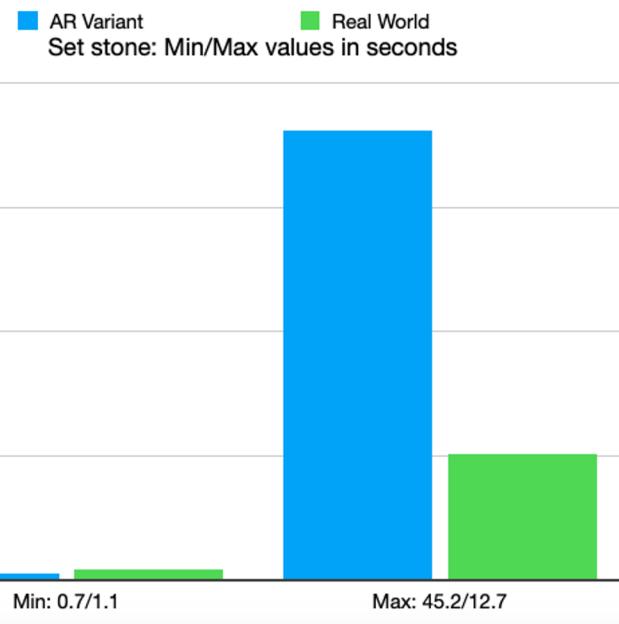
● Set Stone: 107   ● Move Stone: 167   ● Remove Stone: 49  
Total amount of measured real world  
interactions: 323



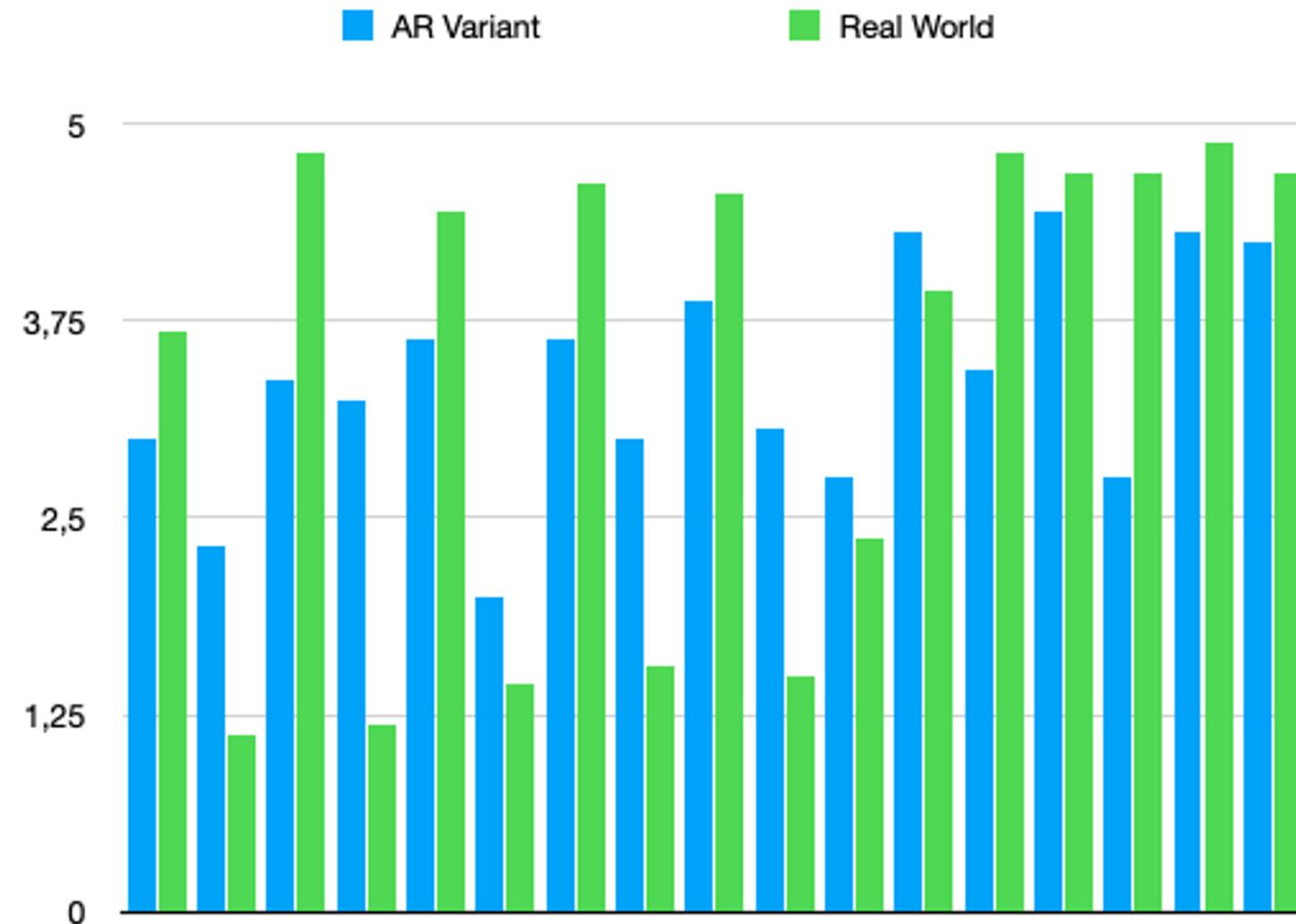
● Set Stone: 122   ● Move Stone: 23   ● Remove Stone: 7  
Total amount of measured AR interactions: 152



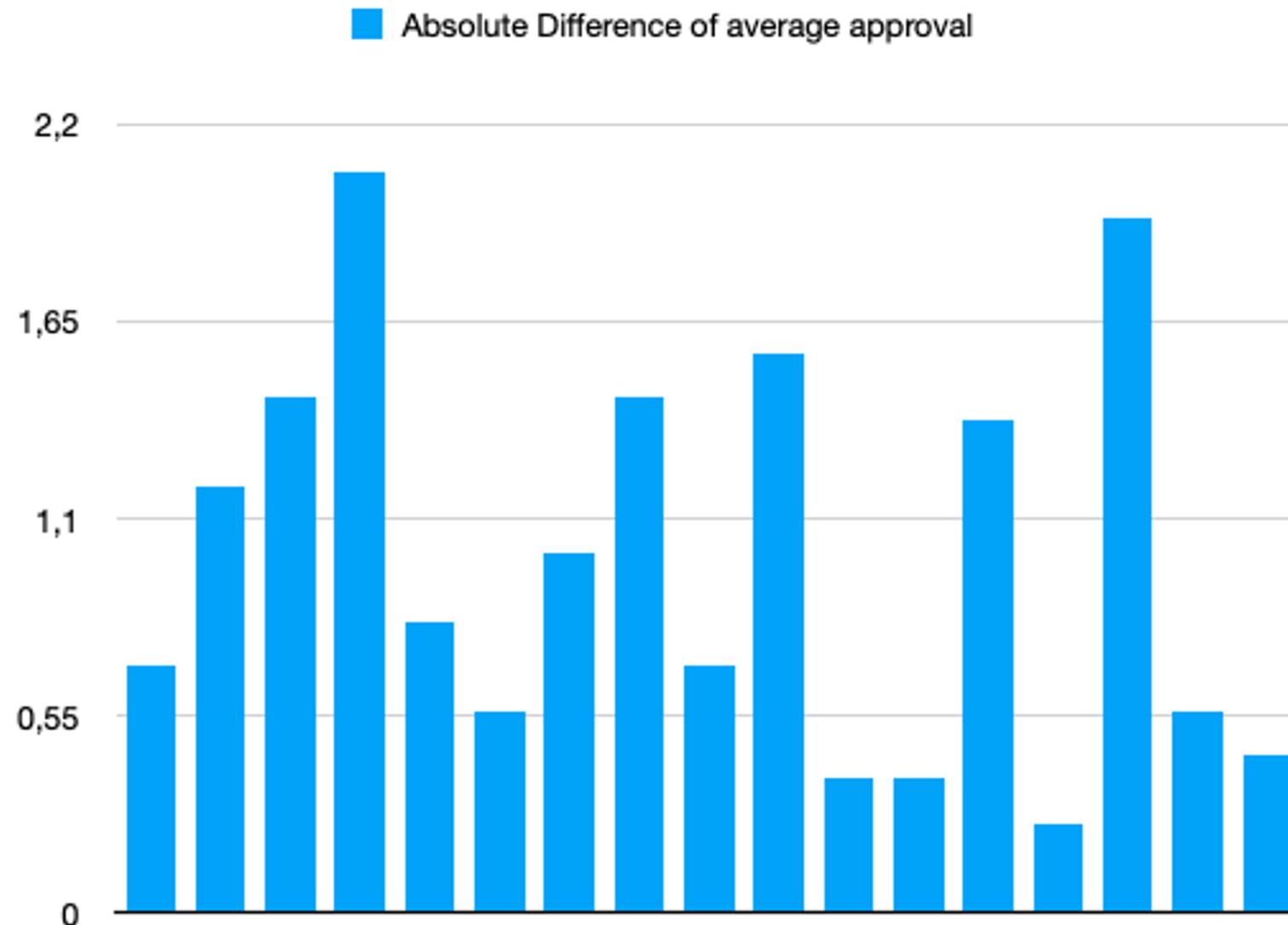
### 3.2) Efficiency - Game interactions: Min and Max values



### 3.3) User satisfaction



### 3.3) User satisfaction



## Remarkable values

- Low difference (< 0.5):

- 11) I found working with my device more or less attractive than with my partner's device
- 12) I had a common feeling of virtual objects' positioning with my partner
- 14) I had the feeling to see exactly the same as my partner
- 17) I had an overview about my partner's assets and game situation

- High difference (>1.5):

- 2) I found the game unnecessarily complex.
- 4) I think that I would need the support of a technical person to be able to use this game.
- 10) I needed to learn a lot of things before I could get going with this game
- 15) I found preparing and set-up for the game quick, comfortable and easy to understand.

- **Effectiveness:**
  - All participants could execute all actions and use the application as intended
- **Efficiency:**
  - Standard preparation takes about 2 minutes
  - Generic interaction modalities fall off compared to real world interaction
- **User satisfaction:**
  - High during game
  - Low during preparation
- **Hypothesis:** Collaboration in multi-user AR applications works, but:
  - More slowly
  - Highly depends on comfortable interaction modalities

# Theorem

Column 1	Column 2	Column 3