The Impact of Computer Interfaces on Multi-objective Negotiation Problems

by

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Submitted to the Program in Media Arts and Sciences, School of Architecture and Planning,
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Abstract

Planning a city is a complex task that requires collaboration between multiple stakeholders who have different and often conflicting goals and objectives. Researchers have studied the role of technology in group collaboration for many years. It has been noted that when the task between collaborators increases in complexity, such as in a decision-making process, the use of computer technology could enhance, or disturb, the collaboration process. This thesis evaluates whether a Tangible User Interface (TUI) is more effective for multi-objective group decision-making than a Graphical User Interface (GUI). To examine this question, I designed and developed the CityGame framework, a web-based negotiation and decision-support game with a multi-modal interface for an urban planning scenario. The interfaces were evaluated in a within-subjects study with 31 participants of varying background, who were assigned a planning task in a gameplay session. Results show that tangible interfaces have some observable advantages over digital interfaces in this scenario.

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Chapter 1

Introduction and Background

Planning a city is a complex task that requires collaboration between multiple stakeholders who have different and often conflicting goals and objectives. This task requires the collaborators to negotiate their objectives and reach a consensus on a final plan. Decision-making tasks are well discussed in McGrath and others on group collaboration [20, 21].

In response to the need to better manage complex operations, new technologies have been developed to support collaborators in their tasks, their communication and/or their information management. Such tools are referred to as Group Performance Support Systems (GPSS), Group Communication Support Systems (GCSS), and Group Information Support Systems (GISS), respectively [20]. All these systems are known as Decision Support Systems (DSS). However, the use of technology—computer technology more specifically—could enhance or disturb the collaboration process and influence task performance in collaborative settings. A study of the impact of alternative computer interfaces on multi-objective negotiation has not yet been reported in the literature.

Therefore, to investigate whether tangible interfaces enhance the decision-making process within groups of individuals with conflicting objectives, I propose to:

- Design and develop an urban planning serious game with rules that address conflicting objectives

- Design and develop two different interfaces for the game, namely a Graphical User Interface (GUI), and a Tangible User Interface (TUI).
- Evaluate the task, user interaction, group communication and the environment of different users collaborating and interacting within the game to reach a consensus using the different interfaces independently.

The details of these objectives and the methodology of implementation are discussed in Chapter 3.

1.1 Collaboration, Negotiation and Decision-making in an Urban Planning Scenario

Urban planners, architects, city developers, residents, mayors and activists are key stakeholders in city planning. To better understand the decision-making process, I interviewed some of the stakeholders and found that the current planning process is contentious, problematic and time consuming, and that reaching a consensus between the different stakeholders is difficult. Each proposed plan is presented to different stakeholders, and their feedback is collected and considered for a future iteration. Each stakeholder who attends a planning meeting represents his/her organization. That is, they need to evaluate whether the plan meets their organization's goals and objectives. This whole process may take several years before a project is approved. In many cases, a consensus is never reached, and stakeholders' satisfaction level with the result is low, or cannot be determined.

Within this process, experts use simulation tools for selected systems, such as traffic, to evaluate aspects of a plan. Unfortunately, those tools require a certain level of experience, which makes it harder for most decision makers to interpret. For an average stakeholder, it's very difficult to evaluate the impact of the plan even with the outputs of expert tools.

In general, when groups of people collaborate, there are three main components in play. First is the participants (players involved in the process), which includes their affiliation, position and hierarchy. Second is the task itself, such as the type of problem (Is there a correct answer? Is it a problem solving task? Idea generation task? or resolving conflicts of different viewpoints task?). Third is the environment where those participants are collaborating. For example, are the participants collocated in the same space, or are they collaborating remotely? Chapter 2 addresses the different aspects of group collaboration as well as negotiation and decision-making as a task for group collaboration.

Urban planning is a complex process due to a) the amount of information needed to make a decision, b) the methods of communication between those stakeholders, and c) the variant backgrounds and objectives that stakeholders have in a decision-making session. There are existing developed tools and interfaces that address some parts of this complexity [26]. Most of these tools use Graphical User Interfaces (GUIs). Other interfaces, such as Tangible User Interfaces (TUIs), introduced by Ishii et al. [15,16], have been used to support group collaboration, but focused on problems with a single objective or common interest problems [26]. Further details on these tools, interfaces and their use in group collaboration are discussed in Chapter 2.

1.2 Tangible, or Graphical User Interfaces?

This thesis evaluates the hypothesis that a Tangible User Interface is more effective for multi-objective group negotiation and decision-making than traditional graphical user interfaces. In this study, I designed and developed an urban planning game where the models were taken from Pont and Haupt (2009) [3] to achieve a close-to-reality urban planning scenario. These models were applied on the scale of a large development project. These model were incorporated into a serious game that enables participants who come from different organizations/school departments with different viewpoints to assess their decision-making in real time and negotiate with other participants.

The different roles, tasks, and objectives of the stakeholders, as well as the gameplay mechanics are discussed further in Section 3.1. The game interface and visualizations are modular. They are applied on different interfaces, and adapted to the different input and output methods, as discussed in Section 3.2.

Chapter 2

Related Work

2.1 Computer Interfaces

In Human-Computer Interaction, computer interfaces are boundaries where users and computer systems exchange information. The design of these interfaces is based on the application in use, as well as the devices they will be displayed on or interacted with. Graphical User Interfaces (GUI), Multitouch User Interfaces and Tangible User Interfaces (TUI) are some of the different types of computer interfaces, where GUIs are the most common, as seen on traditional desktop interfaces.

To apply graphical user interfaces on different devices, such as touchscreens, GUIs require some adjustments. This is because using touchscreens would replace the traditional use of the mouse as an input device. In addition, some interaction behavior would change, as well. For example, hovering behavior is not invoked in the same way that it is with the mouse.

Tangible user interfaces (TUI), which were introduced by Ishii et al. [15, 16], are a way to embed information in physical objects. TUIs allow direct manipulation of data through physical interaction with objects. Patten et al. designed and developed a tangible user interface that electromagnetically tracks the positions and orientations of multiple wireless objects on a tabletop display surface [22]. Papier-Mache, is another example of a TUI, which is a toolkit for building tangible interfaces using computer vision, electronic tags, and barcodes [17]. Other research investigated the use of TUI in different contexts, such as how it could support group collaboration in an office environment [28].

Tangible User Interface research are still lagging behind in the domain of the decision-support systems. Most existing systems are designed for GUIs, and only a few have looked into other modalities [1, 14].

In addition to the work on computer interfaces, DSS require information visualization on those interfaces. Current research is studying the use of tangible interfaces to interact with information visualization [4, 9]. In these studies, table-top displays and physical objects are used to interact with the information on the screen.

2.2 Decision Support Systems (DSS)

Decision-making is "the act or process of deciding something especially with a group of people."[1] As the complexity of such decisions increases, the use of decision support tools is evident: DSS tools use modeling and simulation to assess multiple scenarios and allow users to make better informed decisions. These tools usually do not provide the answer to a problem, but provide a set of solutions/outputs that could result when users select a set of values/inputs feeding their system.

Currently, most tools that support such a process use graphical-user interfaces (GUI), and few are focused on the Tangible User Interface. One example is Urp, a TUI application for the urban planning context, where the authors used scaled physical models of architectural elements to control digital simulation [26].

CoPI is a GUI-based collaborative planning interface that supports the decision-making process in a complex system planning context [14]. The study is continued

[1]Definition of "decision-making" by Merriam-Webster dictionary.

and extended in the framework to adapt it for use with physical constructs [1]. These tools were demonstrated to support user's decisions and assist decision makers in making better informed decisions.

DSS tools could be used by a single user, or multiple users simultaneously. In the latter case, these tools become collaborative tools and support multi-user collaboration. One interesting case, which this thesis considers, is when there are multiple decision makers who have conflicting objectives and have to collaborate and negotiate their tradeoffs to reach a consensus.

2.3 Multi Objective + Negotiation

City planning is an excellent example of a multi-objective problem, which requires negotiation between multiple stakeholders. In city planning, multiple stakeholders with varying backgrounds and experiences meet to discuss future plans of an existing area. Each stakeholder would have a specific target, or objective in mind. To achieve one's objectives could hurt other stakeholder's objectives.

Multi-Objective Optimization Currently, many optimization methods are used for multi-objective problems. Specifically, a genetic algorithm is the most popular optimization method used in a multi-objective land use problem [2, 6, 7]. Unfortunately, optimization methods do not take into consideration the aesthetic of a plan, but rather produce results that are numerically optimized.

Negotiation Negotiation experience could be simulated and optimized, but would not result in a consensus until actual human-human communication is occurred. However, simulation tools could be used to support the negotiation process by providing structured experience. Using simulation tools with well-managed debriefing sessions can increase the effectiveness of negotiation training [24].

CityGame framework is designed to provide real-time simulations, as well as managing the negotiation and decision-making process.

2.4 Serious Games and Game Design

Games have been around for thousands of years ago. These games have evolved over the years, and our interaction and involvement with these games have also evolved over time. Games take place in an artificial universe governed by certain rules as described by Rollings and Adams [23]. One category of games are the serious games. Serious games are scenario driven games designed for a different purpose than just entertainment [5].

Serious games are popular topics these days in Computer Supported Collaborative Work (CSCW) research. They have been studied in collaborative environment and for different applications, such as city planning, defense or scientific exploration [5,25].

Active learning is another form of serious games. de Weck et al. (2005) [11] discussed the importance of active learning games to support classroom education as a pedagogical technique. One of the two benefits mentioned in the article is that it reinforces participants' understanding regarding two key concepts by participating in an active learning activity.

Most of these studies discuss the use of games outside the context of entertainment applications. They also discuss their benefits in learning contexts. Applications designed and inspired by games are gamified applications. To design a game for negotiation and decision-support system it's important to understand the concepts of game design and its elements in a non-game context, or *gamification.* Deterding, et. al., 2011 provide a great description on gamification, its history, and the game design elements in this context [12].

Chapter 3

Methodology

To evaluate the impact and effectiveness of different computer interfaces on the urban planning scenario, a web-based framework and game interface that supports multi-modal interaction were developed to encourage group collaboration and negotiation. This chapter is divided into three main sections: 1) the game, 2) the framework and computer interfaces, and 3) the evaluation methods. In the game section, the process of designing the game, gameplay mechanics, input variables, outputs/key performance indicators and participants' roles are described. The framework section describes the technology used, the different iterations of the game interface, the different interaction modality/setup, and the different visualization elements. Finally, the evaluation methods section describes the different metrics and levels of evaluation that are used in the experiment.

3.1 The CityGame

A game, as defined by the Merriam-Webster dictionary is "a physical or mental activity or contest that has rules and that people do for pleasure". Sometimes games are used for educational purposes and called "serious games".

As any game, the CityGame has a defined structure with rules, challenges, objectives, and rewards. The design of the game is influenced by the Multi-objective

Optimization class city planning game taught by Professor de Weck at MIT[1], and the Spacematrix model [27]. CityGame is not a winning game, which means that there is no victory condition for a player to achieve and thus win the game. In contrast, it is a cooperative game where a group is considered winning if the players finish the game and reach a consensus before there time is up. Additional details are described in the gameplay section.

Designing a multi-player game is not an easy task, especially when the purpose of the game is educational and when it addresses a complex problem. To design such a serious game, the following domains need to be covered: 1) understand the context (urban planning plan and area of development), 2) understand the roles (stakeholders involved and their relationship to each others), 3) understand the objectives (individual, group, game), and 4) understand the rewards and how to assign points (distributing weights and points to different objectives).

3.1.1 Context

The game is designed and developed for an urban planning scenario. The measurements used in this game and its planning scenario are based on the SpaceMatrix model for measuring urban forms [3]. In an urban planning scenario, an area for developments is required. This will set our context for the game. Then, the question becomes: which area should we choose for planning? Should we choose existing plan and redevelop it, or pick an empty area for new development? The answer to this question has to do with the objective of the study, which is to support decision-making and negotiation in an urban planning scenario. Also, if players are not familiar with the planning process, setting up the context with real example or site would help the players get an overview of the scale. For a site to be closer to reality, it needs to have different types of roads (main roads and side streets) and lands for development. There are different types of grids. The main ones are Manhattan grids, Barcelona

[1]The Multidisciplinary System Design and Optimization (MSDO) course, 16.888/ESD.77, covers topics on Multiobjective optimization.

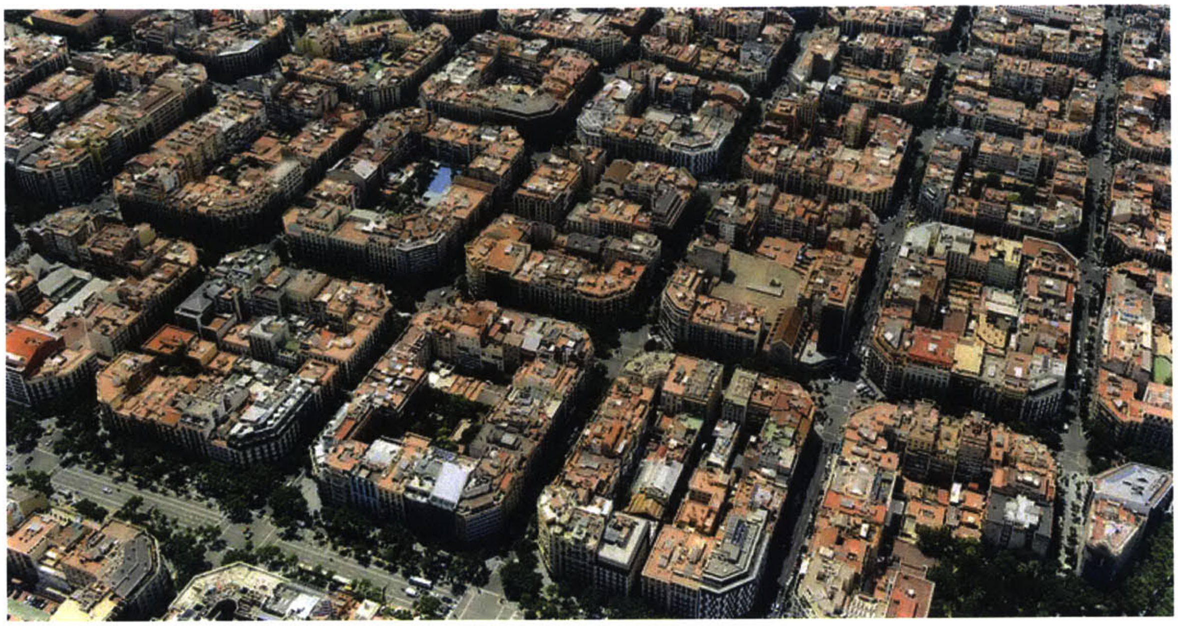


Figure 3-1: La Eixample district, Barcelona, Spain. The current CityGame plan layout is designed based on this district.[2]

grids, and Austin grids. A Barcelona grid, and specifically the "La Exiample" district was chosen as the plan for development in the CityGame (Figure 3-1). Barcelona's plan layout is recognized as one of the most successful master plans. This is due to the high density, modularity and layout, as well as other factors. Figure 3-2 shows The chosen grid layout of the city.

The game site covers four blocks from the Exiample district, where each block is *113.3 m* $\times$ *113.3 m* (Figure 3-2). It includes one main road of 50 m in width, one street of 20 m in width and four surrounding streets each of 10 m in width. The later is half the normal street width due to how an area of aggregation is measured for a plan. Each block is divided into 16 squares that results in 64 squares available for development, which we will refer to as "cells" (Figure 3-4). Players can modify the plan by modifying the amenities in those cells. This scale of the plan is set based on three factors. First, a walkable distance between buildings that could show a noticeable effect when simulating the impact of traffic congestion on the neighborhood. Second, considering a good graspable LEGO brick size per building for the tangible

[2]image credit to gelio.livejournal.com (gelio@inbox.ru)

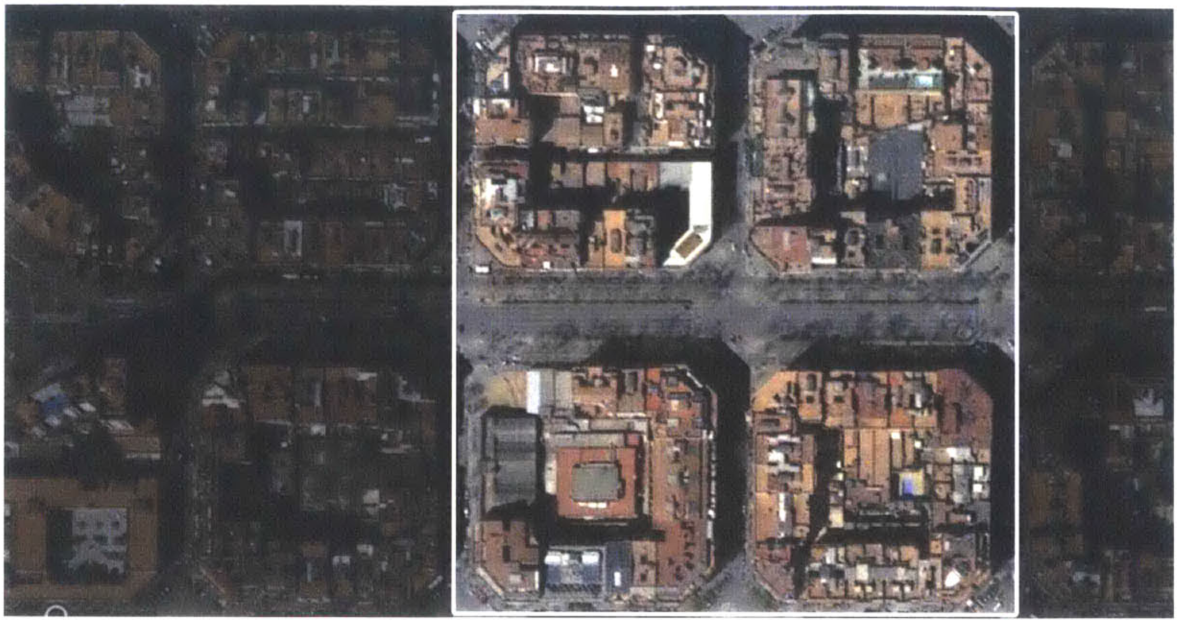


Figure 3-2: The four blocks in the CityGame are highlighted in this Google map image.

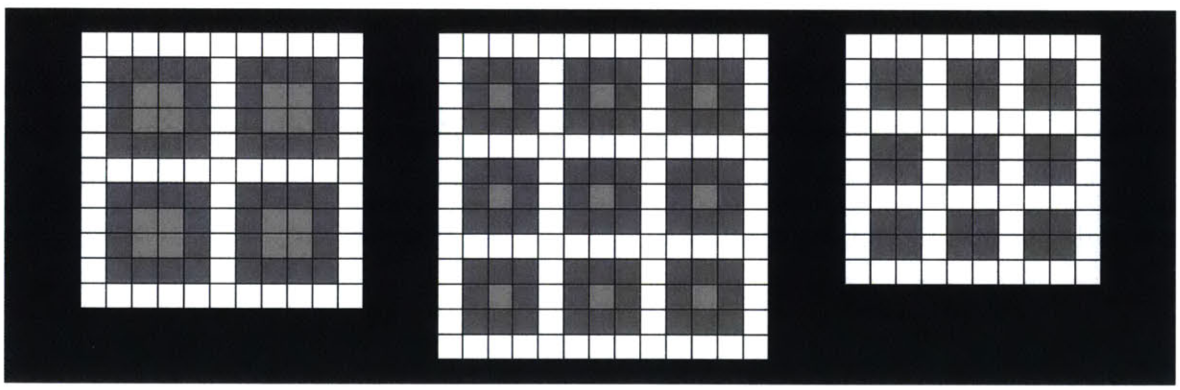


Figure 3-3: Different grid scales considered for the CityGame plan layout.

interface study. Third, allowing multiple building functions and parks within a block. Figure 3-3 shows the different scales considered for this game.

3.1.2 Roles

To identify the roles of the players, I interviewed urban planners from the United States and Europe who have been involved in the planning process. After several iterations, we ended up with four different roles (stakeholders) that are involved in the planning process. These are (Figure 3-5): 1) residential developer, 2) commercial

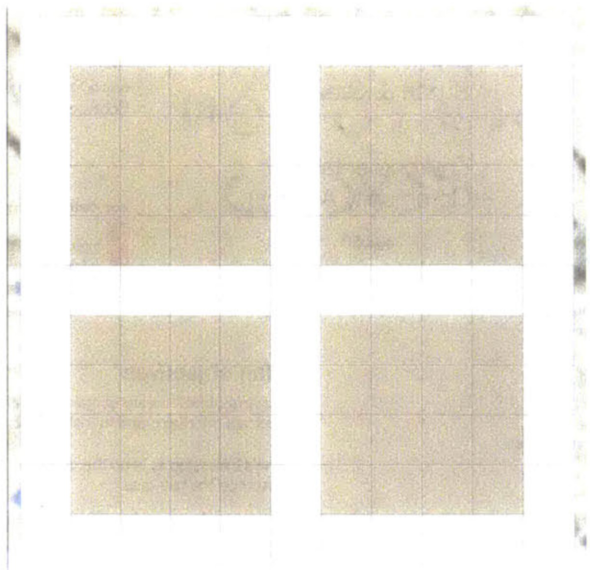


Figure 3-4: CityGame street and block layout area. Each block is *133.3 m* × *133.3 m*.

Figure 3-5: CityGame stakeholders/players roles

developer, 3) retail developer, and 4) environmental and community activist (environmentalist). Table 3.1 shows the initial and current players roles chosen for this game. For each individual role, a persona of the decision-maker (stakeholder) representing each role was created. Figure 3-6 shows an example of the environmental and community activist persona created for the game. To maintain a certain level of contention and cooperation between the stakeholders, and to allow a clear impact on the SpaceMatrix model and Mixed-use Index of the game plan, it was important to create a communication model for these personas/roles. Figure 3-7 shows one of the communication models developed for these roles. For example, from this diagram, player one (P1) and player two (P2) both want to maximize intensity (FSI) and buildings height, and both want to minimize parking structure and heat loss. In

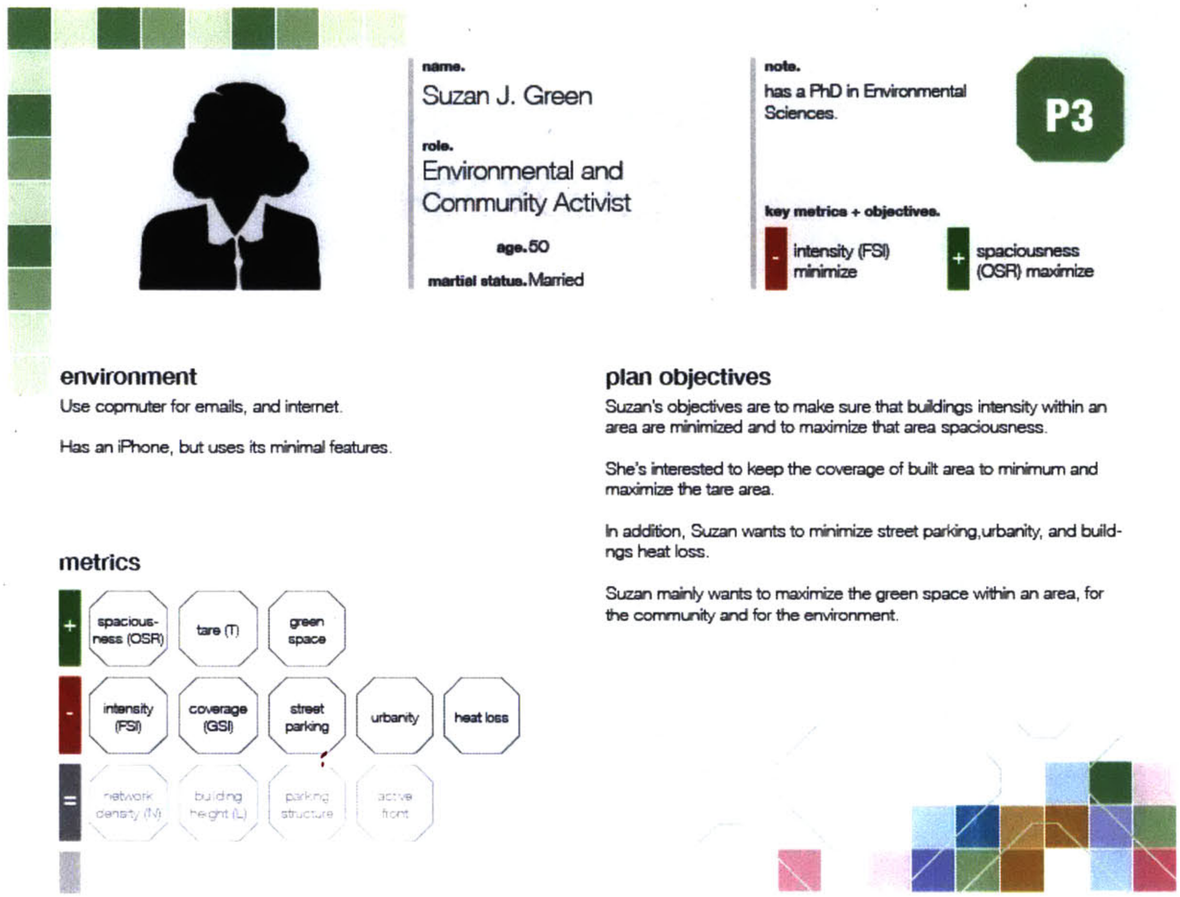


Figure 3-6: An example of the personas created for this game. This is the Environmentalist Persona with basic background, plan objectives and main metrics that this stakeholder cares about (game-based).

contrary, both have conflicts with green space. P1 wants to maximize green space, while P2 wants to minimize green space.

	Initial Roles		Current Roles
1	Luxury Real Estate Developer	1	residential developer
2	Community Development Council	2	retail developer
3	Corporate Office Developer	3	commercial developer
4	Nature conservancy	4	environmentalist
5	Chief Innovation Officer		

Table 3.1: Changes in players' roles (old vs current).

Residential Developer This role is responsible for providing residential units to the plan, and to increase the residential population in the neighborhood.

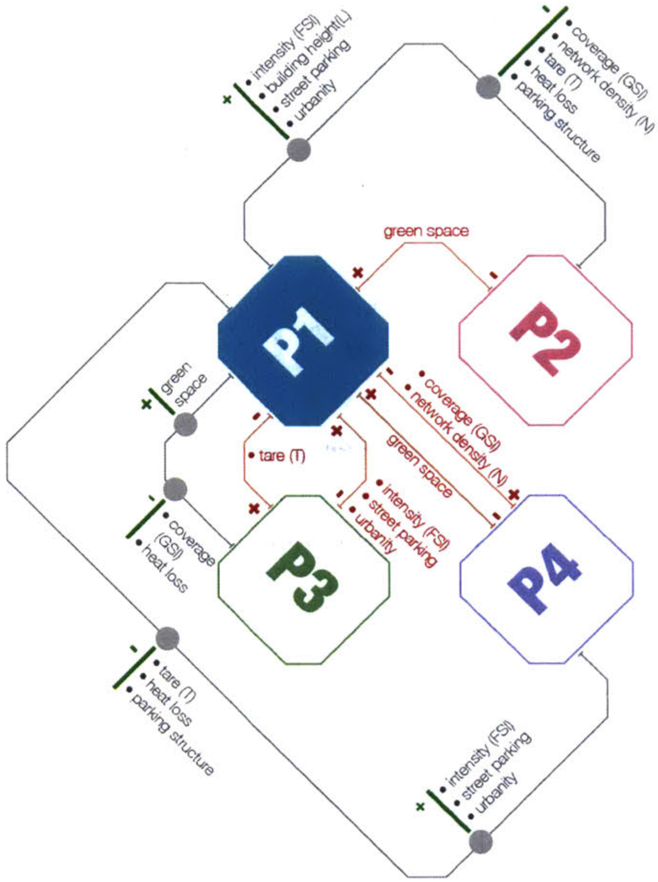


Figure 3-7: Residential Developer Communication Model. Red lines and text indicate points of contention, while the greens indicate points of cooperation.

Commercial Developer The commercial developer role is responsible for providing commercial and offices units to the plan. Also, this role is responsible for increasing jobs and non residential population in the neighborhood.

Retail Developer Similar to the commercial developer, this role is responsible for providing cafes, shops, restaurants and other retail units to the plan. Also, this role is responsible for increasing jobs and non residential population in the neighborhood.

Environmentalist The environmentalist role is responsible for making sure that there are enough open spaces and green areas for resident comfort and to reduce CO_2 emission within the neighborhood.

3.1.3 Amenities

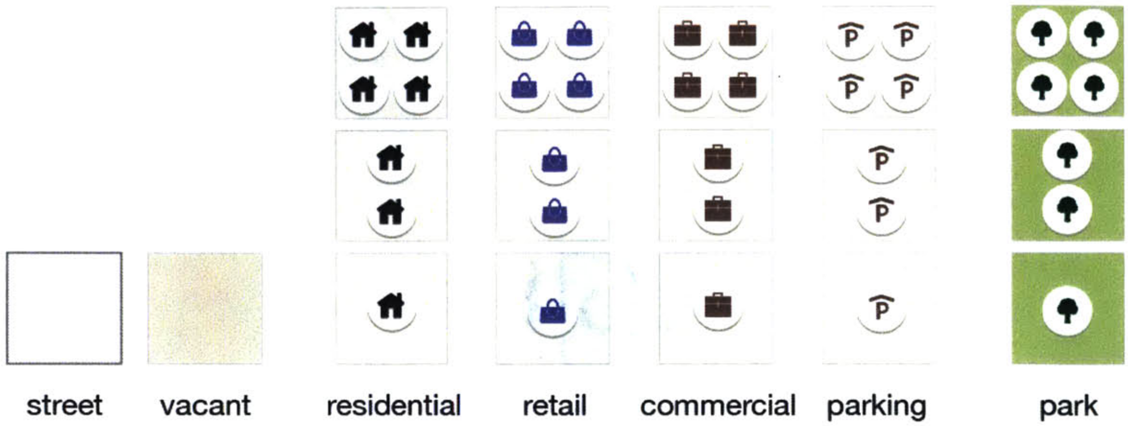


Figure 3-8: Game amenities, and their different levels. 1-icon, 2-icons, and 4-icons relate to the low-rise, mid-rise, and high-rise for buildings; and low-density, mid-density, and high-density of trees for the park.

Based on the selection of roles and key building functions available within a neighborhood, the following amenities are selected to be the input elements in the game: 1) residential buildings, 2) retail buildings, 3) commercial buildings, 4) recreational buildings, and 5) parking structures. Each cell on the game plan can hold one of those amenities at a time. If a cell does not contain an amenity, the cell is considered vacant. There are three levels for each building type that are associated with the floor levels. Level 1 is a *three* story building, level 2 is a *six* story building, and level 3 is a *twelve* story building. Recreation and parks have three different levels that are associated with density of trees. Level 1 is 300 trees, level 2 is 600 trees, and level 3 is 1200 trees planted in one square, which equals to about $13,000\ m^2$ (one game square tile).

To simplify the game, each building is a mono-function building. That is, all floor levels within the same square tile are of the same type of that building. No mixed-use buildings are introduced in this game, yet. Below are some assumptions on the different amenities that are calculated and simplified based on realistic calculations in the US.

Residential Buildings Each residential building has 3 types (low-rise, mid-rise and high-rise) with 3, 6, and 12 floors respectively. Table 3.2 shows the assumed measures for game metrics.

metric	Assumption		
	low-rise	mid-rise	high-rise
Population (people)	50	100	200
Landuse	2%		
Streetscape	6%		
Parking need	1 per unit		
Daylight	varies based on location and neighboring building height		
CO_2 emission (ton)	10,000	20,000	40,000
energy use	100 ppt		
open space per person	0.12%	0.24%	0.42%

Table 3.2: Residential buildings' assumed measures

Retail Buildings Each retail building has 3 types (low-rise, mid-rise and high-rise) with 3, 6, and 12 floors respectively. Table 3.3 shows the assumed measures for game metrics.

metric	Assumption		
	low-rise	mid-rise	high-rise
Population (people)	70	140	280
Landuse	2%		
Streetscape	6%		
Parking need	1 per unit		
Daylight	varies based on location and neighboring building height		
CO_2 emission (ton)	20,000	40,000	80,000
energy use	300 ppt		
open space per person	0.12%	0.24%	0.42%

Table 3.3: Retail buildings' assumed measures

Commercial Buildings Each commercial building has 3 types (low-rise, mid-rise and high-rise) with 3, 6, and 12 floors respectively. Table 3.4 shows the assumed measures for game metrics.

metric	Assumption		
	low-rise	mid-rise	high-rise
Population (people)	70	140	280
Landuse	2%		
Streetscape	6%		
Parking need	1 per unit		
Daylight	varies based on location and neighboring building height		
CO_2 emission (ton)	20,000	40,000	80,000
energy use	300 ppt		
open space per person	0.12%	0.24%	0.42%

Table 3.4: Commercial buildings' assumed measures

Recreational and parks Each recreational area has 3 types (low-tree-density, mid-tree-density and high-tree-density) with 200, 400, and 1200 trees respectively. Table 3.5 shows the assumed measures for game metrics.

metric	Assumption		
	low-rise	mid-rise	high-rise
Landuse	2%		
Streetscape	6%		
Daylight	varies based on location and neighboring building height		
CO_2 absorption (ton)	10,000	20,000	40,000
energy use	300 ppt		
open space per person	0.33%		

Table 3.5: Recreational and park areas' assumed measures

Parking Structures Each parking building has 3 types (low-rise, mid-rise and high-rise) with 3, 6, and 12 floors respectively. Table 3.6 shows the assumed measures for game metrics.

3.1.4 Task

The main objective in this game is to reach a consensus with all the players through adding, removing and changing building types in the plan while maximizing each individual objectives, group objectives and the game KPIs. Therefore, the main task here is to optimize the plan. However, optimizing the plan for which performance is dependent on the players. Players can decide to optimize the plan for a better CO_2

metric	Assumption		
	low-rise	mid-rise	high-rise
Landuse	2%		
Streetscape	6%		
Parking capacity (units)	40	80	160
Daylight	varies based on location and neighboring building height		
CO_2 emission (ton)	15,000	30,000	60,000
energy use	200 ppt		

Table 3.6: Parking buildings' assumed measures

performance, or to reduce traffic congestion. Ultimately, players need to optimize the plan for the different metrics which includes the individual metrics, group metrics, and general game metrics, which leads to a better final score. One constraint considered here is the time limit for playing the game. The following section describes those different metrics.

3.1.5 Objectives

There are three main categories of objectives in the CityGame. These are, individual objectives, group objectives, and game Key Performance Indicators (KPIs). Individual objectives, which are based on SpaceMatrix variables, include urban density, average building height, and urban coverage. Group objectives include land-use, streetscape, and live/work balance. Finally, game KPIs include the parking performance, energy use, access to open space per person, traffic congestion, CO_2 performance, and daylight performance.

The calculation models of these objectives are extracted from the "Space, Density and Urban Form" book [3]. This is one of the reasons for selecting these specific objectives. In addition, I looked into metrics that have a computational and visual impact on different levels (building level, block level, street level, and the neighborhood level) to increase the visual complexity when combined in one view.

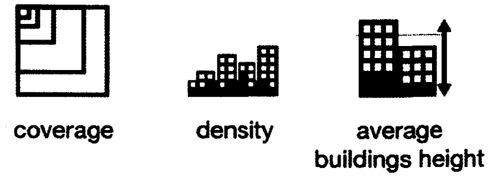


Figure 3-9: Coverage, density and average building height are players' individual objectives. These objectives differ from one player to another.

Metrics	Residential Real Estate Developer	Corporate Office Developer	Environmental and Community Activist	Retails Developer
Intensity (FSI)	+	+	-	+
Coverage (GSI)	-	-	-	+
Spaciousness (OSR)	=	=	+	-
Street Parking	+	+	-	+
Green Space	+	-	+	-

Table 3.7: Players' objectives of some metrics. The (+) sign means that a player's objective is to maximize that metric, (-) sign means that a player's objective is to minimize that metric, and (=) sign means that a player is not required to maximize nor minimize that metric (neutral).

Individual Objectives

After selecting the four different roles of the players, I created a table of players and objectives and discussed it with Prof. Pont to identify which role needs to maximize/minimize which objective. Table 3.7 shows this table.

We decided on the following three metrics, which are the basis for SpaceMatrix model [3, 27]. These are building intensity (we call it urban density in the game), coverage, and average building height.

Building Intensity (FSI) This is known as the Floor Space Index (FSI), or Floor Area Ratio (FAR). It's the gross area (sum of all floor area) over the plan area. Each player is assigned a target value (max/min/mean) to achieve prior to the game. The difference between the measured value of this index and the target value will be calculated and multiplied by the priority points (Table 3.8) of each player.

Roles/Players	Metrics		
	Buildings Intensity (FSI)	Coverage (GSI)	Average Building Height (L)
Residential Developer	2	2	2
Retail Developer	2	2	1
Commercial Developer	2	2	2
Environmentalist	2	2	1

Table 3.8: Giving priority points to metrics based on the players' roles

Coverage (GSI) This is the Ground Space Index (GSI). It describes the relation between built and non built space. Similar to FSI, each player is assigned a target value (max/min/mean) to achieve prior to the game. The difference between the measured value of this index and the target value will be calculated and multiplied by the priority points (Table 3.8) of each player.

Average Building Height (L) This metric measures the overall average building height in the area, and similar to FSI and GSI, L[3] does not have a direct impact on the points a player receive. It's points calculated in the same way as the FSI and GSI are calculated.

When a player achieves his/her individual objective, he/she receives a graphical notification that is visible to all other players.

Group Objectives

Figure 3-10: All participants have the same group objectives. As the group they need to achieve land-use, streetscape, and live-work balance objectives.

[3] L refers to the average building height, which is how the original source [3] refers to it.

The group objectives are rules and policy imposed on the plan. The three objectives are land-use, active-front and population. For the purpose of the game and simplicity, we renamed some of those technical terms. The new terms are, land-use (not changed), streetscape, and live/work balance, respectively.

Land-Use The percentage of each land/building type footprint occupying the plan area. Each unit occupies 2% of the plan.

Active Front (StreetScape) This metric describes the land use of the cells facing the main road of the plan. The main road is a very active and busy road. Residential developers are discouraged from building housing in those cells, while commercial and retail developers are encouraged to add amenities to those cells.

Population (Live/Work Balance) This is the total population in the plan. This includes occupants of residential and nonresidential (commercial and retail) buildings in the plan. Game objectives can vary in terms of population, but we focused on having a balanced ratio between residential and nonresidential occupants.

Game KPIs

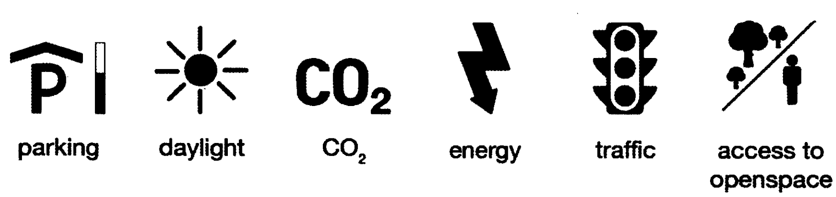


Figure 3-11: Each indicator of these game KPIs represent its performance based on a given plan layout.

Game Key Performance Indicators (KPIs) are the fine adjustments of the plan. You could achieve the group objectives with multiple solution that have variant impact on those indicators. For example, you could use all low-rise buildings vs. all high-rise buildings for your planning, and one has high CO_2 performance, while the other has low CO_2 performance. Players/stakeholders need to negotiate the types and levels of buildings and parks, which will be added to the plan in order to maintain a specific level of game KPIs performance. Some players might push toward a better CO_2 performance, but others may not care about it during the planning process.

Parking performance, daylight access, CO_2 performance, energy performance, traffic/average commute time, and access to open space (spaciousness) are the KPIs used in this game, as discussed next.

Parking Performance Index (PPI) This index is the ratio of the parking need to the parking capacity in the plan. The plan has an initial capacity that is calculated based on the network density and the parking layout (adjacent vs. horizontal, and single vs. double sided). We used a double-sided horizontal parking layout to maximize network parking capacity for game simplicity. Adding a parking building will increase the parking capacity, but to have a good performance, the ratio need to be closer to one. That is, having too much parking will affect the parking performance index.

Daylight The daylight index is represented with an aggregate value of the plan. However, with the current interface, you could get a visual representation of individual buildings performance in the plan. This is based on a simplistic measure of how building's levels block sunlight from the plan cells.

CO_2 Performance This correlates to the energy use index, the higher the energy use the higher the CO_2 emission. This impacts the overall game score negatively. It also correlates to the recreational and park area. Each park/recreational area can store CO_2, which reduces the Carbon footprint in the plan.

Energy Use The amount of energy each building consumes depends on the type of building as well as the average number of floors in the plan. Consumption in KW per floor is respectively 100, 200, 200, and 150 for residential, commercial, retail, and parking buildings. I used the Energy Use Intensity (EUI) formula from the Arch Tool Box website for this metric.

Average Commuting Time/Traffic The average commuting time is measured based on the Euclidean distance, for simplicity[4], between residential and commercial buildings. However, due to time constraints, it was not included in the CityGame experiment. That is, players were not asked to consider this indicator during the play.

Access to Open Space/Spaciousness (OSR) Spaciousness, or Open Space Ratio (OSR), is the ratio of the non-built space to built area at ground level. It describes the available space per person in the plan. Its value is based on the FSI and GSI that are used in the individual objectives, and based on the SpaceMatrix model.

3.1.6 Scores and Rewards

Figure 3-12: Coins, badges and game trophy representation in the CityGame.

The current game has a maximum score of 1,000 points. Each role can receive up to 100 points by trying to achieve their individual objectives. With four roles that add up to 400 points out of the individual objectives. Each group objective has 100 points total that are presented to players, but multiplied by two for the final score. That is a total of 600 points of the total score. The game KPIs didn't have a score that's added to the final count of points at the moment. It left as an open agenda for players to achieve (optional achievements for experiment simplicity).

Player Score Each player's 'final' score should include the final game score, as well as individual ratings of the satisfaction level of the submitted plan. The combined

[4]A algorithm with Manhattan distance is tested, but not incorporated in the current study.

points from each index/factor such as population density and FSI are multiplied by the priority point of each player. Each player has a target value that differs from the other players. The difference between the current value and the target value determines the score each player receives. The farther a player is away from his/her target value, the lower the score. This is independent of the direction of that value ($\pm$, higher or lower).

Badge Players receive a virtual badge when they achieve their individual objectives. A badge will be displayed next to players objectives once these objectives are met.

Ratings Each individual player will submit a star rating (0-5 stars scale) on the final submitted plan. This rating is factored in the overall score of the game.

Game Score The game score is the total points formulated by adding the individual objectives, group objectives and game KPIs together. In addition, the final result should include the time factor to influence the score.

Trophy A graphical trophy is given to groups that submit the plan before the time limit.

3.1.7 Game Flow

To play the game, you need four players. One of the players will act as the host of the game who will create a group and invite the other three players, setup the game and then start it. Details of CityGame interface and the flow to start the game are discussed in Section 3.2. The game flow has three major stages, 1) pre-game setup, 2) gameplay, and 3) post-game review.

Pre-game Setup

In this stage, the host player creates the group name and invite the three other players. Then, the host selects the site for which the group will negotiate their plans;

and selects the time limit for this case/game. After these basic elements are set, each player will receive a random role generated automatically in this stage.

Gameplay

After the game/case is set up and all players have joined the game, they are ready to play the game. The gameplay is designed to follow the consensus-based decision-making approach. Figure 3-13 shows the flow of the game. The following paragraphs explain each step of the gameplay, where the numbers in the paragraph headers refer to the numbers within Figure 3-13

Pre-start Condition (0.0) Once the players are in the simulation/board-game platform, the following shall be considered the initial conditions of the game:

- Site/plan/gameboard/gridded map area is clear/empty.
- Individual objective scores are all 0.
- Individual badges are all deactivated.
- Group objectives are all zeroed, and their scores are 0, as well.
- Plan KPIs are all zeros, and vertically centered.
- Notification Area is empty.
- Overall game score is zero, number of rounds is zero, and the timer is in the initial timer setup (default 30min).

First Round: Populate Plan (1.0) The first round of the game is the preliminary setup, or populate plan phase. Each player take a turn, sequentially by player number, to add 3 amenities to the plan. Each player cannot move/change/modify previous player's placed amenities in the first round.

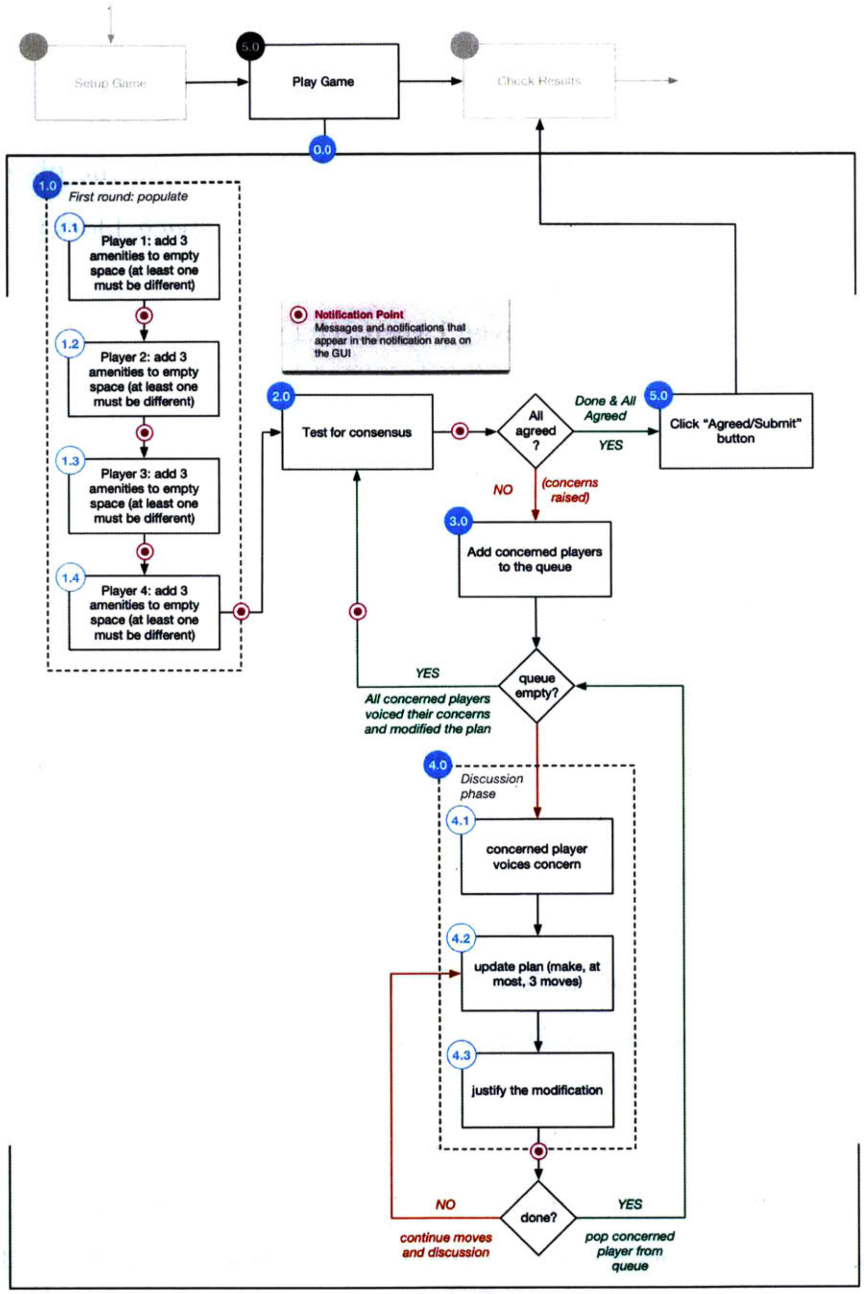


Figure 3-13: CityGame gameplay steps after players have already set up the game and entered the game/gameboard view.

Generally, the first round will be guided by notification messages appearing in the notification area of the game interface. Each player will click a next button after their turn.

By the end of this round, players have populated less than 20% of the plan. Next, they enter into the "Consensus Testing" phase.

Player 1 Turn (1.1) The player needs to add 3 amenities to the plan. The only move available is to add an amenity to an empty lot (grid space/block).

Player 2 Turn (1.2) Same as Player 1 turn. (1.1)

Player 3 Turn (1.3) Same as Player 1 turn. (1.1)

Player 4 Turn (1.4) Same as Player 1 turn. (1.1)

Test for Consensus (2.0) In this phase, the players evaluate their individual objectives, global objectives, and the game KPIs. If all the users have achieved the group objectives, maximized the game KPIs and are satisfied with their individual objectives/score, then they have reached a consensus, and the game ends by clicking the "Agreed/Submit" button in (5.0).

If some users raised concerns in this phase, they queue themselves in a list by order of the player who raised concerns first, which is step (3.0).

Add Concerned Players to the Queue (3.0) If players are in this phase, it means that some players have concerns about the existing plan/proposal in the previous round. Those players with concerns add themselves to the list, which allows them to update the plan based on their order in that list.

A round is completed after this list is cleared. That is, when all the players with initial concerns have made their modifications to the plan.

Discussion Phase (4.0) The discussion phase is where the concerned players with objections to the plan try to negotiate by modifying the plan/proposal to achieve their individual objectives, achieve group objectives and try to improve game KPIs.

Each player in this phase tries to voice his/her concern, make some changes/moves, and justify his/her moves. Players are encouraged to discuss the changes while interacting with the plan.

Each round of the game consists of one round of discussion. That is, one round in the game finishes when the queue of the list of people who have concerns has cleared.

Voice Concern (4.1) The first part of the discussion phase is to raise your objection, or explain why you are objecting to the current proposal verbally to other members. Whether because the group objective not met, individual objectives are way far from target, or you are trying to maximize game KPIs.

Update the Plan/Proposal (4.2) Here, the player starts to update the plan/proposal. He/she can make 3 movies each round as follows:

- Add a new amenity to an empty block (+1: count as one move)
- Remove an amenity from the plan (+1)
- Update the location of an existing amenity to an empty block (+1)
- Update the location of an existing amenity to an occupied block (+2: count as two moves)

Justify the Modification (4.3) After updating the plan/proposal, the player justifies the changes to the other players and discusses it with them.

Agreed/Submit Proposal (5.0) Once everybody has made changes to the plan, discussed the changes, and negotiated the proposal, they can agree to submit the plan as long as the timer did not go off. Once they agree and submit the plan, the game ends, and the players will be directed to the results screen.

If the timer went off before they players agreed on a plan, then the game ends and they will be directed to the results screes.

Game notifications These messages/notifications appear in the notification area of the GUI. Messages about the game flow and alerts will be displayed more frequently in the first part of the game.

Post-game Review

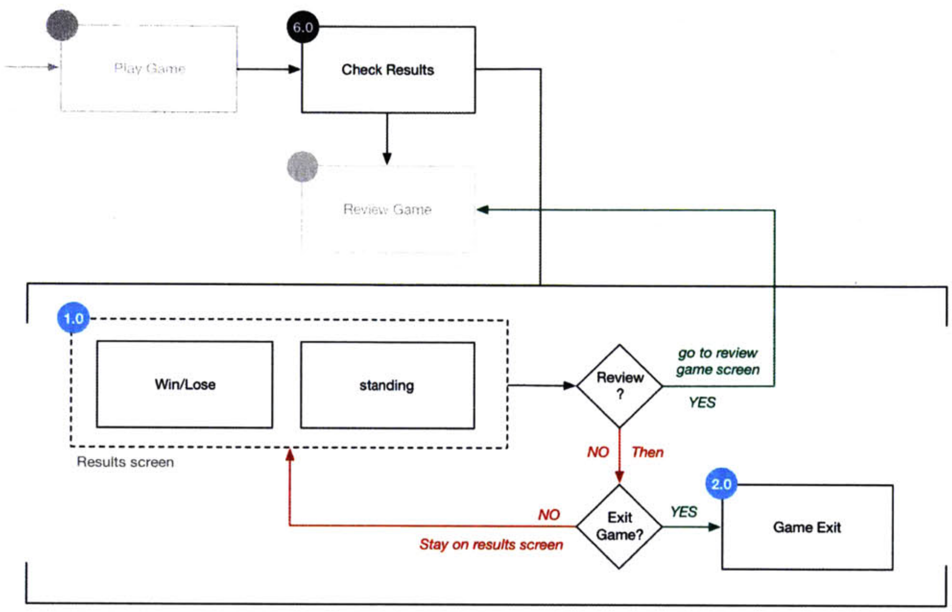


Figure 3-14: Check game results flow.

After the game is over, players will be directed to a different view to analyze and review the performance of their game and negotiation. This is as important as the game itself, as it provides players with additional view of the play and tradeoffs that occurred during the play. Figure 3-14 and 3-15 show game results and review flow that occur in this stage.

3.2 Technological Environment and Framework

In this thesis, my objective is to evaluate the impact of different computer interfaces on a multi-objective negotiation problem. Some aspects considered prior to designing tools for such scenario include group performance support and group information

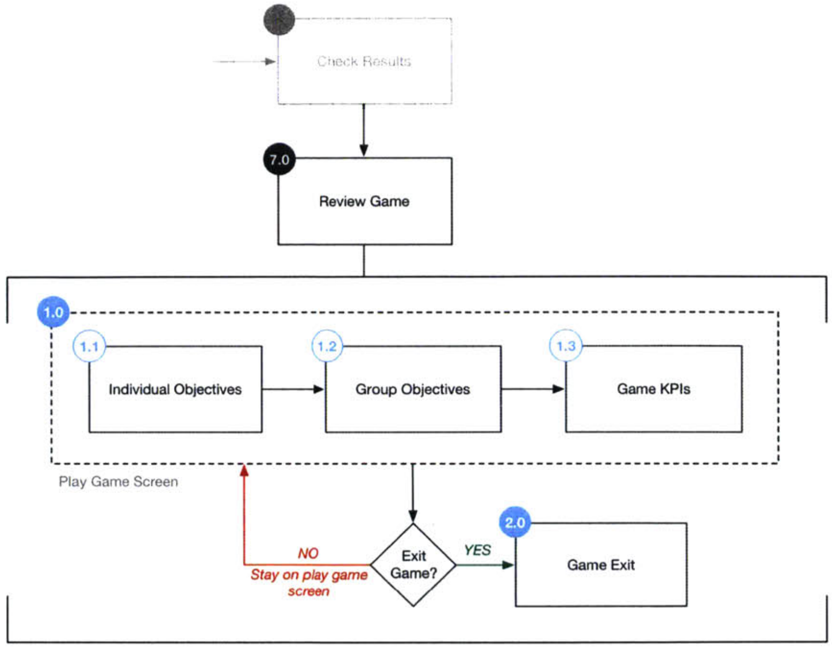


Figure 3-15: Review and analyze game play flow.

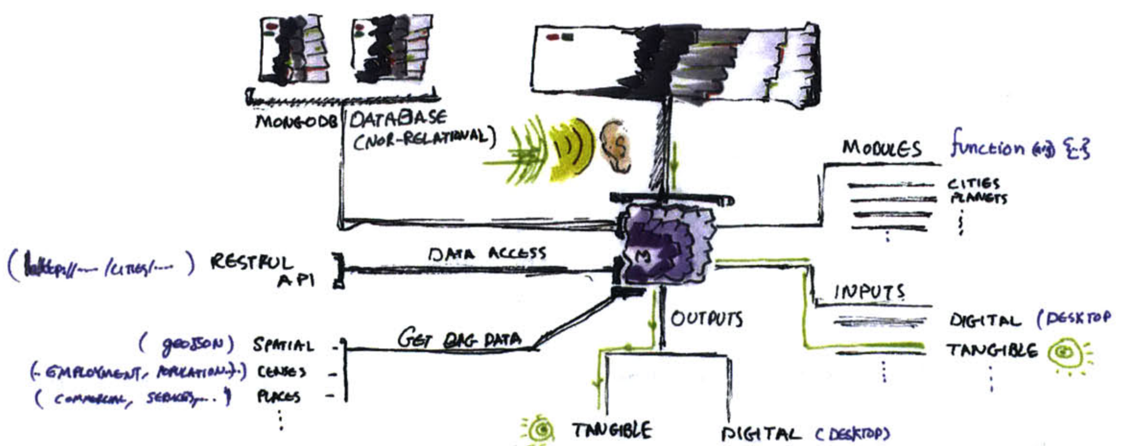


Figure 3-16: CityGame framework (central object) to support multi-modal interaction, client-server communication, and communication with the database.

management. CityGame is designed and developed as a framework to support multi-modal interfaces and multi-player interaction. In addition, CityGame is designed to be a light weight real-time web-based negotiation and decision-support application that enables stakeholders to collaborate remotely, or when they collocated within the same physical space. Currently, CityGame is hosted on a public server which is accessible at *http://citygame.media.mit.edu* (accessed: May 6, 2016).

To support all these features, and future scalability, CityGame is designed as a web-app using the Model-View-Controller (MVC) paradigm. It's developed using the Angular-Meteor environment. In earlier stages of the development, socket.io and node.js were used as the framework. This approach was time-consuming, and a decision was made to move to Angular-Meteor framework for the development. It supports real-time application, and connects to a MongoDB database, which is the primary game database, smoothly. In addition, Angular-Meteor supports the MVC paradigm, which makes it easy to scale and makes the code readable.

In this section, the CityGame framework architecture with its components, data structure, and computational model are discussed. In addition, the Graphical User Interface (GUI) and the Tangible User Interface (TUI) are both presented, as well. Since some of the sections use some terminology from the data structure, it makes sense to discuss it first.

3.2.1 Data Structure

Generally, CityGame structures the data in the following way: On the highest level, there's a case that holds multiple scenarios. Each group that wants to discuss that specific case are playing the game. Then, in each game/case[5], players take turns to make multiple moves.

Groups CityGame groups consist of four different players, one of which is considered to be the owner of that group. Players can be part of different groups, and therefore negotiate/play in different cases/games. In current version of the game, roles are assigned to players in a group randomly. Once a role is assigned to a player, he/she cannot change it within the group, but could create a new group and invite the same players to generate new random roles for the same participants.

[5]game and case are used interchangeably in this section

Cases A case, as mentioned earlier, is the highest level of the data structure. Each case is unique and contains one group, a case owner, a set of scenarios and game/case status (completed, total time, final score, total rounds and moves, and site location...etc). Also, it contains players roles, and their initial condition (scores and numeric values of their objectives).

Scenarios A scenario is a set of inputs and outputs for a specific move. That is, the layout of the plan with results at that time. In the current game, each player's move counts as a scenario. Therefore, the number of scenarios in a given case equals to the total number of moves occurring in one game. Each move results in new outputs of the model, which could affect their next move.

Figure 3-17 shows the Entity Relations Diagram of the CityGame data structure. The detailed JSON structure can be found in the appendices section.

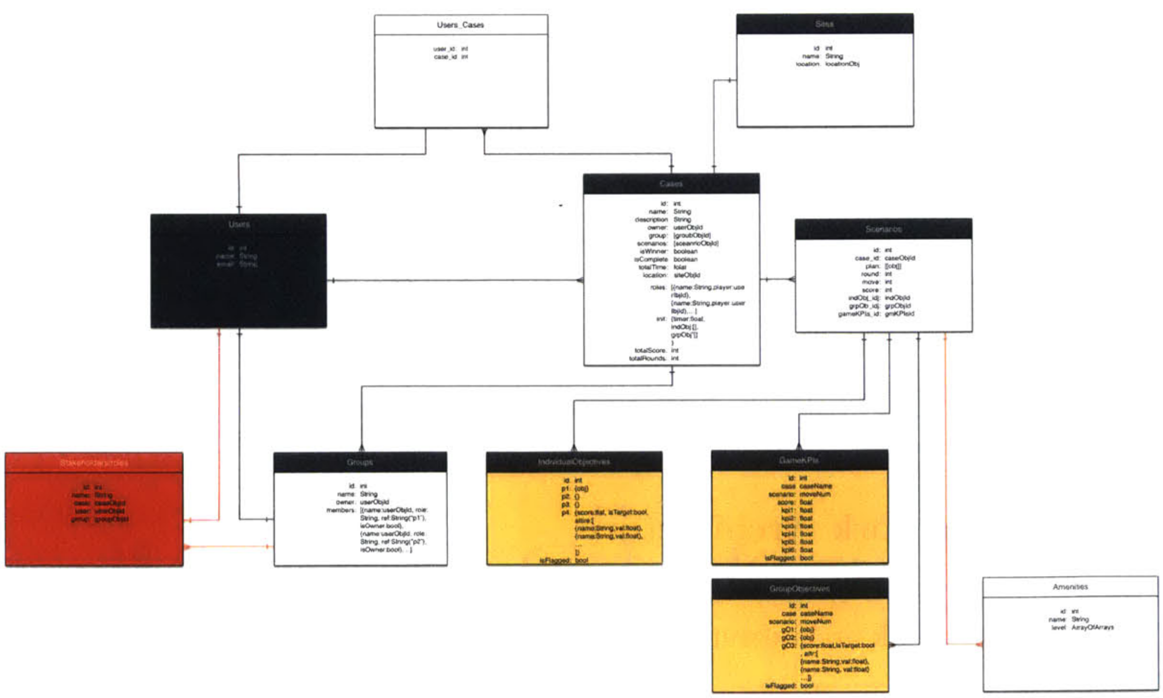


Figure 3-17: Entity Relation Diagram (ERD).

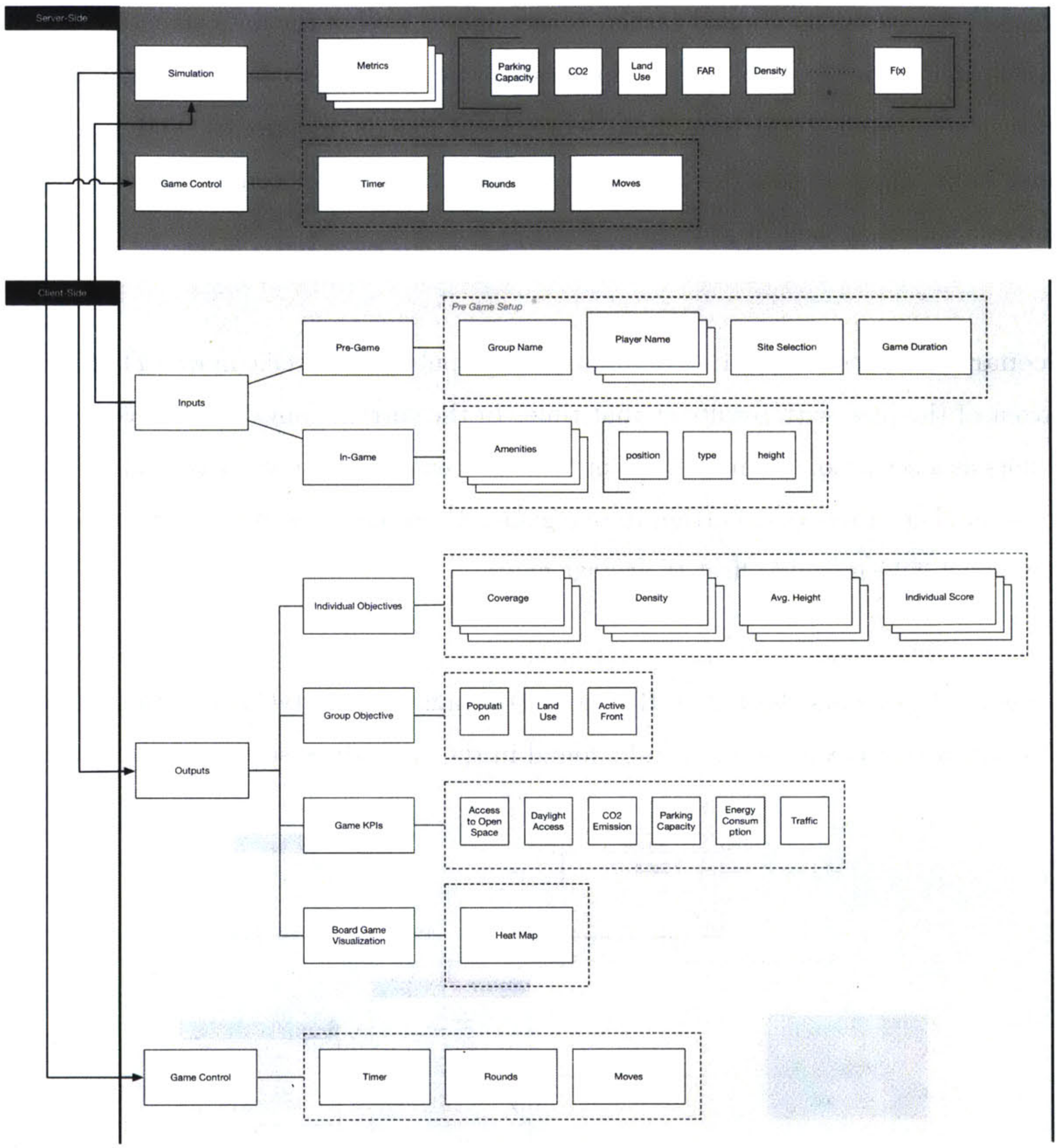


Figure 3-18: System architecture.

3.2.2 Framework Architecture

CityGame framework architecture (Figure 3-18) consists of three main components: 1) the data component, 2) the computational component, and 3) the interface component. With the server-client architecture, both the data and computational components reside on the server-side, whereas the interface components reside on the client-side. Figure 3-19 and Figure 3-20 show the server-side architecture and client side architecture respectively.

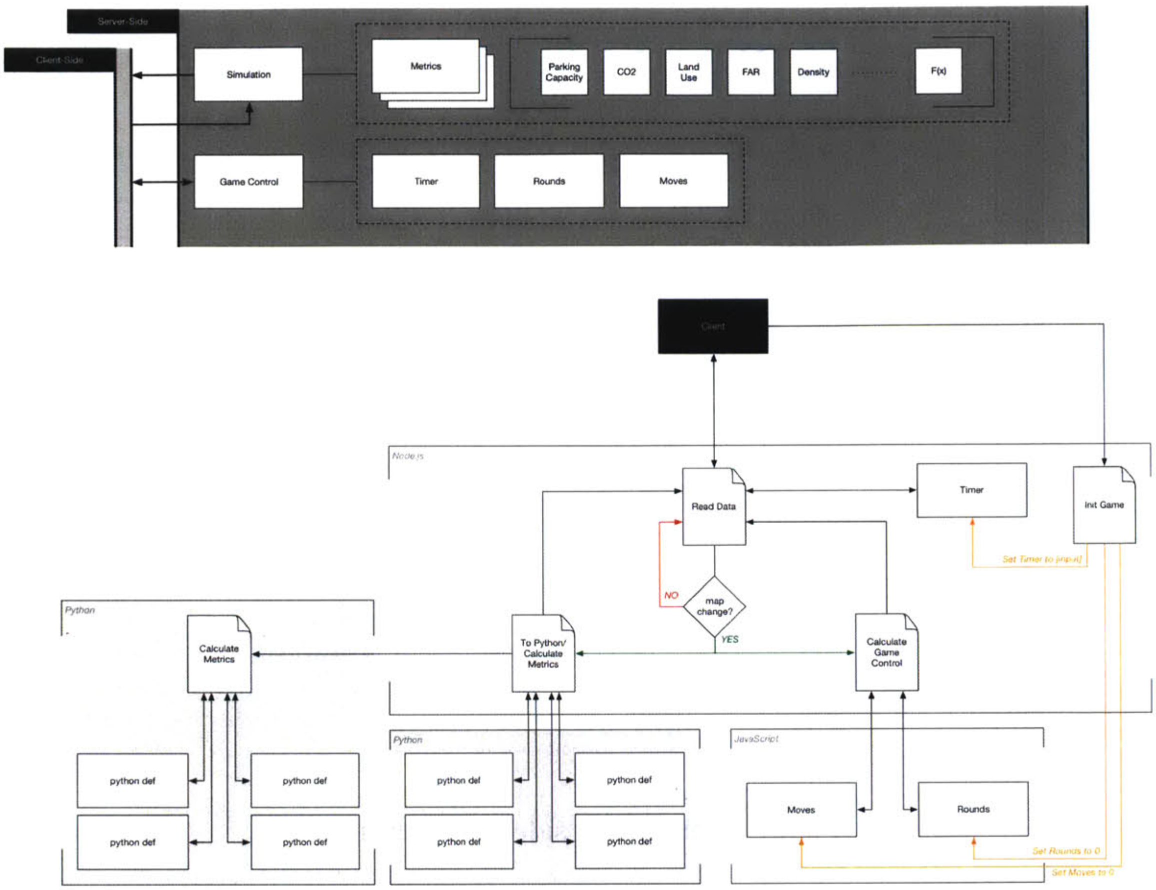


Figure 3-19: Server side architecture.

Data Component

MongoDB is used as the database for CityGame. Groups, Cases and Scenarios each have a separate collection in the database. Each document in the Cases collection contains an array of related Scenarios' IDs instead of embedding the actual scenario data in each document of the Cases collection.

As MongoDB has a separate server, Meteor handles the requests in real-time reliably. Currently, only CityGame users who are logged in can access the game data, review previous games and play the game. Also, to review and check previous cases,

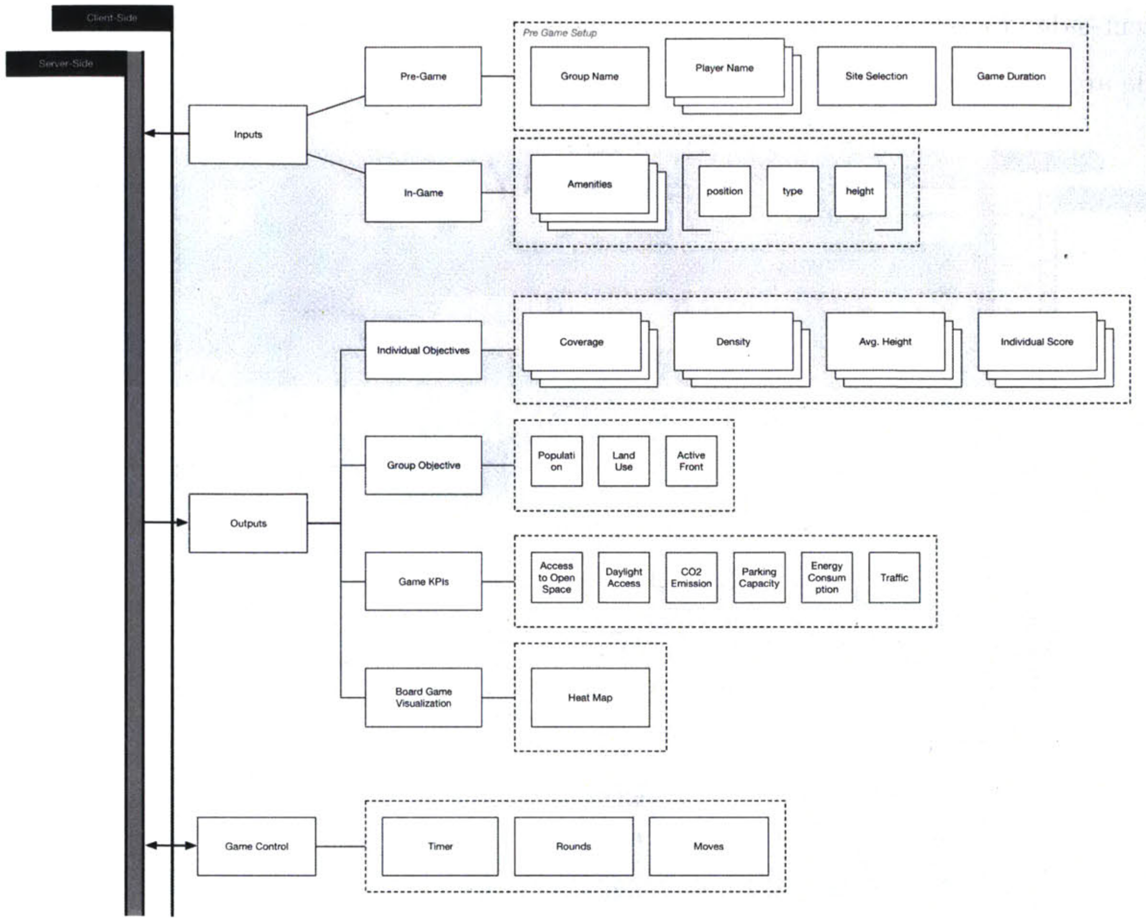


Figure 3-20: Client side architecture.

only players participated in that specific game/case can see/review the results and analyze the scenarios.

Computational Component

For computational performance, computing the different metrics happens in the server-side, but using python. One of the reasons was to accommodate complex computations in real-time. This includes operations to compute graphs/networks problems, and NetworkX python package is recommended for such operations. Some examples include computing traffic and average commute time when we have a populated plan.

Interface Component

The Interface component contains both the tangible and graphical user interfaces, as well as the data visualization. The modularity and flexibility of the interface component allows it to be accessible via different modes of interactivity such as tangible, multi-touch and mouse/pointer. Section 3.2.4 and 3.2.5 discuss those interfaces in depth. I used d3 for visualization and javascript/html/css/less for other interface elements. In addition, LEGO bricks are used for the tangible mode of interaction.

3.2.3 Computational Model

In the game, all computational metrics are computed using python on the server-side. In the python code, a main file exist to call the different metrics as functions. First, it calls a parent function that takes the plan layout and prepares it for the metrics computation calls. In addition, it computes players' scores and the total game scores. This call occurs every time a player makes a move, such as adding, removing or updating an amenity to the plan.

During the game, the Meteor server-side receives a call to compute the passed plan layout. The execution of the python script is called within the Meteor environment. Once it receives the results, Meteor adds the results to the database, which updates the client-side user interfaces.

3.2.4 Graphical User Interface

In this section, earlier prototypes are presented. In addition, the current game interface design and the visualizations used are discussed.

Previous Interfaces

I started by creating a quick prototype with paper and sticks to test the game interface. Figure 3-21 shows the game prototype in an earlier stage of design. One of

(a) Prototyping with papers and sticks (b) prototype of the game board

Figure 3-21: Earlier prototype of the game interface and interaction.

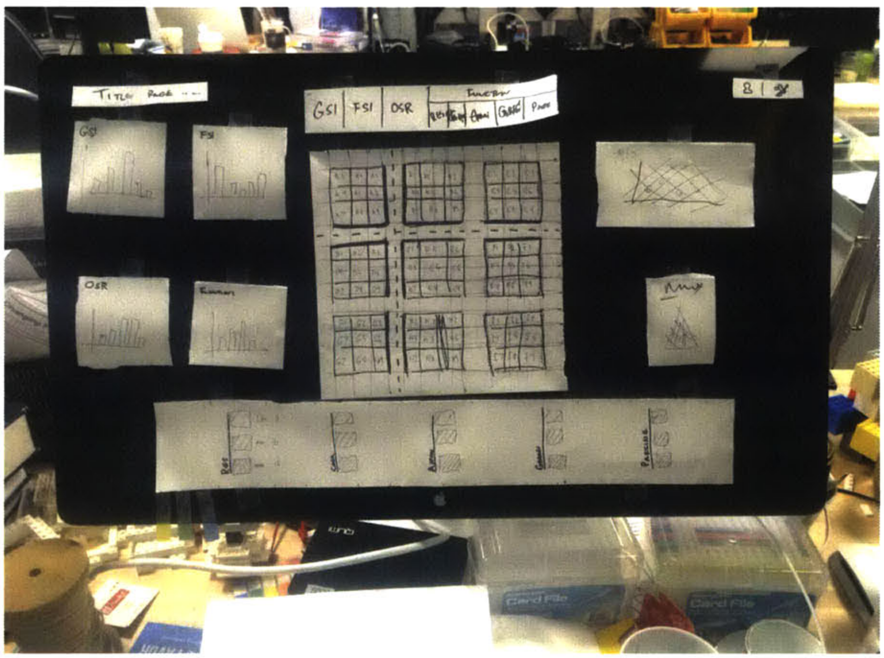


Figure 3-22: Paper prototype on an actual monitor.

the issues in designing the game interface is how much information should be presented on the screen at a time. The game includes four different users with conflicting objectives, which requiring a different view for each user. This is a very expensive process from a design point of view. Therefore, I tried to abstract and standardize the visualization and layout on the screen. Once the metrics were identified, and basic visualization methods were used, I did a quick prototype on how to distribute those visualizations and gameboard on the screen. Figure 3-22 shows the paper prototype of the layout design.

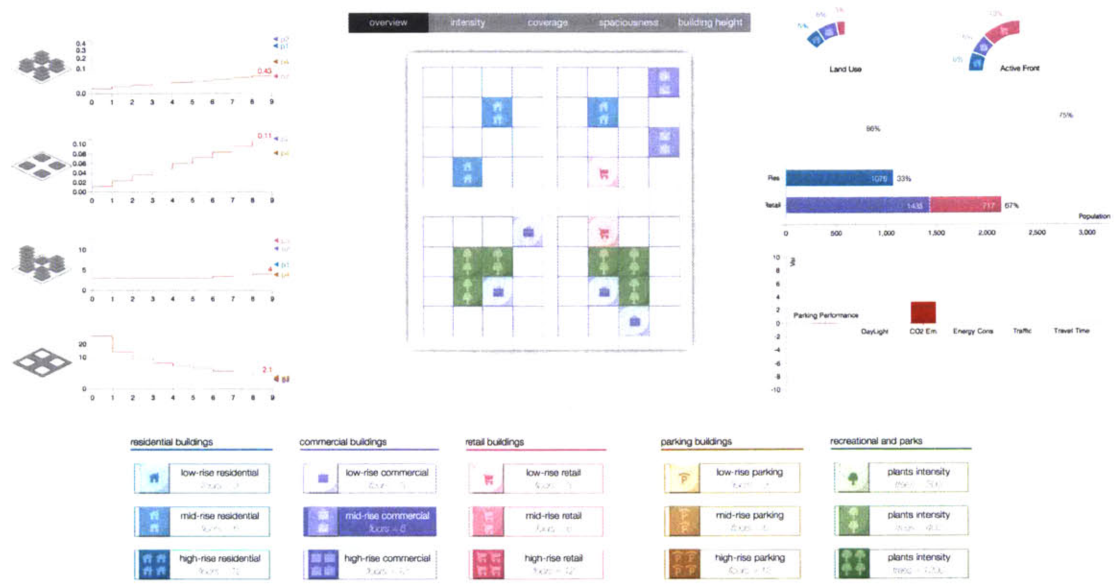


Figure 3-23: An early version of the CityGame game interface.

Once the layout was set, I started to develop the game interface, and test it with users. The early version was very aesthetically pleasing and easy to use. However, the amount of information and the number of elements changing on the screen per move was confusing to players. It was difficult for players to follow the changes. Figure 3-23 shows an earlier version of the game interface.

Current Interface

To continue developing the game, a context to set the mood of players and a general walkthrough was important. Therefore, I designed a whole experience that takes the players from entering and setting up a game, all the way to analyze the results after the game. The game flow starts when a player/user is entering the site, and is required to login to the CityGame webapp. The general flow of the experience is shown in Figure 3-25. Here are general flow details of the game:

Login (1.0) Users need to login to the CityGame platform in order to play the game. This step is required to authenticate different users, and allow them to create

Figure 3-24: CityGame game interface

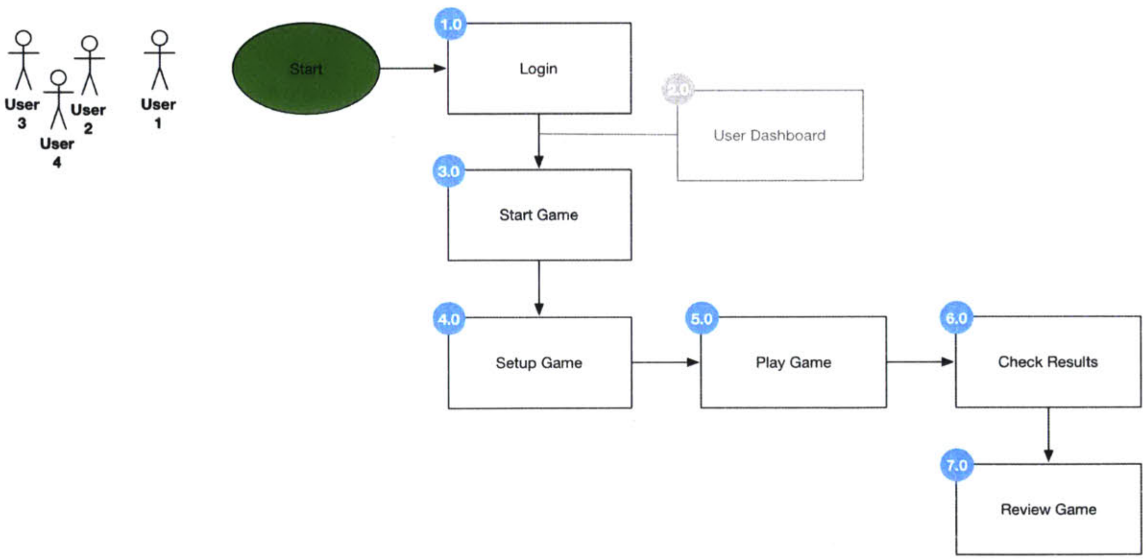


Figure 3-25: Overall game flow.

different groups, check scores, review the game and share results.

User Dashboard (2.0) Not implemented at this stage.

Start Game (3.0) Once the user has browsed the website, and are on the "play" page, they see a "start game" jumbo button, along with simple/quick tutorial of starting a game.

Setup Game (4.0) This is a set of screens to set up the game environment. Users are able to select or create a group name, as well as players names/contact (for survey). In addition, the user sees a confirmation of the entries, and is assigned a role randomly. Then, the user selects a site (existing redevelopment site), or creates a new site. Afterward, the user sets the timer for the game and confirm the entries, and finally starts the game with the entered setups to play.

Play Game (5.0) This is the simulation/game-board screen. Users see two set of analytics, individual analytics, and group analytics (outputs). In addition, a set of KPIs (outputs) is visualized differently, and allows users to toggle through each KPI to visualizes them on the game-board using heat map visualization. A set of amenities (inputs) can be dragged on to the game-board, which affects the game simulation. Two additional components of the game are displayed on this screen, a messages/notifications card area and an overall score and timer area with save/submit buttons. Users spend most of their time on this page until the timer goes off, or until the players submit their proposed plan. After that, players are directed to the results screen.

Check Results (6.0) This screen shows the overall score, number of rounds and overall time of this group compared to others who played the game on the same map. This screen shows a button/link to extend the view and allows users to compare individual performance vs group performance. Users can share their results report online, or email it to themselves, or other people.

Review Game (7.0) Review Game screen provides the user with an area to leave feedback and answer a quick survey on their actual satisfaction of the plan and the game play.

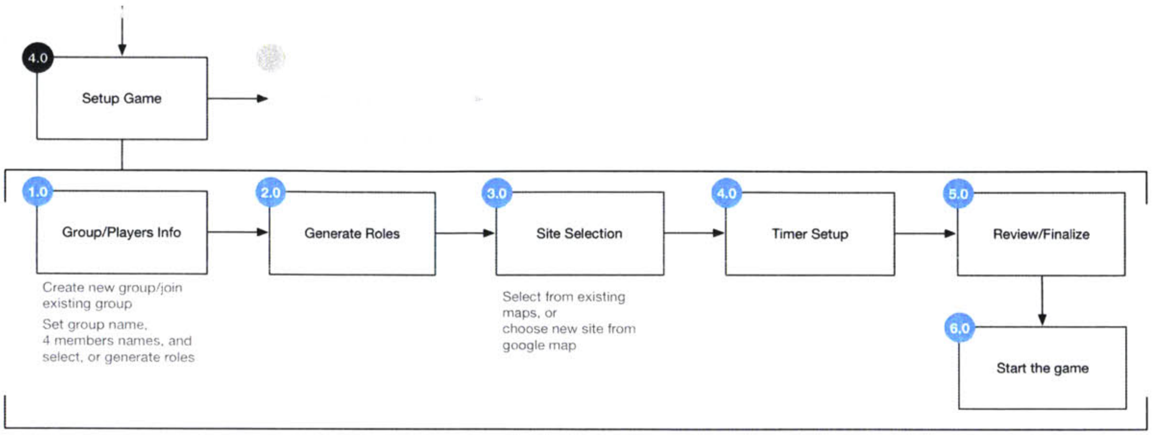
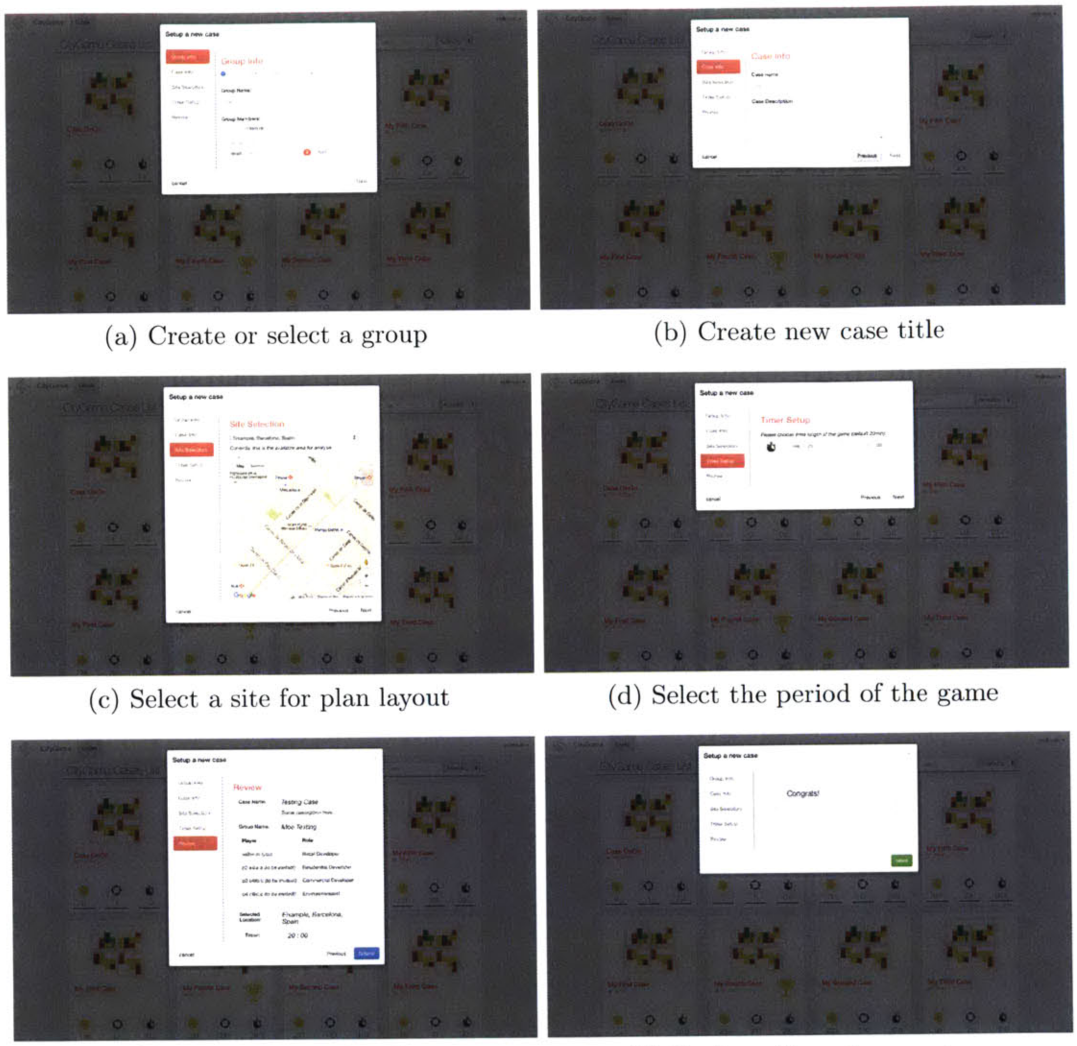


Figure 3-26: Setting up a game for the first time flow.

To setup the game, players need to log in first. The flow of setting up the game is shown in Figure 3-26, and Figure 3-27 shows the interface for game setup. Here are the details of those steps:

Group/Players Info (1.0) In this screen, the user either selects a created group, joins an existing group (advanced feature), or creates a new group name. If the option to create a new group name is selected, the user enters the name of the group and enters four players names with their email addresses. If the user selects a created group, the list of user names and their email address will fill the existing fields. If the user selects to join an existing group, this option allows the user to join online groups and he/she will be a participant and not able to choose a site only to play the game. This is an advanced feature, which will be included in future updates.

Generate Roles (2.0) Once the user fills the group name, and users names and emails and clicks submit, this screen will show the names and their corresponding roles. Then, the user clicks the next button at the lower bottom of the screen to continue setting up the game.



(a) Create or select a group

(b) Create new case title

(c) Select a site for plan layout

(d) Select the period of the game

(e) Review setup details

(f) Confirmation of case setup

Figure 3-27: Earlier prototype of the game interface and interaction.

Site Selection (3.0) In this screen, the user selects a predefined site area from a list, or uses the google map option to browse the map and choose a different site and adjust the resolution/scale of the grid. Once a preferred location is selected, the user clicks "next" to proceed to the "Timer Setup" screen.

Timer Setup (4.0) In this screen, the user sets up the length of the session/game. The timer will be set with a default value, which is the recommended value. Users then can either increase (easy mode), or decrease the timer (challenge mode) as a preference. This is the last setup screen, then the user click the "review setup" button to finalize the entered info before they start the game.

Review/Finalize (5.0) In this screen, the user sees the entered data: Group Name, User's First Name and Last initial, their roles, thumbnail of the site selected, and the game length (timer length). Once the user has reviewed this data, he/she can start the game.

Start the game (6.0) This is a button that appears at the end of setting up the game. It will take the players to the game/simulation platform to start playing the game.

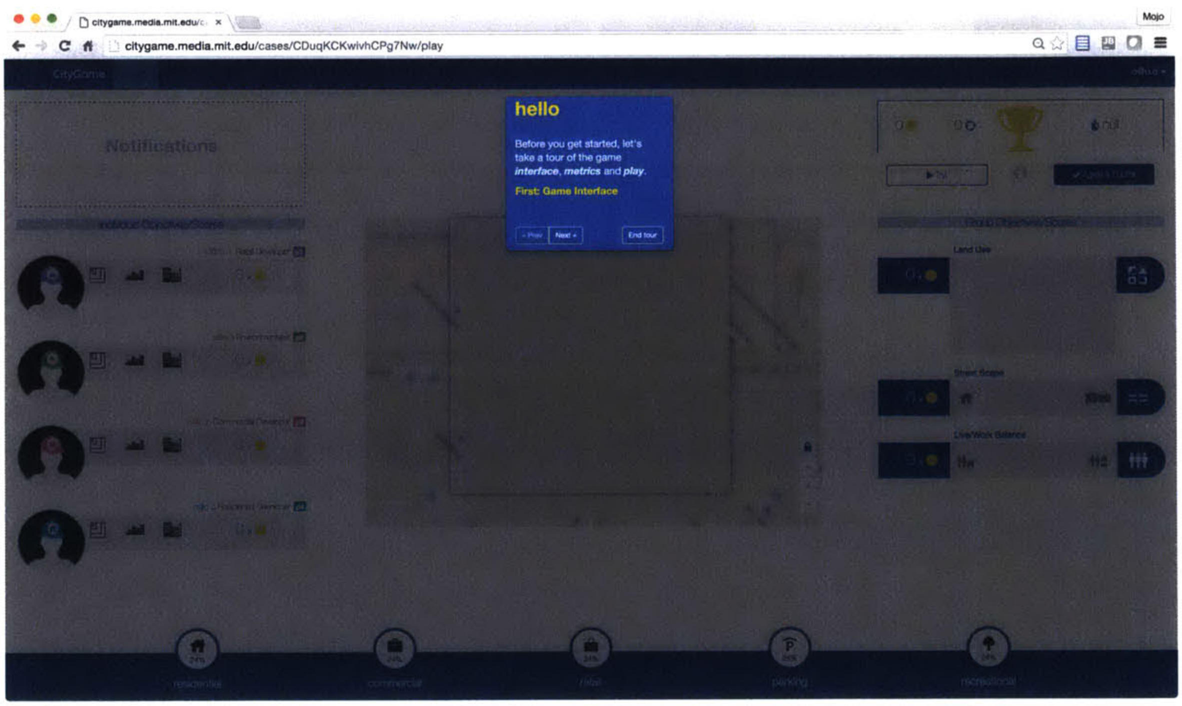


Figure 3-28: A notification to the player about starting a tutorial/guide.

After the game is set, players are ready to start the game. Users have the choice to take an interactive tutorial (Figure 3-28) that guides the players through the game interface, different objectives, and the game KPIs. Figure 3-31 shows the current game interface. The interface has seven main components, namely 1) gameboard, 2) amenities/tiles, 3) individual objective, 4) group objectives, 5) game KPIs, 6) notification area, and 7) overall game stats area.

1) Game-board This is the area where players add the different amenities. In this game, the area is divided into 11 X 11 plan, where the white cells are roads and cannot be modified. The light brown cells are vacant cells and accept inputs from players.

Figure 3-29: A view of the game amenities interface panel.

2) Amenities/tiles This part holds all the different tiles/amenities that are inputs to the system. For each input type (residential, retail, commercial, parking and recreational) there are three levels that are described in Section 3.1.3.

3) Individual objective At this stage, the current interface considers players who are collocated in the same physical space. Therefore, this area shows the score and progress of the four players simultaneously.

4) Group objectives This area visualizes the group objectives, and shows the score for each one.

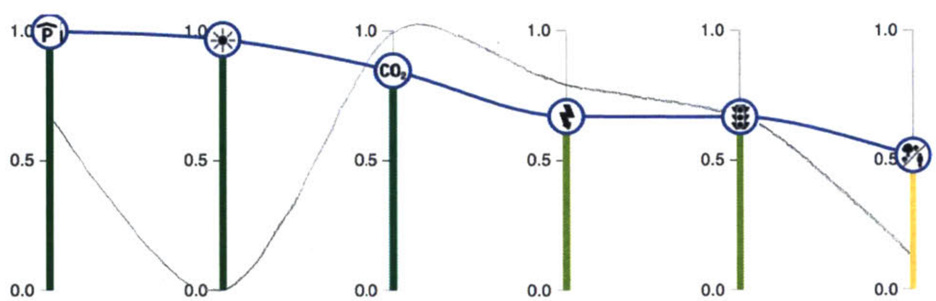


Figure 3-30: Game KPIs parallel coordinate visualization. Each indicator icon can be clicked to visualize the output on the plan layout.

5) Game KPIs Here, players see the the performance of their plan. The higher the value the better the plan is (Figure 3-30).

6) Notification area When each player is done with his/her move, a message will pop up in this area to notify the next player, and coordinate the flow of the game.

7) Overall game stats area This area shows the total game score for every move and the time remaining. Also, to save a state of a plan for a specific user, a save button is visible in this area for users. Also, when players are done and have agreed on the proposed plan, a "submit plan" button is available in this area.

Figure 3-31: CityGame case review interface

When players complete the game, they are redirected to the detailed case page/view. This time, players will see the history of their moves and can go back and forth in time to see the performance move by move.

Visualization

All the visualizations in this game are built using the D3 (Data-Driven Documents) javascript library. In the **game interface**, colors for the visualizations indicate how good or bad that metric is performing. The colors are quantized to five values from

Figure 3-32: Game KPIs parallel coordinate visualization. Each indicator icon can be clicked to visualize the output on the plan layout.

bad performance to good performance (red, orange, yellow, light green and green) (Figure 3-32). For the *individual objectives*, simple bar charts are used for each player objectives in combination with the colors. For the *group objectives*, I used a radar plot with rounded edges to show if the plan is balanced (mixed-use functions) between residential, commercial and retail buildings. To provide a finer detail, a circle in the middle of this plot is visualized, as well. In addition, a simple slider effect is used to visualize the Live/Work Balance. The plan is considered balanced if the rectangle is in the middle. For the Streetscape visualization, the same method is used as in the Live/Work Balance visualization. However, the rectangle needs to be closer the nonresidential side to be performing well. Finally, *Game KPIs* visualization is visualized with parallel coordinate visualization, where each metric has its own axis. This particular visualization keeps records of the performance for every move and visualizes it in gray color. It supposed to show how the current plan is performing compared to the previous ones.

In the **review game interface**, *individual objectives*, *group objectives* and *game KPIs* each uses a single multi-line chart to visualize the performance of each metric over moves. That is the x-axis is the moves per game, and the y-axis is the normalized value of the metrics per move.

3.2.5 Tangible User Interface

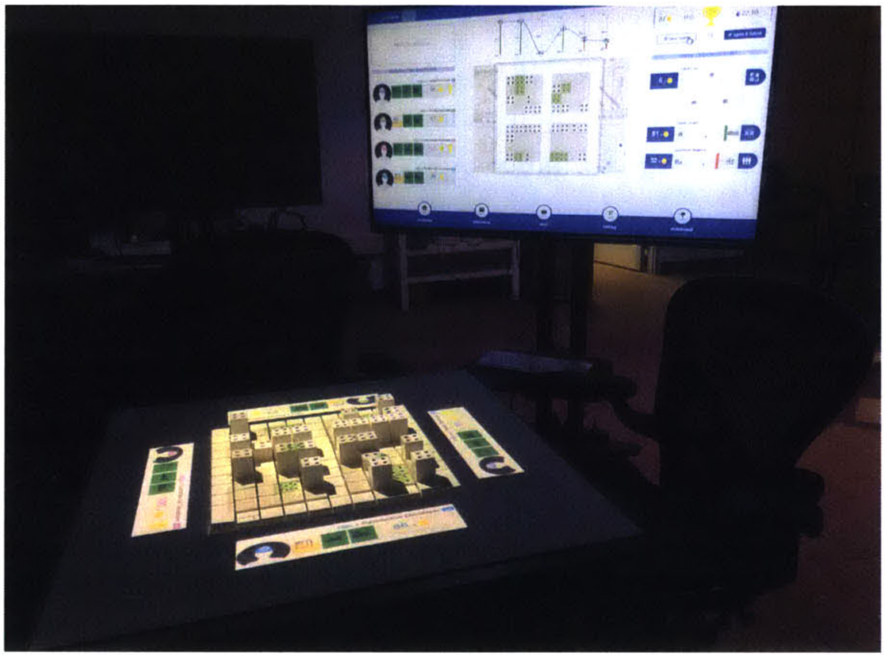


Figure 3-33: CityGame Tangible User Interface combined with a screen to display CityGame GUI with additional game stats.

The tangible interface is similar visually to the graphical user interface. It uses the same framework and interface elements. However, three main differences that differentiate the two interfaces can be seen in the **game interface/view**. These are the 1) game-board area, 2) objectives visualization, and 3) game amenities/input tiles (buildings and parks).

Game-board Area

The game-board area here is a physical transparent gridded board-game. It has a grid of 11 X 11 grooved cells for game tiles inputs.

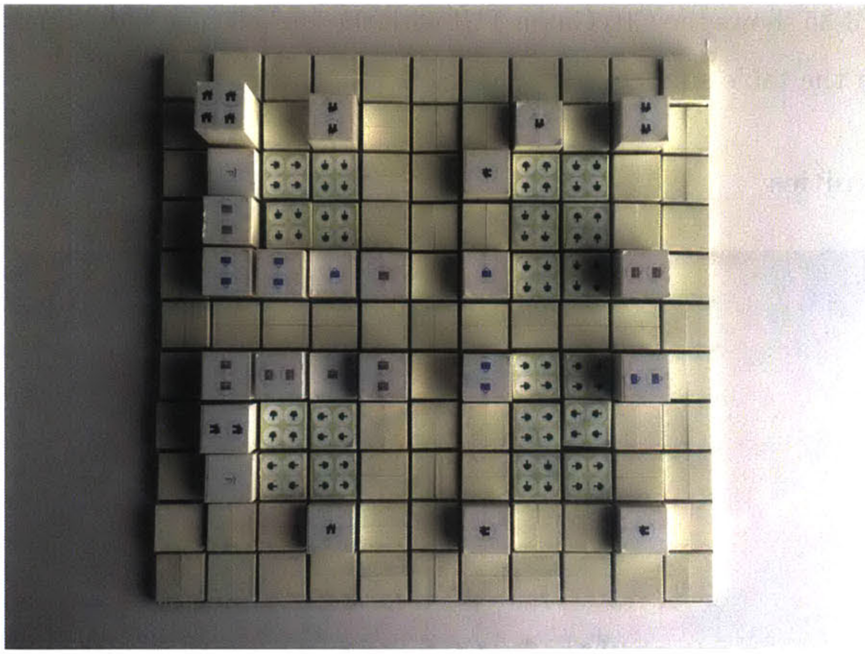


Figure 3-34: TUI gameboard top-view.

Objectives Visualization

Figure 3-35: CityGame Tangible User Interface with boardgame, amenities and individual objectives visualized on the same game surface.

Here, individual objectives are visualized on the table surface in front of the player seat. Figure 3-35 shows the CityGame TUI with the four players' individual objectives visualized on the table surface.

Game Amenities

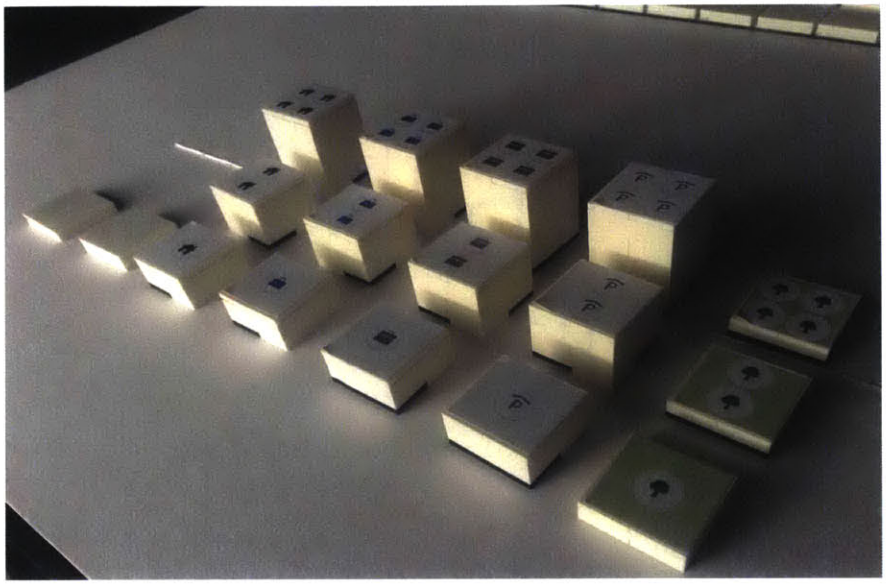


Figure 3-36: TUI amenities code buildings height into LEGO bricks height. Parks different levels don't change with LEGO height.

One aspect of using the tangible interface is to encode some information about the game variables in the physical property of the object itself. Here, I used the height of LEGO bricks to encode each amenity/building level (3, 6, or 12 story building). This can be seen in Figure 3-36. One LEGO brick height, equals 3 story building height. Although this is a linear encoding, its purpose is to reduce the cognitive lode from all digital information, and provide a depth to the 2D plan.

Interaction with Game Environment

Every LEGO piece is color coded from the bottom. Using basic computer vision, and a camera beneath the surface of the table, I'm able to detect the different amenities/tiles of the game and then send it via UDP to the server. The server reads the code and decode the type and insert the plan to a separate collection in the database. In the tangible mode, the framework monitors the activity of the tangible collection in the database, and update the plan with the physical construct of the game plan. This is rendered after the server executes the python script and returns with the computational results.

Chapter 4

Evaluation Criteria

To evaluate the impact of the different computer interfaces on the negotiation and decision-making process, I conducted a user study to evaluate players interaction and communication with each other, as well as their interaction with the different interfaces during the gameplay. Chapter 5 discusses the CityGame experiment in detail.

CityGame evaluation follows the Computer Supported Collaboration Work (CSCW) evaluation methodology. Specifically, I reviewed different methodologies and found the McGrath books on Group communication a great base to evaluate the collaboration process. However, the Methodology for Evaluation of Collaboration Systems article [8,10], simplifies the whole evaluation process, which also references and inherits work from Grudin and McGrath [13,19]. In the evaluation document, the authors described the evaluation on different levels of the system. These levels are, the requirement level, capability level, service level, and technology level. CityGame uses a scenario based evaluation process and follows the framework methodology document for its evaluation. Each evaluation level and all measures and metrics are discussed here. Unfortunately, due to time constraint for this thesis, not all the metrics considered here will be analyzed. However, data is available for further analysis.

4.1 Requirement Level

This level evaluates how well the system/framework supports the work tasks, transition tasks, social protocol and group characteristics.

4.1.1 Work Tasks

There are nine work task types described in [8], which is one task more than what is presented in McGrath [19]. However, CityGame considered the following three task types:

"Type 4: Decision-making Task" Participants will be asked to develop consensus on optimizing a plan layout. For this task, the shift in group and individual decision is measured

"Task type 5: Cognitive conflict task" Participants will be asked to make a series of decisions every round as a group. The related measures considered for CityGame are:

- Agreement among members on the plan layout.
- Changes in player/participant's view in regard to planing strategies, or moves.

"Type 6A: Negotiation Task" The game roles in CityGame assumes that each role represents the organization as negotiator to advocate for their plan/objectives. For example, the residential developer represents the organization that he/she works in to maximize residential development in the area. Therefore, there are tradeoffs between the different players that have to be made in multiple dimensions. Although there are tradeoffs between the players, CityGame is not a zero-sum game. This task will not be studied in this thesis, but it's important to describe when it's used with larger groups. The following are the related measures to be considered for this task:

- Time to reach consensus
- Task completion

- Interpersonal relations between group members

4.1.2 Transition Tasks

CityGame transition tasks include transitions between rounds. That is, transition between populating the plan (modifying the proposal) and the test of consensus task after each round. Also, transition between populating the plan and discussion is considered. In CityGame, time is the main measure considered for these tasks.

4.1.3 Social Protocol

Social protocol in CityGame could impact the outcome of the task. Social protocol includes homogeneity, number of participants (four per group) and type of sessions (GUI and TUI). The related measures considered for CityGame are:

- Conflict in turn-taking/moves
- Awareness breakdown (questions asked)

For the qualitative approach, a coding scheme that categorizes players' behaviors during their collaboration and communication, is used. Every session/scenario is conducted in a lab setting, and video recorded for our observation.

4.1.4 Group Characteristics

Different groups have different requirements, but CityGame has predefined group characteristics. Groups will participate at different times, and there will not be overlap between groups. Participants within a group will be co-located in the same physical space and stay for the whole duration of the experiment. Each group has four participants and receives the same amount of time for training. Gender and background of group participants will be diverse.

4.1.5 Summary of Measures and Metrics

For this evaluation level, the following measures with their metrics are observed during the study:

- Task outcome
- Cost
- User satisfaction
- Interoperability
- Participation
- Efficiency
- Consensus

Task Outcome Metrics

- Calculate the number of scenarios generated per session
- Did they complete the task before the end time?
- User ratings on the submitted proposal (game plan layout)

Cost Metrics

- Learning time
- Number of rounds/turns
- Length of each round and turn

User Satisfaction Metrics Using a Likert scale, participants were asked to rate their satisfaction on the scenario, within group collaboration, and their role.

Interoperability Metrics This includes which tools and features were used, and how often they were used in each session.

Participation Metrics

- $\#sentences/turn$
- User ratings on their individual and group participation.

Efficiency Metrics Percent efficiency is used here.

$$\%\ efficiency = \frac{\#\ scenarios}{time\ (session)}$$

Consensus Metrics

- User rating on agreement with the outcome
- Number of turns
- Length of turn
- Conversational construct

4.2 Capability Level

This level evaluates how well different capabilities support the work tasks, transition tasks, social protocols, and group characteristics [8]. Groups in this study will be collocated in a shared workspace. They will have access to all physical objects (LEGO bricks and keyboard), and software objects (visualization, and graphical elements, timer, rewards...etc). Participants have the capability to modify the plan anytime (on the TUI and GUI), transition between tasks and monitor members' progress over scenarios.

The following are the different measures considered at this level:

Awareness Metrics This includes user ratings on their awareness of the different objectives in the game, and their roles.

Collaboration Management Metrics Mainly looking at the floor control aspect.

Communication Metrics

- Number of turns per participants
- Number of Overlaps (simple and interruption)

Grounding Metrics Similar to metrics used for consensus measure at the requirement level in Section 4.1.

Task focus Metrics This is the ability to focus on the task at hand.

$$\frac{(Overall\ time - Transition\ Time - Other\ Time)}{Overall\ Time}$$

4.3 Service Level

This level evaluates how well a given capability would be supported using a particular type of service [8]. Measures included are:

- Breakdown: how often a user has to rationalize a problem experienced.
- Tool usage (which interface elements were used and how often.)

4.4 Technology Level

This level examines usability measures on CityGame [8]. Using user ratings on Likert scale, CityGame used the USE Questionnaire: Usefulness, Satisfaction, and Ease of use measures [18].

For the addressed measures, and to gather the required metrics, the following methods are used for data collection. 1) logs from the CityGame framework, 2) direct observation during the session, 3) questionnaires and semistructured discussion (group interview), 4) audio recording for those discussion sessions, and 5) video recording for all conducted and observed sessions. The next chapter discusses the CityGame experiment, its design, setup, procedure and analysis.

Chapter 5

The CityGame Experiment

5.1 Experiment Design

In the CityGame experiment, 32 participants volunteered to play the game. They were undergraduate, graduate, staff and faculty, with various backgrounds and ages. Participants were asked to signup with their availability for multiple sessions, so that four participants could be matched to play the game simultaneously while they are collocated in the same physical space. Each group was assigned a group ID and scheduled for a 2-hour session.

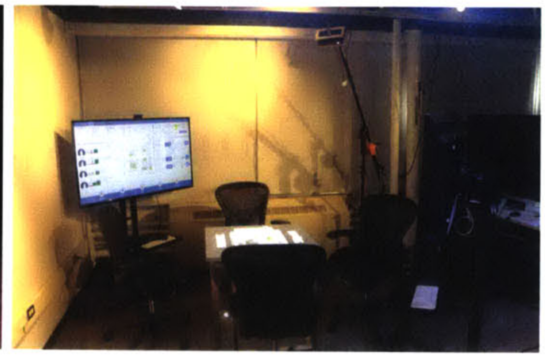
In this experiment, participants were assigned random roles (retail developer, residential developer, commercial developer, and environmentalist). Each participant received an individual objective that slightly conflicts with other players' objectives. Such objectives might be to maximize the density of building in an area, minimize building coverage...etc. In addition to the individual objectives, players need to achieve group objectives and maximize game KPIs collaboratively.

Task All the participants received the same task during the introductory presentation. The task in the game was "to find an **optimal layout** for a new neighborhood, and **reach a consensus** with other stakeholders while **maximizing** your *individual objectives*, *group objectives* and *game KPIs.*"

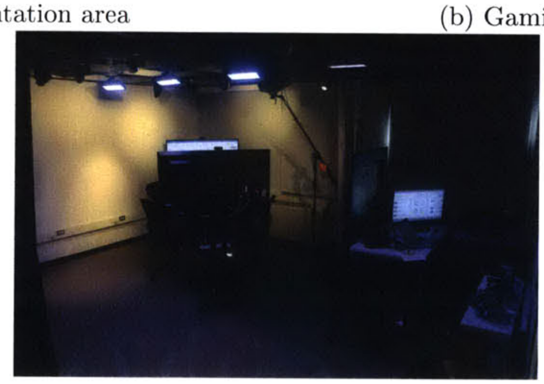
The physical setup, the procedure, and the analysis of the experiment are presented next.

5.2 Physical Setup

(a) Presentation area



(b) Gaming Area



(c) Monitoring and gaming area

Figure 5-1: Room setup for the CityGame experiment. Game introduction and final discussion occurred in the presentation area. Participants engaged with the TUI and GUI of CityGame in the gaming area. Game progress was observed from the monitoring area.

The CityGame experiment tool place in the Center for Complex Engineering Systems visualization lab, MIT building E38. The room was divided into three areas as shown in Figure 5-1: 1) presentation area, gaming area and monitoring area.

5.2.1 Presentation Area

In this area, participants attended the mandatory introduction of the experiment, filled the questionnaire after each session, and participated in the 20 minutes semistructured discussion at the end of the experiment. During the discussion, a camera was placed in the corner of the room to record participants' reactions. In addition to the video recording, the audio was recorded on a separate device as a fallback measure.

5.2.2 Gaming Area

The gaming area is set up with a square table and four chairs facing each others. On two opposite corners of the table, two large monitors were placed (about three feet apart from the table's corner), and a camera on each monitor was set to record the communication between the participants. The two monitors were used to display the GUI interface in both experiment sessions (GUI and TUI). This is to have equal number of rotations per participants to monitor game metrics activities during the TUI session. In addition, a third camera above the table was set to record hand gestures activities for the TUI session. Unfortunately, not all sessions were recorded from this angle due to technical issues.

5.2.3 Monitoring Area

A third part of the room is set to monitor the game and participants activities during the sessions. In the TUI session, a camera underneath the game table is used for scanning the plan grid and building codes during the session. This camera can be easily interrupted during the session, which requires an immediate calibration (hardware and software).

5.3 Procedure

The CityGame experiment is designed to be a within-subjects study and took 2-hours per group. The first 20 minutes was reserved for a pre-session mandatory introduction. Then, two game sessions were followed with 30 minutes for each session. There were 5-10 minute break between sessions. Finally, a 20 minutes semi-structure discussion took place at the end of the experiment.

5.3.1 Introduction

At the beginning of each experiment, participants were invited to the *presentation area*, where they signed the consent forms and filled out a quick demographic questionnaire. In this stage, participants were introduced to each other (name and background) were offered coffee/snacks that were prepared before their arrival. An introductory 10 minute presentation followed to introduce the schedule, nature of the game, tasks, objectives, gameplay and score computation methods. Participants were encouraged to ask questions during this session. In this presentation, it was mentioned that getting all metrics to be green is good, and red is bad. That is for game simplicity if participant got confused about metrics computation logic.

After presenting the objectives, groups were encouraged to discuss and choose what is important to achieve in the game, and whether they want to optimize the plan for a specific metric. That is after they understood how to maximize their game score.

5.3.2 Game Sessions

After the introductory presentation, participants received their roles and went to the *gaming area*. Seats were assigned by role names, and each participant took their role's seat. Participants were guided through each interface, and took 5 minutes to try the game, turns and moves. At least one round is completed before the actual experiment. Participants gave a verbal consent when they were ready to start the experiment. At that point, both cameras over the monitors started to record the session, and the game is initialized with a clear game-board/plan (values were zeroed). The timer in the game interface is set to 15 minutes, and the start button is then clicked.

Players were informed that they can use other roles' amenities, and if they want to pass their turn/move, they can negotiate it with other participants. During the game, each player has three moves to change the scenario of the plan before the turn changes to the next player. After all the players finish their turns, they were requested to discuss the plan and whether they want to submit it, or continue other rounds.

Post Session After each game session, participants were directed to the *presentation area* to fill out a questionnaire about game scenarios, interface usefulness, ease of use, ease of learning, and satisfaction. Participants took 5-10 minute break after filling out the questionnaires. During this time, the *gaming area* was being prepared for the second session with a different interface.

The game case is similar in both sessions, and participants roles were the same in both sessions. However, here are some differences between the two sessions:

GUI Sessions (mouse and keyboard) In this session, participants shared the same keyboard with a mouse pad embedded in it. After each move, each participant need to click next move, or next round button before passing the keyboard to the next player. Both monitors that were used in the TUI setup were left on and updating simultaneously.

TUI Sessions (LEGO bricks) In this session, no keyboard was used, but participants were asked to verbally say "next turn", or "next round" after each turn, or round. Also, to visualize the game KPIs on the plan, participants were informed to ask the experimenter to visualize those metrics on the plan. Finally, participants were informed to ask the experimenter to submit the plan verbally when all participant agreed to submit it. These operations occur in the *monitoring area.*

5.3.3 Discussion Session

After participants completed both sessions and filled the questionnaires, they took 5-10 minute break. Then, participants met in the *presentation area* for a 20 minute discussion session. In this session, the discussion was around the overall game, user interfaces, negotiation and decision-making. Participants also reviewed game performance using the **review game interface**.

5.4 Analysis and Results

In the CityGame experiment, we had 31 participants (one group had three participants). About 75% were male, and 25% female. 77% were between the ages 25-39, 10% over 39, and 13% between 18-24 years old. We had a diverse group of participants, 65% of the participants were graduate students, and the other 35% were mix of faculty, staff, undergraduate and visiting scholars. They have computer science, engineering, agriculture, architecture and arts backgrounds.

We asked the participants if they were familiar with decision-making in urban planning, and about 60% said "No". We asked them if they ever have been in a negotiation situation before, and about 40% said "No". Many of those participants understood the complexity of decision-making in urban planning after using the tool.

5.4.1 Evaluation of Impact

This thesis evaluates whether or not the choice of computer interface has an impact on a multi-objective negotiation problem. Specifically, the thesis evaluates whether the CityGame Tangible User Interface (TUI) is more effective than the Graphical User Interface (GUI) in the city planning task that is assigned to participant in this experiment.

The following sections test the effects of computer interfaces on game final score, per group and number of moves. **R** programming language is used for the statistical analysis.

5.4.2 Order Effects (Learnability)

The first test looks at the differences in the scores between the first sessions and the second sessions. This is despite which interface they started with. Half of the groups started with TUI, while the other half started with GUI.

Hypothesis 1 *Scores from the second session are higher than scores from the first session.*

$$H_0 : scores_{session2} \leqslant scores_{session1}$$
$$H_1 : scores_{session2} > scores_{session1} \quad (5.1)$$

A paired *t-test* is used to analyze the statistical significance for this hypothesis. The resulting *p-value* of **0.13** means that there is no statistical significance for the hypothesis. However, it means that there is a trend for scores to be higher in the second session over scores from the first session.

However, conducting the paired *t-test* on the number of moves between the first and second sessions result in a *p-value* of **0.05**. Although, it is not statistically significant, but we can infer that there's a trend for having a learning effect between first and second sessions results.

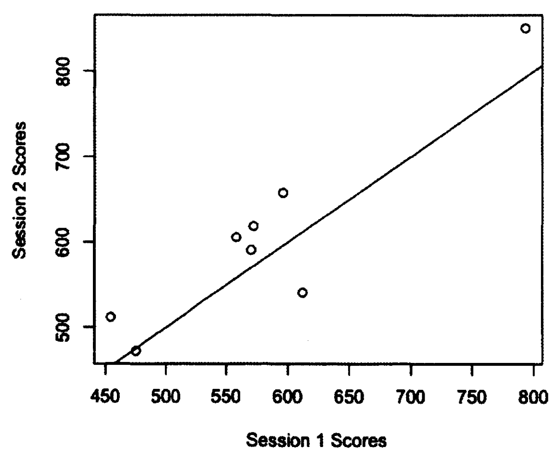


Figure 5-2: Scatter Plot of scores from session 1 compared to scores from session 2.

5.4.3 Effects on Score

The second test looks whether TUI and GUI have effects on groups scores.

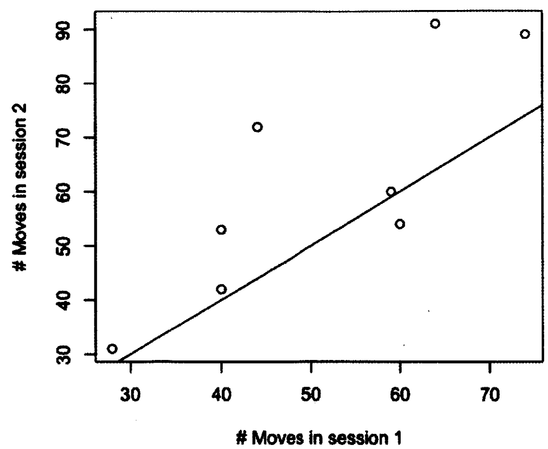


Figure 5-3: Scatter Plot of # of moves from session 1 compared to # of moves from session 2.

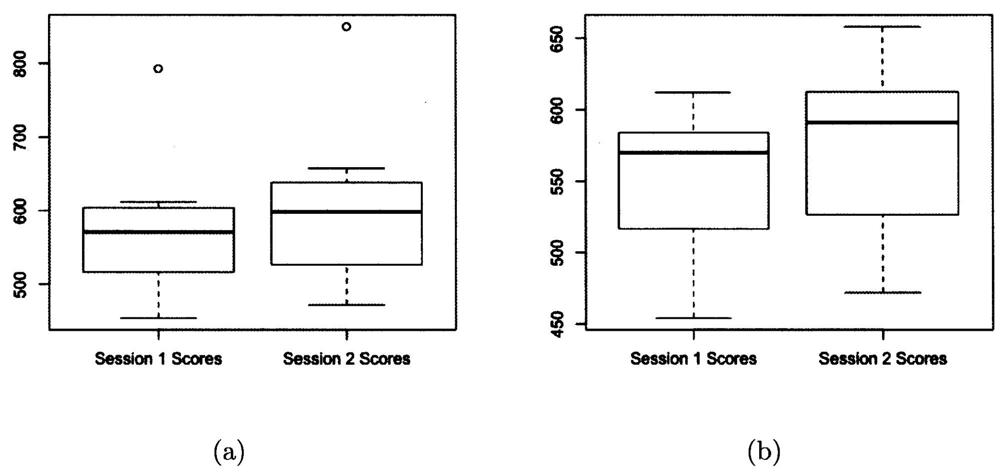


Figure 5-4: Box Plot comparing scores from session 1 to scores from session 2. (a) with outliers, and (b) without outliers

Hypothesis 2 *Scores from TUI sessions are higher than the scores from the GUI sessions.*

$$\begin{aligned} H_0 &: scores_{TUI} \leqslant scores_{GUI} \\ H_1 &: scores_{TUI} > scores_{GUI} \end{aligned} \quad (5.2)$$

A paired *t-test* is used to analyze the statistical significance for this hypothesis. The resulted *p-value* of **0.34** means that there is no statistical significance for the hypothesis. However, if the test is applied on the first sessions only, the resulted *p-value* is **0.013**. This means that there's a statistical significance, and the null hypothesis is rejected. Therefore, the alternative hypothesis that scores from TUI sessions are higher than the scores from the GUI sessions is accepted.

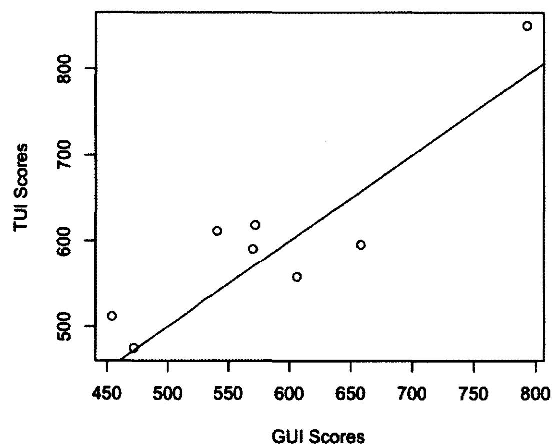
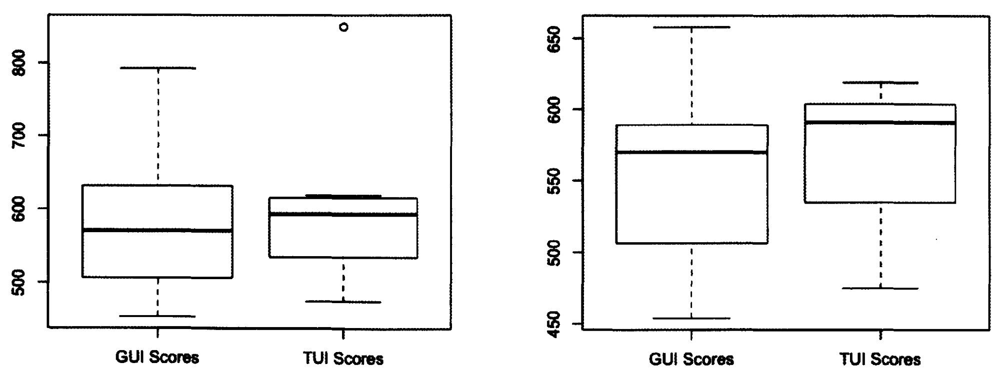


Figure 5-5: Scatter Plot of scores from GUI sessions compared to scores from TUI sessions.



(a) (b)

Figure 5-6: Box Plot comparing scores from GUI sessions compared to scores from TUI sessions. (a) with outliers, and (b) without outliers

5.4.4 Effects on Number of Moves/Turns

Instead of looking at game scores, this test looks at whether TUI and GUI have effects on the total number of moves per session.

Hypothesis 3 *Number of moves in the TUI sessions are higher than the number of moves in the GUI sessions.*

$$\begin{aligned} H_0 &: \#\ moves_{TUI} \leqslant \#\ moves_{GUI} \\ H_1 &: \#\ moves_{TUI} > \#\ moves_{GUI} \end{aligned} \tag{5.3}$$

A paired *t-test* is used to analyze the statistical significance for this hypothesis. The test evaluate the moves from the first sessions only. The resulted *p-value* of **0.15** means that there is no statistical significance for the hypothesis. However, it means that there is a trend for participants to make more moves with the TUI, than GUI.

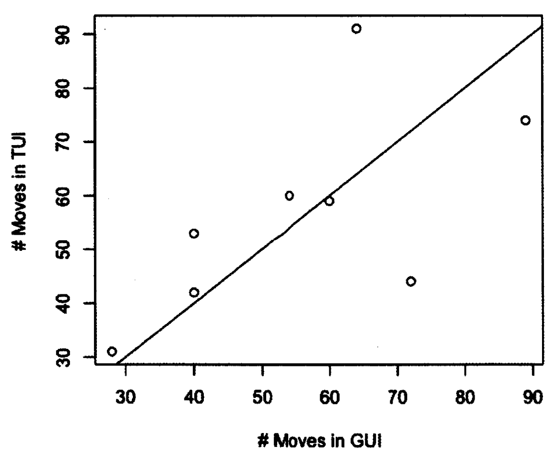


Figure 5-7: Scatter Plot of scores from GUI sessions compared to scores from TUI sessions.

5.4.5 User Ratings

After each session of the experiment, users were asked to evaluate the interface using Likert scale on the following areas: a) game scenario and objectives (Figure 5-10),

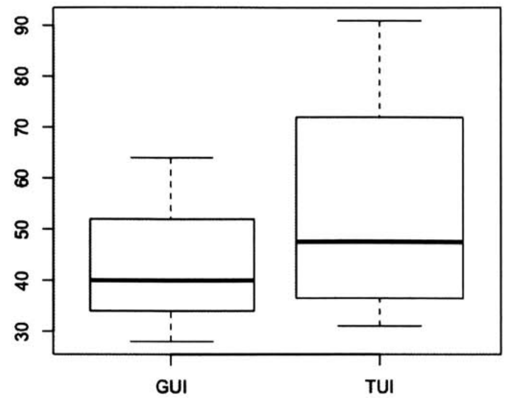
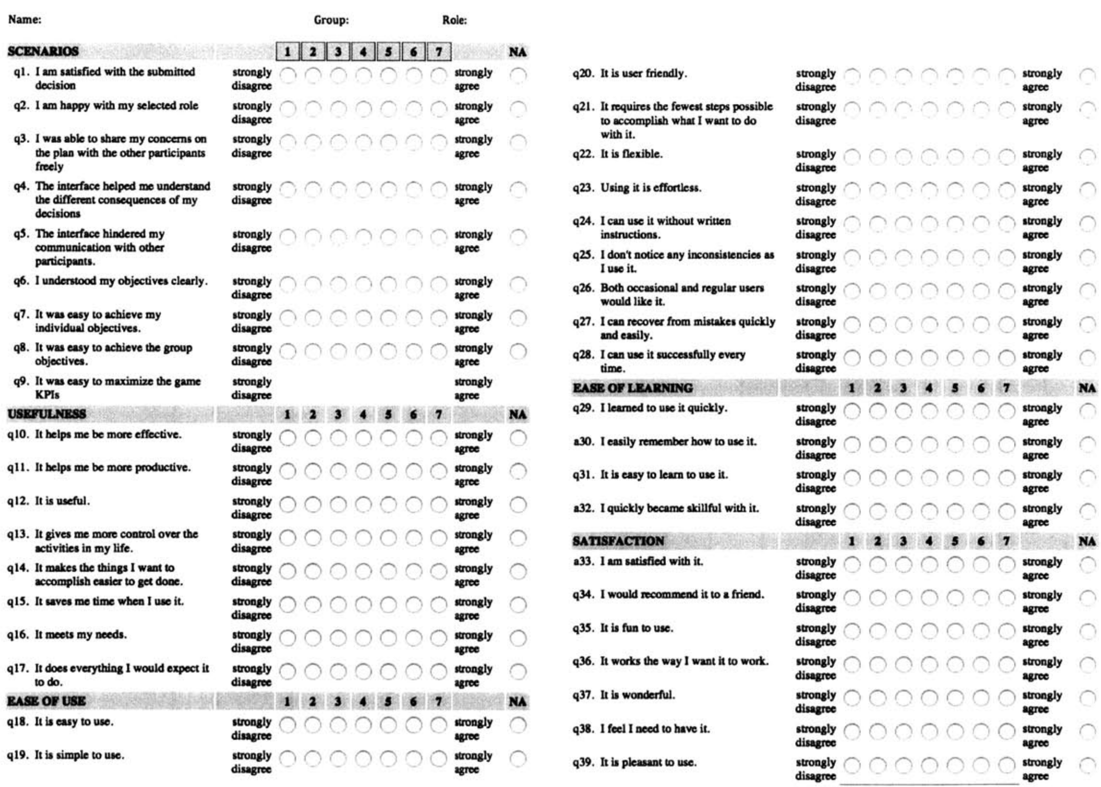


Figure 5-8: Box Plot comparing # of moves with GUI vs TUI in first sessions.



Name: Group: Role:

SCENARIOS 1 2 3 4 5 6 7 NA

q1. I am satisfied with the submitted decision — strongly disagree / strongly agree
q2. I am happy with my selected role — strongly disagree / strongly agree
q3. I was able to share my concerns on the plan with the other participants freely — strongly disagree / strongly agree
q4. The interface helped me understand the different consequences of my decisions — strongly disagree / strongly agree
q5. The interface hindered my communication with other participants. — strongly disagree / strongly agree
q6. I understood my objectives clearly. — strongly disagree / strongly agree
q7. It was easy to achieve my individual objectives. — strongly disagree / strongly agree
q8. It was easy to achieve the group objectives. — strongly disagree / strongly agree
q9. It was easy to maximize the game KPIs — strongly disagree / strongly agree

USEFULNESS 1 2 3 4 5 6 7 NA

q10. It helps me be more effective. — strongly disagree / strongly agree
q11. It helps me be more productive. — strongly disagree / strongly agree
q12. It is useful. — strongly disagree / strongly agree
q13. It gives me more control over the activities in my life. — strongly disagree / strongly agree
q14. It makes the things I want to accomplish easier to get done. — strongly disagree / strongly agree
q15. It saves me time when I use it. — strongly disagree / strongly agree
q16. It meets my needs. — strongly disagree / strongly agree
q17. It does everything I would expect it to do. — strongly disagree / strongly agree

EASE OF USE 1 2 3 4 5 6 7 NA

q18. It is easy to use. — strongly disagree / strongly agree
q19. It is simple to use. — strongly disagree / strongly agree
q20. It is user friendly. — strongly disagree / strongly agree
q21. It requires the fewest steps possible to accomplish what I want to do with it. — strongly disagree / strongly agree
q22. It is flexible. — strongly disagree / strongly agree
q23. Using it is effortless. — strongly disagree / strongly agree
q24. I can use it without written instructions. — strongly disagree / strongly agree
q25. I don't notice any inconsistencies as I use it. — strongly disagree / strongly agree
q26. Both occasional and regular users would like it. — strongly disagree / strongly agree
q27. I can recover from mistakes quickly and easily. — strongly disagree / strongly agree
q28. I can use it successfully every time. — strongly disagree / strongly agree

EASE OF LEARNING 1 2 3 4 5 6 7 NA

q29. I learned to use it quickly. — strongly disagree / strongly agree
a30. I easily remember how to use it. — strongly disagree / strongly agree
q31. It is easy to learn to use it. — strongly disagree / strongly agree
a32. I quickly became skillful with it. — strongly disagree / strongly agree

SATISFACTION 1 2 3 4 5 6 7 NA

a33. I am satisfied with it. — strongly disagree / strongly agree
q34. I would recommend it to a friend. — strongly disagree / strongly agree
q35. It is fun to use. — strongly disagree / strongly agree
q36. It works the way I want it to work. — strongly disagree / strongly agree
q37. It is wonderful. — strongly disagree / strongly agree
q38. I feel I need to have it. — strongly disagree / strongly agree
q39. It is pleasant to use. — strongly disagree / strongly agree

Figure 5-9: Questionnaire used for user ratings.

b) usefulness (Figure 5-11), c) ease of use (Figure 5-12), d) ease of learning (Figure 5-13), and e) satisfaction (Figure 5-14). Parts b, c, d, and e are based on the

USE Questionnaire: Usefulness, Satisfaction, and Ease of use measures [18]. A summary of the responses are visualized in boxplot diagrams. Each figure represents a group of questions per category/area. Figure 5-9 shows the questionnaire used in the experiment.

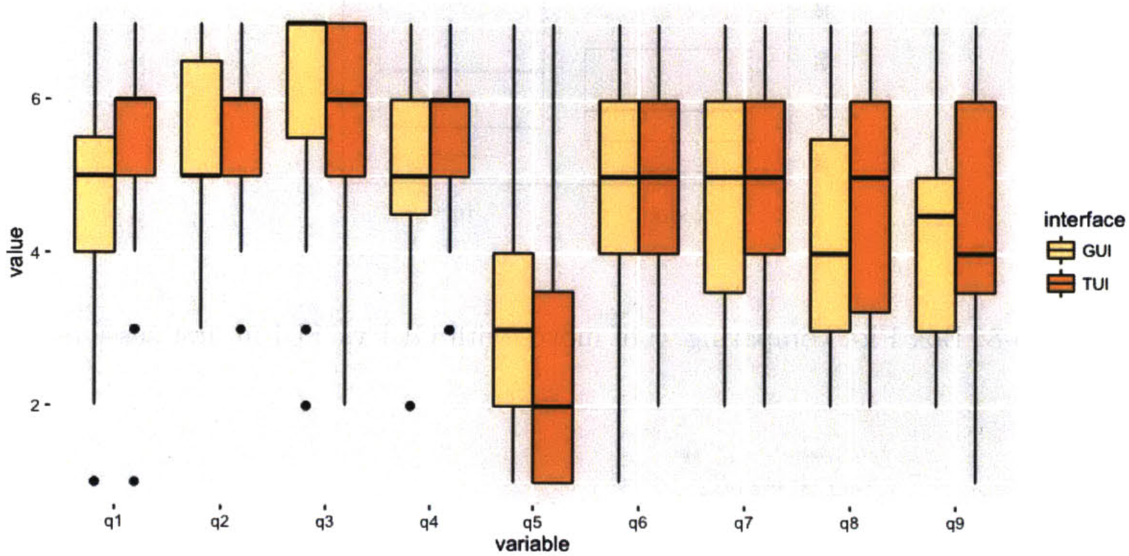


Figure 5-10: Box Plots of users rating on scenario-related questions. Comparing GUIs responses with TUIs responses.

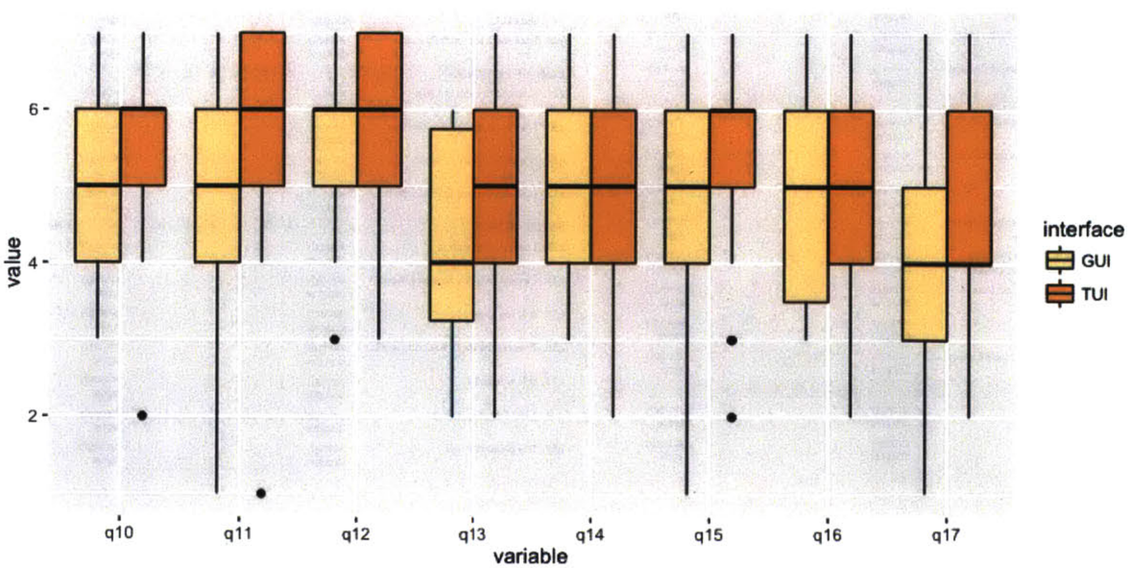


Figure 5-11: Box Plots of users rating on interface usefulness-related questions. Comparing GUIs responses with TUIs responses.

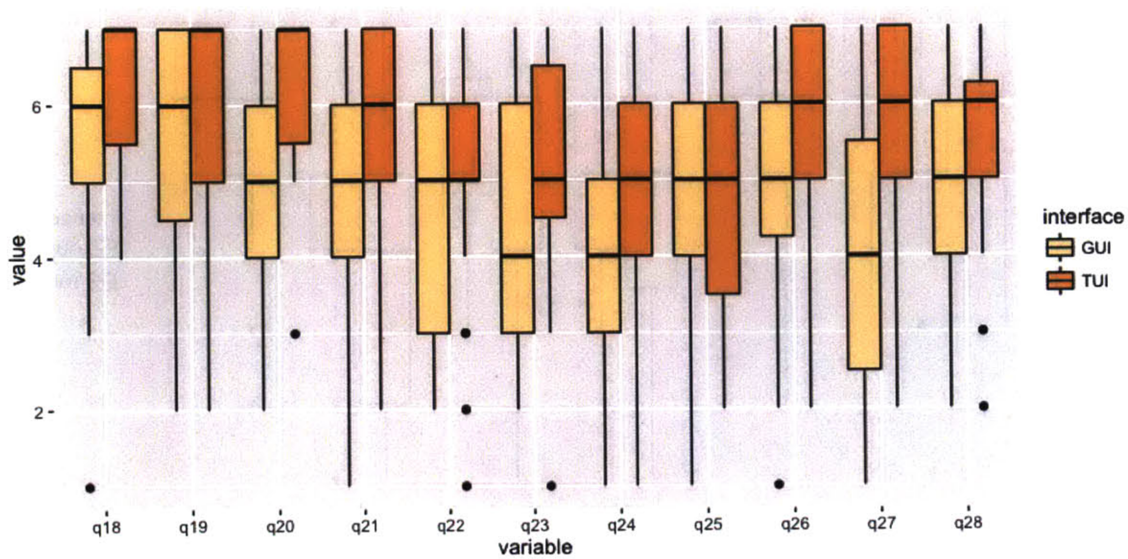


Figure 5-12: Box Plots of users rating on interface ease-of-use-related questions. Comparing GUIs responses with TUIs responses.

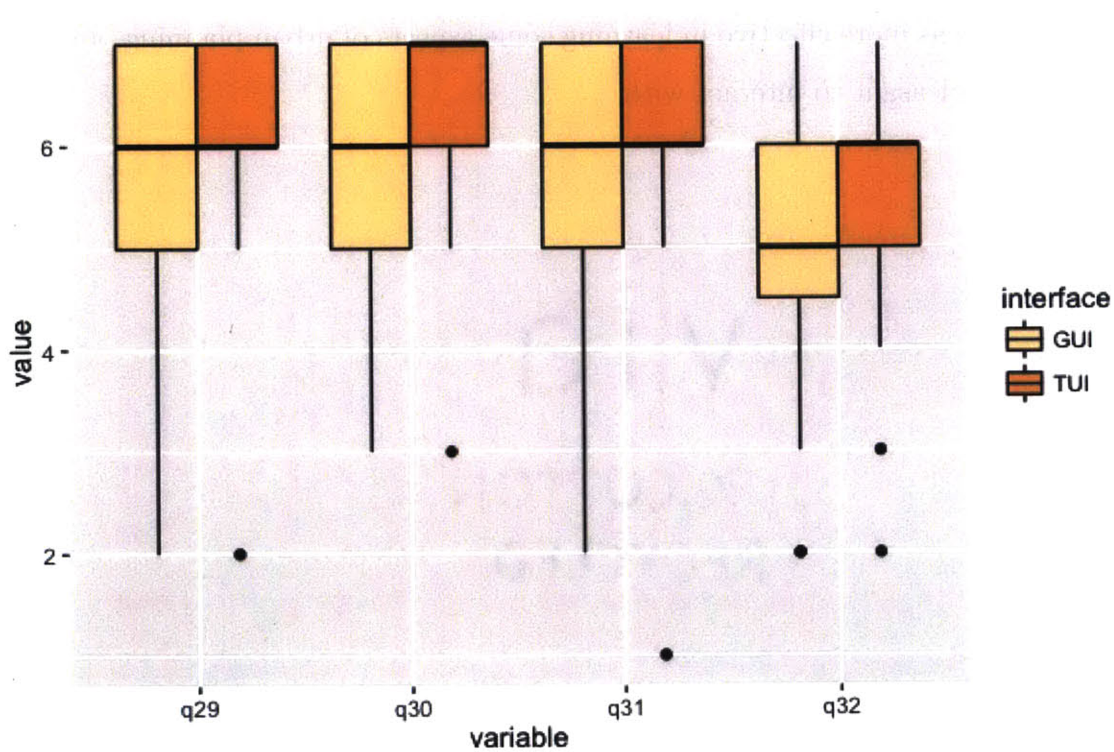


Figure 5-13: Box Plots of users rating on interface ease-of-learning-related questions. Comparing GUIs responses with TUIs responses.

From the previous figures on users ratings, there's a trend that TUI is performing better in almost all the questions asked. From users observation, and qualitative

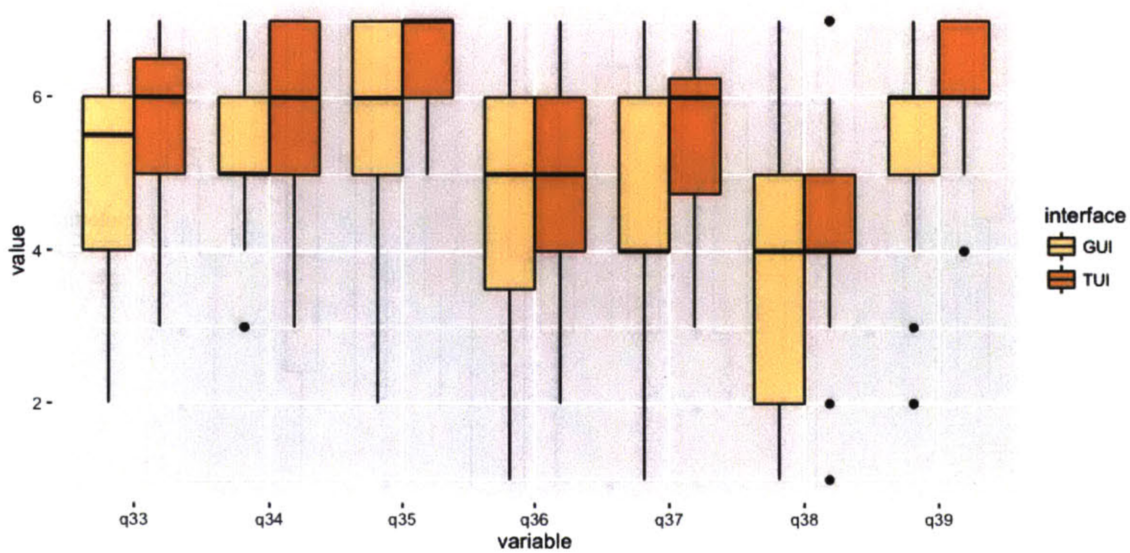


Figure 5-14: Box Plots of users rating on their satisfaction using the system-related questions. Comparing GUIs responses with TUIs responses.

analysis, TUI was more effective in learning some aspects of urban planning, and was more fun and pleasant to interact with.

Chapter 6

Conclusion, Discussion and Future Work

This thesis has evaluated whether a Tangible User Interface (TUI) is more effective for multi-objective group negotiation and decision-making than a graphical user interface (GUI). The results suggest that there is a trend for the tangible user interface to be more effective than the graphical user interface. The following sections reflect on the experiment, data analysis and user observations.

6.1 Discussion

Why was statistical significance not reached? The quantitative analysis results did not show statistical significance when GUI was compared to TUI. This is because there were not enough experiments to get enough data points. There were 31 participants who split into eight groups. Four groups started with TUI, and the other four started with the GUI. This within-subject study require a 2-hour commitment, which made it difficult to get participants to sign up for the experiment. Therefore, due to the sample size, it was difficult to reach statistical significance.

Is GUI catching up with TUI? Figure 5-5 shows improvements in game scores when TUI is used. Although the results are not significant, the question should again be asked whether our interaction with GUI interfaces is as good as our interaction with the TUI. We interact and experience GUI interfaces every day, and the number of physical objects with GUIs are on the increase (phones, computers, cars, home appliances, etc.). Therefore, are GUIs compared to TUIs nowadays becoming more effective than they were in the past?

Outliers? From the data analysis, one group was an outlier compared to the other seven. Figure 5-6 shows the scores of the outlier near the 800. This is because the participants in this group were experts in urban planning and programming. They were able to discover the underlying model faster, and their main objective was to get the highest possible score.

6.1.1 Interface

Learning tool or decision-support tool? Maybe both? Participants think that the current platform is more of a learning tool than a decision-making tool. However, the ability to learn about inputs' implications is one aspect of decision-support systems. The tool supports collaboration and understanding of the level of complexity, which enables participants to make better-informed decisions. If participants learned something about planning, then it means they have better information and understanding of the scenario than before they used the tool. This aspect of learning supports the decision-making process.

Setting the stage Every TUI session, participants aligned their LEGO bricks amenities in front of them, which can not be done in the GUI. This aspect of ownership and close proximity with physical objects allows participants to react fast when their turn is up.

Time constraint or number of moves? Holding the physical objects allows for faster moves. Participants noticed that the more moves, the better the scores got. Some participants spent three seconds for their turn (1 second per move), while others spent more than 10 seconds for their turn. Should we consider constraining a participant's turn with a temporal aspect?

Complexity and the linear relationship encoding with physical construct During discussion with participants, one participant mentioned that the physical construct of the amenities "helped convey what the meaning of open space is". This linear relationship encoding was effective in this particular scenario. However, how can we encode the physical construct with non-linear multidimensional data? That is, how to encode the change in the different metrics (traffic, parking performance, energy efficiency) in the physical construct based on its location and the type of amenity.

It was noted earlier that simulation tools are used by expert users during the planning process, which makes it difficult for an average decision-maker to evaluate the impact of that plan. In CityGame, participants who lacked a background in urban planning were able to negotiate, evaluate the plan during the game, and use it to support arguments on what amenities were missing from the neighborhood.

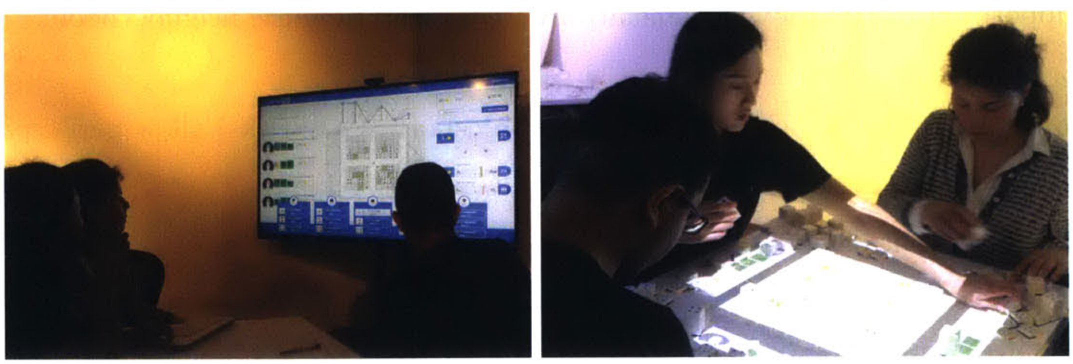
Memory work load Using the physical objects (LEGO bricks) allow participants to hold their next scenarios (moves) in hand, while observing the changes in the plan. This conveys that participants off-loaded their scenario/moves strategy to the LEGO bricks. When GUI was used, participant thought about their scenarios during their turn. Further measures are necessary to validate this point.

6.1.2 Group Communication

Group communication is essential in negotiation and group decision-making tasks. From the game observation, groups who started with the TUI session adapted to each other early in the game compared to groups who started with the GUI session. In the GUI session, participants communicated their ideas by using the mouse pointer, and not facing each other; whereas in the TUI session, participants had to face each other. Therefore, it was very important to have the participants interact with each other before the game. It helps participants communicate better during the game.

Let's discuss. It was evident from user observation that participants were discussing the impact of plan amenities (single building, or park) on the neighborhood, and their reasoning on placing those amenities on their specific location, more with TUI, than with the GUI. In GUI, participants were observing numeric values associated with the plan more than the plan itself, and how to get those numbers up.

To observe, or to engage? Group behavior and participants' body language was observed during the TUI and GUI sessions. Participants were more engaged interacting with the TUI, whereas, in the GUI session, users tended to be in an observing mode more than an engaging mode. Figure 6-1 and Figure 6-2 show participants' engagement within groups under GUI and TUI sessions. In the TUI session, participants were passing LEGO bricks to each other while asking questions about amenities. In contrast, in the GUI session, participants were passing the keyboard silently.



(a) GUI (b) TUI

Figure 6-1: A snapshot to compare group dynamic, communication and interaction in (a) GUI session, and (b) TUI session. Participants are more engaged together and with the game interface in a TUI session than in a GUI session.

Session 1 GUI, or Session 1 TUI? For most participants, it was more uncomfortable to start with the digital interface rather than the tangible interface. Players were less collaborative and less engaged. In the GUI session, all the information is

(a) GUI (b) TUI

Figure 6-2: A snapshot to compare another group dynamic, communication and interaction in (a) GUI session, and (b) TUI session. Participants are more engaged together and with the game interface in a TUI session than in a GUI session.

displayed on the monitor, and participants directed their communication to the screen instead of the group. This was not the case in the TUI session.

Group hierarchy One of the three aspects that is essential in studying group collaboration and communication is the participants of a collaborative task. It was noted during the game that participants' hierarchy had an impact on the group communication and decision-making process. This happened when a non-environmentalist advocated for improving the plan's CO_2 performance. One factor in this group, though, was that a faculty member and his/her student were playing in the same group. In this game, the faculty member encouraged other participants to populate the plan with parks/trees. Among all the 16 plans, this one was the greenest plan. A lesson learned from this game is that if you want to improve the environmental aspects of a city, or even on a global scale, don't leave it for the environmentalists, or the activists alone. Someone with authority outside environmental organizations needs to advocate for it.

6.1.3 Negotiation and Decision-making

Is it easier to punish with TUI, or GUI? As noted earlier in this thesis, reaching consensus is a difficult task in urban planning. This was evident in this game. Most groups were cooperative during the game. That is, players always added new amenities to the plan, and asked for consent when they wanted to remove/modify other players' amenities. However, in GUI sessions when participants removed other players' amenities, they apologised after or during the removal of that particular amenity. One example with one of the groups, the environmentalist tried to negotiate with other players about improving the plan's CO_2 performance, and since it had minimal effects on game score, other players didn't care. However, that player removed a commercial high-rise building as a punishment, which affected that player's individual objective. That move made an impact on players' decisions afterward. Almost every player after that move added a park as part of their 3 moves, or reduced the number of high-rise buildings they used. This act reduced the rate at which the CO_2 performance worsened. Figure 6-3 shows that plan at the point where the commercial building was removed.

When I asked the participants for their feedback about the game, they mentioned that it's more of a learning tool. Experts users require more complex models than what the current game has. This includes traffic, wind simulation, and other models that could be rendered in real time.

6.1.4 Gameplay

Participants had fun planning the neighborhood while playing the game. Most participants thought of the TUI as a board game. When participants saw the TUI setup for the first time, both as a first or a second session, they got excited. "Wow", "cool", "amazing" and "awesome" were few words participants used when they saw the TUI setup.

Let's win Most groups tried to maximize the game final score, and few cared about the virtual trophy. Participants asked about the maximum score achieved across all other groups before they started the game. However, none of the groups knew about other groups' scores until after the discussion session.

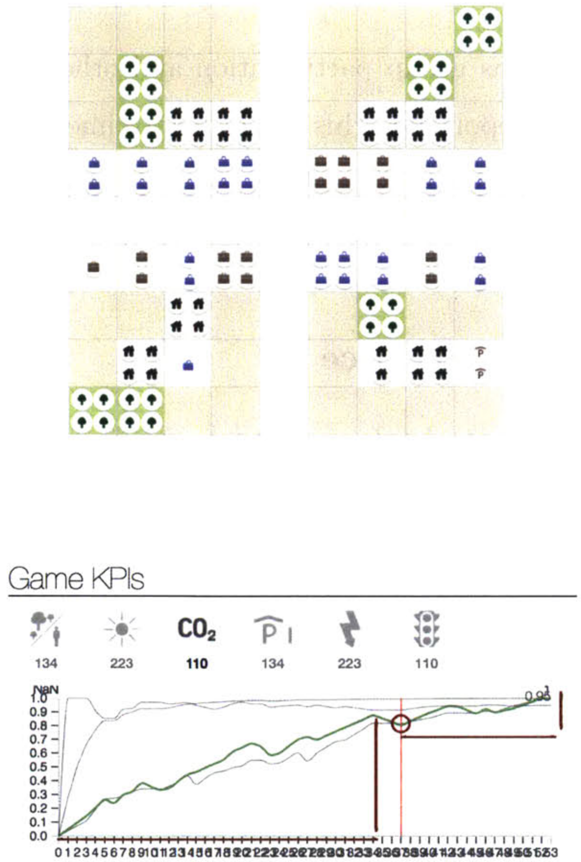


Figure 6-3: The rate of CO_2 performance changed after one of the environmentalists removed a high-rise building from the plan as a form of punishment.

My score vs. our score During the few first rounds, individual objectives were more important than group objectives. Most participants in the developer role were focused on maximizing their individual objectives by adding high-rise buildings for the first few rounds. When participants noticed how group scores affected, they started to balance between the group and individual objectives.

Turns/Moves Most participants were in favour of the turn-taking rule. It balances out the participation among the group participants especially when there are people who are "either too shy, or too leader" as one participant described it. Some participants thought that the turn-taking was helpful during the first few rounds, but was challenging toward the end; "It was a barrier to fix immediate problems" later in the game.

Other observations such as group participation and other usability metrics were recorded, but could not be reported in this thesis due to time constraints. In addition, observations and analysis on the individual level such as turn-taking, role satisfaction, individual score vs group score were recorded but not reported.

6.1.5 Literature and Practice

As literature suggested, using technology enhances group communication if there are well designed tools to support it. CityGame is not a game interface only. CityGame is a framework that supports real-time negotiation and decision-making, as well as managing group information and scenarios generated during sessions.

Participants favored group negotiation and discussion with the tangible interface. On the other hand, participants favored reviewing and analyzing the results with the GUI. CityGame framework provides both modalities, which supports different tasks, such as multi-objective negotiation and decision-making tasks. Although, the main purpose of this thesis is to evaluate the impact of the different interfaces, it was important to design and develop the CityGame framework. There is no tool that supports both modalities and real-time simulation for multi-objective negotiation and decision-making problem to evaluate.

6.1.6 Lessons Learned

Within-subjects experiments are very expensive and time-consuming. It requires a large sample size, and higher budget.

Evaluation studies are complex; investigating and conducting the whole experiment alone was stressful and overwhelming. Having one more person, at least, is very useful. All technical issues from setting up cameras, preparing the game area for both session during the experiment, checking missed questionnaire answers, monitoring sessions and documenting observations require careful planning and flawless execution. Participants' time is valuable. We need to have the whole experience planned and ready from the moment they sign up for the experiment, all the way to the follow up after experiment.

The 2-hour session was not enough to eliminate the learning effect. The results suggested that the 5-minute training session plus the 15-minute game session is essential to reduce that learning effect. Therefore, the game should be at least 30-minute long.

Data analysis is another expensive task specially for the within-subject studies where experiments are conducted twice. Transcribing data, coding videos and analyzing them are time consuming. Again, assistance is encouraged.

6.2 Future Work

6.2.1 General Directions

To further this research, the following are general direction for future work:

• **Multiple keyboards and a table-top screen** Instead of using a vertical display and one keyboard, use multiple keyboards and a table-top display.

• **Multi-touch screen vs TUI** This is a definite next step, and it was proposed earlier. Most participants asked if there is a multi-touch screen session during the discussion.

• **Mixed modality interface** Using multi-touch with tangible interface. Discussed in Section 6.2.3.

• **Other computational models** Need to add other levels of complexity. This includes adding traffic congestion to the models. The model partially exits, but is in need of calibration.

- **Online experiments** As participants suggested that this is a learning tool, it would be very interesting to test the game with online users and ask participants to design their neighborhood and collect different design guidelines for cities.

- **Machine optimization and planning** A genetic algorithm has been developed and is widely known in urban planning optimization. It would be interesting to compare plans optimized by machine vs. plans optimized by humans. One problem with machine optimization is that it does not take into account plan aesthetic. To allow machines to process design aesthetic will require advanced machine learning techniques in addition to hundreds of plans submitted by different stakeholders.

- **Developed plans vs blank plans** It would be interesting to have participants start the game from a developed site instead from a blank one. Negotiation becomes more interesting when there are tradeoffs and vacant spaces are limited.

- **Financial rewards and revenue** One important aspect resulted from group discussion is about incentives and rewards. Participants believed that financial commitments instead of coins would be more intriguing. Coins were perceived as points instead of financial virtual currency. In addition, it would be more realistic to see a revenue indicator for each stakeholder to drive their negotiation.

- **Non linear realationship with physical construct** In this study we encoded the LEGO brick with one variable, that is the building height. It would be interesting to find ways to ascribe multiple dimensions to the physical object to interact with such complexity.

- **Learning (pre-game) time** The five minute training was not enough. To reduce the learnability effect, try to increase the training time from 5 to 15 minutes, as mentioned earlier, before the game starts.

6.2.2 Game Specific

- **Player role card** The player role card provides players with their role's profile and key metrics that impact that role and its score. Such a role card would guide participants on how to approach certain scenarios from the point of view of that role/stakeholder.

- **Objectives card** The objectives card gives detailed information on the role's objectives. As an example, the residential developer would receive an objective card that says "your target is to reach the building intensity of New York downtown area", while the retail developer would receive an objective card that says "your target is to reach the building intensity of Barcelona downtown area". There are predefined values for each FSI, GSI and OSR metric per area. Therefore, player's score is based on how closely those values from the plan match the ones on the objectives card. In addition, the objectives card contains the group objectives, which are similar for all players.

- **Moves preview before the actual play** Participants pointed out that they wanted to know how each piece affects the scores before it counts as a move during the play.

6.2.3 Mixed Modality (Multitouch + Tangible Interface)

I expect that a mixed modality of a tangible interface and multi-touch screen would be the ideal solution for decision-support systems. It includes the flexibility of touch screens to modify digital information, such as views and visualization, and the power of the tangible or physical elements to support the learning experience.

The multi-touch interface would use the same CityGame framework, but displayed on a multi-touch screen. The panels around the table would be used for visualization and a place to keep game tiles.

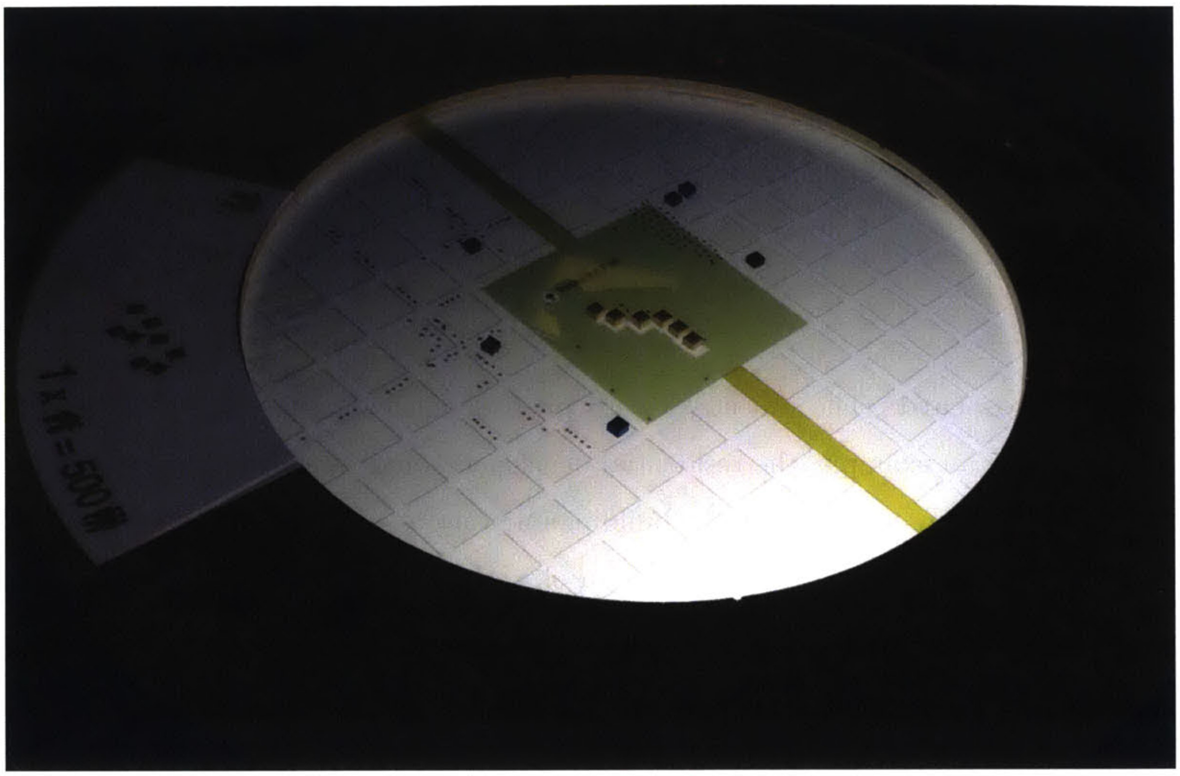


Figure 6-4: Earlier version of the Multitouch + Tangible User Interface.

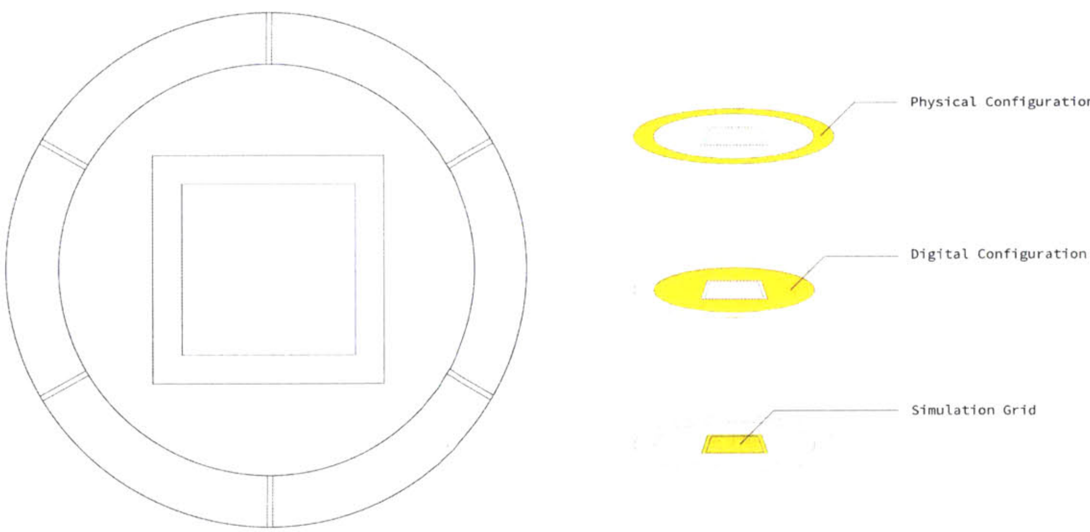


Figure 6-5: Table-top interface layers.

6.3 Conclusion

In conclusion, the premise of this thesis that Tangible User Interface is more effective for multi-objective group negotiation and decision-making than traditional graphical user interfaces is neither accepted nor rejected. The results showed a trend in the effectiveness of TUI over GUI, but due to the sample size the study did not reach statistical significance. This thesis discusses the design and development of CityGame framework and its use as a consensus-based negotiation and decision-support tool.

To design effective user interfaces for decision-support systems, we need to adapt the engineering mindset in the design process. Engineering the User Interface (EUI) involves the understanding of machine-machine interaction, and human-machine interaction. Based on my experience engineering the CityGame, seven main components are critical to be considered in the design process: 1) stakeholders, 2) context, 3) data, 4) models and relationships, 5) medium, 6) interface layout, 7) visualization methods. Therefore, I recommend utilizing these seven components as a base for designing and developing future DSS tools.

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