A Computational Tool for Evaluating Urban Vitality Using Kendall Square Development Proposals as a Case Study

by
Waleed F. Gowharji

B.S. Aerospace Engineering
Embry-Riddle Aeronautical University, 2008
M.S. Mechanical Engineering
Embry-Riddle Aeronautical University, 2011

Submitted to the Program in Media Arts and Sciences,
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Signature of Author Signature redacted

Waleed F. Gowharji
Media Arts and Sciences
August 30, 2016

Certified by Signature redacted

Kent Larson
Principal Research Scientist of Media Arts and Sciences
Thesis Supervisor

Accepted by Signature redacted

Pattie Maes
Academic head, Program in Media Arts and Sciences

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Abstract

Kendall Square, home to MIT, a world-class university and a district known globally for its reputation as an epicenter of ideas and innovation, has recently seen a new wave of development seeking to turn it into a place for people. Typically, multiple developers and private investors will bid on developing the area. The competitive nature of this process suggests that involved parties have varying and potentially conflicting objectives. For example, the soaring office and residential rents in Kendall Square make it attractive to private developers looking for monetary gains. Furthermore, in an area with an already high employment density, the addition of more office and commercial spaces could increase the stress on the public transportation system that is struggling to keep up with current demand. This becomes a design problem with no optimal solution. The question becomes, how do we design districts to be more livable for people? In this research we propose a computational evaluation decision support platform to facilitate collaborations between stakeholders in their interactions within the contexts of urban planning. Whether planned interventions or new developments, the aim of this research is to give stakeholders the ability to weigh the implications from these interventions on the vitality of districts. Chapter 1 lays the foundation of the theoretical contributions put forth by Jane Jacobs regarding urban vitality. Chapter 2 discusses the four-diversity conditions for urban vitality and early attempts to validate these conditions. Chapter 3 presents an overview of the urban elements of both Kendall Square and Harvard Square as a case study. In chapter 4 we apply Jacobs' vitality conditions to both case studies. We find that Harvard Square is balanced in terms of Jacobs' conditions, while Kendall Square suffered form an imbalance in residential density. Chapter 5 presents the computational evaluation platform "CityMatrix" and uses the Volpe and MIT development sites as examples of urban interventions. We find that the current plan, approximately 16,000 employees and 3,500 residents is not enough to increase the population density to make Kendall Square a more vital district. Lastly, chapter 6 provides a conclusion and future steps for this research.

Thesis Supervisor: Kent Larson
Title: Principal Research Scientist of Media Arts and Sciences

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by

Waleed F. Gowharji

The following has served as a reader on this thesis:

Signature redacted

Reader: ________________________

Sandy Pentland
Professor of Media Arts and Sciences

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Waleed F. Gowharji

The following has served as a reader on this thesis:

Signature redacted

Reader: ______________________

Olivier de Weck
Professor of Aeronautics and Astronautics
And Engineering Systems

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Table of Contents

Table of Figures

List of Tables

List of variables

Variable Name	Variable description
Pi,j	Percentage of land use
n	Number of land uses
LUM	Land use mix
SP	Small Parks
dist(x,y)	Distance between two centroids
closest(x,Y)	Proximity of x to list of Y
RNR	Residential to non-residential
nonRes	Non residential units
Res	Residential units
Housing types	Housing types
hc,i	Number of buildings in height category c
zc	Number of floors of height category c
Commercial	Commercial Places
Nightlife	Nightlife Places
Nightlife Density	Nightlife Density
3rd Places	Third Places
Block Area	Block Area
Intersection Density	Intersection Density
Population Density	Population Density
Employment Density	Employment Density
Internal	Internal apartments
Daily places density	Daily places density
Non daily places density	Non daily places density
Places	Number of places in district i
Area	Area in m2

Units

All units are in m^2, except where noted other wise.

Introduction

Recently, the Kingdom of Saudi Arabia announced its' "Saudi Vision 2030", which aims at a complete transformation of the Saudi economy in the coming years. In the document, Deputy Crown Prince Mohammed bin Salman makes an effort at salvaging the King Abdullah Financial District (KAFD), which was designed to diversify the economy beyond oil as well as creating jobs, see figure 1. Amongst its design flaws, KAFD was initiated "without consideration of its economic feasibility" and remains unconvincing to investors and potential tenants. The goal aims to transform the district into a special business zone with competitive regulations, visa exemption for foreigners working there, and a direct connection to Riyadh's King Khalid International Airport, see figure 1. The report also mentioned re-appropriating some of the already built areas and changing "the real estate mix, increasing the allocation for residential accommodation, services and hospitality (Arab News, 2016). "

Since its conception, which began in 2006, the district has been plagued by lack of enthusiasm for the development, which offers 42 buildings of prime real estate in the heart of the Saudi capital—similar in scale to London's Canary Wharf. As was the case with Canary Wharf, new office districts often take time to come to fruition. Canary Wharf faced similar skepticism before becoming the success it is today. It is yet to be seen whether KAFD will live up to the idea it was meant to be: "a sober Saudi alternative to Dubai's exuberant International Financial Center." One of the main contributing issues is that the new financial district boasts three times as much high-end office space as the rest of Riyadh. This combined with a slump in Saudi Arabia's economic growth—fueled by the glut in the oil market—means that businesses cannot digest nor afford unsubsidized rent of the extra property (The Economist, 2013).

Figure 1: King Abdullah Financial District in Riyadh under construction in Riyadh, Saudi Arabia. The district boasts three times as much prime real estate than Riyadh in its entirety (Arab News, 2016).

As is the case in the Saudi Context, despite grand efforts, planning in Europe isn't panning out as expected, either. The Association of European School of Planning—an annual convention—has called for new approaches toward rethinking concepts of planning. Global urbanization carries multiple complexities along with unintended consequences and unanticipated outcomes, regardless of context. Given the stochastic nature of future events, planning in a linear fashion is certainly planning for failure (Flint, 2015). These approaches are based on the understanding that urban planning is facing challenges, "not only related to the self-organizing and self steering character of urban reality and the way that the city is undergoing transformations at different scales, but also related to the massive spread of technology, a phenomenon that should be acknowledged in planning procedures and methods (Horelli, Kannen Kuvat, & Johansson, 2013)."

Horelli et al. claim that transformations which urban fabrics undergo are not the direct results of the planning process itself, rather, they are emergent outcomes of contingent fluctuations of external and internal pressures within the city, including the self-organization of different groups and networks (Horelli, Kannen Kuvat, & Johansson, 2013). Therefore it is crucial to include local actors, such as citizens, politicians, administrators, entrepreneurs and their networks, to design viable urban solutions for everyday urban life. These methods should allow key actors to analyze, develop, implement and monitor physical, functional and participatory structures at a district level (Fulton, 1996) (Jacobs, 1961).

So then, what are the constituents of living urban space that facilitate human activity? How do we quantify the vibrancy of activities that happen in districts? And how can we use this knowledge in order to design tools that allow planners to engage local actors to design vibrant, viable urban solutions for everyday urban life? Figure 2 below shows a break down of "what makes a great place?" Under the four main categories, uses & activities; comfort & image; access & linkages; sociability; the key attributes that shape "great places" are uses & activities and access & linkages. These attributes characterize a place as being "fun, active, vital, special, useful, walkable, proximal and convenient." They are measured by metrics such as "business ownership, land-use patterns, property values, mode splits and pedestrian activity (Moskerintz, 2014)."

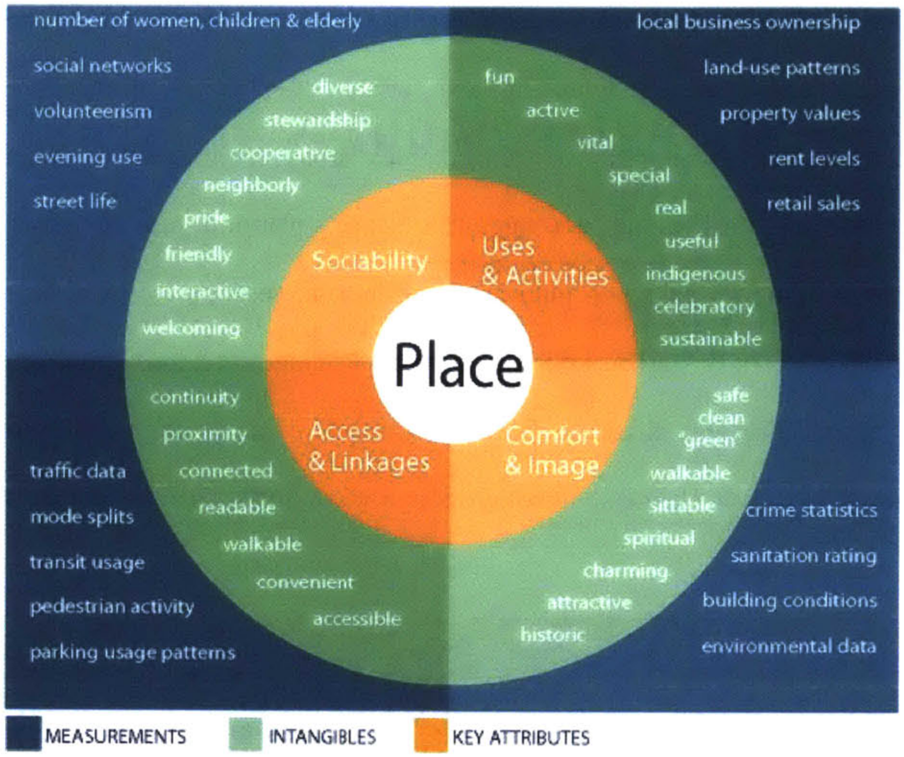

Figure 2: What makes a place great? Great places offer a plethora of activities and different types of building uses, as well as great accessibility, and diversity of residents and dwellers (Moskerintz, 2014).

In this research, the goal is to develop a simulation platform based on empirically grounded mathematical models that will ultimately enable players to quantify, compare and change vitality measures of urban districts through curated interventions. The platform utilizes insights and metrics derived by renowned urban sociologist Jane Jacobs, in *the Life and Death of Great American Cities*, to score urban vitality & vibrancy measures. Although, considered as on of the most influential books in city planning, until recently, the claims made by Jacobs have gone unsubstantiated (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106). However, through works presented by Sung and De Nadai, the claims, theories and axioms presented by Jacobs have been empirically validated using data from multiple cities.

The Changing Places group at the MIT media lab develop simulation systems to predict and quantify the potential impact of disruptive interventions within new and existing cities. The

DSS places special emphasis on augmented reality (through a blend of hardware, software, human interface design, cloud computation, and variants of so-called big data) that facilitates non-expert stakeholder collaboration within complex urban environments (Larson, Reinhart, Alfaris, & Al-Wabil, 2014). The resulting "CityScope" platform can be used for shared, interactive computation in an urban planning environment, see figure 3. The work presented herein is an extension of this urban DSS platform that leverages previously published works by Jacobs and others. The aim is to use DSSs as a means of answering fundamental research questions posed by urban planners, sociologists and economists, such as "what creates urban life?"

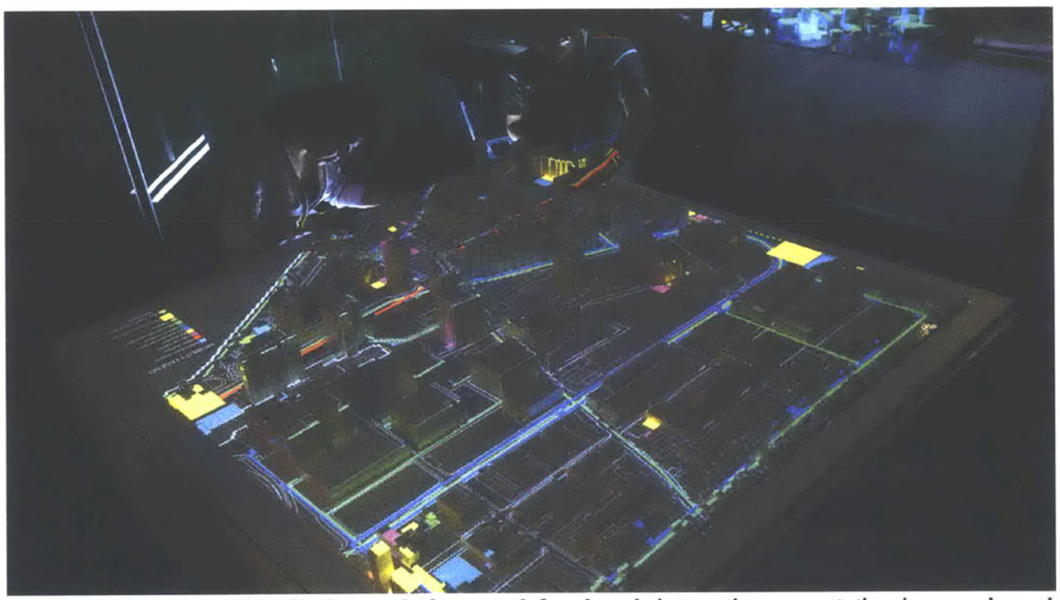

Figure 3: The second generation CityScope platform used for shared, interactive computation in an urban planning environment (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

The key constituent for urban vitality, according to Jacobs, is the physical environment *"the urban fabric."* She argued that urban life/vitality is facilitated with the presence of human activity (pedestrians) throughout the entirety of a 24-hour period. Conversely, urban *death* is caused by the elimination of pedestrian activity, through the promotion of highway construction and large-scale development projects (Jacobs, 1961). In other words, in order to breathe life into large cities, the urban fabric should be characterized by diversity at both the district and street level. Extending upon this, Jacobs claims that diversity is promoted with four essential conditions (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106):

1. *Mixed land use*: districts should be as multipurpose as possible, as monothematic districts lead to vacuums at different times of the day. Mixed land use also attracts a diversity of people, all with different purposes.
2. *Small blocks:* block size has an impact on promoting interaction opportunities between people.
3. *Building age diversity:* age diversity makes it possible to mix high-rent and low-rent tenants. This leads to higher likelihood of diverse interaction between residents working and living in a given area.
4. *Density:* sufficient density of buildings and people lead to more frequent and diverse interactions between people living and visiting a given area.

According to De Nadai et al., these fundamental principles have carried little weight, as the conditions have never been empirically tested until recently (Sung, Lee, & Cheon, 2015). The reason for this is due to the difficulty associated with collecting data of districts that are full of urban vitality and districts that are not. This remained the case until the publication of the works by Sung et al., which surveyed and tested pedestrian activity in Seoul against Jacob's conditions; and De Nadai et al., which used mobile phone data to extract human activity measurements in six different Italian cities (Bologna, Florence, Milan, Palermo, Rome, Torino) and test them against Jacob's conditions. In both instances (Italy and South Korea), although different from locations from which Jacobs spelled out her conditions (great American cities), these four conditions held true in both studies.

In order to complement these efforts, this work will put forth the use of contribution from both studies in conjunction with the urban design DSS developed in the Changing Places group. The outcome of this research effort will present a stylized abstraction of selected districts (using data from Kendall Square and Harvard Square) that will allow users to score districts along multiple measures, improve particular vitality related metrics and compare these results to the results from other districts. Running these simulations under various scenarios will allow users to draw insights into the inner workings of urban systems. In addition, it will lead to key insights as to how urban interventions (special places) will impacts districts under a variety of conditions, giving players a chance to effectively compare and evaluate multiple districts.

Background & Related Works

Overview

The economist reported that 9% of the world's population is expected to live in 41 mega-cities—each with a staggering 10 million inhabitants—by 2030 (The Economist, 2015). As more and more people gravitate towards mega-cities looking for more prosperous lives and higher standards of living, the infrastructure (housing, water, food and sewage systems, and transportation networks) within these cities becomes evermore burdened (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106). That is to say, on one end; cities are "essential crucibles" for economic activity, innovation, novelty and tolerance, while on the other end; they are vessels for pollution, poverty and criminal activity, and traffic congestion (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106). The overarching question then becomes, how can life in cities be supported along with all the prosperous aspects (such as innovation, economic prosperity, novelty and tolerance), while reducing the negative aspects (such as overcrowding, poverty, criminal activity, traffic and pollution) (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106).

The main focus of this work is not to look at the impacts of all these aspects; rather, it will focus on the aspects that impact urban vitality by reflecting on previous works by the likes of Jane Jacobs as well as others. There are three competing approaches for examining urban vibrancy (Storper & Scott, 2018). Richard Florida theorizes that metropolitan areas with high concentrations of technology workers, artists, musicians as well as a group he defines as "high bohemians" are more likely to be vibrant (Florida, Cities and the Creative Class, 2005), while Glaeser focuses on human capital (Glaeser, 2011) and Clark et al. focus on urban amenities and fixed infrastructure. This research builds upon the contributions of the latter's approach (Clark, Lloyd, Wong, & Jain, 2002).

This body of work lends itself to an emerging interdisciplinary field of research called "urban computing." By definition, it crosses computer science and software approaches with traditional urban planning, urban economy and urban sociology to develop software solutions to growing urban challenges (Zheng, Capra, Wolfson, & Yang, 2014). Up until recently, this has been the missing link that prevented theories, such as those presented by Jacobs, from being empirically tested and validated. Therefore, attempts to leverage her theoretical contributions in simulation models were of little impact, as there was no way to test them. This notion has changed as data from novel sources (such as, social media, online images, mobile phones) has widely and readily become available (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106).

Jacobs' Theories

According to Jane Jacobs, humans are the primary constituents of a healthy, vital and vibrant urban core. More specifically their presence throughout urban areas and particularly on sidewalks is what breaths life into neighborhoods. She surmised that, in order for urban life to be sustained, a continual flurry of activity consisting of sidewalks filled with pedestrians at all times of the day must be present. Urban "death", as she called it, is caused by the exclusion of pedestrian activity from urban cores. This notion feeds into the idea of public safety as "a well-used city street is apt to be a safe street and a deserted city street is apt to be unsafe" (Jacobs, 1961) (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106).

In order for this statement to hold true, planners and policy makers must provide residents (as well as visitors) with areas filled with attractors that support continuous activity throughout the daytime as well as nighttime. In addition to the increased public safety that is created by these "eyes on the street", urban areas thrive with face-to-face interactions throughout the day and night, which can contribute to the local economy. Jacobs prescribes a set of diversity conditions essential for the generation and maintenance of urban life to achieve the desired outcomes (Jacobs, 1961).

Figure 4: During summertime in New York, free yoga classes are offered as part of a multitude of recreational activities (Habtat New York, 2016).

The first condition stipulates that districts should be *multifunctional* in terms of attractors. The idea of a monocentric city limits the diversity of potential interactions between people from multiple backgrounds. Whereas polycentricism provides a location where people with diverse purposes seek common facilities. The benefits of these diverse interactions become compounded as primary uses are combined in a manner that attracts people at different times of the day (Viton). This, according to Jacobs, can lead to positive local economic impact. As we will see in the coming chapters, Kendall Square is a prime example of this monocentric planning. Districts that are planned for the sole purpose of offices will likely only provide the area with leisure facilities for those that are present during office hours; 9 am to 5 pm. Afterhours will likely see a drastic decrease in human activity, whereas the presence of secondary function, such as cafés and theaters, will likely attract more visitors and local residents, see figure 4 (Jacobs, 1961).

The second condition pertains to the *size and shape of block*. Jacobs theorized that large rectangular blocks, much like those common in big cities such as New York, result in an ineffective mix of use and people. As can be seen from the figure 5, large rectangular blocks result in sidewalks that intersect infrequently, which stymie the chances of diverse interactions (Jacobs, 1961).

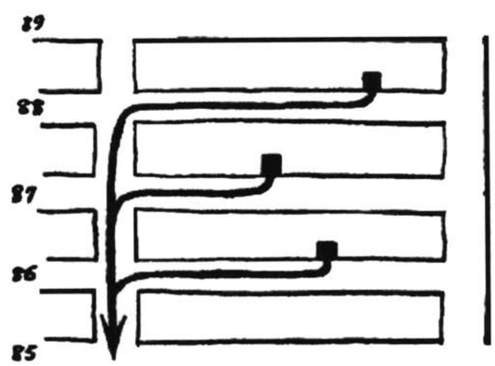

Figure 5: Large block, such as those found in New York impede foot traffic and interaction frequency (Jacobs, 1961).

Conversely, presence of small block increases the likelihood of meandering pedestrians to converse over a coffee at a sidewalk café. More interestingly, as Jacobs put it, these smaller blocks also urge cars to slow down—if not discourage their presence entirely—which is likely to increase pedestrian activity due to street safety. Figure 6 elucidates the benefits of smaller streets blocks.

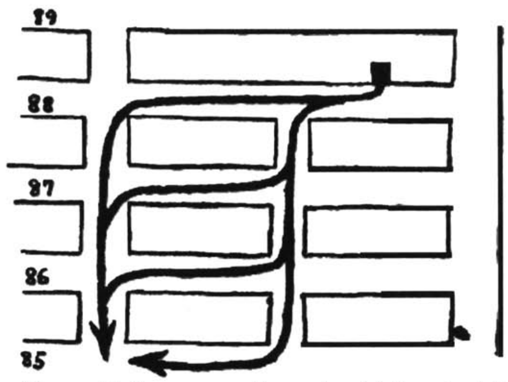

Figure 6: Conversely, small blocks offer multiple avenues through which pedestrians can socially run into one another (Jacobs, 1961).

The need for aged building is the third condition prescribes by Jacobs to increase urban vitality. According to her, old buildings are key for the growth of streets and districts. By her definition, old buildings are those of the "plain, ordinary, low-value old buildings, including some rundown buildings" in addition to newly renovated and re-appropriated real estate. By contrast, if a development area is filled with only new construction, the area will only thrive with residents and enterprises that can afford the high cost of new construction. By ensuring a good mix of new and old construction, planners can assume flourishing diverse districts supported by high-yielding, middle-yielding, low-yielding and no-yielding enterprises as well as high-rent, mid-rent and low rent residential tenants (Jacobs, 1961). To support her theories, she observed that the large-scale developments in New York (in the sixties) did not change over time nor adapt to the surrounding environment, whereas old building helped cultivate new primary uses in neighborhoods (start up companies tended to start in and grow in old, low-rent buildings) (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106).

The final ingredient to realizing Jacobs's conditions is *the need for concentration.* Population density is an important measure for understanding cities. By definition it is the number of people per square unit of measure. Jacobs argues that neighborhoods with high population density benefit a city economically and culturally. She theorizes that neighborhoods, which increase safety, economic vitality and prosperity, are those with high population densities. "...it still remains that dense concentrations of people are none of the necessary conditions for flourishing city diversity. And it still follows that in districts where people live, this means there must be a dense concentration of their dwellings on the land preempted for dwellings." Finally, she stressed that the mutual exclusivity of all four conditions: density alone cannot foster urban diversity, and mixed land use would not flourish in areas with low density and big blocks (Jacobs, 1961).

Contextualizing Jacobs' Theories

Early Attempts

Recently, the large-scale datasets, such as those available from cell phone data networks has opened new possibilities for studying city dynamics at granularities that were previously not attainable. This data has allowed researchers to examine mobility patterns of city dwellers (Gonzales, Hidalgo, & Barabasi, 2008), to map functional uses, to identify places that play a major role in the life of citizens (Isaacman, et al., 2011), to compare cities based on spatial similarities and differences (Louail, et al., 2014) and to predict socio economic indicators such as crime (Bogomolov, et al., 2015) (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106). In the latter effort, predicting crime, the researchers were able to validate Jane Jacob's observations regarding crime. Jacobs hypothesized that people diversity as well as visitors in a neighborhood increased the likelihood of *natural surveillance*, which in turn reduces the crime rate in the surrounding area. The constant presence of watchful eyes moving around becomes a deterrent for crime.

Urban sociologist Kevin Lynch proved that there is a strong impact of the geographical environment (features of an area) and the routes that individuals choose to navigate the area

(Lynch, 1960). Subsequent efforts validated his findings using a web application that crowd-sources the collective "mental images" that Londoners have of their city. The findings from this study went on to show that areas that suffer from social problems, bad living conditions and crime were not constituents of the mental images painted by residents (Quercia, Pesce, Almeida, & Crowcroft, 2013). These findings echoed Lynch's theory that navigable cities are more recognizable.

Further attempts were made at classifying urban areas based on visual cues. For example, (Quercia, Pesce, Almeida, & Crowcroft, 2013) investigated the urban elements, which locals use to assess the safety, prosperity, and attractiveness of streets using similar crowdsourcing approaches via web applications. A similar approach leveraged social media data from Flicker and Foursquare to assess the walkability of neighborhoods.

This approach used the time of day when photographs were taken and key words used to tag streets as a proxy to whether a street is walkable or not (i.e., walkable streets were tagged with walkability-related words, and safe streets were pictured during different times of day as well as nighttime) (Quercia, Aiello, Schifanella, & Davies, 2015).

Recent Attempts

De Nadai went beyond assessing the safety of roads and looking at crime and conducted a comprehensive validation of Jacobs' four conditions for urban vitality. This effort leveraged 6 primary data sets: Mobile phone activity, OpenStreetMaps, Census data, land use data, infrastructures and Foursquare data (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106). Mobile phones are used as a proxy for human activity. Call records are generated every time a cell tower delivers a communication through the network from a cell phone device. These call records include date pertaining to the time, tower location, and Internet activity. For the study, they focused on (passive) Internet activity, as mobile phones are more likely to be connected to the Internet for background traffic and push notifications, regardless of direct activity.

In addition, De Nadai used OpenStreetMaps (OSM) used to construct the virtual abstraction that visualized the specific case study. Information pertaining to the population (Census) and building (Infrastructure) was gathered from the Italian National Institute for Statistics (ISTAT). Land use data was gathered from the Urban ATLAS European projects, which provides satellite images that, categorize cities into 20 classes (such as continuous urban fabric and agriculture areas). Lastly, Foursquare data was used to observe the locations and categories of POIs that people frequent through a given day. The findings from this work showed that Jacobs's four conditions for maintaining a vital urban life held for Italian cities, as they held for the case of Seoul, Korea and in the context in which Jacobs hypothesized. The results found that simple static and structural fixtures explain the variability of district activity (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106).

Table 1: District Size (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106)

City	#Districts	Size (avg)	Population (avg)
Bologna	23	3.34	15.918
Florence	21	2.89	16.633
Milan	85	1.72	14.551
Palermo	43	2.01	15.075
Rome	146	3.24	17.312
Turin	56	2.00	15.543

With regards to the size of a district, De Nadai et al. specify that it is a loose constraint, and suggest that districts be defined in which ever way is more appropriate. They verified that districts from their datasets cover an approximate average area of 2.5 Km2 with and average population density of 10,000 people per km2. Table 1 reflects these findings. "Jacobs did not define any strict criterion concerning district size: she simply proposed that the edge of an administrative district should not exceed 2.4 km, and that each district should have a minimum population of 50,000 people" (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106).

Jacobs's Four Conditions for Urban Vitality

Mixed-land use

According to De Nadai et al., "Mixed land use matters only in cities in which functional uses were historically separated." Their findings show that mixed land use neither contributes positively nor negatively to the urban vitality in a district. In Milan for example, city largely separated by functional areas, vitality was experienced in the mixed districts only. More interestingly though, their results showed that land use mixes with more *third places* had the highest beta coefficients. Daily attractors, such as supermarkets, were important; however third places were more so correlated with activity density. 3rd places are defined as pubs, cafés and restaurants or "public places in which people can hang out [with] good company and lively conversations, putting aside the concerns of home and work (their first and second places)"[30].

Small Blocks

De Nadai et al. report that block size does not greatly impact urban vitality, as super-blocks do not exist in European cities (such as Milan and Rome) as they do in American cities (such as New York and San Francisco). Their findings, however, do show that the density of intersections matters greatly. In fact, vibrant areas are those with densely packed streets, which facilitate pedestrian movement and slows down traffic [9]. This is what Jacobs refers to as *sidewalk ballet,* that, in addition to facilitates vibrant areas (through countless pedestrian interactions), they build communal trust and perceived safety in these urban areas. Kids playing in the streets, unattended street vendors, and people walking their dogs are all images that come to mind when thinking about safe and livable areas. One way of making this happen is through areas with dense intersections.

Aged Buildings

Neighborhoods with a healthy mix of aged buildings are attractors to what the likes of Richard Florida labels as "high bohemians". These metropolitan areas are more likely to be economically developed; have communities that offer an abundance of mixed-use housing and co-working spaces; are densely packed with innovative companies, as well as learning institutions; offer a wide range of amenities where city dwellers can go to after work hours; and are transit friendly by making everything accessible either by walking or public transport. They are also geographic areas where leading institutions and companies cluster next to start-up companies, business incubators, and accelerators (Katz & Wagner , 2014).

According to (Katz & Wagner , 2014), compact, amenity-rich enclaves in urban cores are becoming the prime choice where young talented workers choose to congregate and co-locate. In order to leverage the abundance of this widely available talent, key companies in knowledge intensive industries are locating their facilities in close proximity to other firms, research labs and universities in order to facilitate the practice of "open innovation" (Katz & Wagner , 2014).

As Jacob explains it, neighborhoods with aged buildings tend to have diversified local economies. The presence of buildings of varying age and conditions, ranging from high-end construction to rundown old buildings with a mix of plain ordinary ones, attracts both high-earning enterprises as well ordinary and innovative ones. This was not the case in the past. Jacobs claims, "in Miami Beach, where novelty [were] the sovereign remedy, hotels ten years old are considered aged and are passed up because others are newer" (Jacobs, 1961).

They conclude that mixing of buildings from different eras in the European context is not as important as it is in the American context. This is the result of centuries of preservation that resulted in districts that are defined by age. Because the case study we selected contains mostly new development, we argue that measures relating to the age of building do not apply to this work.

Density

Richard Florida states that density and building height are not the key ingredients in fostering urban vitality and innovation. He claims the "this rush to density: this idea that density creates economic growth" is not the way to creating livable areas, see figure 7. Florida highlights the importance of creating "real, walkable urban environments that stir the human spirit. Skyscraper communities are vertical suburbs, where it is lonely at the top." He maintains that the ideal density that fosters urban vitality is that describes by Jacobs.

Figure 7: Richard Florida that a vertical drive for density is not the solution to fostering urban vitality. Rather, a carful mix of diverse residents and workers living in a walkable environment is key (Yeung, 2016).

Jacobs's final condition for urban vitality is the *need for concentration,* or what De Nadai et al. refer to as dense concentration of both buildings and people. Their results show that the most impactful factor that adds to the vitality of cities in the Italian context is office workers. They report that office workers have the highest beta coefficient under the density variables that contribute to vitality. They surmise that this is a reasonable finding as the first three conditions (mixed-land use, small blocks and aged buildings) have impact of the urban vitality contributed by residents, whereas the need for concentration impacts urban vitality by means of the urban dwellers in the area for the purpose of work.

Vacuums

As a warning, Jacobs discusses the dangers of massive single uses in cities as they form borders, which can lead to destructive neighborhoods. She refers to the railroad tracks as a classic example of active borders, as they came to stand, long ago, for social borders—"the other side of the tracks". As such, the economic prosperity of a district lying on one side of the tracks might do better than the district of the other side, however, the areas that are most negatively impacted are those typically next to the tracks (Jacobs, 1961). To this extent, De Nadai et al. observe that being close to highways generally end up being detrimental to the urban vitality of a neighborhood. See figure 8 (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106).

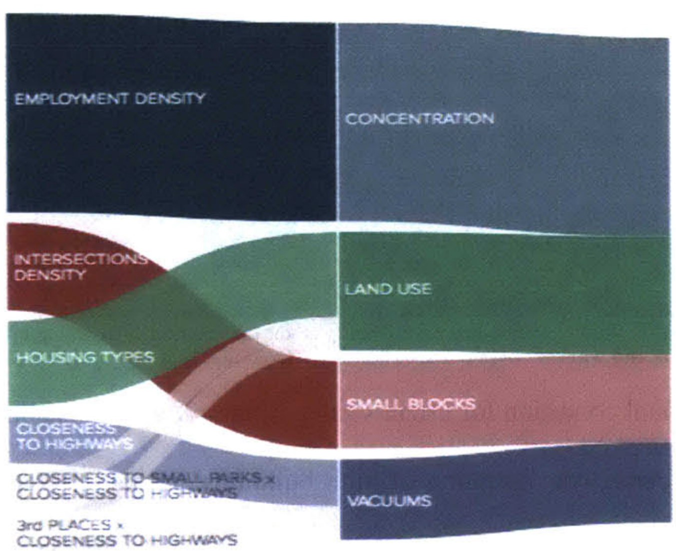

Figure 8: summary of the most important variables that impacts each of the conditions Jacobs referred to in the *Death and Life of Great American Cities* (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106).

As can be seen, employment density impacts **Concentration**; housing types, proximity to small parks and third places impact **Land Use;** interaction density impacts **Block Size**; and **Vacuums** are impacted by proximity to highways. As we did with the impacts of aged buildings, we will ignore all contributions from vacuums, as there are none in the areas under study in this work.

Urban Computational Platforms

Recent attempts at creating software solutions that facilitate decisions regarding urban planning have focused on a variety of topics raging from walkability of neighborhoods to energy usage of buildings. The CityScope platform for example is a tangible collaborative decision support system designed to facilitate collaborations between stake-holders of varying levels of proficiency with technology and domain knowledge in their interaction within the contexts of urban planning. The goal is to model the complex systems of city infrastructures and the behaviors of these systems along with their interdependencies in interactive tangible interfaces in order to assists stakeholders in designing and predicting future scenarios (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

The CityScope platform is designed to utilize a tangible user interface along with a computational platform to support collaborative city planning. The platform provides a tangible interface through a modeling environment that supports various dynamic visualization and interaction capabilities (Larson, Reinhart, Alfaris, & Al-Wabil, 2014). The platform has previously been used to analyze urban (CitySchema/CityScope-Riyadh), transportation (BAR project), and energy systems. The customizable aspect of this platform makes it a favorable tool in workshop settings. It can be used for: 3D physical model, 3D projection mapping, static information display, real time observatory model and urban intervention simulator (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

The 3D physical model is a useful way to conceptualizing city plans using Lego bricks to rapidly study and iterate on a series of alternative designs. The projection mapping utilizes projectors to illuminate each surface of the physical model: "one to project directly down on the ground and roof planes of a physical model, one projector for each of the four vertical surface orientations (north, south, east, and west) (Larson, Reinhart, Alfaris, & Al-Wabil, 2014)". The platform offers the flexibility of correcting the projections required for 3D mapping on to curved surfaces. The size and scale of the platform can easily be modified by networking multiple city scope platforms together. The static information mode can be used to project data such as land use patterns, GIS data, and other information from existing datasets onto the physical model. Similarly, multiple real-time data streams can be projected onto the physical model, such as flows of traffic, energy, water, and social media activity (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

Figure 9: City Scope can be used to simulate a wide variety of urban interventions, such as the introduction of shared-use autonomous vehicles, new roadway and pathway designs, or the impact of new developments on pedestrian and vehicle movement (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

CityScope tools are designed for early-phase planning, allowing non-expert stakeholders to engage with high-level parameters that frame urban development and infrastructure scenarios, see figure 9. Stakeholders interact with models, allowing them to quickly and intuitively understand constraints, challenges, and possible solutions for various development scenarios

(Larson, Reinhart, Alfaris, & Al-Wabil, 2014), as will be presented in future chapters. According to Larson et al., "this tool is built to inform stakeholders, build consensus, and ultimately streamline the process of community engagement throughout major development projects." The platform can act as an urban data observatory and intervention evaluation tool by utilizing the key features of the platform (Larson, Reinhart, Alfaris, & Al-Wabil, 2014). This research focuses on the urban intervention simulation mode, which can be used to simulate a wide variety of urban interventions, such the impact of new developments on district vitality.

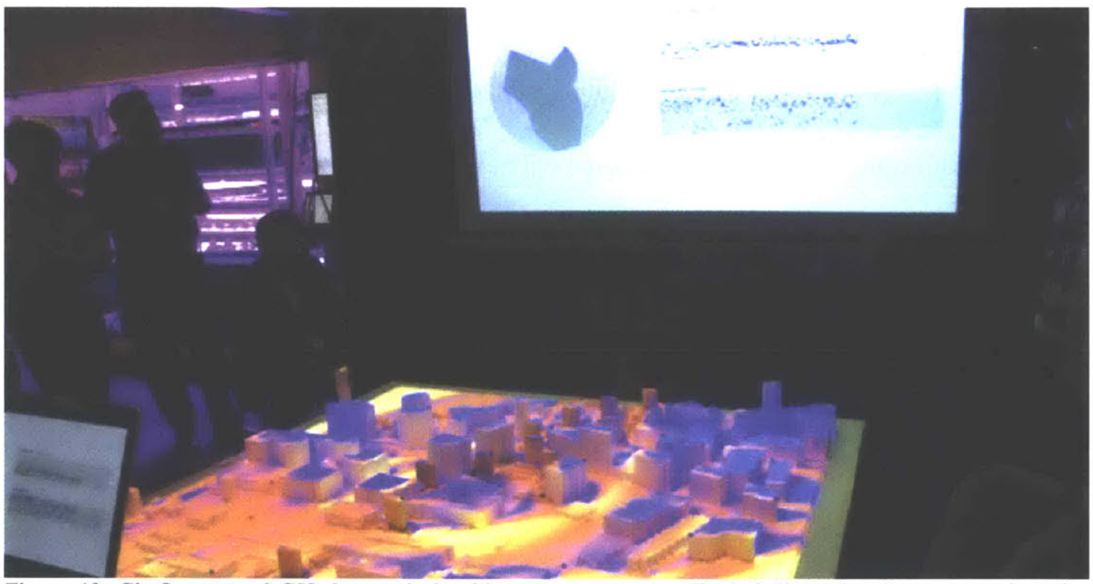

Figure 10: CityScope used GIS data and algorithms to create a voxelized, 3-dimensional representation of an existing urban area in Kendall Square, Massachusetts (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

Initially, CityCope began as a static platform that used Legos as a way of rapidly ideating different city plans. The research team selected Legos for the range of design flexibility, as a single Lego brick can represent a single residential unit and scaled up accordingly (Larson, Reinhart, Alfaris, & Al-Wabil, 2014). In addition to the scalability factor, the familiarity of Legos offered another aspect that made these design tools a viable option. As the limitations of this static approach became apparent, the researcher then began to make this design tool more flexible. By invoking projection mapping along with visualization software, such as Processing, the researchers were able to push the application of the software tool to represent a physical city while using actual data to represent different aspects of that city. CityScope used GIS data and algorithms to create a representation of existing neighborhoods, see figure 10. Information layers included satellite imagery, solar insolation, wind flows, social media activity, mobility systems, and business intensity (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

The next iteration of the platform transformed the static projection mapping onto a canvas for land use planning, allowing rapid prototyping with immediate evaluation, see figure 11. The platform evolved to further project onto multiple sides of 3D objects, such as the facades of design spaces (Larson, Reinhart, Alfaris, & Al-Wabil, 2014). Subsequently, the platform evolved to work with other platforms to evaluates operational energy use, embodied energy use, walkability and daylight availability throughout neighborhoods (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

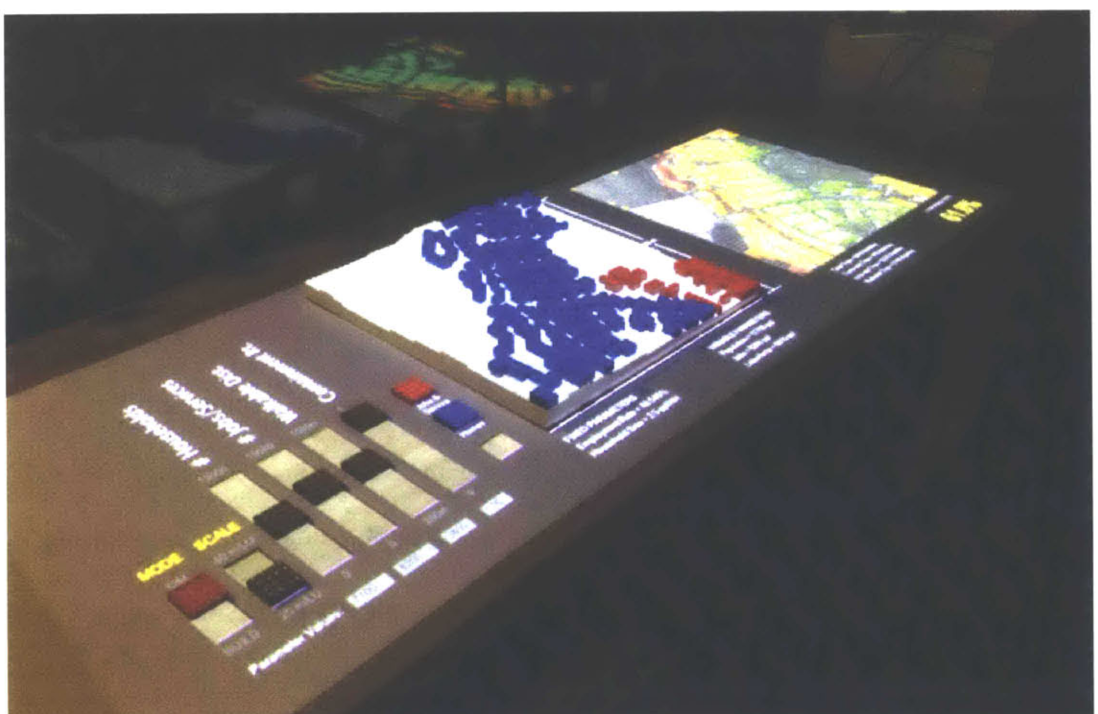

Figure 11: CityScope MarkII Scout Table, using static projection mapping onto a canvas for land use planning, allowing rapid prototyping with real-time evaluation (Larson, Reinhart, Alfaris, & Al-Wabil, 2014).

Case Study

Kendall Square Profile

Kendall Square, is bounded to the north by Broadway and Main Street, the Charles River to the east, and the Boston & Albany Railroad tracks to the west, as shown in figure 12. It is almost entirely occupied by the MIT campus. The Kendall Square transit stop connects the district to the rest of Cambridge and Somerville as does the Longfellow and Harvard bridges connect it to Boston. The major recreational resource is the Charles River Reservation (Cambridge Community Development Department, 2013).

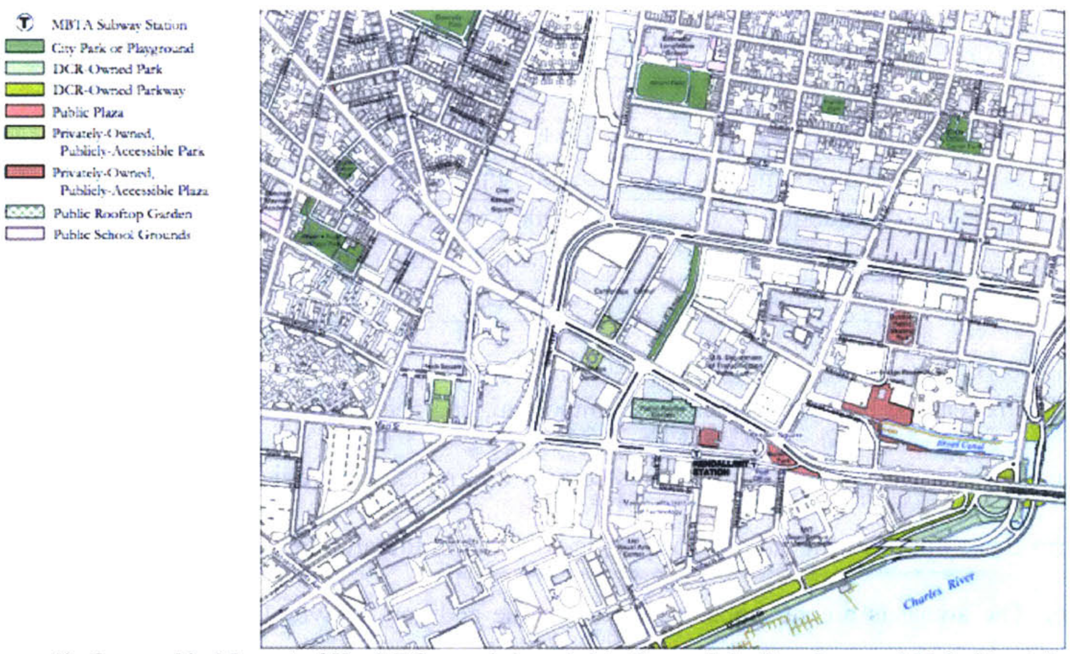

Figure 12: Geographical Layout of Kendall Square is bounded to the north by Broadway and Main Street, the Charles River to the east, and the Boston & Albany Railroad tracks to the west (Cambridge Community Development Department, 2013).

In the last three decades, Kendall Square has been transformed from a former industrial district to one of the world's leading centers for biotech research and innovation. The Square has seen the accompanying growth of hotels, restaurants, and shops that serve the area's cluster of life science and technology firms, the MIT community, and surrounding neighborhoods. Several major developments occupy part of the Kendall Square area, including Cambridge Center, Cambridge Research Park, Technology Square, and One Kendall Square. Area 2 contains the core of MIT's academic and research facilities in addition to various student campus-housing options. The residents in Kendall Square largely consist of undergraduate and graduate student dormitories and fraternities (Cambridge Community Development Department, 2013).

Next, we extracted statistics of the market profile for the area to form the general spatial abstraction of the modeling platform that represent the district, such as total area, residents, students, working population and number of registered businesses in the area. For Clarity, these numbers are tabulated below (Cambridge Community Develpment Department), see table 2.

Table 2: Kendall Square Market Profile Summary

Kendall Square MIT	
Total area	1.3 km^2
Employment	52,000 Ppl (.5 mile radius)
Students	12,000 Ppl
Population	6815 Ppl (.5 mile radius)
# of Businesses	140 Places

The registered businesses include architectural, engineering, biotech, energy, consulting, financial, government, health/shopping, restaurants and residential registered firms. As can be seen form these numbers the number of people working in the area far outweigh the number of residents. The area has recently been rezoned for the addition of over 1 million square feet of new space on a series of underutilized properties between Main Street and Memorial Drive. However, these plans have not materialized (Cambridge Community Develpment Department).

Figures 13 and 114 illustrate the land use patterns in Kendall Square. As can be seen in the legend (figure 14), land use categories are divided into the following categories: residential, residential with ground floor commercial, mixed use, commercial and industrial, and other (such as health, education, government, etc.) As will be shown in the next section, this land use taxonomy will be used to label the tags for the Lego blocks.

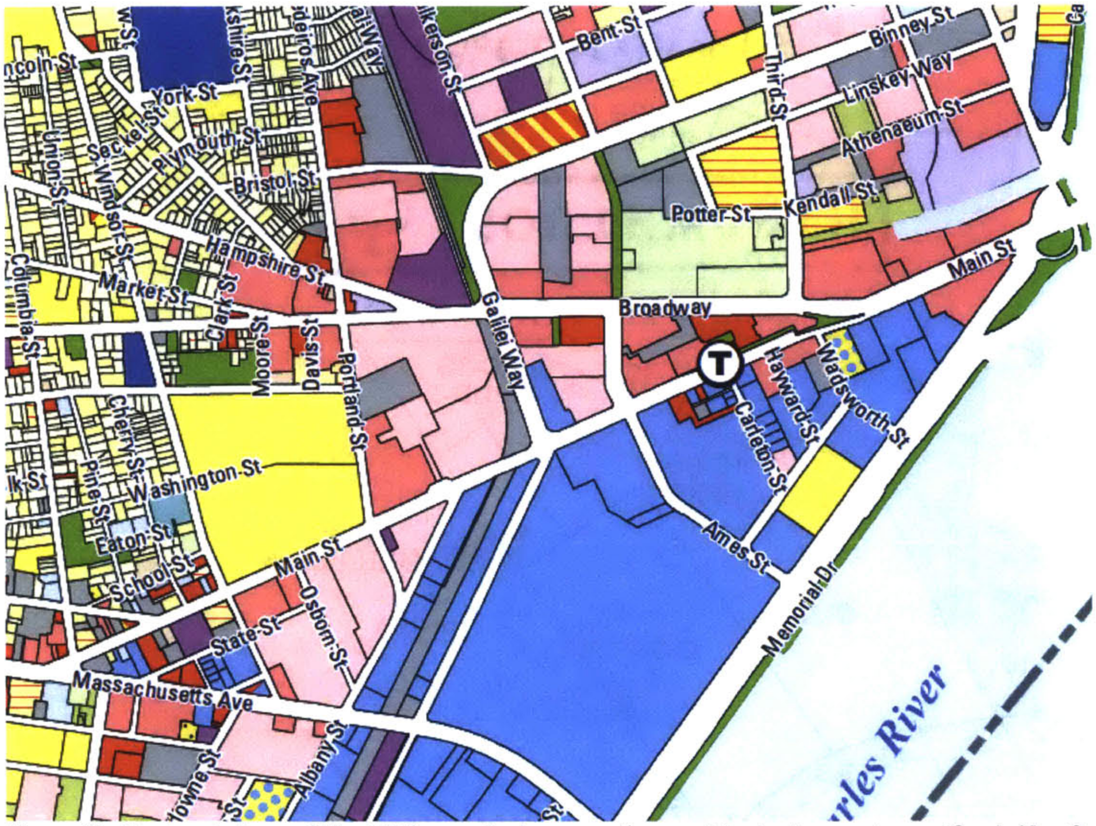

Figure 13: The break down of Kendall Square (and surrounding area) by land use category (Cambridge Community Development Deprtment, 2015).

Figure 14: List of all land use categories in Kendall Square (Cambridge Community Development Deprtment, 2015).

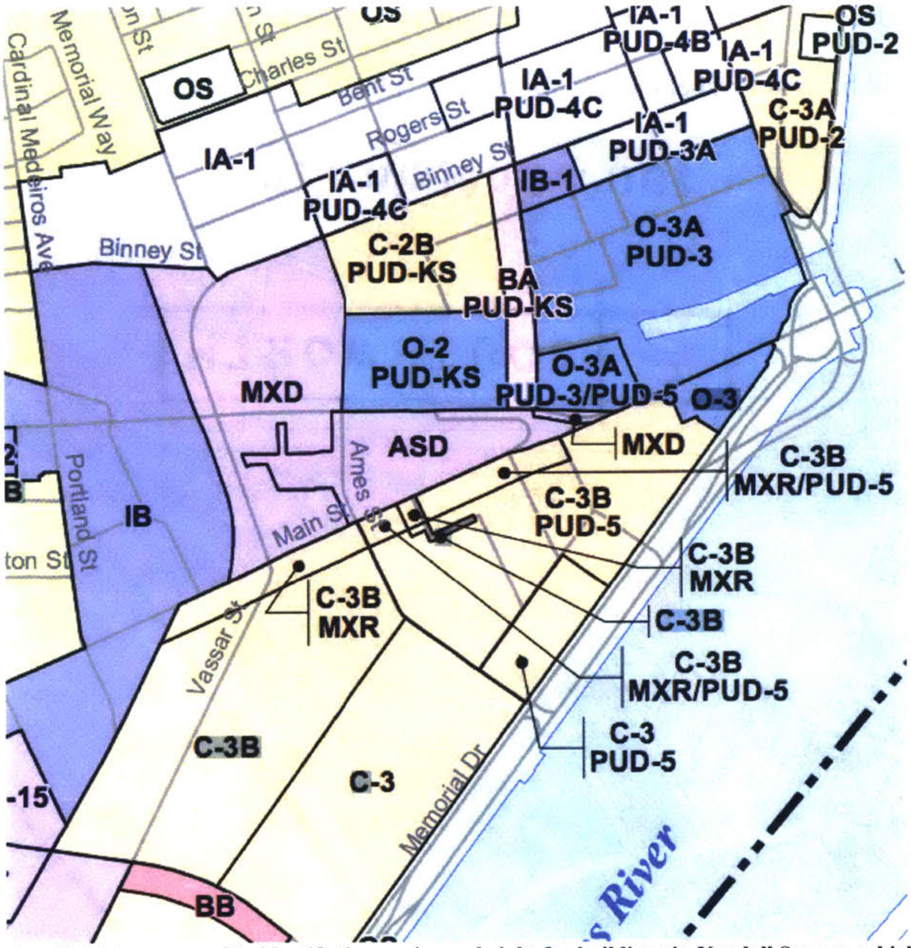

Figure 15: Zoning districts were used to identify the maximum height for buildings in Kendall Square, which will later be used to calculate used to calculate "Building Types" (Cambridge Community Development Deprtment, 2015).

Harvard Square Profile

Home to Harvard University, this square is an international destination, mixing history and learning with contemporary arts and entertainment. A unique blend of restaurants, shops and cultural offerings draws residents, students, professionals and visitors. With approximately 900,000 square feet of retail space, Harvard Square functions as a regional center for shopping in an urban, pedestrian-friendly context. The character of Harvard Square reflects three and a half centuries of growth and change. At the center is Harvard Square Station, one of the busiest on the Red Line with bus links both underground near the trains, and along Massachusetts Avenue next to Harvard Yard and the Cambridge Common. Figure 16 below show the geographical location of Harvard Square (Cambridge Community Development Department, 2015).

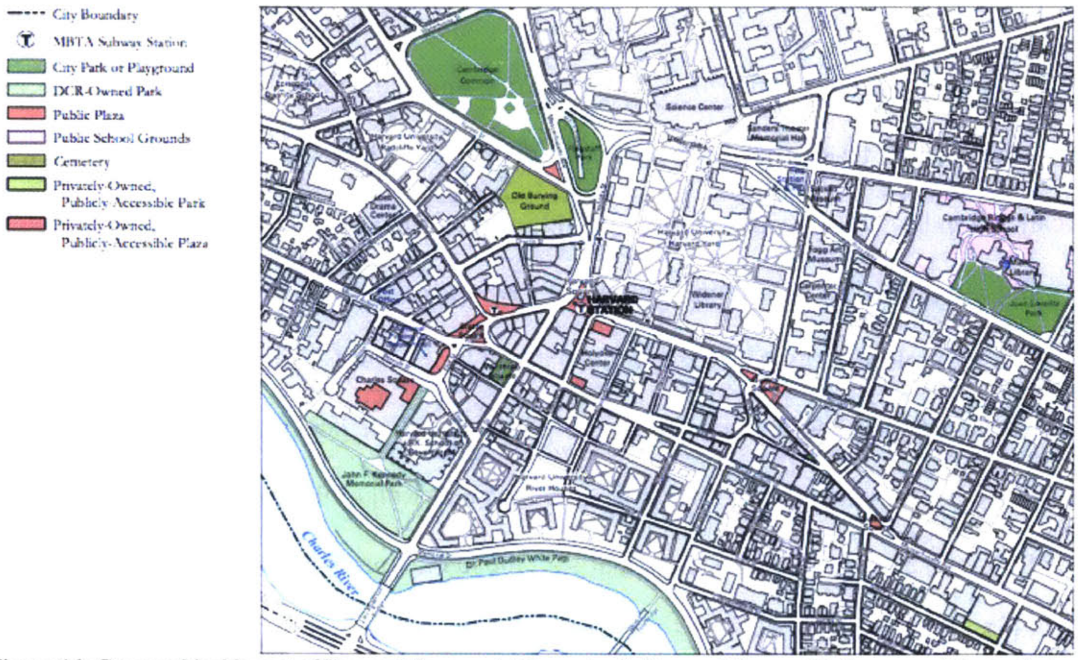

Figure 16: Geographical layout of Harvard Square. At the center is Harvard Square Station, one of the busiest on the Red Line with bus links both underground near the trains, and along Massachusetts Avenue next to Harvard Yard and the Cambridge Common (Cambridge Community Development Department, 2013).

Next, we extracted statics of the market profile for the area to form the general spatial abstraction of the modeling platform that represent the district, such as total area, residents, students as well as the working population. For Clarity, these numbers are tabulated below (Cambridge Community Development Department, 2015) see table 3.

Table 3: Harvard Square Market Profile Summary

Harvard Square	
Total area	1.47 km^2
Employment	17,860 Ppl (.5 mile radius)
Students	24,357 Ppl
Population	16,978 Ppl (.5 mile radius)
# of Businesses	337 Places

In contrast to Kendall Square, the number of people working in the area is close to the number of residents living in Harvard Square. Also, the number of registered business in the area are more than twice that of Kendall Square. Figures 17 and figure 14 illustrate the land use patterns in Kendall Square. Similar to Kendall Square, land use categories are divided into the following categories: residential, residential with ground floor commercial, mixed use, commercial and industrial, and other (such as health, education, government, etc.)

Note***: Initially, the data sets representing both Kendall Square and Harvard Square were gathered from multiple sources. Since the initial data set for Harvard Square was not as complete as the data gathered for Kendall Square, I used the Market Profile data set for both Kendall and Harvard Square, However, both reports list the population as well as the workplace population as the population in a .5 mile radius. As a comparison, the market profile report lists the number of residents in Kendall Square as 6815, whereas the neighborhood profile for the general Area2/MIT reports the number of population as 5057.

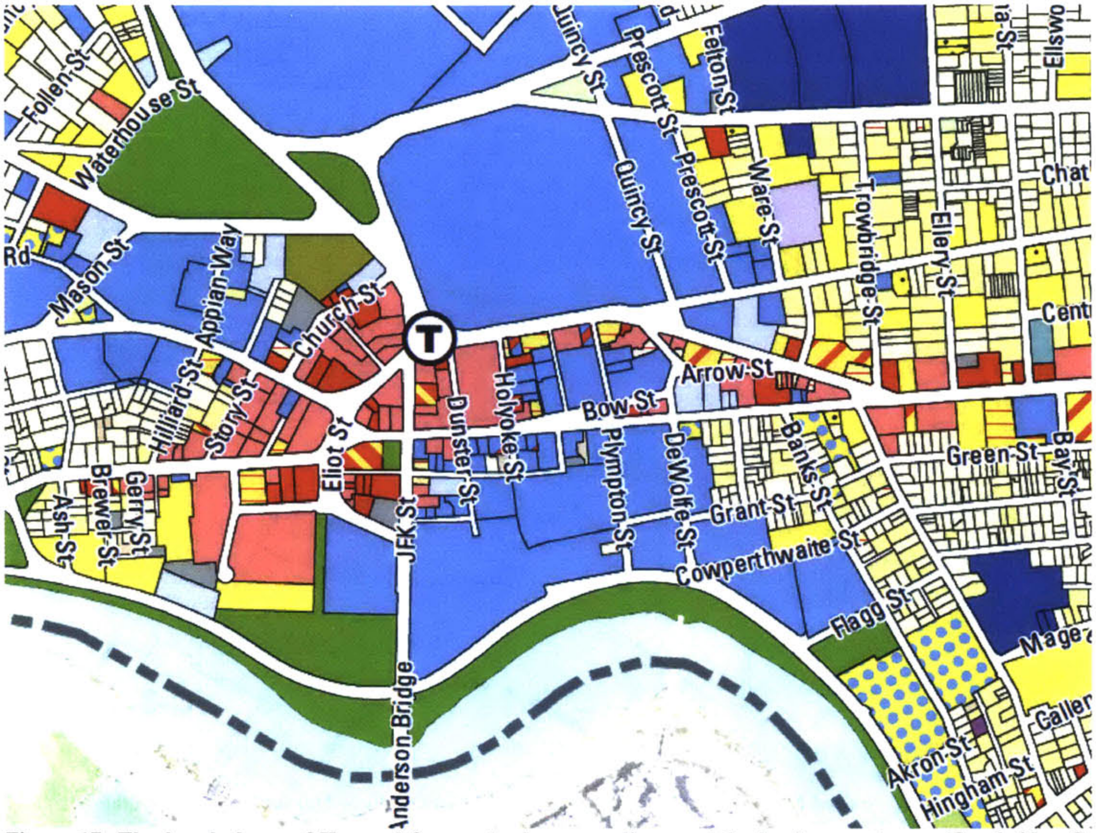

Figure 17: The break down of Harvard Square (and surrounding area) by land use category (Cambridge Community Development Deprtment, 2015).

As was shown for Kendall Square, figure 18 illustrates the zoning districts in Harvard Square within Cambridge. This is the most recent map published by the Community Development Department, in June 2016 (Cambridge Community Development Deprtment, 2015).

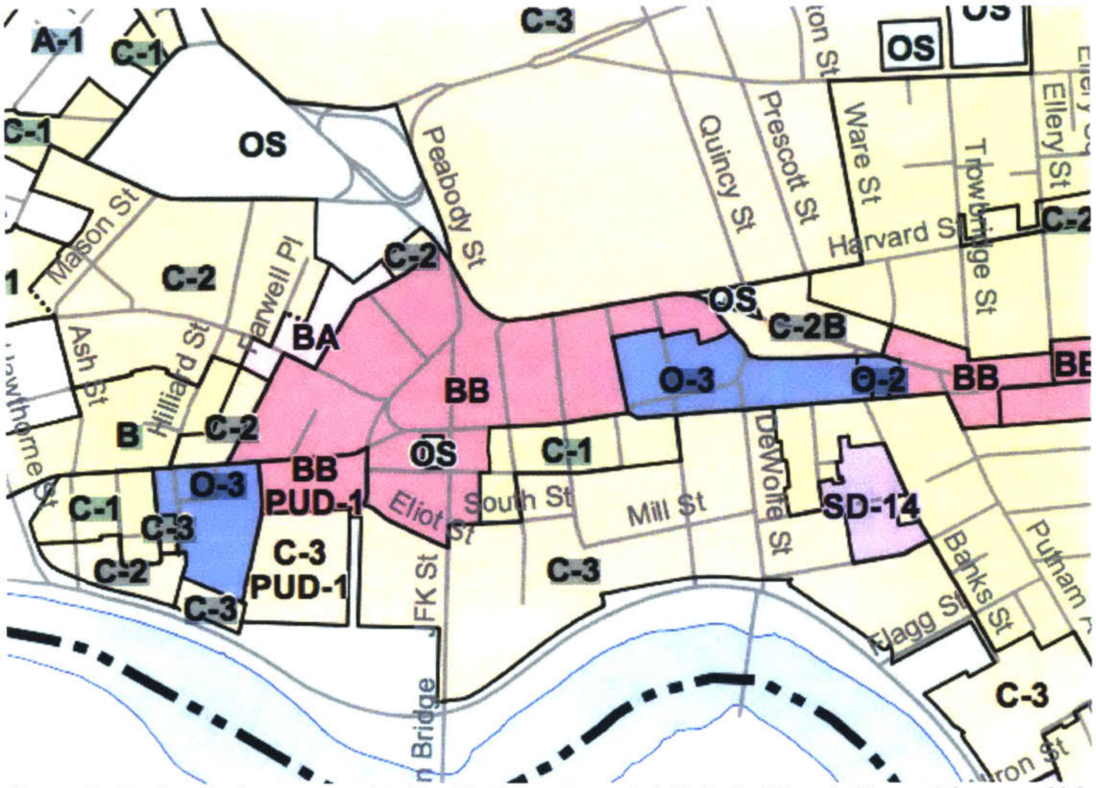

Figure 18: Zoning districts were used to identify the maximum height for buildings in Harvard Square, which will later be used to calculate "Building Types" (Cambridge Community Development Deprtment, 2015).

Table 4 below illustrates the zoning districts for the Kendall Square area along with maximum height for each zoning district ID within the area. Refer to figure 13 for the location of each of the entries in the table. This data is used to calculate the housing types, which utilized the number of buildings in a given category and the number of floors in each category. The zoning districts for Harvard Square are tabulated in table 5. Refer to figure 17 and figure 14 for the locations of each of the entries in the table. This data will be used to calculate the housing type parameter, as will be seen the following section.

Table 4:Zoning Districts for Kendall Square

	General range of allowed uses	Building Height (feet)	Num bldgs	Num flrs
O3	Most types of residential dwellings, most institutional uses, offices and laboratories	90 (non-residential) 120 (residential)	4	9
O3A,PUD-3, PUD-5	Most types of residential dwellings, most institutional uses, offices and laboratories	90 (non-residential) 120 (residential)	5	9
O3A, PUD-3	Most types of residential dwellings, most institutional uses, offices and laboratories	90 (non-residential) 120 (residential)	8	9
IA1, PUD-3A	Most types of residential dwellings, most institutional uses, offices and laboratories, Some Retail, Light Industrial, Heavy industrial	Max 45	5	4
C2B, BUD KS	single- and two-family detached dwellings townhouse dwellings multifamily dwellings (apartments, condos) some institutional uses	Max 45	6	4
MXD, ASD	Mixed use district: light industry, office, biotechnology manufacturing, retail, residential, hotel, entertainment, and institutional uses	Max 250, with up to 2 may reach 350	27	28
IB	Most types of residential dwellings, most institutional uses, offices and laboratories, Some Retail, Light Industrial, Heavy industrial	Max 120	20	11
SD-15	Similar to IB	Max 120	5	7
BB	Most types of residential dwellings, most institutional uses, offices and laboratories, most retail uses	Max 80	5	7
C1	Single and two family detached dwellings town house dewellings multifamily dwellings limited institutional uses	Max 35	56	3
C3 B	single- and two-family detached dwellings townhouse dwellings multifamily dwellings (apartments, condos) some institutional uses	Max 120	72	11
O2. PUD K	Most types of residential dwellings, most institutional uses, offices and laboratories	70 (non-residential) 85 (residential)	8	7
OS	open space, religious, or civic uses	Max 35	N/A	N/A

Table 5: Zoning Districts for Harvard Square

	General range of allowed uses	Building Height (feet)	Num bldgs	Num flrs
OS	open space, religious, or civic uses	Max 35	20	3
C-1	Single and two family detached dwellings town house dwellings multifamily dwellings limited institutional uses	Max 35	48	3
C-2	single- and two-family detached dwellings townhouse dwellings multifamily dwellings (apartments, condos) some institutional uses	Max 85	52	8
C-3	single- and two-family detached dwellings townhouse dwellings multifamily dwellings (apartments, condos) some institutional uses	Max 120	56	11
B	Single - and two- family detached dwellings townhouse dwelling (special permit)	Max 35	32	3
BA	Most types of residential dwellings, most institutional uses, offices and laboratories	Max 45	5	4
BB	Most types of residential dwellings, most institutional uses, offices and laboratories	Max 80	29	7
O-3	Most types of residential dwellings, most institutional uses, offices and laboratories	Max 90	4	8
A-1	Single family detached dwellings	Max 35	5	3
A-2	Single family detached dwellings	Max 35	4	3

Computational Model

Overview

As discussed in Chapter 2, this work utilizes the theoretical contributions from Jane Jacobs made in the Death and Life of Great American Cities, which has recently been validated by researchers in multiple cities across the globe. As a result, the simulation model presented herein leverages these contributions to building a tool for assessing the urban vitality of districts and planned interventions to make them more livable. Sung and De Nadai extracted several variables to quantify the four conditions as prescribed by Jane Jacobs (Sung, Lee, & Cheon, 2015) (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106). Here we explain the details of these metrics and show how both Kendall Square and Harvard Square perform along these metrics.

Variable Discussion

Land Use Variables

As discussed earlier, land use metrics contain multiple outputs that relate vitality of a district in terms of both the static infrastructure (land use mix, closeness to parks, residential vs. non residential, and housing types) as well as available activities in the area (commercial, night life, nightlife, nightlife density, daily places, and third places). The first of these conditions is land use. As Jacobs prescribed, districts that have more mixed primary uses are those that exhibit greater vitality. These primary categories include residential buildings, education facilities, recreation facilities, museums, libraries and galleries. Land use mix in a given district is characterized by the following mathematical equation (Sung, Lee, & Cheon, 2015) (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106):

$$LUM_i = -\sum_{j=1}^{n} \frac{P_{i,j} \log(P_{i,j})}{\log (n)}$$

$P_{i,j}$ is defined as the percentage of square footage with land use j in district I. N is the number of possible land uses. LUM_i is zero for districts with single purpose uses, if it is used equally in all n purposes, then LUM_i is equal to one. As the value of LUM_i increases, the more mixed a given district's land use is. Land uses are divided into the following: residential, commercial, park and recreational. To find LUM, we first computed the percentage of the total area dedicated to each of the three types of uses (residential, commercial, and office/industrial) and then divided by the total available land use types (3). As can be seen, the results for both areas are similar to the LUM reported by De Nadai et al. in the Italian context, see figure 19.

The next variable that impacts land use is the proximity to parks, as defined by the following (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106):

$$SP_i = (\frac{1}{|B_i|} \sum_{j \in B_i} dist(j, closest(j, SP)))^{-1}$$

B_i is the set of blocks in a given district. Closest(j, SP) is the geographical distance from a given park to the centroid of block j. Dist(x,y) is the geographical centroid between two given elements. Closeness to parks involved determining the distances form the centroids of all blocks within both Kendall and Harvard Square to the nearest small park in that respective area. The result gives the average distance in inverse meters (1/m) to the closest park. The approximate distance in meters for Kendall and Harvard Square is 338m and 412m respectively. As both case studies focus on small University districts, this measure is expected to be higher (closer average distance) than the Italian context, as the scale of the study in the Italian context was much larger.

One variable that indicates the vitality of districts in terms of its dwellers is the residential to non-residential (RNR_i) balance in a given district, as shown in the equation below (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106) (Sung, Lee, & Cheon, 2015):

$$RNR_i = 1 - \left|\frac{Res_i - NonRes_i}{Res_i + NonRes_i}\right|$$

Res_i is the area occupied by residential buildings in a given district, and $NonRes_i$ is the geographical area covered by non residential buildings. Higher values of RNR_i indicate more balanced districts in terms of residential vs. non-residential uses. The RNR measure finds the ratio of the total available residential area to the total non-residential area. The result shows that Harvard Square has more total area dedicated to residential purpose than Kendall Square. In the case of Kendall Square, the result does indicate a higher employment density; however, this could imply that activity from employees drastically decreases on weekends, which can be detrimental to neighborhood vitality.

Next, housing types are computed based on the average number of floors per building in a given district (Sung, Lee, & Cheon, 2015) (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106):

$$Housing\ Types_i = \frac{\sum_c h_{c,i} z_c}{\sum_c h_{c,i}}$$

$h_{c,i}$ accounts for the number of buildings in a given height category, and z_c is the number of floors that correspond to a given category (categories are included in table 4 & table 5). Housing types reports the average number of floors per building by taking into account, the number of building categories in the area and the corresponding number of floors per building. The results show that, on average, each building contains approximately 5 floors for both Kendall and Harvard Square. This is similar to the findings from the Italian study, not taking into account the scale of both studies. The current study focuses on areas with busy commercial and office/industrial activity, disregarding the larger surrounding residential area.

These first four variables characterize spatial use in terms of land use and fixed infrastructure, whereas there is no characterization to this utility in terms of activity. As previously stated by Jacobs, in order for districts to be lively, people need to be on the street during different times of the day. De Nadai et al. extracted the following variables that will be used as proxies for human activity (Sung, Lee, & Cheon, 2015):

$$Commercial_i = \left|\frac{non\ daliy\ places_i}{places_i}\right|$$

$$Nightlife_i = \left|\frac{nightlife\ places_i}{places_i}\right|$$

$$Nightlife\ Density_i = \frac{|nightlife\ places_i|}{area_i}$$

These variables are characterized as daily use or non-daily use, day or nighttime use. Nightlife and nightlife density give a sense of the available nighttime activity available in an area. This measure includes activities such as nightclubs, lounges and bars. Nightlife is computed by finding the ratio of the number of nightlife place in a given area to the total available places, while the nightlife density represents the number of nightlife activities in a given area. We used Foursquare to find the list of available nighttime activity in each area and Google maps to find the number of places and surface area.

The next distinguishing variable delves more into the characterization of utility in terms of activity. De Nadai et al. capture this relation in the form of 3rd places. 3rd places function as general public spaces for social interaction, which helps foster community building as well as sociability and emotional expressiveness (Oldenburg & Brissett, 1982). These are attractors that foster community and communication among people outside of their first and second places (home and work). These places beckon people to gather and enjoy each others' company during all hours of the day and weekends (Oldenburg & Brissett, 1982).

These 3rd places are subsequently categorizes as noted by Jeffers et al: eating and drinking (coffee shops, bars and restaurants); organized activities (clubs, community centers, places of worship); outdoors (plazas and parks); commercial venues (stores, malls, markets, barbershops and beauty salons, etc.) As such, third places in a given district are mathematically computed as follows (Oldenburg & Brissett, 1982) (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106):

$$3^{rd}places_i = \left|\frac{3^{rd}places_i}{places_i}\right|$$

3rd places represent locations that are used for social gatherings; commercial venues, outdoor activate, and organized activities. To find the 3rd places measure, we used Foursquare to find the total number of attractors that fall with in the definition defined by (Oldenburg & Brissett, 1982). As expected, the results show that Harvard Square outperforms Kendall Square in terms of the abundance of 3rd places.

Block Size Variables

The next sets of measures focus on the size of blocks and includes block area and intersection density. As previously discussed, Jacobs mentioned the idea of sidewalk ballet, which is facilitated by areas that are conducive to walking. She theorized that smaller block sizes and areas with more intersections help support street activity and allow for more random short-term human interactions. According to Jacobs, small blocks help promote stationary activities as well as short term and low intensity interactions (Jacobs, 1961). This provides opportune moments for people to ease into relaxed unplanned rendezvous. She states that these types of encounter, as random as they may appear, provide the small changes from which a city's wealth of public life may grow. She counters this ideal scenario with the prevalent super-blocks of some major cities, which demotes urban mobility through longer travel distances while also limiting the frequency of random human interactions (Jacobs, 1961). Block size is thusly calculated as follows (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106):

$$Block\ area_i = \frac{1}{|B_i|} \sum_{j \in B_i} area_i$$

Again, B_i is the set of physical blocks in a given district i. To compute the block area, we computed the average block area in the set of all the blocks in both areas. The average block area for Kendall Square is approximately 28367 m2 whereas the average block size in Harvard Square is approximately 12640 m2. The smaller block size in the latter lead to more frequent intersections, as suggested by Jacobs. The takeaway here is that, the physical layout of Harvard Square is more conducive to spontaneous interactions between random people than in Kendall Square.

Similarly, as the number of intersections increase in a given block, so do the number of expected human interactions. The intersection density as defined as follows (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106):

$$Intersection\ Density_i = \frac{|intersections_i|}{area_i}$$

To calculate intersection density, we visually find the number of intersection for both case studies using Google maps. It is important to note that the CityScope platform requires a great deal of abstraction to fit a geographic district onto the platform, that these two variables (block area and intersection density) become somewhat skewed.

Concentration and Density Variables

Lastly, we focus on concentration related metrics. The following variables relate to Jacobs's fourth condition, sufficient concentration. This condition necessitates concentration of both residential and non-residential buildings, in addition to residents and non-residents. The first concentration measures relate to people, as shown in the following equations (Sung, Lee, & Cheon, 2015):

$$Population\ density_i = \frac{|population_i|}{area_i}$$

Population and employment density account for the number of people (residential) and number of employees (employment) per given district area (Sung, Lee, & Cheon, 2015).

$$Employment\ densiy_i = \frac{|employment_i|}{area_i}$$

Subsequently, the population to employment density can be calculated as shown below. The higher this number is, the more residential (verses commercial/office) a given district is. This number may vary according to the social texture of a given district (Sung, Lee, & Cheon, 2015).

$$\frac{Population\ density_i}{Employment\ density_i}$$

Beginning with population and employment density, we find that the population density in Harvard Square is much greater than that of Kendall Square. Conversely, the employment density in the latter is higher than Harvard Square. The population to employment ratio speaks to the balance of live work in a given district.

The following equation focuses on the concentration of infrastructural elements (buildings, open space, etc.). $internal_i$ finds the average number of apartment per building (Sung, Lee, & Cheon, 2015).

$$internal_i = \frac{|internal\ apartments_i|}{|buildings_i|}$$

Internal Apartments finds the average number of dwellings in a building based on the different category of buildings in a given area. As shown, the average number of apartments in Kendall Square is approximately 10 apartments per building and 16 apartments per building in Harvard Square.

Lastly, the density of both daily and non-daily places is also calculated by looking at the number of both daily and non-daily places in a given district. This measure gives a temporal sense to an area by revealing whether a district is dominated by daily or non-daily places (Sung, Lee, & Cheon, 2015).

$$Daily\ places\ density_i = \frac{|Daily\ places_i|}{area_i}$$

$$NonDaily\ places\ density_i = \frac{|NonDaily\ places_i|}{area_i}$$

As previously noted, daily places consist of groceries, medical and sports facilities, whereas non-daily places include cultural and meeting facilities, sales and business facilities, education and research facilities (Sung, Lee, & Cheon, 2015).

Summary of Results & Discussion

For the case study provided in this section, we examined both Kendall and Harvard Square. The first step involved gathering the data for both areas, as presented in the previous section. The metrics previously discussed were computed with both Kendall and Harvard Square data. For clarity the results are tabulated in the table below. As can be seen, the first two columns represent the base line scenarios for Kendall Square and Harvard Square using the raw data, while the far right column reports the findings reported for the Italian studies. The density measures are reported with area in m2, while closeness measures are computed in inverse distance (1/m). The last column contains the results provided by (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106) from the Italian study and is presented as a reference for the first two columns, see table 6 and figure 19.

Table 6: Summary of Model outputs for Kendall & Harvard Square

	Results		
	Calculated Kendall Square	Calculated Harvard Square	Reported (Italian Cities)
	Land Use		
Land Use Mix	0.78	0.68	0.73
Closeness to Parks	2.95E-03	1.89E-03	1.00E-03
Residential vs. Non-residential	0.45	0.75	0.67
Housing Types	5.82	5.29	4.98
Commercial	0.41	0.36	0.3
NightLife	0.08	.09	0.1
NightLife Density	1.10E-05	3.00E-05	1.00E-05
Daily Places	0.23	0.35	0.02
3rd Places	0.21	0.27	1.00E-04
	Small Blocks		
Block Area	2.82E-02	1.26E-02	9.61
Intersection Density	2.70E-05	7.50E-05	1.00E-04
	Concentration		
Population Density	5.24E-03	1.70E-02	0.01
Employment Density	4.20E-02	1.79E-02	5.00E-03
PER	0.13	0.95	3.75
Internal Apartments	10.01	15.53	15.31
Density Daily Places	1.05E-04	9.10E-05	5.00E-03
Density non Daily Places	1.02E-04	6.00E-05	3.00E-03

In Kendall Square, we find that this metric is heavily biased towards employment, whereas in Harvard Square, it shows that there is more of a balance between the residential and working population in the area. As shown in figure 19, one key characteristic of Harvard Square is how balanced it is across all diversity conditions stated by Jacobs. One variable that could be improved is the employment density of Harvard Square. Jacobs states that in order for a district to be livable, it should have a balance of all four diversity conditions, as seen in the case of Harvard square. Conversely, Kendall Square for example is characterized by low residential density and high employment density.

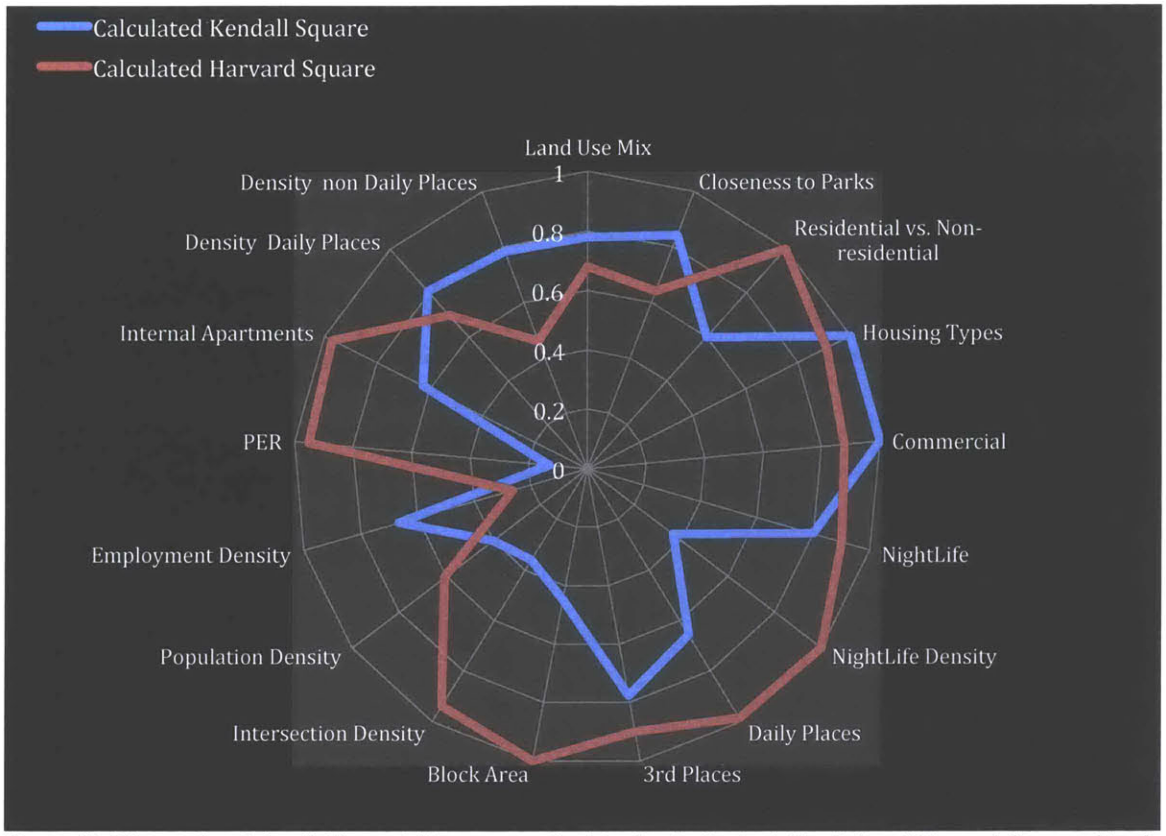

Figure 19: The results of the vitality variables as prescribed by Jacobs for both Kendall and Harvard Square. Clearly visible from the radar chart, Harvard square is more balanced in terms of the diversity conditions spelled out by Jacobs. In contrast, Kendall Square is less uniform. The ideal case would show a more circular coverage. Kendall Square (blue) and Harvard Square (red).

De Nadai et al. summarize their findings in the following, "active Italian districts have dense concentrations of office workers, third places and walking distance, small streets and historical buildings." They also demonstrated that most variability (77%) in district activity can be explained by static features and infrastructure (intersections, housing types, highways, etc.). The extent to which these features matter does not drastically change across different cities. To demonstrate this, they compared the conditions from the largest and smallest cities, Rome and Florence respectively, and found that the main features (employment density, housing types, intersection density, closeness to highways, 3rd places, and closeness to small parks) mattered to a similar extent. In the next chapter, we will discuss the evaluation platform that leverages key variables from the works of Jacobs and De Nadai to build a planning tool that facilitates designing plans that revolve around the vitality and vibrancy of districts, see figure 20.

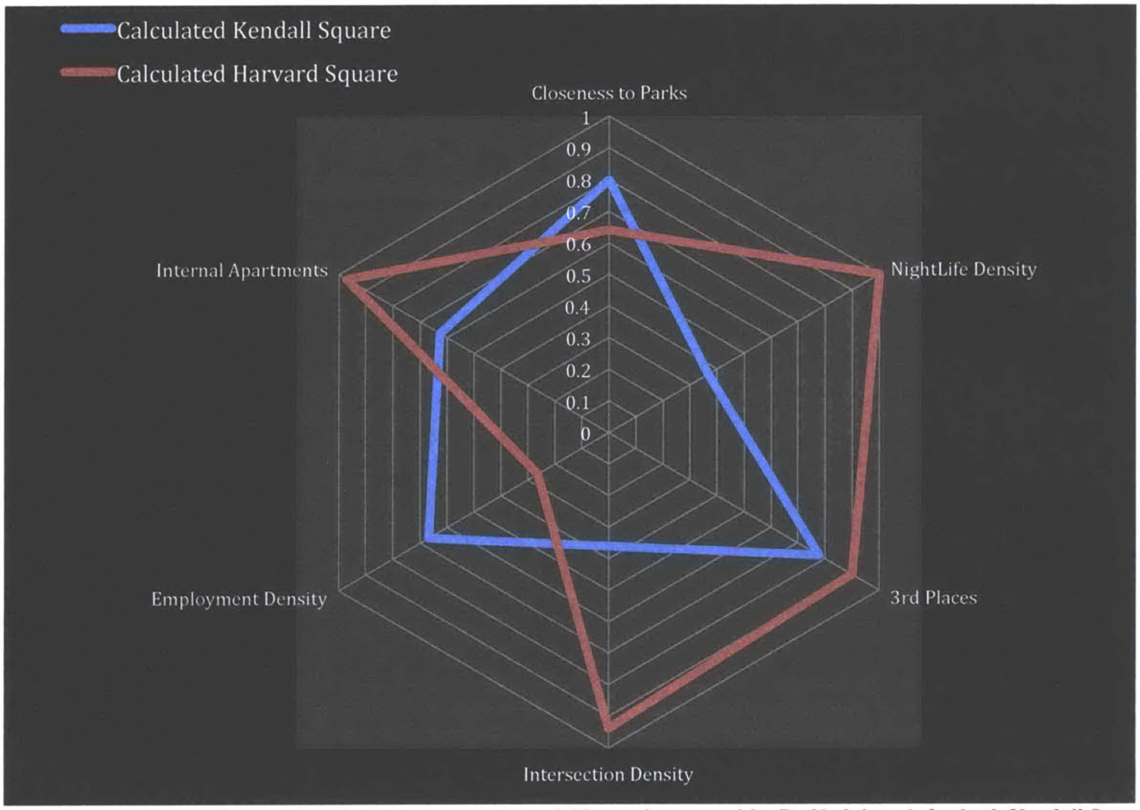

Figure 20: Summary plot showing the most important variables and proposed by De Nadai et al. for both Kendall Square (blue) and Harvard Square (red). The results indicate that Harvard Square performs better than Kendall Square in some aspects while Kendall Square outperforms Harvard Square in others.

Computational Evaluation Platform & Model

Overview

This body of work focuses on building a modeling framework to facilitate decision makers in assessing the urban vitality resulting from interventions to an urban core. Typically, a development site will see multiple bids from investors and developers. The competitive nature of this process, which is the case with the Volpe site, suggests that many of the companies ("ranging from biotech real estate companies to national players with deep pockets (Logan, Boston Globe, 2015)") have varying and potentially conflicting objectives. In order for development plans to go through however, they must be scrutinized by entities with vested interests, such as the U.S. Department of Housing and Urban Development (HUD). HUD's role "is to provide housing and community development assistance and to make sure everyone has access to fair and equal housing (Fontinelle, 2014)."

The proposed 14-acre Volpe site, for example, could solve some of the housing shortage problems currently facing Kendall Square (Logan, Boston Globe, 2015). However, the soaring office rents (the highest on the east cost) also make the area attractive to private developers looking to capitalize on rent. Furthermore, in an area with an already high employment density, the addition of more office and commercial spaces could increase the stress on the public transportation system that is struggling to keep up with the current demand (Logan, Boston Globe, 2015). This becomes a design problem with no optimal solution. As Jacobs suggested, cities are people systems and hence should not be planned as mere networks of brick and mortar, rather, they should be planed as systems that support urban life.

To this extent, we have developed an evaluation tool (figure 21) to assess the vitality of districts based on the theoretical contributions of Jacobs (later validated by Sung and De Nadia) in order to facilitate the development process. The tool computes the impact of commercial interventions, office/industrial interventions, residential interventions, and open spaces interventions on the vitality of a particular district. Vitality is assessed based on a subset of the applicable diversity conditions (Jacobs, 1961) that support urban life. Here we focus on employment density, residential density, employment/residential density, closeness to parks, and housing diversity. Based on recommended amenity thresholds, we also approximate the number of 3rd places to support a vital community.

Using Kendall area, we identify the planned development sites and some proposed plans for the sites. Then, we translate the actual plans onto the physical space of the computational evaluation model. Finally, we examine the impact of the individual proposals on the vitality of the surrounding (previously computed) Kendall Square and discuss the implications.

Figure 21: Overview of the CityMatrix— an urban vitality computational evaluation tool. There are three main physical components to the platform: the Lego table, overhead projection, and camera (for reading Lego tags)

Methodology

Kendall Square Case Study

As previously discussed, the area of interest in Kendall Square is approximately 1.30 square km. The aim now, is to fit the irregular shape of Kendall Square onto the Lego table. Although this comes at the cost of model resolution and accuracy, it does however help simplify the scaling aspect for the proof of concept stage. For the base case scenario, we use the exiting (previously calculated) urban vitality metrics for Kendall Square as the baseline from which interventions in future steps are evaluated and compared. Figure 22 shows the outline of the area of interest along with neighbouring districts.

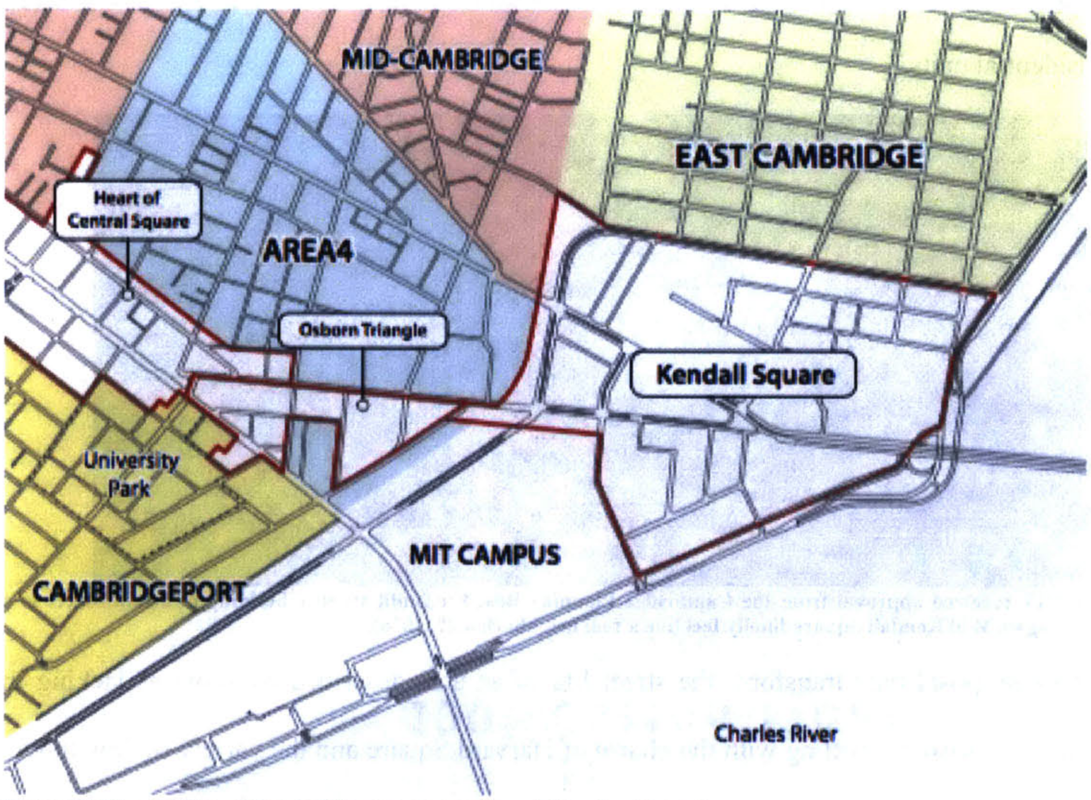

Figure 22:The out line of Kendall Square along with neighboring districts.

Curated Intervention

As reported in the Boston Globe, Kendall Square has undergone a real estate market boom in recent years. Aside from a world-renowned university and a reputation for being a hub for innovation and start-ups, it lacks basic daily needs such as grocery stores, pharmacies and public spaces. It has been reported that the Massachusetts Institute of Technology received approval from the Cambridge Planning Board to develop along Main Street and Broadway (Logan, Will Kendall Square finally feel like a real neighborhood?, 2016), see figure 23. In addition to new offices, housing and graduate dorms, the plans call for plazas, storefronts and public spaces to be integrated into the new development. The plans show that in total, there will be an additional 1.15 million square feet (106,838 square meters) of office space, and "perhaps 2,000 residential units."

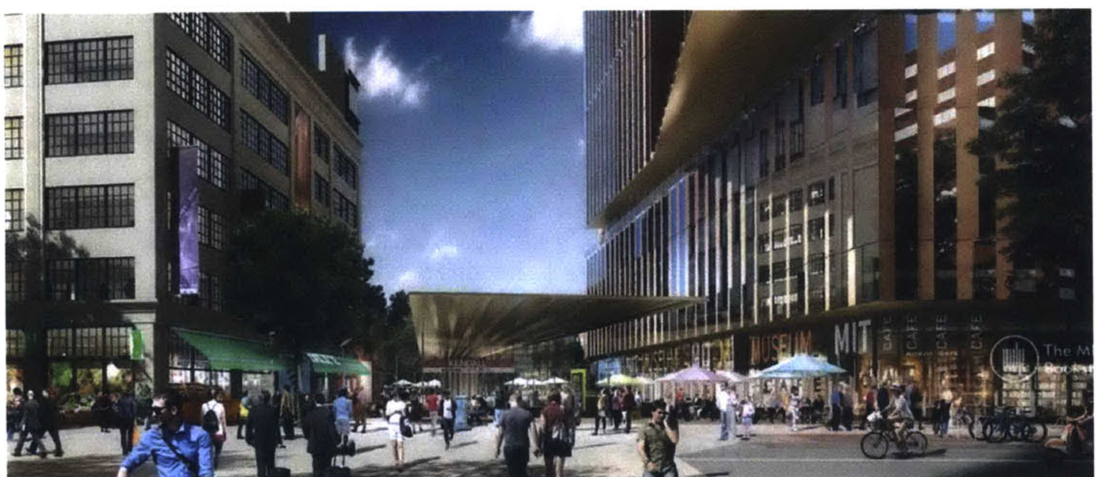

Figure 23: MIT received approval from the Cambridge Planning Board to build six new building on Main Street and Broadway (Logan, Will Kendall Square finally feel like a real neighborhood?, 2016).

This proposal may transform the street life of an area described by some as lacking in personality, to a district bustling with the charm of Harvard Square and the variety of Downtown Boston (Massachusetts Institute of Technology, 2016). The aim of this project, according to the MIT provost Martin Schmidt, is to "...create a great sense of place to live and learn, not only for the community but for our neighbors and the whole area." Figure 24 shows the area under development along with the proposed uses for each of the development sites (Logan, Will Kendall Square finally feel like a real neighborhood?, 2016).

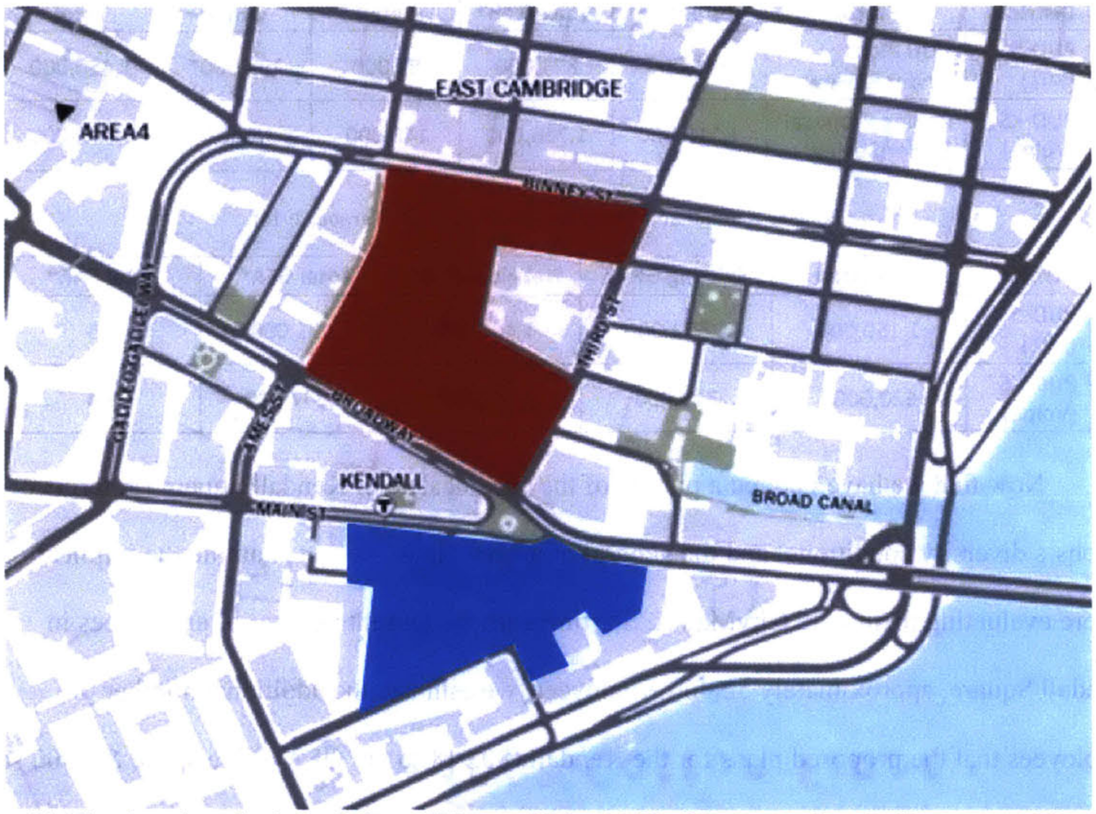

Figure 24: The plans show that in total, there will be an additional 1.15 million square feet of office space, and "perhaps 2,000 residential units" to the MIT development site (blue) and 620,00 square feet of residential and office space for the Volpe site (red) (MIT, 2016).

Another upcoming development in the Kendall Square area is the Volpe Transportation Center, a federal research facility along Broadway. The proposed development site will boast an additional 57600 square meters office space, open spaces and affordable housing. At least eight companies have responded to the federal government's official development proposal for the Volpe site. The bidders range from biotech real estate companies to Boston developers to national developers with a lot of money to spend (Logan, Boston Globe, 2015). Table 8 and table

9 break down both development sites by additional gross floor area (in sq. ft.) for residential, office/lab, retail and other categories (Farooq, 2016).

Table 7: Kendall and Volpe development plans (Farooq, 2016).

District	Status	Residential	Office/Lab*	Retail	Other	Total
PUD-5 (MIT)	PUD Plans Under Review	285,000	871,000	87,000	207,000*	1,450,000
PUD-KS (Volpe)	Zoning Proposal Under Review	1,116,000	1,716,000	140,000	None *	2,972,000

Table 8: Kendall and Volpe development plans (Farooq, 2016).

District	Land Area	Existing GFA*	Net New GFA*	Total GFA*	Total FAR*
PUD-5 (MIT)	1,150,000	2,571,000	1,450,000	4,021,000*	3.5
PUD-KS (Volpe)	620,000*	375,000	2,972,000	3,347,000	5.4

Now that we have painted a picture of the current state of Kendall Square (in terms of Jacobs's diversity conditions) and the general proposed plans, we can examine the implications before evaluating them with CityMatrix. Starting with the current number of employees in Kendall Square, approximately 52,000 employees, we estimate the additional number of employees that the proposed plans for the Kendall (80,918 sq. m. GFA office space & 8000 sq. m. GFA commercial space) and Volpe (159,431 sq. m. GFA office space & 13,000 sq. m. GFA commercial space) development sites. Assuming that an office/ lab occupancy rate of approximately 16 sq. m. per person (Maryland, 2007) and retail/commercial occupancy rate of approximately 23 sq. m. per person (Maryland, 2007), the proposed plans will add approximately 16,000 jobs to Kendall Square, raising the total employment number to 68,000 people.

Next, we approximate the number of residents that the plans will accommodate in addition to the existing 6815 residents in Kendall Square. Referring to table 8, the plans call for an additional 26472 sq. m. GFA (Kendall) and 107,767 sq. m. GFA (Volpe) of residential space. Assuming an affordable housing occupancy rate of 350 sq. ft. per person (Maryland, 2007)and mid-pricing occupancy rate of 550 sq. ft. per person (Maryland, 2007), this will add approximately 3500 residential units to the area, raising the total population to 10,150 residents. Next we take the existing number of 3rd places in Kendall Square, and approximate the additional 3rd places required to meet the demand. Assuming the following urban amenity thresholds:

Table 9: Amenity threshold suggestion per population (Kaufman, 2014)

Amenity	Threshold (Person/Amenity)	Total Amenities	Additional Amenities
Supermarket	20,000	2	2
Bar	10,000	5	2
Restaurant	8,000	6	7
Baker	20,000	1	2
Nightclub	20,000	1	0
Pharmacy	18,000	3	3
Bookstore	15,000	3	1
Art Gallery	20,000	2	1

We can approximate the total number of additional 3rd places by subtracting the current available number of third places in Kendall Square (30) from the additional required amenities from current population and employment numbers. Lastly the plans call for an additional 207,000 sq. ft. of open spaces. Table provides a summary of the discussed implication.

Using figure 20 (combined metrics), we first identify the main measures that separate Kendall Square from Harvard Square in terms of urban vitality. We can see that Kendall Square is lacking along the following metrics: *closeness to parks*, *third places*. We can also improve other metrics such as, *population density*, *population to employment ratio*, and *commercial* spaces. Moving to the computational evaluation table, we now examine the impact that the proposed plans have on the area. The objective is to maximize each of the output metrics using the available interventions; affordable housing, mid-range housing, luxury housing, office space, open spaces and density.

Abstraction and Implementation

Lego Block Definition

The Lego blocks are based on figure 13 and figure 14, we extract the actual land use patterns in Kendall Square. We find the following land use types: Higher education, general commercial, office, office/R&D, industrial, residential, education residential, transportation and public spaces. For the sake of simplicity, we will group similar land uses together, which reduces the number of uses to: education, residential, commercial, office/industrial, transportation and public spaces. Next, from the land use map we identify the percentage of the Kendall Square dedicated to each of these 5 land use categories. Table 10 summarizes the breakdown of each land use type for Kendall Square.

Table 10: Kendall Square Land Use Types and Percentages of Each Category

	Total Area (Km2)	Percentage
Commercial	0.029	2.46
Residential	0.2268	22.67
Public	0.076	6.45
Office	0.396	33.49
Transportation	0.065	5.51
Education	0.333	28.12
Vacant	0.015	1.30

Figure 25 illustrates the unique identification tags the software uses to differentiate between the different land use types as they are added onto the table. Each of these tags reference the data shown in table 6 and table 7 above. As Lego pieces are added and removed from the table, the software calculates and updates the urban vitality metrics discussed in the previous sections.

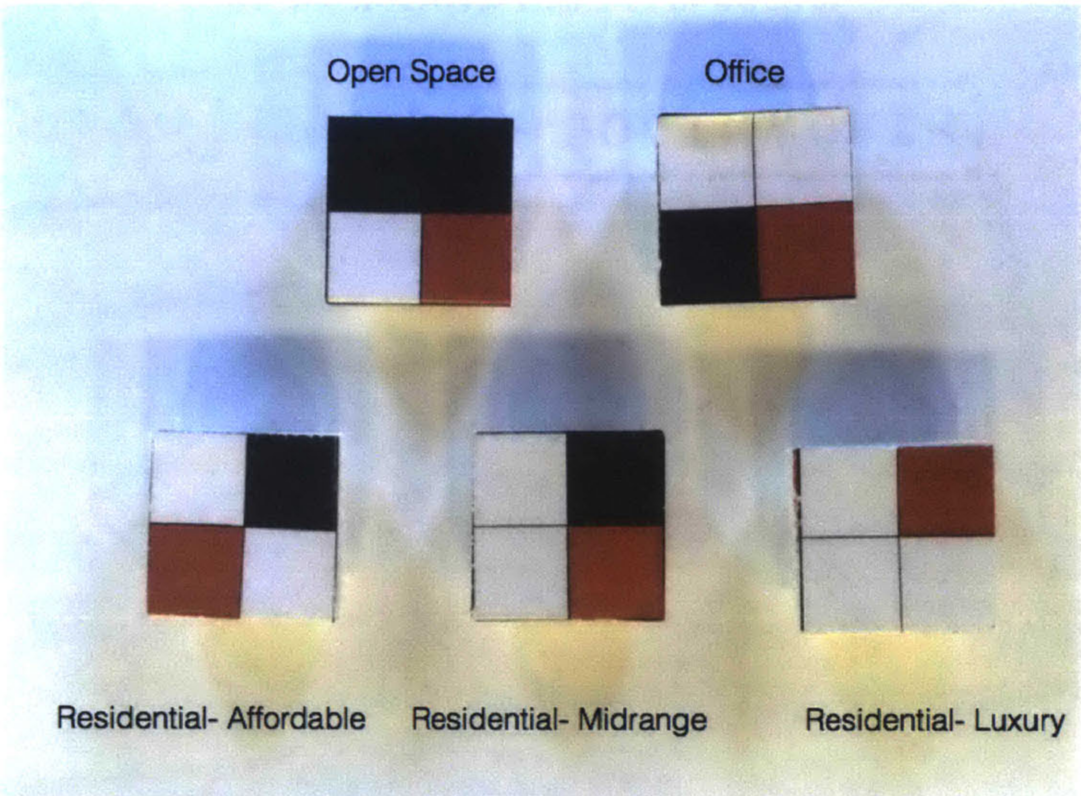

Figure 25: The simulation platform utilizes QR codes that represent residential, educational, commercial, office public spaces, open spaces, and parking.

Lego Block Scale And Table Setup

The *first step* in setting up the CityMatrix table is to abstract the development site. Figure 26 shows a close up of both MIT (blue) and Volpe (Red) development sites. As can be seen, we have zoomed in on the development areas to increase the number of Lego blocks that can be used as interventions. Figure 26 also shown the size of the grid 16X16 that will span the CityMatrix tabletop. To find the area that each Lego piece represents, we first approximate the widest part of the development site using Google maps (approximately 800 m) and divide it by the width of the grid, 16 pieces wide. The result is a 2500 sq. m. footprint per piece. The entire area will be covered with Lego pieces; however, only the area highlighted in red and blue will represent the active computation evaluation space. The surrounding area will be filled with static pieces that represent the baseline scenario.

Figure 26: Abstracting the development area on the City scope table is the first and crucial step. The imposed grid is a 16X16 matrix that will later be filled with Lego bricks. The highlighted regions in red are the active areas the simulation will base the vitality metrics from.

The *second step* involves visualizing Kendall Square's baseline scenario. For this step we fill in the 16X16 grid with the appropriate Lego pieces (figure 25) based on the different land use types in Kendall Square. The previously calculated vitality variables (such as residential density, employment density, closeness to parks, land use mix, etc.) represent the base line scenario. The resulting abstraction is shown in figure 27, with the following land uses: office space (O), education (E), luxury residential (R$$$), open spaces (OS), and parking (P). The development sites are highlighted in red.

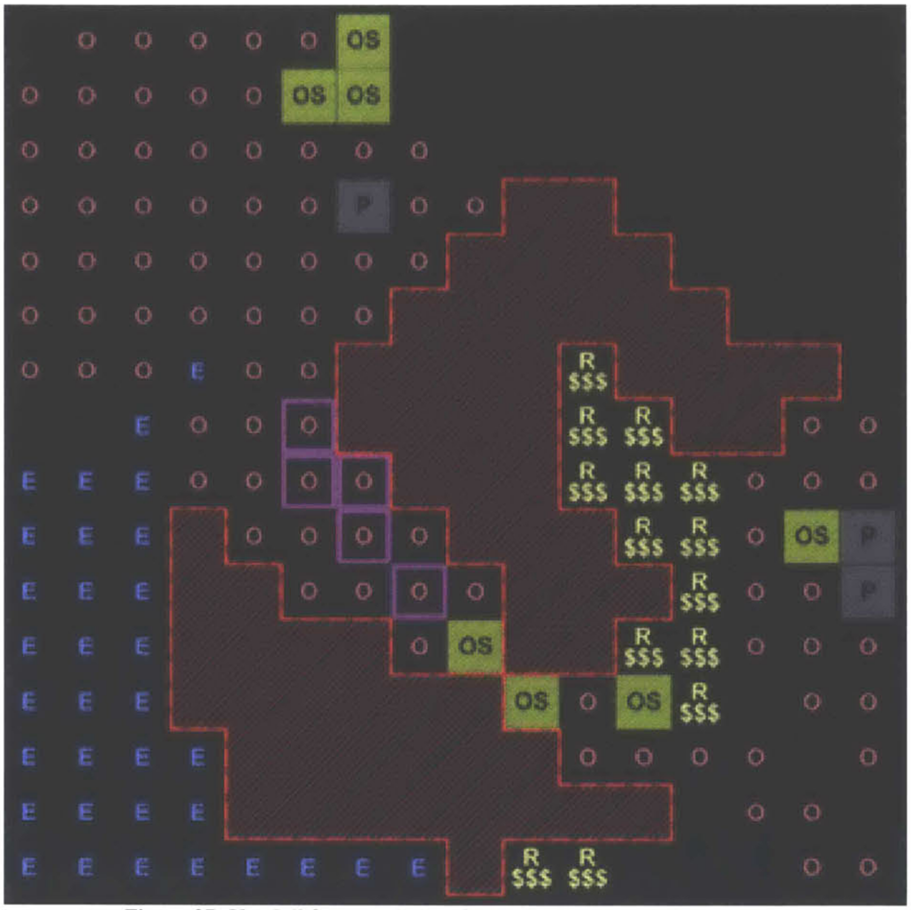

Figure 27: Kendall Square abstraction including the existing land use

The *final step* involves finding the number of necessary Lego pieces to execute the proposed plans on the CityMatrix table. Using the proposed commercial and office gross floor areas (GFA), land area, and the floor to area ratios (FAR) for both sites (see table), we find that we can represent the total development of office space using 25 Lego pieces (8 pieces for MIT and 16 for Volpe). Similarly, we find the number of Lego pieces to represent the residential plans to be 11 (3 for MIT and 8 for Volpe). Table 11 provides a summary of the Lego piece interventions that will be used to replicate the proposed plans for both sites.

Table 11: We approximate the number of Lego pieces to replicate the residential, office and commercial plans for both sites, and add them the evaluation platform

Piece Types	Number pieces - MIT Development	Number pieces - Volpe	Number of floors
Residential Luxury	3	0	7
Residential Midrange	0	4	7
Residential Affordable	0	4	7
Office	8	16	7
Open Space	3	0	7

The platform then calculates the impact that the proposed plans have on the vitality metrics. Users may then intervene by increasing the density, by adding floors to residential units, increase open spaces, or increase land area for residential and office space.

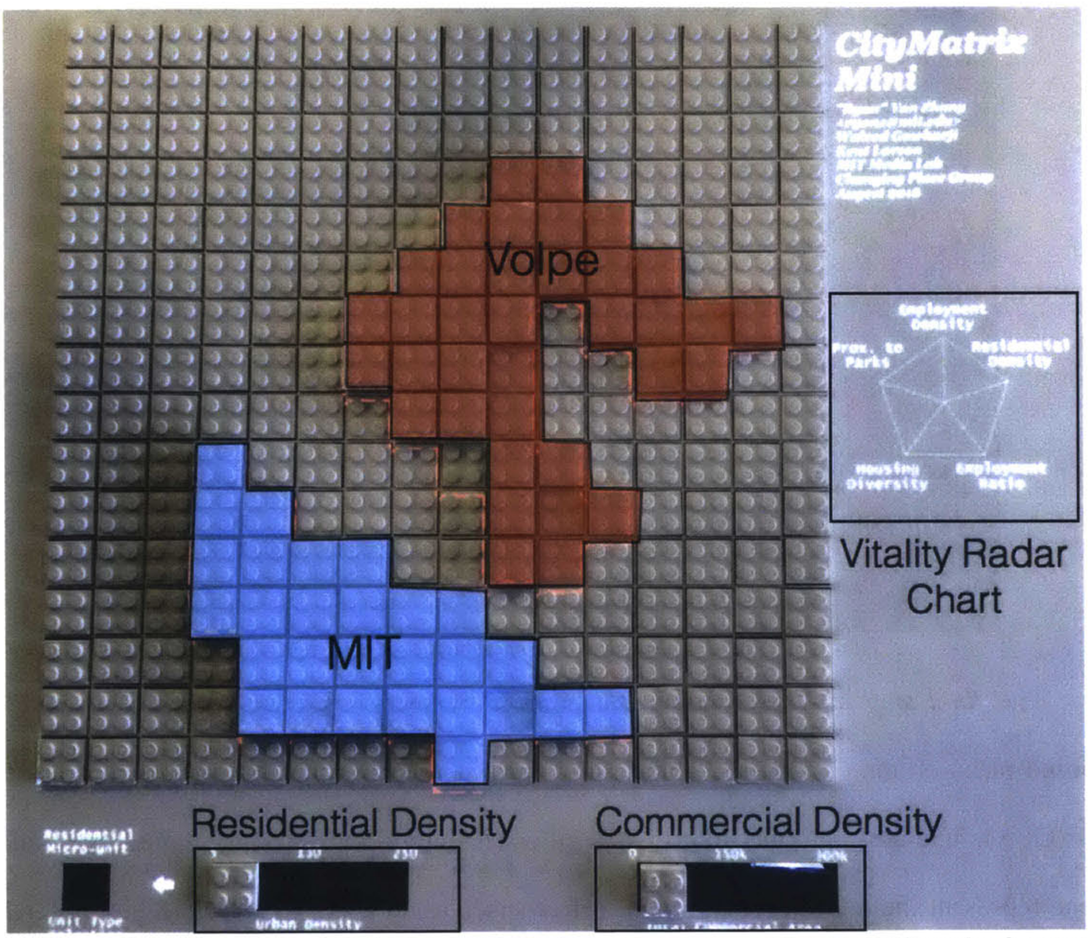

Figure 28: Overview of the simulation platform including the inputs: Active simulation area, density scalar & commercial area scalar and outputs: vitality indicators. The Volpe development site is highlighted in red and the MIT development site is highlighted in blue.

Figure 28 show an over view of the simulation platform along with the inputs: Active simulation area, density slider & commercial area slider and outputs: vitality indicators. As we implement the proposed plans for Kendall and Volpe, the software recalculates the urban metrics including the updated interventions. Users can then identify the selected metrics that require strengthening in order to increase the overall vitality score using the previously computed metrics for Kendall Square in addition to the impacts from the proposed plans.

Evaluation Metrics

As discussed in the variables discussion section of the previous chapter, we assumed that the features extracted by De Nadai et al. (Employment Density, Intersection Density, Housing Types, Proximity to parks, 3rd Places) hold true in the American context, because the extent to which these features matter does not change across different cities. However, for the purpose of this research, we make the argument that the diversity of living spaces (not addressed by De Nadai et al. nor Dung et al.) is important to the diversity metrics outlined by Jacobs.

As such, we break residential units into three categories, affordable, med-range, and high-end dwellings with the assumption that a balanced mix of all three-unit types will contribute to the vitality score of the area. We label this metric as *housing diversity* and add it to the list of diversity features previously discussed, see figure 29 below. In addition, since changing block size or intersection density is not realistic, we chose to exclude these variables from the decision platform. Instead, we propose replacing this metric with the residential density as we believe a balance between residents and employee will help create a vibrant area. The resulting decision platform scores district layouts and interventions along the following metrics:

1. Employment Density: is calculated by adding the existing employment density in Kendall Square to the added employment from the proposed commercial and office construction.

The lower limit of employment density is set to 2000 people sq. km. while the upper limit is set to 88500 people per sq. km. These numbers are base on the employment densities of the highest and lowest employment densities in down town Los Angeles. (Southern California Association of Governments, 2000)

2. Housing Diversity: is calculated by finding the percentage of square footage dedicated to either affordable, mid-range or luxury housing, (similar to the calculation for Land Use Mix). If district housing options are only dedicated towards one housing option, housing diversity will be zero. The higher housing diversity, the more mixed housing options there are in the district the lower bound of this metric is zero and the maximum.

3. Third Places: is based on recommended amenity thresholds per population (Kaufman, 2014), see table 9 (see page 62). As the number of residents and employees increase with the addition of the various building types, the simulation calculates the number of required supermarkets, bars, restaurants, bakeries, nightclubs and pharmacy based on the current. The numbers shown reflect the number of required 3rd places to meet a population of 40,000 people in Kendall Square.

4. Proximity to Parks: the simulation finds the distance between each block in the active area of the simulation, and the nearest open space and then reports the total average distance to open spaces. The lower limit to this measure is 1000 m, while the upper limit is 100 m.

5. Residential Density: is calculated by adding the current number of residents in Kendall Square to the number of additional residents introduced from the residential planned construction. Because there is only a fixed land area that can be developed, the users can increase the residential density by adding more floors to the residential developments. Here we assume

the lower limit to be 1000 people per sq. km, while the upper limit is approximated to the residential density of Manhattan (approximately 28,000 people per sq. km).

6. Resident to Employee ratio: is ratio of residents to employees of the proposed design. The ideal case would have a high number of both residents and employees. Here the lower limit is set to 0 and the upper limit to 1.

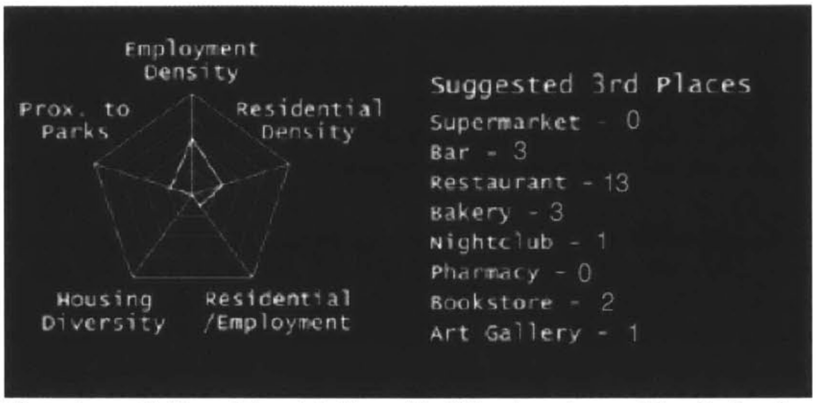

Figure 29: CityMatrix captures vitality metrics related to residential and employment density, housing diversity, closeness to parks and 3rd places.

Computational Evaluation Results & Discussion

Baseline Scenario

We start with the *baseline scenario* that reflects the current layout of Kendall Square without the proposed plans. The highlighted regions in red represent the MIT and Volpe development sites. Referring to the radar plot in figure 30, we see that CityMatrix produces the following vitality outputs (the baseline case is white):

1. Employment Density: As previously indicated, Kendall Square has an already existing high employment density. Jacobs and de Nadai asserted that the employment density is an important variable to the vitality of a district. The activity from employment adds to the overall entrepreneurship and innovation, which is evident in the case of Kendall.

2. Residential Density: Conversely, the residential density in the area is very low. Which, according to Jacobs, can be detrimental to the overall vitality of the district. This suggests that Kendall Square places more emphasis on commercial, office, and education activity than residential activity. This is particularly evident during evening hours and weekends when Kendall Square has very little activity.
3. Residential/employment density: This ratio gives a sense of how off balance the residential density is compared to employment density. The focus of this exercise is to increase this ratio and examining how the overall vitality of the district changes.
4. Housing Diversity: We assume that the only available housing option in the baseline scenario is luxury units. CityMatrix calculates housing diversity in the same way we calculated land use mix. When there is only one available housing type, the housing diversity is *zero*. Conversely, the more options there are in a district (i.e. luxury housing, mid-range housing and, affordable housing) the closer the value is to *one*.
5. Proximity to Parks: The average distance to parks in Kendall Square was previously found to be approximately 400m, which is a good score. However, as there are currently no intervention Lego pieces added to the active computational area, this radar chart shows a low score relative to the highest closeness to parks score (assumed to be 100m).

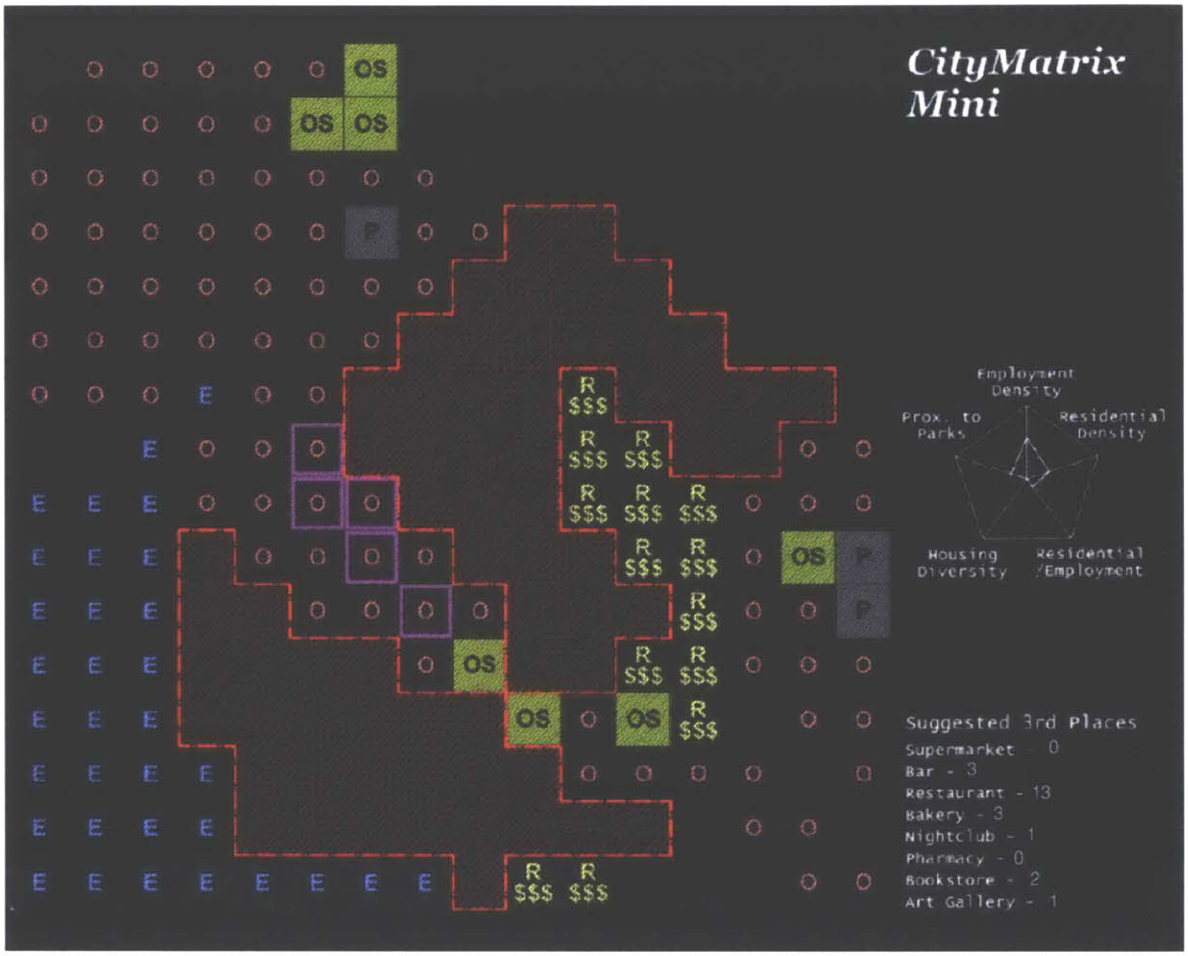

Figure 30: Simulation output reflecting the baseline and proposed development sites in Kendall Square. The radial chart shows the current vitality score (orange) and baseline score (white). Finally, a list of recommended 3rd places, approximated using the current population number, see figure 34 for a close up of outputs.

The next step is to visualize the impact of the proposed interventions to the MIT development site on the vitality of Kendall Square. Ideal scenarios are those that do not show heavy bias in one particular vitality variable, employment density. These types of layouts should be avoided, as they put the community out of harmony, see table 12.

Table 12: Baseline scenario results for the number of required amenities

Amenity	Total required
Supermarket	0
Bar	3
Restaurant	13
Baker	3
Nightclub	1
Pharmacy	0
Bookstore	2
Art Gallery	1

Adding MIT Development Site Scenario

The proposal for the MIT development site suggests that we need a total of 3 residential Lego pieces, 8 office/commercial Lego pieces and 3 open spaces Lego pieces. To exaggerate the importance of the housing diversity, we assume that the additional residential units are of the luxury type. The highlighted regions in red (lower left corner) represent the MIT development site. Referring to the radar plot in figure 31, we see that CityMatrix produces the following vitality outputs (the baseline case is white, while the active score is orange):

1. Employment Density: The employment density increased by a small amount. Although the plans called for an additional 871,000 sq. ft., Kendal Square does not need the additional density, as the employment density was already high in the base line scenario.
2. Residential Density: The proposed residential units made very little impact on the density of Kendall Square's residential density.
3. Residential/employment density: Similarly, the ration of residential to employment density did not improve considerably.
4. Housing Diversity: Since we only added the luxury residential pieces, the housing diversity remains zero.

5. Proximity to Parks: As we added office, residential, and open space pieces to the CityMatrix platform, we see that there is a big increase in the proximity to park variable. The platform only calculates the proximity measure of elements in the active region. For this reason, the change looks more exaggerated.

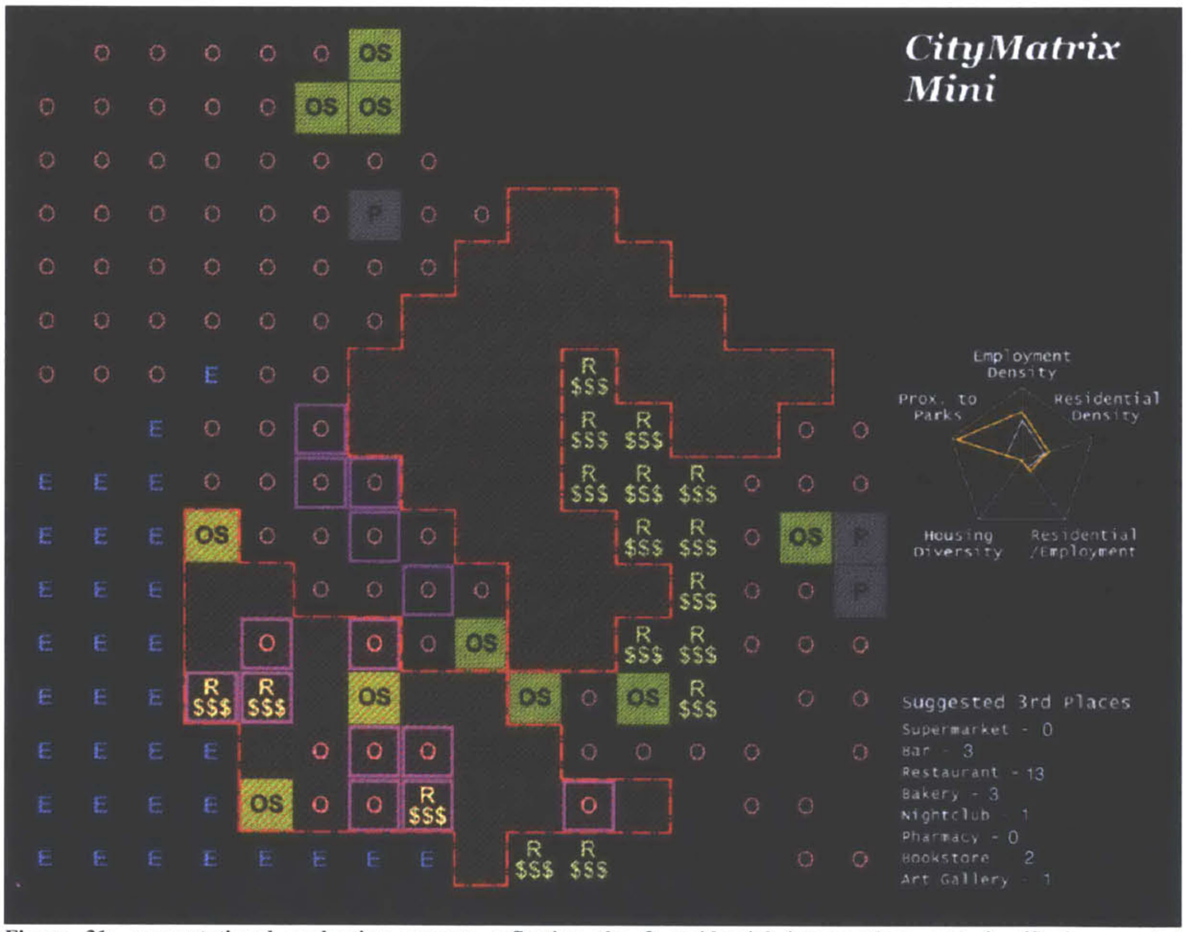

Figure 31: computational evaluation outputs reflecting the 3 residential interventions and 8 office/commercial interventions proposed for the MIT site. The results indicate that these plans are not enough to increase the residential density of Kendall Square; a variable that Jacobs claims to be crucial to urban vitality, see figure 35 for a close up of outputs.

Form this scenario we find that the additional residential and office spaces add very little to the overall vitality of the area. The closeness to parks measure improved, however, the area continues to be out of harmony in terms of Jacobs' diversity condition for urban vitality. Next, we examine the impact of the Volpe development site.

Table 13: MIT development site results for the number of required amenities (the number does not increase as the number of resident did not increase greatly)

Amenity	Total required
Supermarket	0
Bar	3
Restaurant	13
Baker	3
Nightclub	1
Pharmacy	0
Bookstore	2
Art Gallery	1

Volpe+MIT Scenario

The proposal for the Volpe development site suggests that we need a total of 7 residential Lego pieces, 17 office/commercial Lego pieces. To exaggerate the importance of the housing diversity, this time we assume that the additional residential units are of the mid-rage (3) and affordable (4) housing types. The highlighted regions in red (center) represent the Volpe development site. Referring to the radar plot in figure 32, we see that CityMatrix reports the following vitality outputs (the baseline case is white, while he active score is orange, and the previous output is blue):

1. Employment Density: As one would expect, the increased volume of office and commercial spaces increases the employment density in Kendal Square.
2. Residential Density: Similarly, the additional housing options slightly increase the residential density, although not to an extent that balances out the housing and office/commercial options in the area.
3. Residential/employment density: As a result, the residential to employment ratio of Kendall Square is still skewed towards employment.

4. Housing Diversity: The biggest change occurs with housing diversity, as the housing options are almost equally distributed between the three different housing types (luxury, mid-range, and affordable).
5. Proximity to Parks: The average distance to parks is updated based on the location of the additional housing and commercial/office spaces in relation to open spaces. The more evenly distributed open spaces are, the closer proximity to parks is to 1.

The shape of the radar chart is beginning to show that the interventions from both development sites have increased the overall urban vitality of the area. However, the residential density remains to be low. In order to increase this, we can either propose additional residential developments to both sites, or increase the number of floors or residential Lego pieces. Finally, we try to achieve a balance between the vitality metrics.

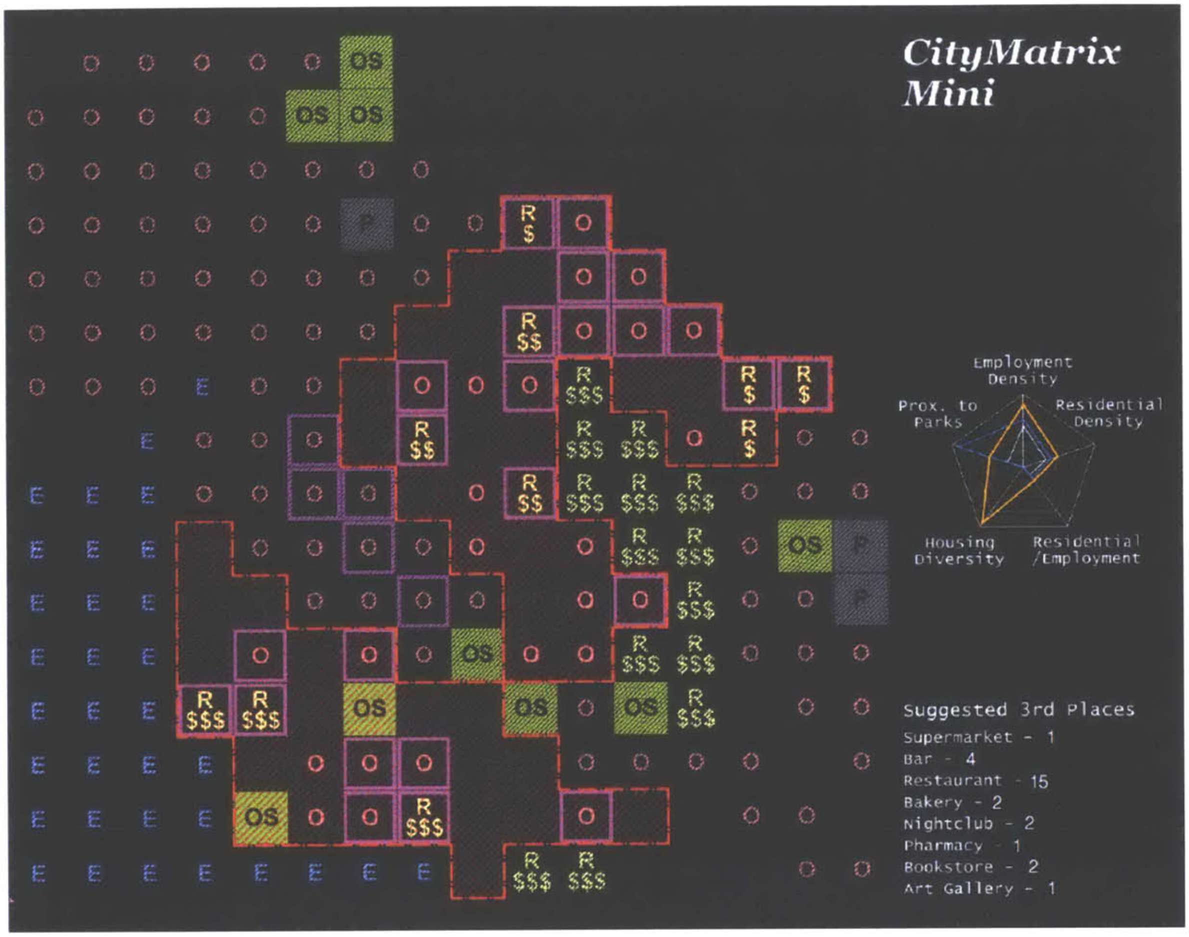

Figure 32: A final increase to the number of open spaces and residential (luxury and affordable) increases the contribution of housing diversity and proximity to parks to the overall vitality score. The radial chart clearly shows that carefully scripted interventions can add to the overall vitality score (the baseline case is white, while he active score is orange, and the previous output is blue), see figure 36 for a close up of outputs.

Table 14: Summary of Volpe development site results for the number of required amenities

Amenity	Total required
Supermarket	1
Bar	4
Restaurant	15
Baker	2
Nightclub	2
Pharmacy	1
Bookstore	2
Art Gallery	1

Desired Scenario

Together, the MIT and Volpe development sites have brought a total of 16,000 new employees and 3,500 new residents to the area. However, from the previous evaluation output, we see that the vitality of the district is still out of balance. The outputs suggest that more residential spaces are needed to bring harmony to Kendall Square. We start with the *desired scenario* by first, increasing affordable housing and mid-range housing by one Lego piece each, and second, increasing the residential number of floors to 20 floors. Referring to the radar plot in figure 33, we see that CityMatrix produces the following vitality outputs (the baseline case is white, while he active score is orange, and the previous output is blue):

1. Employment Density: Remained constant, as we did not add any additional commercial/office spaces to either of the development sites.
2. Residential Density: The number of residential floors had a large impact of the residential density. By increasing the number of floors, using the density slider allowed us to increase the number of residents without needing to add any new residential developments
3. Residential/employment density: As a result, the ratio of residential to employment density goes up, bringing a live/work balance to the area.
4. Housing Diversity: The housing diversity remains high, as there are three different housing types for resident to select from.
5. Proximity to Parks: The proximity to parks measure also increased as the walking distance between the different building blocks and parks has decreased.

This result is a noticeable increase in the overall vitality metrics. As the local working (currently 68,000) and living population (approximately 13,655) in the district increases, so does the 3rd places output gives an updated tally of the required supermarkets, bar, restaurants, nightclubs, bakeries, pharmacies and art galleries required to meet the growing population. Users can utilize these recommendations, as a means of approximating the required additional commercial space to accommodate these places.

Finally, we can look at improving other metrics, such as proximity to small parks and housing diversity. The more central open spaces are to working and living blocks, the higher the vitality score. Similarly, adding different types of housing units (i.e. affordable, midrange and luxury) increases the housing diversity, which boost the overall score, see figure 33.

Table 15: Summary of the desired scenario results for the number of required amenities

Amenity	Total required
Supermarket	2
Bar	8
Restaurant	19
Baker	4
Nightclub	2
Pharmacy	2
Bookstore	5
Art Gallery	2

It is important to note that, our objective is not to make recommendations regarding the actual required amenities to support urban vitality, rather, to show the relationship of static infrastructure elements (such as housing types, open spaces and 3rd places) and vitality. These numbers can be determined using different methodologies, which is not in the scope of this research. Our aim is to develop a platform that will open a dialogue between developers and the general community regarding what is in the best interest of the locals in terms of makes a place more livable.

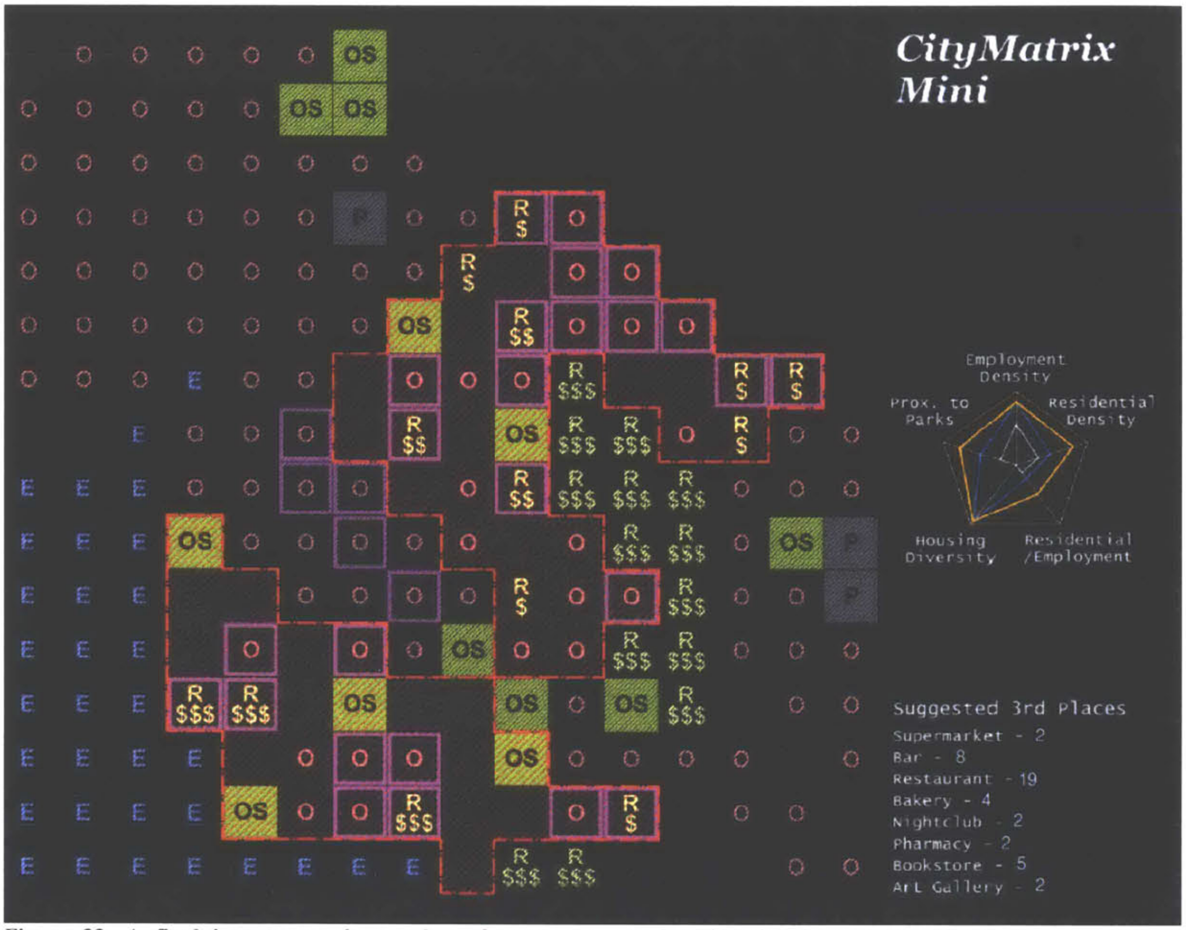

Figure 33: A final increase to the number of open spaces and residential (luxury and affordable) increases the contribution of housing diversity and proximity to parks to the overall vitality score. The radar chart clearly shows that carefully scripted interventions add to the overall vitality Kendall (the baseline case is white, while he active score is orange, and the previous output is blue), see figure 37 for a close up of outputs.

Figures 34 through 37 show close ups of the of the CityMatrix evaluation tool for the four scenarios outlined above. The radar charts show three different chart colors: the baseline scenario is shown in white, current evaluation plots are shown in orange, while the outputs from the previous scenarios are shown in blue.

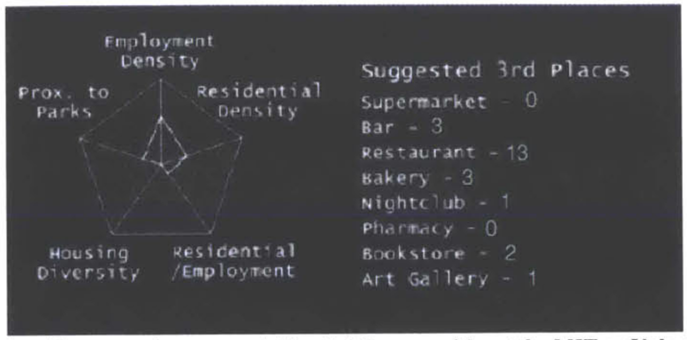

Figure 34: The baseline scenario represents Kendall Square without the MIT or Volpe sites.

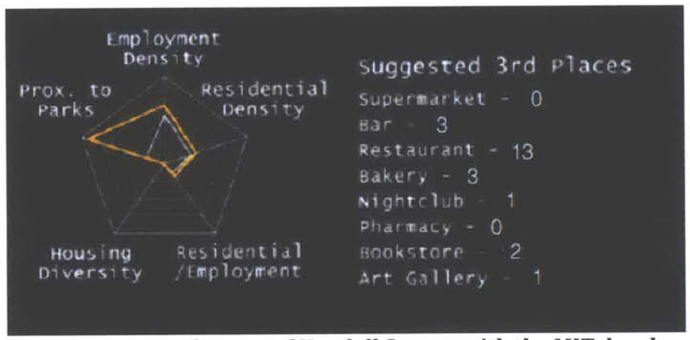

Figure 35: MIT scenario represents the case of Kendall Square with the MIT development site.

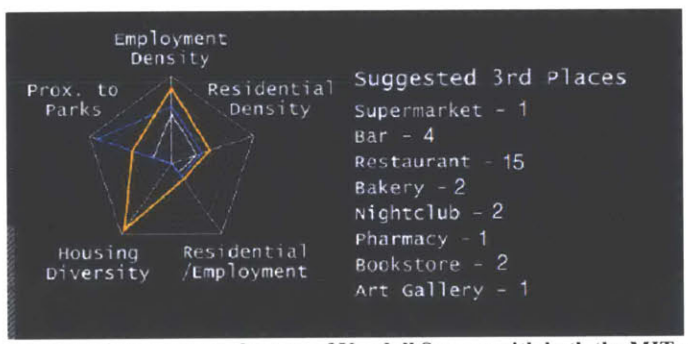

Figure 36: The MIT+Volpe scenario represents the case of Kendall Square with both the MIT and Volpe sites

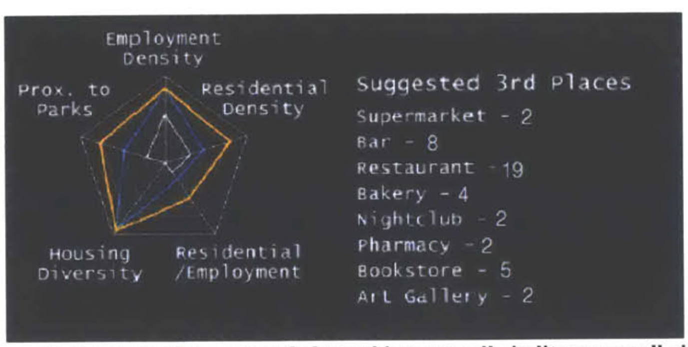

Figure 37: The desired scenario represents the case needed to achieve overall vitality across all vitality indicators.

Conclusion

Presented herein is a continuation of the works put forth by (Jacobs, 1961), (Sung, Lee, & Cheon, 2015) and (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106). They introduced and operationalized the four-diversity condition necessary for urban vitality. The main contribution of this body of work builds upon these empirically grounded theoretical works to build a computational evaluation decision support platform to facilitate collaborations between stakeholders of varying levels of proficiency and domain knowledge in their interactions within the contexts of urban planning. Whether planned interventions or new developments, the aim of this research is to give stakeholders the ability to weigh the implications from these interventions on the vitality of districts.

Typically, development sites will see multiple bids from investors and developers. The competitive nature of this process suggests that involved parties have varying and potentially conflicting objectives. In addition, areas with soaring office and residential rents (like Kendall Square) also make these areas attractive to private developers looking for monetary gains. Furthermore, in an area with an already high employment density, the addition of more office and commercial spaces could increase the stress on the public transportation system that is struggling to keep up with the current demand. This becomes a design problem with no optimal solution. The question becomes, how do we design districts to be livelier?

Based on the recommendations of Jacobs and De Nadia, we created a rapid prototyping tool for district planning based on static features (housing types, land use mix, number of intersections, number of commercial and office spaces), as well as activity-based features (3^{rd} places) to increase district vitality. As opposed to negotiation over static plans, this approach offers an intuitive sense—in terms of the number of commercial, office, and residential spaces—

of how to design districts to be more vital. This approach also allows stakeholders to rapidly change the scale of the spatial area of interest through the use of Legos.

To demonstrate this, we used Kendall Square and Harvard Square as case studies. Beginning with data for both areas, we gathered information pertaining to the four-diversity condition for urban vitality to build profiles for the respective districts. Firstly we computed the performance of both district across the features defined by Jacobs. Next, we compared the results from the models, and identified the weak variables that define Kendal Square (such as residential density). Using existing plans that are in the works for Kendall Square, we measured how impactful the development plans could be to the area in terms of vitality. Finally, we showed that it is possible to improve upon the vitality score of the proposed plans, by increasing the number of floors (residential density), proximity to parks, and housing diversity in a simple and intuitive way.

In this study we found that, combined, the MIT development site and the Volpe development site will add a total of approximately 16,000 jobs and 4,000 residents to Kendall Square. In terms of achieving vitality, these proposals are not adequate. Firstly, the residential density remains low, which can result in a stagnant district during nighttime and weekends. Secondly, the low volume of residential units implies that rents will remain high, edging out the younger generation (that breathes life into districts) from living in area. Other implications relate to the transportation system and how it can support the additional employees (that cannot live in the area due to increased rents) commuting to Kendall Square. With this computational evaluation platform, we strive to connect these interdependencies in order to inform planners and developers on how to design districts with the most crucial element in mind: people.

Future Work

This work begins with the assumption that the urban vitality features defined by (Jacobs, 1961), (Sung, Lee, & Cheon, 2015) and (De Nadai, Staiano, Larcher, Sebe, Quercia, & Lepri, 2106) hold true in the American context. Their contributions showed that the extent to which the different features attribute to vitality does not change across cities. Sung et al. demonstrated this in Seoul, South Korea, as did De Nadai in Bologna, Florence, Milan, Palermo, Rome, and Turin in Italy. The results from these studies were used as a reference for the simulation outputs in this research. To fully calibrate this computational evaluation platform, Jacobs's theories would have to be verified using individual call records from mobile phone data for multiple cities in the US (outside the scope of this research), as was performed in the Italian context.

Next, it is crucial to take the areas surrounding Kendall Square to examine the mobility patterns of individuals commuting to Kendall Square for work purposes. This will allow us to model the impacts of additional jobs in Kendall on the Red Line. The next following step for this research would be to focus on the following question: how can we assess the impact that these interventions will have on social interactions within these districts? This will require the use of Agent Based Modeling (ABM), to capture the aggregated impacts of inter-agent interactions). This approach could reveal some insights into the underlying dynamics that drive the emergence of economically productive clusters within districts. Additionally, it will also allow us to delve into economic dynamics drivers of rent in these districts, see appendix.

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Appendix

Modeling the Impact of Urban Interventions on Interactions in Abstracted Simulation Environments

Abstract

The standard geographic model of innovation, science parks that are driven by people working form 9 to 5, has been overtaken by what the literature is calling 'innovation districts'. These are vibrant round-the-clock communities that offer a wide range of living, working and recreational spaces, most of which within walking range. However, with these urban elements already in place, how can we assess the impact that interventions, such as special places and events, will have on interactions within these communities? Furthermore, how can we use this to weigh in on decisions regarding investments in such interventions? The hypothesis presented in this work is: Carefully choreographed events and special places will create opportunities for creative collisions with said districts. Examples of this are evident during hackathons, where people from mixed backgrounds congregate around a special event for the common goal of innovation. This happens organically, similar to conventional workspaces, however at an accelerated pace. The motivation behind this body of work is to produce a modeling platform that allows urban developers and policy makers to explore the impact of urban interventions on the emergence of new social interactions within cities, by simulating special places and planned events. This will be accomplished by leveraging Agent Based Modeling (ABM), to capture the behaviors and interactions of agents (people) on both the micro (agents interacting on an individual level) and macro (aggregated impacts of inter-agent interactions) scales. The results of the model will reveal some insights into the underlying dynamics that drive the emergence of economically productive clusters within economically productive districts in addition to developing a framework to quantify the performance of these cities.

Introduction

In many parts of the world, urban cores are the driving forces behind economic growth. This is evident in major cities, where high socioeconomic diversity of residents has lead to an increase in productive human capital (Malik, Cooks, Root, & Swartz , 2015) (Lucas, 1988). Cities such as London and New York are examples of prosperous cities that are largely considered as hubs of creativity. These cities share the same characteristics in that they attract top talent by offering the best professional and educational opportunities, as well as the highest quality of public services (transportation, health care, bike lanes, etc.) and urban amenities (theaters, open spaces, restaurants, art galleries, etc.) (Malik, Cooks, Root, & Swartz , 2015). In addition, appropriate policies are put in place to avoid "exclusionary development and rent-seeking" as a measure of encouraging inclusion. In doing so, this gives residents the opportunity for better socioeconomic assimilation as well as better access to urban services (Malik, Cooks, Root, & Swartz , 2015) (UN-HABITAT, 2010).

This new paradigm of thinking about urban cores refers to what many are calling 'creative cities' (Florida, Cities and the Creative Class, 2005) and 'innovation districts' (Katz & Wagner, The Rise of Innovation Districts: A New Geography of Innovation in America , 2014). By definition, These are communities that offer an abundance of mixed-use housing and co-working spaces; are densely packed with innovative companies, as well as learning institutions; offer a wide range of amenities where city dwellers can go to after work hours; and are transit friendly by making everything accessible either by walking or public transport. They are also geographic areas where leading institutions and companies cluster next to start-up companies, business incubators, and accelerators (Katz & Wagner, The Rise of Innovation Districts: A New Geography of Innovation in America , 2014). According to (Katz & Wagner, The Rise of Innovation Districts: A New Geography of Innovation in America , 2014), compact, amenity-rich enclaves in urban cores are becoming the prime choice where young talented workers choose to congregate and co-locate. In order to leverage the abundance of this widely available talent, key companies in knowledge intensive industries are locating their facilities in close proximity to other firms, research labs and universities in order to facilitate the practice of "open innovation" (Katz & Wagner, The Rise of Innovation Districts: A New Geography of Innovation in America , 2014).

In this research, I propose to build a simulation model that will help explore the impact of urban morphology (through the addition of special places and events) on human interactions and their potential socioeconomic outcomes (see figure 2). By leveraging works by (Malik, Cooks, Root, & Swartz , 2015), (Heine, Meyer, & Strangfeld, 2005) and (Meyer, 2011), I will design a modeling platform that allows city and event planners to explore the impact of urban interventions on the formation of social ties within cities. Furthermore, the model will aggregate these human interactions and socioeconomic outcomes into measurable scores, see figure 2. Previous contributions modeled this relationship by utilizing "stylized facts to simulate key findings from empirically grounded theoretical contributions focusing on the dynamic processes underlying the emergence of economically productive clusters within cities" (Malik, Cooks, Root, & Swartz , 2015). (Sim, Yaliraki, Barhona, & Stumpf, 2015) argue that physical, face-to-face social ties in highly functioning cities are rarely observed in their entirety and are at best, estimated using unrealistic overly simplified assumptions such as spatial homogeneity. These stylized facts will be strengthened by some of the empirically grounded relationships derived in the (Sim, Yaliraki, Barhona, & Stumpf, 2015) model of human interactions that maximizes the number of beneficial connections attainable under the constraints of limited traveling time. In addition to characterizing the connectivity of complex cities, the model also quantifies the impact of transport developments and population growth on a city.

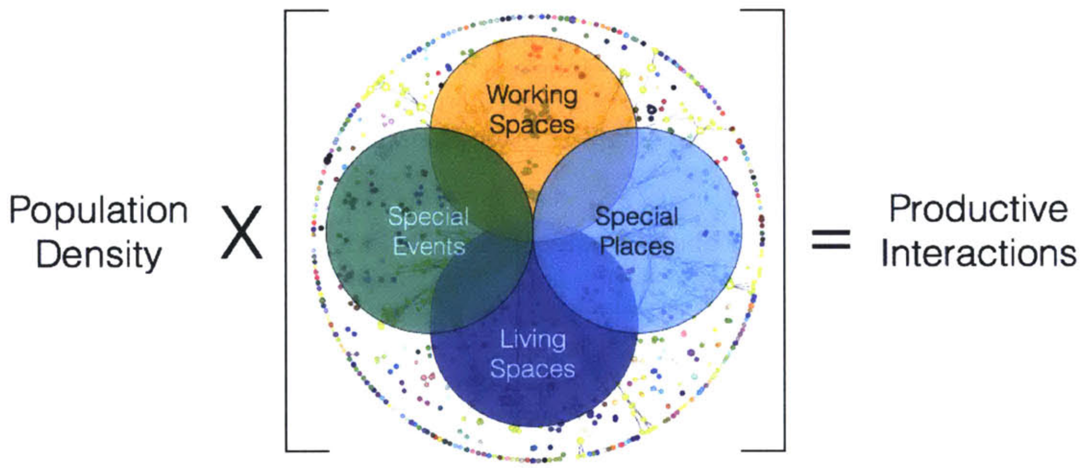


Figure 2: Carful choreographed scenarios of the appropriate mix of work and living spaces and special places and event at the right density lead to greater likelihood of productive interactions.

In order to simulate these dynamics, I will be using agent based modeling. Agent-based models are useful for abstracting and mimicking social systems through simple rules that govern the behavior of agents on an individual level, which provides an alternative to the conventional urban and regional modeling tools. Agent-based modeling also allows us to shift our focus away from 'big picture' models, which offer little insights on the inner workings of complex systems to highly dynamic and informative models that operate at the micro-scale (Batty, 2005) (Malik, Cooks, Root, & Swartz , 2015).

"The result is a stylized abstraction of a theoretical city containing autonomously interacting agents under various scenarios to draw insights in the workings of dynamic urban systems" (Malik, Cooks, Root, & Swartz , 2015). This will lead to key insights as to how such urban interventions (special places and events) will behave/evolve under a variety of conditions, giving users a chance to play and compare scenarios. These solutions can then be brought to the real world and scrutinized by domain experts.

Related Work

There are three competing ways of looking at urban economic growth (Storper & Scott, 2008). (Florida, Cities and the Creative Class, 2005) theorizes that metropolitan areas with high concentrations of technology workers, artists, musicians as well as a group he defines as "high bohemians" are more likely to be economically developed. (Glaeser, Triumph if the City, 2011)'s theory focuses on human capital while (Clark T. , Lloyd, Wong, & Jain, 2002) focuses on urban amenities. The Term 'innovation' and 'creativity' have many meaning across a wide range of disciplines. For the purpose of this research I will be using them as a means of exploring the dynamics between urban morphology and potential economic activity that is a result of human interactions with each other and their environment (Malik, Cooks, Root, & Swartz , 2015). In particular, I will be paying attention to how these dynamics change with the introduction of special places and events.

To this extent, Agent Based Models have been used to model socio-economic systems (Helbing, 2012). They have been applied to a variety of urban applications including: housing and land markets, informal settlements growth, crime reduction humanitarian assistance, vehicle movement, location theory, evolving landscape of cities, and evacuation plans where poisonous gases spread in the environment (Helbing, 2012) (Malik, Cooks, Root, & Swartz , 2015). Depending on the problem at hand, agents may be used to simulate individuals, groups of people, companies or countries (Helbing, 2012). The behaviors of agents can be generalized by either using equations or specified using decision rules (if then logical operations). This characteristic allows for grater flexibility, as it is easily to add individual variations in the behavioral rules (heterogeneity) and random variations (stochasticity) (Helbing, 2012). In addition, agent based models are not only suited to simulate interaction between different agents; they have the advantage of contributing toward generating hypotheses as well as building theories (Helbing, 2012) (Malik, Cooks, Root, & Swartz , 2015) (Crooks & Heppenstall, 2012). Other favorable attributes of agent-based simulations include: modularity, flexibility, large expressiveness and the possibility of executing them in parallelized ways (Helbing, 2012) (Spencer, 2011).

Of the available literature on agent-based simulations, there is a lack of emphasis placed on the relation ship between the physical landscape of cities and its impacts on social ties. (Spencer, 2011) used agent-based simulations in order to mimic the diffusion process of creativity using network analysis. His model is "supported by stylized facts from social psychology and network analysis that allow us to explore the interconnectivity between social networks and physical location and their economic implications" (Malik, Cooks, Root, & Swartz , 2015). The results show that the diffusion of creative ideas if precipitated by social diversity in large physical spaces. Liu and Silva simulate market dynamics between affordable housing and firms locating closer to potential workers using ABM in order to gain insights into creative diffusion (Malik, Cooks, Root, & Swartz , 2015) (Liu & Silva, 2013). This model does not shed any light on the social interactions of agents or the emergence of innovative clusters (Malik, Cooks, Root, & Swartz , 2015). (Malik, Cooks, Root, & Swartz , 2015) used ABM to "capture the nuances of dynamic urban environments" and to shed light on the emergence and formation of creative clusters.

(Sim, Yaliraki, Barhona, & Stumpf, 2015) (Watts & Doodds, 2007) claim that the greatness, or success, of a city via its size is unsubstantiated without a reference to travel-time constraints just as title and rank a poor indicators of influence in social ties. According to (Louf & Bathelemy, 2014) (Sim, Yaliraki, Barhona, & Stumpf, 2015), the simplest objective measure of this success is the extent to which a city can fulfill its primary purpose of maximizing the number of "face-to-face, opportunity-spawning" interactions between its inhabitants. The extent to which these interactions/connections are facilitated throughout the urban fabric is a measure of both the eminence of individuals and the success of whole cities (batty, 2013). Measuring this connectivity, however, remains difficult to estimate. Unlike secondary socioeconomic indices, the number of face-to-face social ties on a city scale in not straight forward. Assumptions that ignore heterogeneity in favor of simple statistics (population size (Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007), density, (Pan, Ghoshal, Krumme, Cebrian, & Pentland, 2013)congestion sensitivity (Louf & Bathelemy, 2014)) mask a forbidding richness of real-world information such as diversity, distributions, topologies and geometries, transport modality infrastructure as well as behavioral differences (travel time tolerance). This makes it challenging to compare cities that vary on any of these obscured metrics rendering such models unsuitable for assessing the impact of urban interventions on the emergence of creative clusters within cities.

(Pan, Ghoshal, Krumme, Cebrian, & Pentland, 2013) took major strides towards building generative and exploratory models of cities where the observations behind the super-linear scaling relations were shown to be consistent with the assumption that the probability of social-tie formation between two individuals is inversely proportional to the number of people in close proximity. According to (Sim, Yaliraki, Barhona, & Stumpf, 2015), this suggests the existence of an underlying set of behavioral principles governing the formation of social tie networks within cities. Subsequently, (Sim, Yaliraki, Barhona, & Stumpf, 2015) built a mechanistic model that captures social interactions derived in terms of a set of agent-driven rules. The model is based on four fundamental principals:

1. Heterogeneity: Individuals are characterized by a set of attributes
2. Utility optimization: Individuals seek social ties with higher attribute values
3. Resource constraints: Individuals are constrained to a travel-time budget

Intervening opportunities: Individuals form ties with lesser attribute values based on proximity.

As defined by (De Propris & Hypponen, 2007), creative clusters are urban spaces that attract highly creative people in large numbers with the common goal of generating novel ideas (Malik, Cooks, Root, & Swartz , 2015). Through density, diversity and proximity, innovative ideas have a higher chance of diffusion, which leads to overall higher economic productivity. In the model presented herein, Agents possess multiple attributes that are parametrically controlled by the user, which will give insights to the dynamics of the formation of innovative clusters within urban environments.

Proposed Work

In this body of work I propose to build a modeling framework that allows decision makers to assess the economic potential resulting from urban interventions to an urban center. Urban interventions are applied by placing either special places and or events to a stylized abstract urban simulation environment that consists of living and working spaces. Central to the physical model, are the building functions that constitute the fabric of the urban space. Figure 3 below gives an overview of the different building functions available to the user.

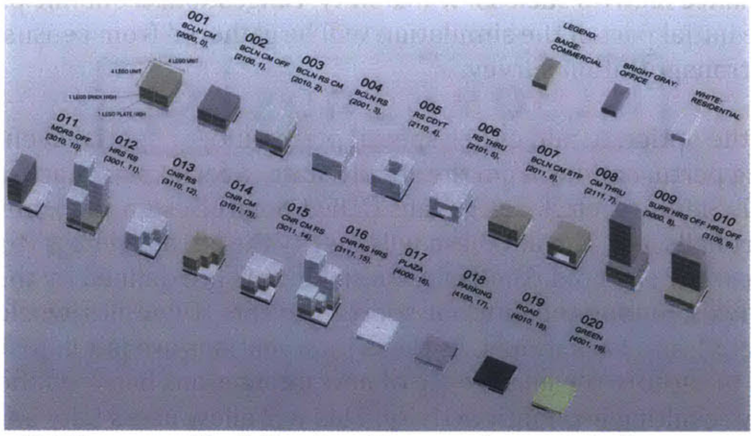


Figure 3: Diagram of building functions and associated enumerations

The figure above references a database that contains the different living space (affordable, mid-range, expensive) and workspaces (commercial - high, mid, low- rise as well as co-working - spaces). Figure 4 illustrates the color codes that are designated for each of the different building functions. The platform works by scanning the bottom of the physical model and is programed to pick up any changes to the layout of the building blocks. The model is then updated and the output parameters reflect the changes made to the physical model.

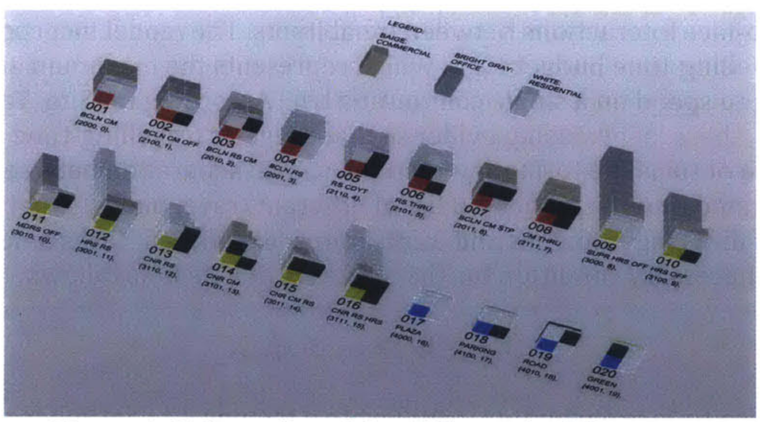


Figure 4: Color codes of the different building types

The simulation will begin with users placing the various building functions throughout the simulation environment. Each of the housing blocks is predefined with the following: number of resident agents, type of agents (high, medium or low creativity), income level (high, medium, low), and number of parking spaces available. Next, users specify the number and location of working spaces (points of interest for the agents). Based on the proximity of working spaces, agents are most likely to either walk, bike or drive from home to work and vice versa. Once this relationship (home-work) has been established, third places are generated based on the number and congregation patterns of agents in their home dwellings and workspaces. As the simulation reaches a steady state, the users can examine performance metrics such as: walkability, congestion, economic productivity, and rent. Data for the initial part of the simulation will be gathered from census data provided in the MIT 2012 transportation survey.

Users then have the option to add either special places and/or special events in order to examine resulting perturbations from the steady state. Special places are defined by: Universities (MIT, Stanford, etc.), design labs (IDEO, Smart Design, etc.), museums, art institutes, concert halls, etc. The database will specify the attractiveness (to agents) that each of these interventions hold. Similarly, special events are defined by the following: concerts, art festivals, indoor and outdoor sporting events (Olympics, world championships, etc.), and hackathons. As these interventions are put in place, the goal of the simulation is to capture the emergence of new interactions between the different types of agents and any resulting economic activity. This will allow users (city and event planners) to study the potential impact (both positive and negative) that planned interventions will have on a given community.

Model constraints:
In order to ensure the simulation is realistic, the model will also include tradeoffs between density, diversity and proximity, as is the case in real-world applications. For example, the model will capture the following negative impacts related to density: road congestion, competition and overall increase in social disorder, as well as the positives: increased economic activity and more living options (Palm, Gregor, Wang, & McMullen, 2014). The emergence of social ties for example, is largely dependent on how the urban space facilitates face-to-face interactions between inhabitants. The model incorporates the concept of a travelling-time budget τ_{max}, which represents the maximum amount of time a person is willing to spend on a single commuting trip. According to (Sim, Yaliraki, Barhona, & Stumpf, 2015), there is increasing evidence that suggests travelling-time is a more relevant measure of social tie formation than the spatial separation between pairs of people. Incorporated into the model is a list of different travel budgets that reflect the heterogeneity of differing priorities and motivations for different tasks amongst the population. The necessary condition for the existence of a tie is as follows:

$$(i \longrightarrow j)_Z \Rightarrow \tau_{ij} \leq \tau_{max}^{Z}.$$

Each potential face-to-face encounter is subject to a temporal social sphere within which agents evaluate the merit of interaction against other less costly options. The shortest traveling path between two individuals defines this cost objective. According to (Sim, Yaliraki, Barhona, & Stumpf, 2015), these temporal sphere define the set of people S_{ij} in a population of size N_{pop}. The, resulting social tie is defined by the following relation:

$$(i \longrightarrow j)_Z \Rightarrow z^{(i)} \leq \max z_{k \in S_{ij}}^{(k)}.$$

In addition, as economic productivity is increased, so does rent associated with living in these more productive areas. Users can counter these emerging phenomena by introducing strategies such as subsidized housing to accommodate agents with less disposable income. Similarly, the number of creative people, disposable income as well as available space will impact interventions (special places and events).

Agent Behaviors:

1. Agent satisfaction,
2. Creativity diffusion,
3. Income and rent,
4. Population growth and brain drain.

Agents are free to roam about the simulation environment until they have acquired their desired level of satisfaction. The satisfaction of an agent is dependent on two parameters; rent affordability and segregation. Rent affordability is measured by the affordability of housing within the user specified rent threshold (see equation 1). Where R_{im} is the monthly market rent in any given neighborhood, $\propto$ is the user specified rent percentage of income threshold and ρ_{im} is the level of monthly income for a given agent (Malik, Cooks, Root, & Swartz , 2015).

$$R_{im} \leq \propto \rho_{im}.$$

Segregation is based on the Schelling segregation model, which specifies that the satisfaction of an agent is dependent on how similar a given agent is to agents in surrounding cells. If this value falls bellow the user specified constraints, the agent relocates. This behavior is expressed in equation 2. In order to determine similarity, any given agent will check to see if the agents in the surrounding 8 cells satisfy the user specified tolerance threshold. Where T_j is the tolerance level for any 8 cells surrounding a given cell, τ_j is an individual agent's tolerance level, and β is a user specified percentage tolerance for surrounding cells (Malik, Cooks, Root, & Swartz , 2015).

$$-\beta(T_j) \leq \tau_j \leq +\beta(T_j).$$

(Florida, Cities and the Creative Class, 2005) and (Glaeser, Triumph if the City, 2011) state that urban spaces endowed with mixed land-use, walkability, public spaces and transport accessibility cultivate a culture of entrepreneurship and innovation. These cells are therefore enriched with creative opportunities. (Sim, Yaliraki, Barhona, & Stumpf, 2015) models the variety inherent in city life by including - in addition to attributes such as wealth, beauty artistic skills and criminality - the spectrum of skills and levels in those attributes across the population. These heterogeneous attributes is defined as follows:

$$\{X, Y, Z, \ldots\}.$$

In the Malik et al. model, diffusion is defined as the summation of the different agent types interacting with each of the cells in the simulation environment multiplied by a user specified creativity weight parameter (see equation 3). The following expression is a proxy for measuring "urban amenity endowments" of cells, or the creative value. Where CV is the creative value of a given cell and ch_n, cm_n, cl_n represent the agents with high, medium and low creativity. The creative value of a cell increases or decreases depending on the continual interaction of medium and high creative agents interacting with that given cell.

$$\Sigma_{i=1}^{n} CV = \Sigma_{i=1}^{n1} 10(ch_n) + \Sigma_{i=1}^{n2} 5(cm_n) + \Sigma_{i=1}^{n3} 1(cl_n).$$

Based on income data from multiple countries, (Malik, Cooks, Root, & Swartz , 2015) states that the per-capita income follows a two-peak distribution, each corresponding to the upper- and lower- income stratums of society. During initialization, each agent is assigned an annual income. As the simulation progresses, agents interact with each other, creating more opportunities for agents to become more creative. Similar to the (Sim, Yaliraki, Barhona, & Stumpf, 2015) model, whereby individuals seek to build beneficial ties, agents will simply search for social ties deemed to be in their own perceived best interest. For a given attribute Z, the condition for a directed social tie from person I to person j is expressed as:

$$(i \rightarrow j)_Z \Rightarrow Z^i > Z^j.$$

Agents that change their creativity state receive a user specified percentage increase in income (Malik, Cooks, Root, & Swartz , 2015). This is supported by (Florida, Cities and the Creative Class, 2005)'s claim that the creative class enjoy higher per-capita income levels. This dynamic is the driving force behind rental prices in the model. As demand for highly creative cells increases and the supply remain static, rent for that given cell will increase.

Population growth and brain drain are both user specified inputs at the beginning of the simulation. Population growth impacts high, medium and low creative agents, while brain drain only impacts the high and medium creative agents, as specified in equation 4 (Stark) (Malik, Cooks, Root, & Swartz , 2015). Where P_t is the total agent population, p^c and p^{nc} represent the creative and none creative agents, while $\Delta\beta$ and ΔP and the annual user specified population brain drain and population growth parameters respectively.

$$P_t = [(p_{t-1}^{c}\, \Delta P) - \Delta\beta] + (p_{t-1}^{nc}\, \Delta P)$$

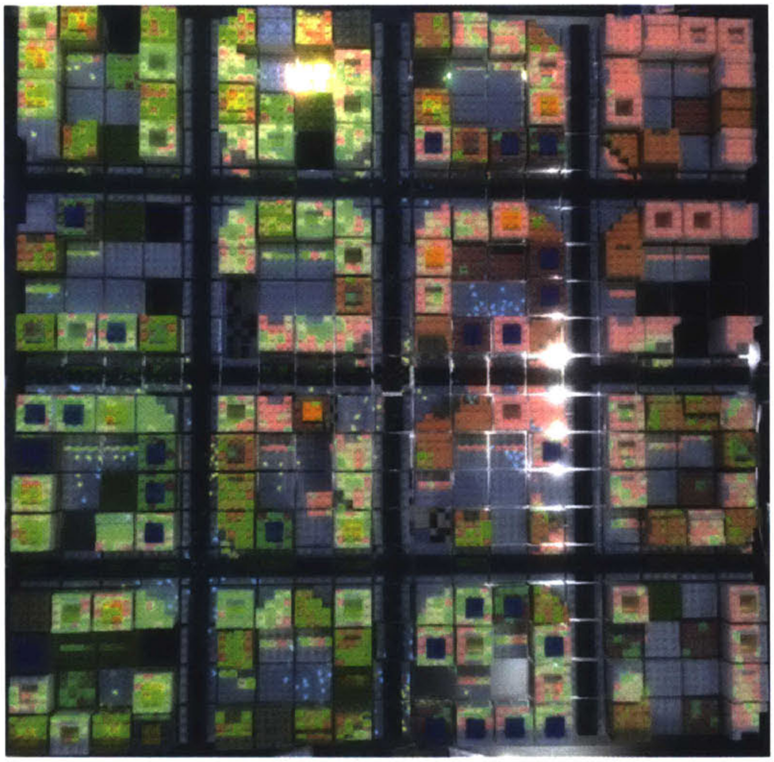


Figure 5: Layout of the design space

Counting Social Ties:
As denoted by (Sim, Yaliraki, Barhona, & Stumpf, 2015), the conditions defined by equations x, y and z are the building blocks upon which directed social ties between $(i \longrightarrow j)z$. The probability of for these conditions to be satisfied is thusly $\text{Prob}(i \longrightarrow j) = \frac{1}{n_{ij}+2}$. From this relation, (Sim, Yaliraki, Barhona, & Stumpf, 2015)derive the total number of ties $T_Z$corresponding to an attribute Z in a population size of N_{pop} is the sum of each individual set of probabilities up to a finite τ^z_{max}. The distance matrix $\tau_{ij}$is replaces with a smaller sample distance matrix $\hat{\tau}_{ij}$to represent a subsampled geographical extent of a city $N_S\,(\ll N_{pop})$. From this representation we obtain the following representation:

$$T_Z \approx N_{pop}\left[\ln\left(\frac{N_{pop}}{2N_S}\right) + \frac{1}{N_S}\sum_{i=1}^{N_S} \ln n_i^z\right] + \frac{2N_S}{\overline{n^z}},$$

where n_i^z: is the size of the social sphere, as related to attribute Z, of the location of the subsampled city.

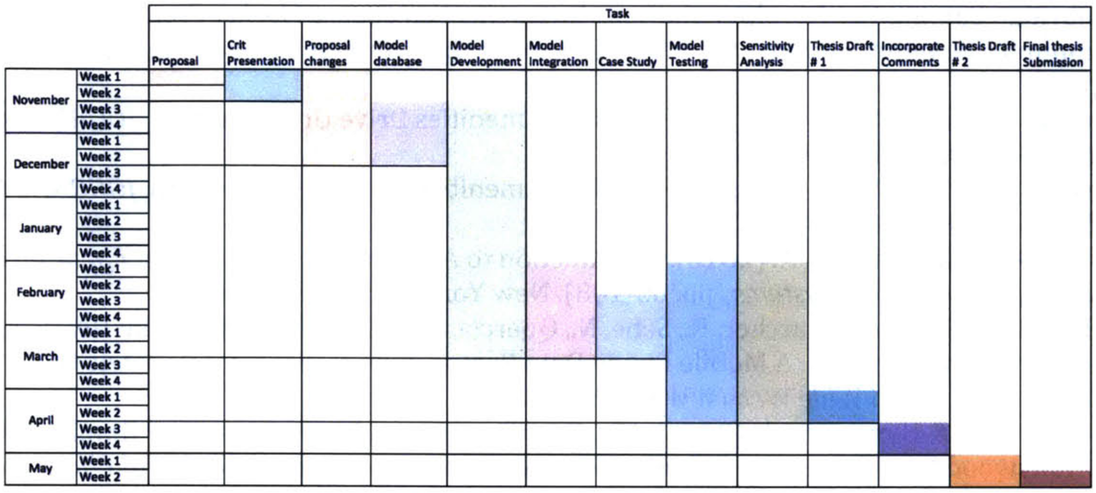
Contribution

The first contribution of this work is the integration of a physical model (that represents an abstraction of a real-world urban landscape) with an agent-based model. The physical model was previously developed and deployed in multiple cities around the world as part of the CityScope platform in the Changing Places Group. The second contribution is to expand upon the theoretical foundation discussed in the Related Work section by means of agent-based simulations. This will be accomplished by simulating the interactions between the various building types in the physical model and the different agent categories of the agent-based model. These contributions will allow users to visually realize the impacts of the urban interventions on the innovation potential of cities by means of the emergent social ties and creative clusters within the model; resulting in more informed decision.

Evaluation

In order to verify the out put of the model, I will be performing the following evaluative study. The first will include a sensitivity analysis of the input parameter to crucial outputs. The key output from the model is the emergence of creative clusters depending on various input configuration from the interactions of individual agents. However, before interpreting any results from experimentation, it is important to verify results in order to gain confidence in the workings of them model. This is important to ensure that the model results broadly follows the theoretical claims previously discussed in the introduction. For example, does greater population density and social diversity levels lead higher innovation potential through diffusion if creativity? While this may seem to be an obvious outcome of the model, the verification and consistency of the model can be achieved by systematically testing each of the input parameters (Malik, Cooks, Root, & Swartz , 2015). The baseline inputs will be gathered from survey data from the 2012 MIT transportation survey.

Time Frame



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