Mobility-Aware Integrated Urban Design

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16. Abstract

Rapid urbanization, with new construction estimated to be 250 times NYC by 2050, is increasing traffic congestion, pollution and related health threats. This is a worrisome development but also a unique opportunity to improve urban mobility and quality of life. Understanding consequences of urban design choices on mobility, sustainability, and health is a necessity and requires development of a framework that enables such co-design processes. We propose a new design-toolkit to incorporate mobility, sustainability, health, and thermal comfort metrics into urban design projects. Process accuracy and impact is validated in collaboration with leading design practitioners and the NYC Planning Department.

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Mobility-Aware Integrated Urban Design: Developing software tools that incorporate active transportation, pollution, and outdoor comfort models for healthy urban design

ABSTRACT

Rapid urbanization, with new global construction estimated to be 250 times the floor area of NYC by 2050, is increasing traffic congestion, pollution and related health threats. This is a worrisome development but also a unique opportunity to improve urban mobility and quality of life. Understanding consequences of urban design choices on mobility, sustainability, and health is a necessity and requires development of a framework that enables such co-design processes. Existing transportation modelling tools are detached from the design process as they require technical expertise in traffic modelling, extensive preprocessing steps and heavy computational power, all of which make it difficult to be accessed by urban planners and designers. We propose a new, easy to use, CAD integrated, design-toolkit, called "Urbano", to model active transportation and to evaluate access to amenities and public transport. Urbano introduces a fully automated workflow to load in contextual GIS, OpenStreetMap and Google Places data to set up an urban mobility model. Kicking off by computing validated walkability metrics like a more flexible and modifiable version of the Walkscore, the tool will include other urban scale mobility metrics to aid the urban design process.

Keywords

Urban Design; Mobility; Big Data; Network Analysis; Walkability; Access; Walkshed; Amenities

1 INTRODUCTION

Traffic congestion in road networks is a major problem in cities worldwide, with a corresponding economic cost of roughly $121 billion per year or one percent of GDP in the United States [1]. This includes 5.5 billion hours lost due to sitting in traffic and the additional consumption of 2.9 billion gallons of fuel responsible for 56 billion pounds of carbon dioxide and other greenhouse gases that released into the atmosphere. Further, studies attribute 3.3 million and rising premature deaths globally to traffic-related pollution [2]. This is a worrisome circumstance, especially in the context of rapid population growth and urbanization that require us to densify existing cities and to build new urban habitats equivalent to 250 times the floor area of New York City in the next thirty years [3]. This massive construction volume, however, can also be seen as a unique opportunity to improve our built environment, urban mobility and quality of life through integrated and well-informed urban design processes. In particular, with the continuing migration of people towards cities, there are huge public health, economic, environmental and societal gains that can be attained by the co-design of the urban built environment and active transportation infrastructure. Current planning paradigms promote high density, walkable neighborhoods to improve public health, economy, environment, urban social life. Studies have shown that the risk for chronic diseases may be reduced significantly if the neighborhoods are walkable and the urban environment promotes physical activity [4],[5]. Further, economic growth and prosperity have been linked to the walkability. Walkable neighborhoods support local business, promoting tourism, and encouraging inward investment. The attracted investors, in turn, ensure higher employment and property values. In sum, this leads to a competitive return of investment of up to $12 for every dollar spent [6]. Finally, it has been shown that walkable cities foster an increase in social capital and political participation due to more time spent in public areas leading to higher engagement, likelihood of knowing their neighbors, political participation and trust in their community [7]. In addition, travel mode choices also affect the environment in terms of carbon and other greenhouse gas (GHG) emissions. In the United States, 27% of GHG emissions are credited to transportation-based sources, of which 60% are light-duty passenger vehicles. The portion of GHG emissions caused by the transportation sector has increased since 1990, more than any other sector. Promoting walking and biking instead is widely recognized as strategy to mitigate traffic related emissions.

Hence, understanding the implications of urban design choices on the mobility of cities while incorporating this understanding into very early stages of an urban design process, provides a unique opportunity to address mobility, sustainability, and health-related issues. This is particularly important because street grids hardly ever change once the urban design is set. One of the major hindering factors in this process is the lack of tools for designers that can quantify these trade-offs and assist with the design process [8].

While many urban mobility simulators and urban design tools exist, mobility aware urban design remains challenging. State-of-the-art travel demand modeling software like TransCAD [9] have detailed and sophisticated travel demand models, and focus on the precision of transportation modelling and forecasting processes. These tools are intended to be used by transportation professionals and traffic engineers and thus can be challenging to use for non-specialized urban designers and planners. Large-scale urban modelling tools are also computationally costly, and sometimes require dedicated hardware to run. This makes it difficult to employ these methodologies in design processes. Further, their standalone character tends to separate the design and simulation-based analysis processes. This lack of interactivity between the two processes is not feasible for a co-design process where immediate feedback on the effects of their design choices is critical.

Other tools are integrated in computer aided design (CAD) software and compute simplified urban mobility metrics that are more suitable in urban design. The Urban Network Analysis (UNA) toolbox [10] for ArcGIS [11] and Rhinoceros [12], allows designers to analyze urban street networks using Geographic Information Systems (GIS) data. However, UNA only computes spatial metrics like network centrality measures (reach, closeness, straightness). While, the above metrics are fast to compute and rely only on widely available street network data, they do not incorporate key urban design parameters such as program allocation, amenities and attractions as well as the population density distribution in the model.

In order to identify walkable cities, efforts have been made to rank them based on a shortest-distance analysis between different points of interest. These walkability ratings, commonly referred to as Walkscore [13], are computed on a scale of 1-100 and include factors such as accessibility to services and amenities like grocery stores, doctors, parks, schools, hospitals, and public transportation. The Rhino3d plugin Urban Modelling Interface [14] can compute the Walkscore metric. The main challenge with this tool is to provide the required inputs such as street networks, buildings and the locations of amenities. While this data is readily available online for most cities, the absence of a workflow to easily gather and utilize the data in one place is one of the major bottlenecks urban modelers currently face.

Furthermore, a simple metric like the Walkscore does not provide adequate information to help improve the design process. For example, the services and amenities that are important to have walking access to, differ by demographic groups and it's important to be able to measure demographic specific metrics. Also, while adding a large number of services and amenities might improve a metric such as the Walkscore, having a large number of businesses that provide a certain service or amenity may not financially viable without adequate demand. Thus, the design process requires striking a balance between the availability of services and the demand to sustain these services.

To facilitate the design of walkable and sustainable neighborhoods through mobility-aware urban design, this paper introduces a new modeling framework for Rhino3d and Grasshopper that overcomes several of the previously mentioned shortcomings. The tool is targeted towards urban designers and planners working in early design stages and aims to support design decision making that involves street layout and program and density allocation. The provided simulation feedback may then be used to make designs more conducive to walking and improve other mobility areas. This tool aims to bridge the gap between the design and simulation process by creating an integrated fast-paced design process that has an active feedback system for various travel-related metrics. More specifically, the following contributions are made: (1) Automated model setup from GIS data sources such as NYC Open Data [15], Open Street Maps [16] and Google Places API [17], (2) The ability to create detailed models of the population via personas that describe the needs and preferences of different demographic groups, (3) Introducing an Amenityscore that describes the demand for services at a particular amenity based on the persona distribution, (4) A fully customizable mobility toolkit that includes the ability to define customized performance metrics.

2 METHODOLOGY

The Urbano tool allows designers to effortlessly build a mobility model and run network analysis and transportation simulations on the popular Rhinoceros3D [18] CAD platform. The tool runs as a plugin to Rhino's visual scripting platform, Grasshopper [19] and a screen-shot of the toolkit interface is shown in Figure 1

Figure 1 Urbano Grasshopper plugin toolbox

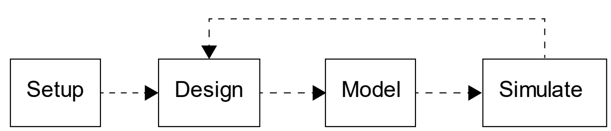

Figure 2 Urbano workflow

2.1 Tool Description

The toolkit follows a four-step workflow that promotes smooth transitions between the modeling steps (Figure 2.) The model is initialized during the setup step by downloading the necessary meta data files (e.g. road-network from Open Street Maps) and executing some preprocessing functions to read and process this data. This step requires processing some large data sets and therefore can be time consuming, but only needs to be done once per network. Once a contextual model is initialized, in the next three steps the designer can interactively change the design and contextual model. After each modification, the tool can automatically build the network analysis model and run necessary simulations. These three steps have been optimized for responsiveness to allow designers to iteratively modify the model to improve the relevant metrics. An overview of all elements that participate in an Urbano simulation are given in Figure 3.

2.2 Setup

The setup step includes establishing the built environment, the existing condition of the study area. The two fundamental requirements to build a travel model, are the street network and building outlines with meta data. Urbano can import this data from existing data sources such as shapefiles from municipal GIS data [15] and OpenStreetMap (OSM) [16]. Both data sources usually have the minimum required information to build the required geometry. The model setup is made seamless by automating the process of network initialization by parsing and processing the OSM files and shapefiles. Additionally, the tool provides the functionality to easily extract location information using the Google Places API [17]. This allows modelers to build an up-to-date contextual model including the different places or amenities that can be found inside the study area's buildings. The metadata provided by Google, such as popularity ratings or opening hours can be used to filter or influence the simulations in the following steps. This allows users to run simulations on an activity-based travel models without having to manually add the most recent amenities data to buildings.

Once the input data is loaded, the tool runs several routines to clean up the data and geometry to initialize the network analysis model. Since, both input data gathering, and network initialization can become time-consuming with larger study areas, the tool caches this information in the Rhino file by baking all geometric objects with their meta data. This workflow makes the setup persistent and allows for both geometric adjustments and metadata edits in the typical Rhino fashion.

2.3 Design

The baked geometry in Rhino is the designer's canvas to seamlessly start modifying, adding to and deleting from. As the buildings and streets are represented as curves with user data, the design process is simply to edit the geometry. The workflow here is the usual curve-editing workflow. The toolkit further allows the designer to edit the embedded metadata from within Rhino, thus establishing an undisrupted design workflow.

2.4 Modeling

The modeling step builds the mobility system (a travel model), from the given geometry and meta data. This step, is responsible for a multitude of tasks.

The street network is processed to check for intersections in streets and splitting the street curves into segments to account for these intersections. A topological graph is built using streets segments as edges and the intersections (and endpoints) as vertices. This graph is later used for path-finding. The street network is always in sync with the underlying graph. As part of this processing, a shortest distance path matrix is computed for all the vertices of the graph using Dijkstra's algorithm [20], which speeds up the path-finding process during simulations.

The buildings are also processed to find the connection to the closest street, which is the physical link between the buildings and the street network. This computation for connections avoids the problem of having the designer ensure that every building has a connection to a street, reducing logistical workload.

An elementary population synthesis step also takes place where the size of the population in each building is determined using common assumptions based on people per unit floor area in residential and commercial buildings. As the characteristics of the population are key to running simulations in an activity-based travel model, these details are intentionally not embedded within the buildings. This gives the designer freedom to modify the characteristics of the population during the simulation process and run simulations for different types of populations. The tool also

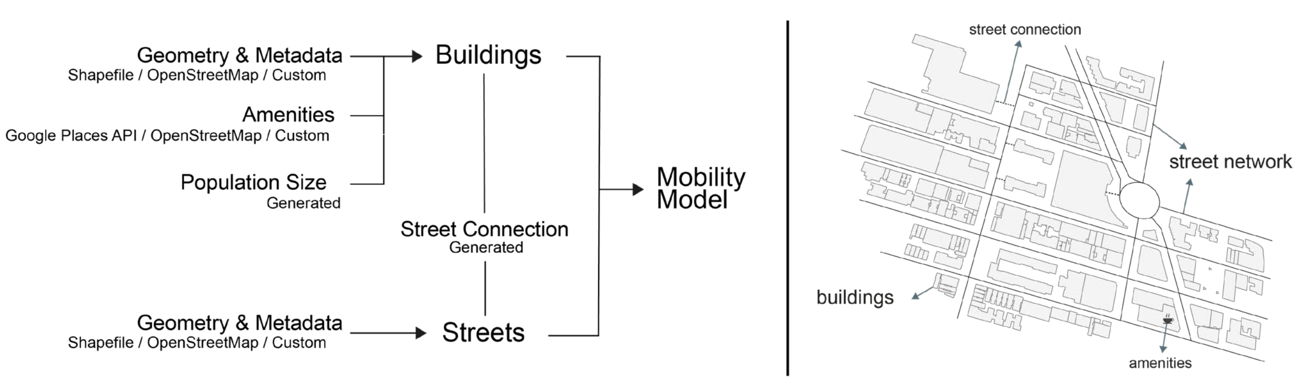

Figure 3. Data that is used to build an Urbano model

provides the ability to define subgroups of people within the population with different characteristics, which we call personas. The modeling step is made as interactive as possible to smoothen the iterative process between designing and modeling, but speed depends heavily on the size of the study area.

2.5 Simulation

Once the model has been built, the designer can now run simulations as required and visualize the results within the Rhino/Grasshopper framework. The tool is designed specifically to allow maximum extensibility in terms of the different kinds of simulations that the user can run and the metrics that can be computed. The model has functionality to find the shortest path trip between two buildings or find a trip to the nearest amenity for a specific activity from an origin building. The tool also allows simulations to be run based on the characteristics of the people (personas) inside these buildings, like the list of activities that they want to do during a day. This can be expressed using a population model, which has a distribution of various personas. Using the above functionality, the tool provides some simulation components, but the authors recognize the need and room for more work and extensions in this section of the workflow.

2.6 Metrics

The initial release of Urbano ships with three basic mobility metrics: (1) It computes a building-specific modified version of the Walkscore[13], a popular walkability metric that gives a point score in the range of 0 to 100 based on the proximity to amenities such as grocery stores, restaurants, shops, banks, coffee shops, etc., and rewards higher street intersections and lower average block length. A decay function (Equation 1) is used to grade trips based on distance, with the score going down to 0 with increasing trip length. While this metric is initialized to consider a generic persona that has a certain set of amenity preferences and corresponding levels of importance, the tool allows the user to define persona specific sets of activities that one wants to compute the Walkscore for. Additionally, the tool allows the user to specify a distribution of different personas, and the final score is a weighted average of the scores for the different personas, based on the distribution. This allows a large amount of flexibility for the users as they can customize the score to the target market that they are working on. At the neighborhood-scale, a cumulative Walkscore for each building as well as a neighborhood average can be calculated to represent the overall condition of the design.

$$\begin{aligned} Decay(x) = \; & -17.15x^5 + 89.45x^4 - 126.37x^3 \\ & + 4.639x^2 + 7.58x + 99.5 \end{aligned}$$

Equation 1. Decay function for the Walkscore implementation

(2) The Walkscore was developed to evaluate the walkability of neighborhoods in the context of static preexisting networks, and its application in a design process requires some thought. It is easy to increase the Walkscore arbitrarily by adding more amenities to the neighborhood, but there is both a cost of adding these amenities and the question of whether there is enough user demand to sustain these amenities. The more amenities the designer adds of a certain type, the lower the demand will be for each of them and leads to the question of economic viability as the customer base thins out. To measure such effects, we introduce an Amenityscore for each amenity that computes the overall demand it should expect given the personas in the population. During the Walkscore simulations, each trip that is made from a building to an amenity carries with it a specific population, which is determined by the population size in the building as well as the distribution of personas. These trips are used to determine how many people visit an amenity during the simulation process. A way to interpret these counts is to weigh them against a target value of a desired occupancy. Default people densities can be derived for each building and amenity type by using architectural standards [22] [23] as well as architectural handbooks [24] or building /fire codes. These density values are then used to calculate maximum or desired occupancy for different amenity types based on floor area which could further be used to determine how much the demand for the amenity differs from the baseline numbers computed from the standards. This could indicate either excess demand or supply of the amenity type. This counter-balancing metric deters the designer from adding too many amenities to the design to drive up the Walkscore.

(3) The third metric is a measure of how many people use each street, which is also computed during the same simulations. This allows the designer to measure the pedestrian utilization of each street, which is important to know when deciding on things like sidewalk width, where to put pedestrian crosswalks and even consider pedestrian only streets. The computation time needed to perform these simulations depends heavily on number of buildings, personas and amenities.

2.7 Case Study Description

We show four case studies to demonstrate the workflow and effectiveness of the tool that we have developed. The first case study conducts a high-level comparison of two neighborhoods in New York City to establish a benchmark for the Walkscore metric: The study areas (1) Manhattan Columbus Circle and (2) an outtake of Queens is shown in Figure 4. The two neighborhoods differ in density, block size and distribution of amenities. Data from NYC Open Data GIS database as well as Google Places API was imported to produce the models. In both cases the persona is querying amenities of the following type:

$$\begin{gathered} Restaurant,\ Coffee(x2),\ Park,\ Shopping, \\ Entertainment,\ School,\ Grocery,\ Bar,\ Subway. \end{gathered}$$

Table 1 provides an overview of all elements in the model and the resulting neighborhood scores.

Figure 4. Neighborhoods for case study. a) Manhattan b) Queens

Table 1. Summary of the neighborhood model components

Objects in Model	**Manhattan:**	**Queens:**
Buildings	679	608
Streets	156	83
Amenities	987	55
Neighborhood Walkscore	**95.7%**	**41.8%**

In the second case study we analyze a region around the Eiffel Tower in Paris that consists of 4,170 buildings and 815 streets (Figure 5). We query the model with two different personas to showcase a potential use case of the personalized Walkscore. Persona A travels to {*school, library, café (x2), fast-food (x3)*} amenities while B looks for {*restaurant (x2), bar (x2), bank, cinema*} amenities. In addition, the persona's street utilization is calculated using the above mentioned Streetscore.

The third study presents an urban design use case that investigates the impact of a mixed used development in an area where amenities are scarce. The site model contains 34,556 buildings and a street network of around 3,070 segments. The as is condition is shown in Figure 6. The new development is given in Figure 7. The site is located near a highway that limits accessibility across it. Further, a footbridge is inserted to improve site accessibility. Both building level Walkscore and Streetscore are computed to show the effects of these changes.

In the fourth study we demonstrate how the Amenityscore can be used to find a promising location for a new cafe within the model of the urban design use case shown in Figure 6. Four locations are compared and are labeled A, B, C, D.

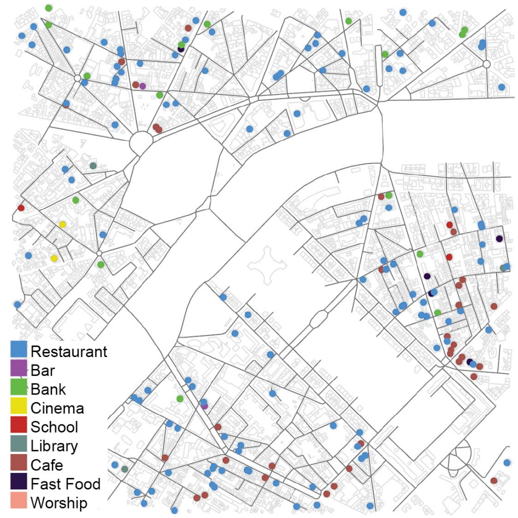

Figure 5. Paris case showing distribution of amenities

Figure 6. Urban design case showing distribution of amenities

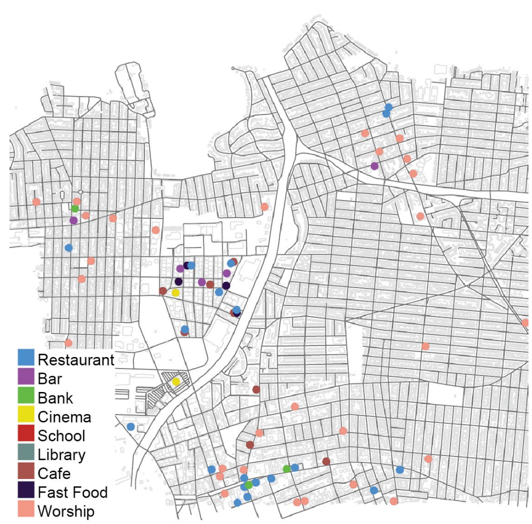

Figure 7. New mixed-use development and its amenities

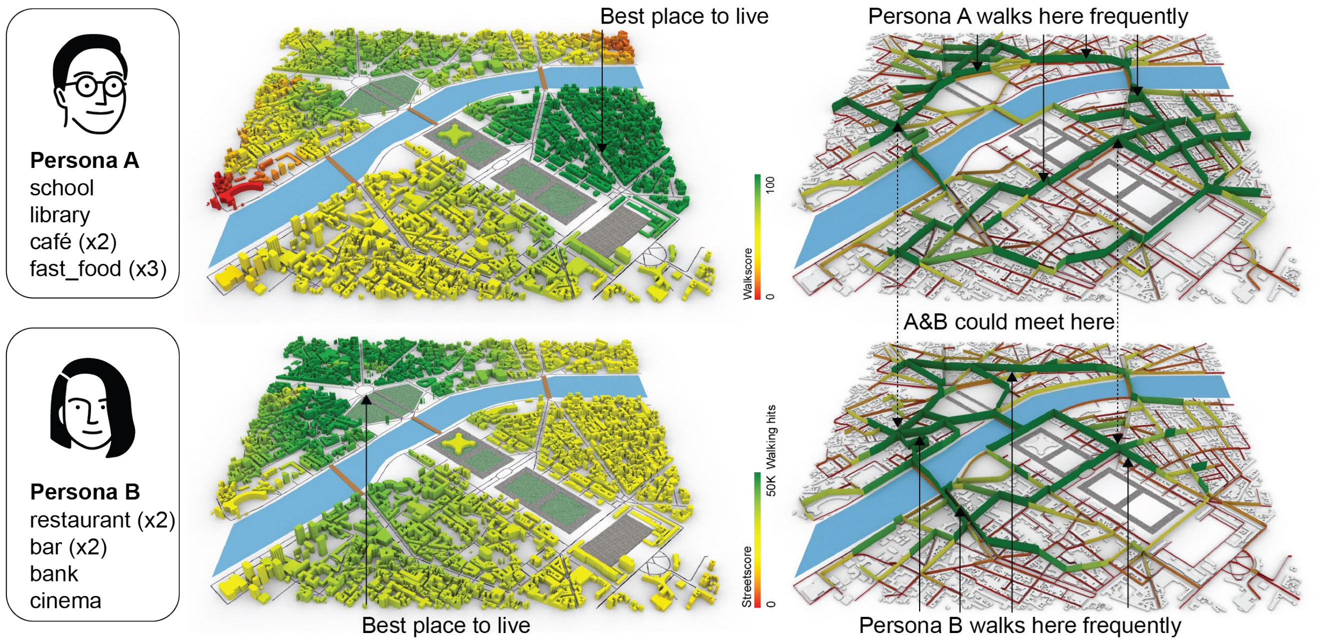

Figure 8. Personalized Walkscore and resulting street utilization

3 RESULTS

Table 1 summarizes the high-level comparison between the Manhattan and Queens based neighborhoods. The Manhattan neighborhood is dense and has a good distribution and quantity of amenities resulting in an average Walkscore of 95.7. The Queens neighborhood has a lower density and has a limited number of amenities yielding a lower average score of 41.8.

Results of the personalized persona study are shown in Figure 8. While both analyses were run on the same model the results differ given the different interest in amenities described in a persona. Persona A would ideally be at home in the mid-eastern region of the map. Persona B would most efficiently reach the desired amenities in the north-western corner of the map. The Streetscore results are shown on the right-hand side of the figure. Utilization rates for the streets would also be different for each persona. However, overlaps exist in arteries and important nodes.

The urban design use case is shown in Figure 9. The upper part shows the current condition of the neighborhood with a north-western region that is underserved with amenities and encircled by a motorway and water. Three overpasses exist in the model and the two southern ones are utilized more frequently as they connect to an area with a cluster of amenities in the south. Along the motorway a hypothetical mixed-use development is inserted. The mixed-use infill significantly boosts the Walkscore in the north-western and southern region, however, has no effect on the area across the motorway. The addition of an additional overpass significantly extends the catchment area of the newly introduced amenities.

Table 2 shows the number of hits received by a newly inserted café at the four different locations labeled A, B, C and D in Figure 6. Location B receives the most hits out of the four locations. While there are no other cafes around Location A, it is placed in a corner of the study area and isn't accessible from the region on the left of the highway. Thus, it receives hits only from the small region around it bounded by the motorways, and some customers from the extended region below the motorway. Location D has similar issues in terms of extended accessibility to regions beyond the island it is on. Location C is an area where there are already existing cafes which causes the hits to get distributed amongst the various cafes. Location B is positioned so that there are no other cafes around to take away hits. Further, it is centrally located to allow maximum accessibility in all directions.

Table 2. Amenity analysis. Hits per analysis for a café that is placed in different locations in Figure 6

A	B	C	D
102161	157628	90605	88776

4 DISCUSSION AND CONCLUSION

The immediate value of the Urbano toolbox is that it provides architects, planners, geographers and other scholars of the built environment an opportunity to measure active transportation indicators such as Walkscore and access analysis for amenities and public transport such as the proposed Amenityscore on spatial networks which currently is prohibitively labor intensive without computers and accessible software. The presented tool operates in the widely popular CAD environment Rhino3d, that the targeted user group is already familiar with. This facilitates tool adoption and significantly lowers barriers of entry for non-specialized urban designers and planners. Applications for network analysis measures and mobility aware urban design tools offered in the toolbox are rapidly growing with the increasing availability of geospatial data and improvements in computational power. Such measures allow one to investigate how urban form, program and people allocation as well as activity patterns are interrelated and in combination can become a significant part of urban life.

The results computed by the Walkscore, Amenityscore and Streetscore are intuitive and easy to understand since they are in direct relationship with the density and distribution of amenities as well as the connectivity within the network. While the neighborhood scale results presented in Table 1, where an abundance of amenities leads to high Walkscore are hardly a surprise for an experienced urban designer, the other cases demonstrate the need for a tool that allows designers to explore the more complex interrelationships between urban network, availability and location of destinations/amenities as well as user preference that may differ substantially by demographic group. The ability to quantify these qualitative differences between preferences, neighborhoods or different design variations is of inherent value and enables one to make a more informed decision.

A critical reader might object and say that such “simple” metrics as they have been presented in the paper fall short in realistically depicting urban life since they are not taking into

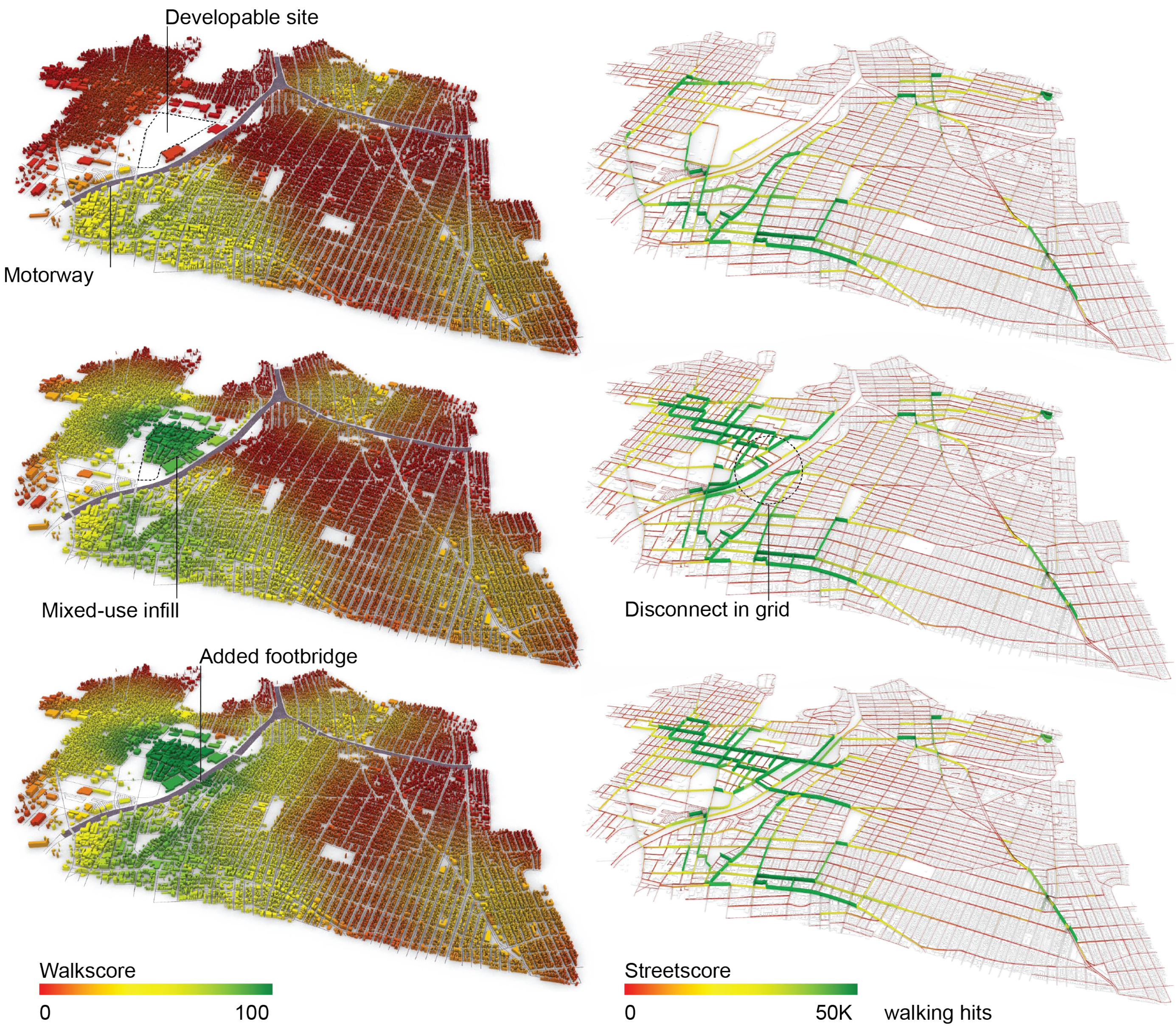

Figure 9: Design use case showing the impact of mixed-use development on surrounding neighborhoods

account other influential factors. Whether dwellers will choose to walk within a neighborhood is not only dependent on the distance to amenities but also on other factors such as outdoor thermal comfort, exposure to pollution and safety. Further, a pedestrian might not always walk the shortest route but instead might select a path according to other parameters such as shade, sun, number of other people as well as attractiveness of amenities. While methodologies to quantify street quality exist [21] that could potentially bias route selection exist, further research regarding validity and applicability needs to be undertaken for a generalized implementation in an urban mobility tool. However, it is important to mention that the proposed tool allows the user to override the street length or street resistance in the network analysis. This enables users to do custom what-if studies that could incorporate biased route selection.

Hence, it is the authors' hope that the presented tool facilitates and promotes mobility-aware urban design to improve urban design proposals and their inherent active transportation potential.

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