GNOME TRADER: A LOCATION-BASED AUGMENTED REALITY TRADING GAME

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ABSTRACT

We explore a location-based game concept that encourages real-world interactions and gamifies daily commuting activities. Enhanced with augmented reality technology, we create an immersive, pervasive trading game called *Gnome Trader*, where the player engages with the game by physically traveling to predefined locations in the city and trading resources with virtual gnomes. As the virtual market is a crucial component of the game, we take special care to analyze various economic game mechanics. We explore the parameter space of different economic models using a simulation of the virtual economy. We evaluate the overall gameplay as well as the technical functionality through several play tests.

1. INTRODUCTION

Through their unique combination of visual, narrative, auditory, and interactive elements, video games provide an engaging medium of expression within our society. The proliferation of mobile devices that combine computation and graphics processing with video and GPS sensors holds great potential to enhance gaming. Furthermore, augmented reality (AR) provides the ability to blend virtual and real-world experiences so that location-aware games extend past our televisions, weaving the magic of gameplay into cultural locations such as the cities in which we live. In this way, games become an augmented version of real settings, bridging between imaginative worlds and the reality around us.

In this article, we describe the design, testing, simulation, and implementation of an online multiplayer location-based AR game called *Gnome Trader*. In Gnome Trader, newspaper boxes throughout the country of Switzerland are augmented with virtual gnome characters who trade resources—nuts and peas—with players. Gnomes inhabit the boxes and vary their resource prices according to supply and demand. The core game mechanic is based on players increasing their wealth by buying and selling resources at different locations for different prices, allowing them to make a profit and to purchase upgrades. The use of augmented reality enforces the impression that a gnome is physically located in a particular box at a particular location, and thus can have a unique price compared to gnomes located elsewhere.

Although Gnome Trader follows core game design principles (Fullerton 2008) with a focus on being fun and entertaining, it has a deeper component that connects to serious gaming. At its heart, Gnome Trader represents a virtual economy. The prices of nuts and peas evolve depending on location-based transactions. Since the game is designed for large-scale deployment, it holds a unique promise to validate different economic

models and better understand how the forces of supply and demand interact with pricing policies and player actions. By experimenting with the game economy, we hope to gain valuable insights about real-world economic challenges.

2. RELATED WORK

Creating a stable virtual economic model is a non-trivial process because the distribution and temporal progression of prices can greatly affect gameplay in unforeseen ways. In fact, constructing balanced economies is an ongoing topic in the gaming industry. Market crashes or hyperinflation are common ailments that can afflict even blockbuster productions, such as Diablo 3 (Earle 2013). Research related to game economies has been conducted with the focus on online trading games or massively multiplayer online games (MMOs), such as Eve Online or Everquest (Reeder et al. 2008, Castronova et al. 2009). However, virtual markets in online games often rely heavily on free trading between players and the ability to exchange in-game currency or goods for real money (Yamaguchi 2004, Debeauvais et al. 2012).

Research in the context of virtual economies often refers to agent-based modeling, an approach that consists of computational objects that interact according to predetermined rules. This approach allows one to consider richer environments with more complex behavioral perspectives and dynamic market prices. Agent-based modeling has been employed for the financial sector by modeling asset prices (Rekik, Hachicha & Boujelbene 2014), for food consumption (Deguchi et al. 2001), and for the Swiss wood market (Kostadinov et al. 2014). Most of these agent-based simulations attempt to mimic real-world markets as closely as possible, which differs from our goal of exploring the virtual market of a trading game in a more open-ended fashion. In Gnome Trader, our simulation models two core components. First, the simulation controls gnomes that represent non-player characters and do not exhibit individual needs. Second, it models player agents whose sole goal is to accumulate in-game currency by trading resources. The level of control over prices in our virtual trading game is unique and is not necessarily comparable to models of real markets. Therefore, special care must be given to the economic model used in the game design of Gnome Trader. We describe our exploration of dynamic and spatially varying pricing models that reflect the emergent behavior of real markets.

Location-based games received much attention in the past years, as demonstrated by games such as Ingress[1] and Geocaching[2]. AR applications on mobile devices benefit from versatile and intuitive interaction mechanisms and create a strong connection to the physical world. AR has been widely used, for instance, to enhance creative play and interactions (Zünd et al. 2014, Zünd et al. 2015) such as coloring books (Magnenat et al. 2015) and interactive narratives (Kapadia et al. 2015). Combining location-based technologies with AR enables a host of novel and highly immersive experiences.

3. GAME DESIGN

In Gnome Trader, the player embodies a virtual trader, equipped with a bag to carry resources and gold pieces. The goal of the player is to travel within the country and trade resources at specific locations to make a profit. Each newspaper box across Switzerland represents a registered trading location. The logo of the newspaper box acts as an AR marker. Combined with the mobile device's GPS location, our software can uniquely identify every box. We choose this marker and GPS setup as it obviates the costly task of physically altering the boxes in order to add QR codes, near-filed communication beacons, or other disambiguation technologies. Upon arriving at a newspaper box, the player opens the game app and points the smartphone's integrated camera at the box's logo. A virtual gnome with a trading interface appears on the screen, integrated into the video, to give the impression that the gnome is physically located inside the box. Figure 1 illustrates the Gnome Trader gameplay using screenshots from our prototype implementation.

Four types of trading locations exist: each newspaper box either contains a gardener gnome selling peas or nuts or a gnome family buying peas or nuts. Gardener gnomes produce resources at a constant rate until their storage is full. Analogously, family gnomes consume resources at a constant rate until their storage is empty. A crowdsourced approach is employed for adding new trading locations to the game. After the marker on an
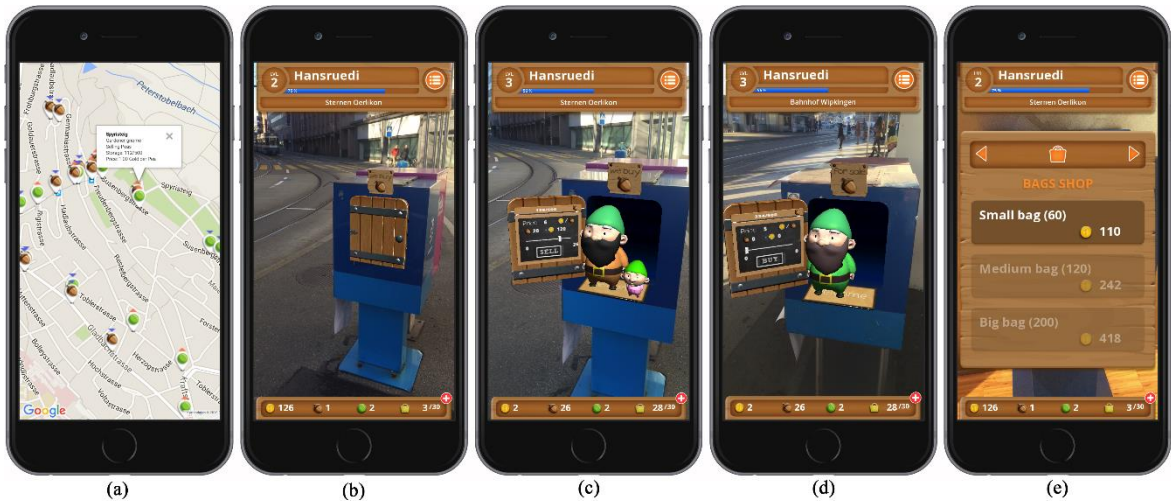

Figure 1: Screenshots of the prototype game. (a) The game map indicating trading locations. (b) A player approaches a trading location; the gnome's door is superimposed onto the newspaper box using AR. (c) A gnome family waiting to purchase nuts from the player; they offer 6 gold pieces per nut. (d) A gardener gnome offering nuts to the player at a price of 5 gold pieces per nut. (e) The bag shop menu; the player has enough money to unlock the next larger bag.

unknown newspaper box has been recognized by the game client of sufficiently many different players, a new trading location is inserted at that position in the city. Thus, the population of gnomes grows as players from new regions join the game.

The price of each resource is dynamically calculated by an economic model. We implemented two economic models, both of which are described in Section 3.1. Generally, a player can buy resources for a low price from a producer gnome with high storage and sell resources for a high price to a consumer gnome with low storage. For simplicity, in the current prototype, players cannot trade directly with each other. Their interaction is limited to the computer-controlled gnomes.

The player can access a city map depicting all gnome locations and information about their resources. This feature encourages the player to find an appropriate gnome to sell the currently carried resources at a higher price than purchased. The resource carrying capacity of the player is limited by the size of a resource bag. With enough gold, the player can purchase larger bags to carry more resources, therefore increasing trading efficiency. Thus, with increased wealth, the player can buy more resources to make an even higher profit.

The player can compare his or her performance to the other players on a global leaderboard, providing motivation to compete and continue playing. The total number of traded resources and gold is summed up for each player and displayed as a score.

3.1 Economic Models

A controllable and sustainable economic model is key to the success of the game as it defines how prices evolve over time and adapt to the behavior of the players. The goal of the economic model is to create a stable supply and demand behavior for the gnomes. Gnomes who are visited frequently by players should raise their prices, while gnomes who are rarely visited should lower their prices until a minimum price is reached. This behavior models a gnome's desire to maximize profit, while also introducing competition to the market. If an individual gnome's selling price is higher than those in the vicinity, players will buy elsewhere, forcing the gnome to lower prices. Such pricing models open up fascinating possibilities for gameplay. However, they are very hard to configure in a way that achieves a well-balanced market. We developed two specific models, inspired by existing work (Smith 1994, Davis & Williams 1986), that model the effects of asymmetric supply and demand configurations on prices converging toward a competitive equilibrium.

3.1.1 Model A: Production-Consumption

In the Production-Consumption model, each gnome continuously produces or consumes its resources at a fixed rate until the storage is full or empty, respectively. The resource price p is directly calculated from the storage ratio $r = \frac{S_{cur}}{S_{max}}$, where S_{cur} is the number of resources currently in storage and S_{max} is the storage size.
In a fixed interval, each gnome updates its price

$$p = w \cdot v(r) + k,$$
$$v(r) = \begin{cases} -2(r-1), & r < 0.5 \\ 1.5 - r, & otherwise \end{cases},$$

where w is the real world market influence described in Section 3.1.3, which is a constant scaling factor across all trading locations, and k is a randomization term that varies the price. The randomization term adds a certain amount of chance to the game, which increases suspense for the players. In the prototype, k was defined such that it decreases or increases the price up to ten percent. The price modifier term $v(r)$ doubles the price if the storage is empty and halves the price if the storage is full. A producer gnome with low storage is considered successful and should increase its price to make more profit. Analogously, a consumer gnome with a low storage will starve soon and should increase the price it is willing to pay.

3.1.2 Model B: History-Based

In the History-Based model, gnomes keep track of their trading success over time and adjust prices according to trends. A trading history logs how many resources were sold and purchased over the last couple of days. At each update step, the current earnings are compared to the history and evaluated for performance. If a producer gnome is successful, that is, if it was able to sell more resources than before, the selling price is increased. If the gnome sold less, the price is reduced. A consumer gnome is considered successful if it traded many resources recently, in which case it tries to lower the buying price, otherwise it is increased. Producer and consumer prices at time t are calculated as

$$p_{prod}^t = p_{prod}^{t-1} + m \left(\sum_{i=0}^{d-1} n_s^{t-i} \Big/ \sum_{i=1}^{d} n_s^{t-i} - 1 \right) + (w^t - w^{t-1})$$
$$p_{cons}^t = p_{cons}^{t-1} - m \left(\sum_{i=0}^{d-1} n_b^{t-i} \Big/ \sum_{i=1}^{d} n_b^{t-i} - 1 \right) + (w^t - w^{t-1}),$$

where the parameters n_s^t and n_b^t denote the amount of resources sold or bought by the gnome at time t, d controls the history depth, and m is a scalar model parameter used to weight the history influence. The term w is the real market influence described in Section 3.1.3. An important difference to the Production-Consumption model is that in this model gnomes have access to an unlimited number of resources.

3.1.3 Real World Economy Influence

To create a more realistic playing experience, the game's virtual economy is loosely tied to the real world economy. This feature gives the player a feeling of immersion and suspense as he or she can utilize real world measurements and estimates of the economy to make decisions in the game. This connection is created by introducing a gnome market index term w, which is calculated from a real market index, such as Dow Jones, NASDAQ, or Nikkei. As a result, fluctuations in the real market index are mirrored in the virtual market and visible in the individual gnome's price calculations. We calculate the gnome market index term

$$w^t = 3 + 1.9 \operatorname{atan}\big(0.005(I^t - I_{AVG60}^t)\big)$$

for a time t by scaling the real market index I and removing low frequencies. The term I_{AVG60}^t denotes the 60-day moving average of I. In our prototype, the Swiss Market Index (SMI) was employed for I. Specific values for the equation were found empirically.
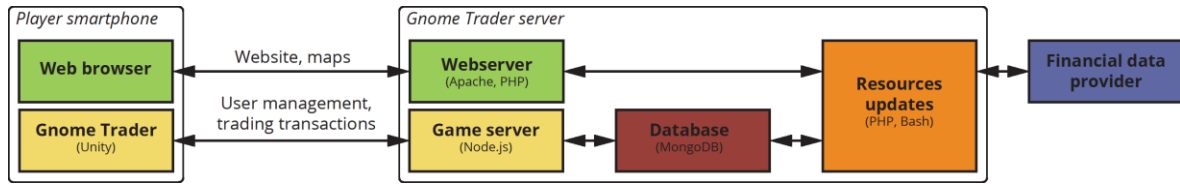
3.1 Implementation

Figure 2: Gnome Trader client-server architecture overview. The game server provides user and trading location data to the Unity-based game client app. The game map, provided by a webserver, is viewed on any browser. Regular resource update and maintenance tasks are performed directly on the database. Financial data is retrieved from an external data provider.

Figure 2 depicts the client-server architecture. The game client is implemented using the Unity[3] game engine, relying on the Vuforia SDK[4] for AR processing. A real-time websocket communication architecture based on socket.io[5] is employed to pass messages between the Unity client and a node.js[6] based server application. The server application stores user data, transaction data, and trading location data in a MongoDB[7] database. Maintenance scripts perform updates on the database at regular time intervals to, for example, recalculate prices and distribute resources. The game map is made accessible to the players on a website running on Apache[8]. The Google Maps API[9] allows our system to overlay gnome locations, their prices, and storage levels over the city street map. Financial data is retrieved from Quandl[10].
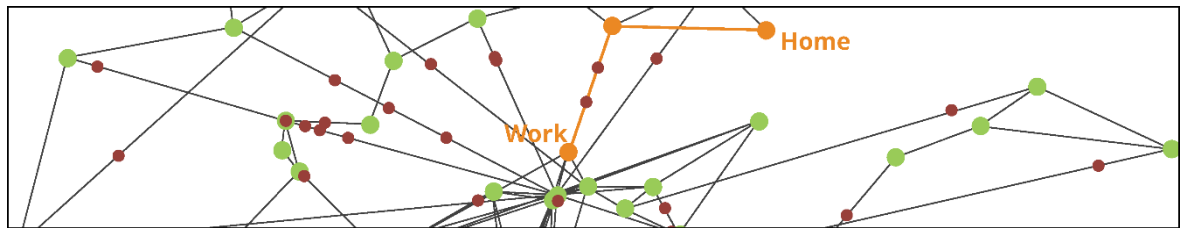
4. SIMULATION

Figure 3: Part of a randomly generated city map with 40 player agents (red dots) and 40 gnomes (green nodes). An example agent's daily commute path from home to work is highlighted in orange.

It is crucial to be able to analyze potential pricing schemes of a trading game in a controlled manner before launch to reduce the risk of problematic behaviors such as massive inflation or market crashes. For this purpose, we propose an agent-based framework that simulates the virtual economy of Gnome Trader. The simulator uses a simplified model of the game. Players cannot buy upgrades or spend money in any way other than buying resources. There is only one type of resource to trade. The city map is generated at random, using an algorithm that is inspired by scale-free graphs (Li et al. 2005) and exhibits similar properties. Part of an example generated city map is depicted in Figure 3. The simulator was implemented using MASON[11], an agent-based modeling toolkit for Java.

4.1 Player Behavior Model

Players are represented by agents in the simulator. The model distinguishes player movement and trading behavior and assumes the two to be independent. Agents never move to a gnome for the explicit purpose of making an advantageous trade. The reasoning for this choice is that traveling takes real effort. Thus, players are unlikely to go out of their way just to play the game. Instead, they will go about their business as usual, and

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[3] https://unity3d.com/
[4] https://developer.vuforia.com/
[5] http://socket.io/
[6] https://nodejs.org/

[7] https://www.mongodb.org/
[8] http://www.apache.org/
[9] http://developers.google.com/
[10] https://www.quandl.com/

[11] https://cs.gmu.edu/~eclab/projects/mason/

only stop to play when a convenient opportunity presents itself. Because of this assumption, the agent behavior model used for the simulation tries to mimic the movement patterns of average people going about their daily lives in an urban environment. Players are assumed to commute between two fixed locations once per day, such as going to school or work. Agents can trade with gnomes they visit during their daily commute. They try to maximize profits by conservatively selecting the best trading opportunities along that path. Agents only sell when there is no better offer along their path. They also avoid selling a resource for less than it was bought, which is represented by the resistance price. The resistance price decays slowly over time to avoid locking agents out of trading indefinitely. Agents buy when a producer's price is lowest and there is a guaranteed profit to be made elsewhere by selling the resource for more money. The last condition prevents player agents from buying up worthless resources simply because they are cheap.

4.2 Results

Both economic models described in Section 3.1 were simulated under various configurations to explore the parameter spaces. The real world influence and the randomization term were omitted for the simulation, to observe the properties of the economic model without the interference of these added effects.
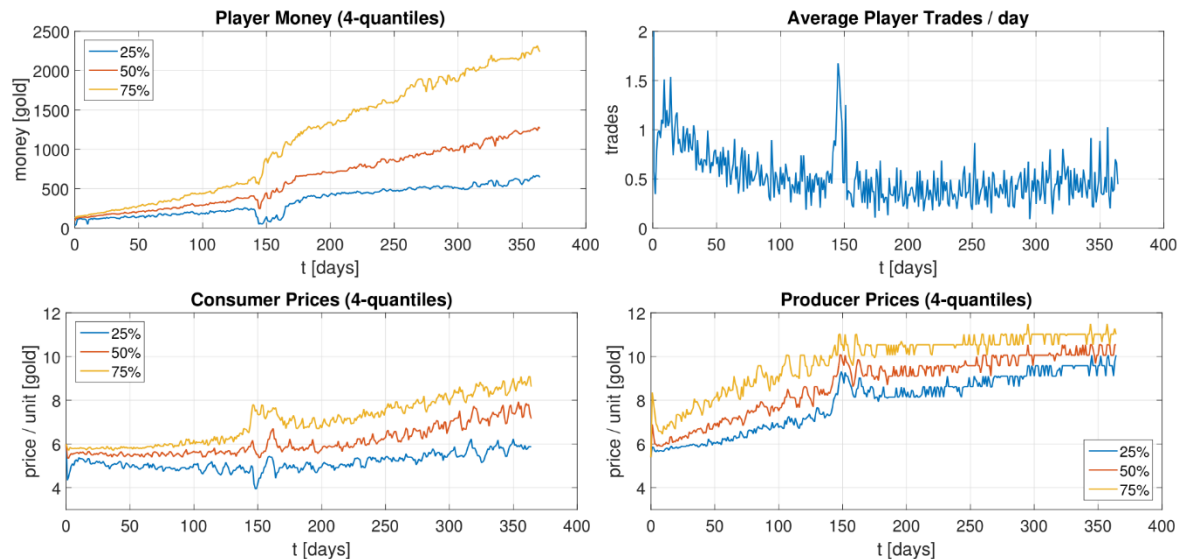
4.2.1 Model A: Production-Consumption

Figure 4: Simulation output of an undersupply scenario in the Production-Consumption economic model. The city contains 102 consumer gnomes and 98 producer gnomes. The market index is fixed at $w = 6.0$ and gnomes have a maximum capacity of 500 units. Production and consumption rates are at 20 units per day.

The behavior of the Production-Consumption model depends on the ratio of consumer and producer gnomes as well as their production and consumption rates. If the parameters are chosen such that the inflow of resources into the system equals the outflow, then the economy is stable and prices fluctuate around a constant value. However, by upsetting this balance we can simulate a variety of interesting real market phenomenon, such as shortages and oversupply. For example, Figure 4 shows the output of a scenario with a slightly higher number of consumer gnomes than producer gnomes. This imbalance results in an undersupply of resources that causes the producer prices to rise continuously. The shortage causes consumer prices to spike after about 140 days. Player agents recognize the opportunity for profit, as evidenced by the subsequent increase in trading activity. Player wealth drops momentarily due to the investment. Prices fluctuate for a few days before the simulation continues normally.

The Production-Consumption model can be fine-tuned dynamically and offers developers a high level of control over the market behavior. The ability to reproduce real world phenomenon makes it an interesting choice for a game economy.
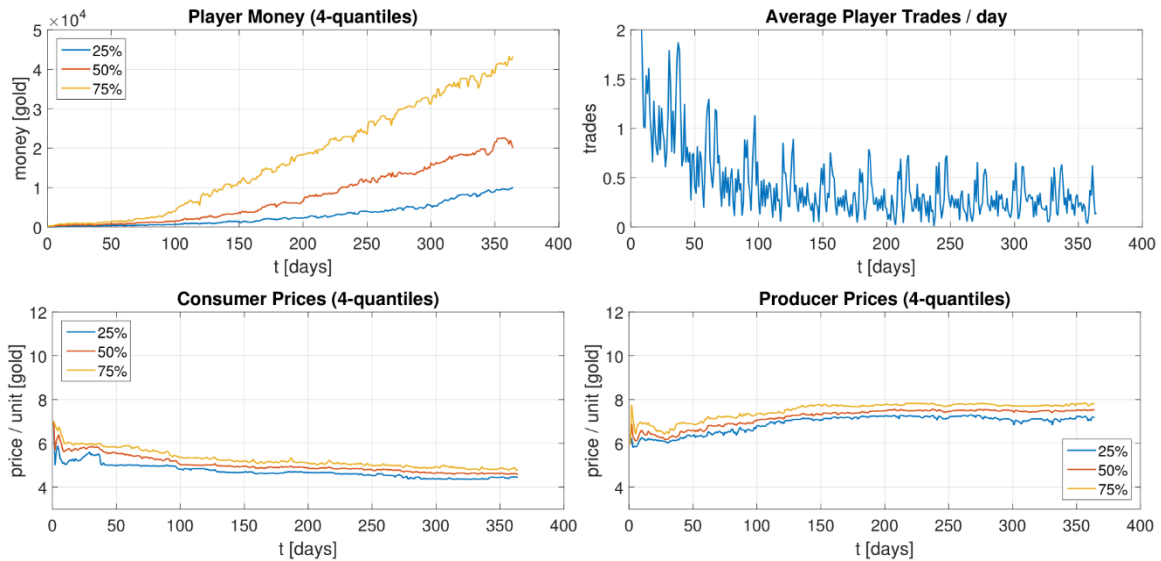
4.2.2 Model B: History-Based

Figure 5: Simulation output with the History-Based economic model. Gnomes store trade histories for 30 simulation days and the multiplier is set to m = 2.0.

Figure 5 shows a simulation run of the same scenario using the History-Based economic model. The imbalance between consumers and producers has no apparent effect on this economic model, because its prices are only dependent on the sales and purchase volumes, not on the absolute amount of resources in the system. As such, it is more robust to variations in population sizes, but also easier to influence by certain player strategies. While the unlimited supply and demand for resources causes players to gain wealth at a much faster pace than in the Production-Consumption model, this phenomenon can be accounted for by balancing the initial prices accordingly.

5. PLAYTESTING

We tested the game prototype to evaluate the technical functionality and the appeal of gameplay. Following the agile development concept, we started with tests early during the development and finally conducted two more formal playtesting sessions.

In the first playtesting session 8 participants (5 male and 3 female, aged 17 to 26 years) played the prototype in Zurich, Switzerland. Each participant was engaged in the game for 2 hours in total over the course of a week. Afterwards, the participant's feedback was collected with a questionnaire. Most users needed some time to appreciate the concept of traveling physically to successfully play the game. While the participants did not lose interest in the game during that week, some mentioned that without any changes it may become less interesting to continue playing. The limited accuracy and robustness of the measured GPS location sometimes led to inconsistent trading location information, which negatively influenced the gameplay. Some participants also suggested that direct trading between players would be desirable.

A second playtesting session was conducted in Barcelona, Spain, with 19 participants over the course of an afternoon. The game was played again successfully and additional insights could be gained through a questionnaire. To generate a single figure that would encapsulate the player's satisfaction with the game, the Net Promoter Score was used. The average results for the score were very positive, standing at 73.5%. After playing, 79% of the participants indicated that they would play the game a few times per week or more. Feedback from the participants included that the AR approach requires good lighting conditions, which can be problematic at night time. Participants also mentioned that the high battery consumption should be addressed.

6. CONCLUSION

In this paper, we demonstrated a game prototype for a city-wide trading game. AR and real world market influence contribute to a rich and immersive gaming experience. Our simulator showed that the Consumption-Production economy model is well suited for implementation because it can be fine-tuned as required and reproduces the phenomenon of real markets. Alternatively, the History-Based economy model is more robust to variations in player and gnome populations but, at the same time, is also vulnerable to certain player strategies. We conclude from two play testing sessions that the game concept is functional and well received.

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