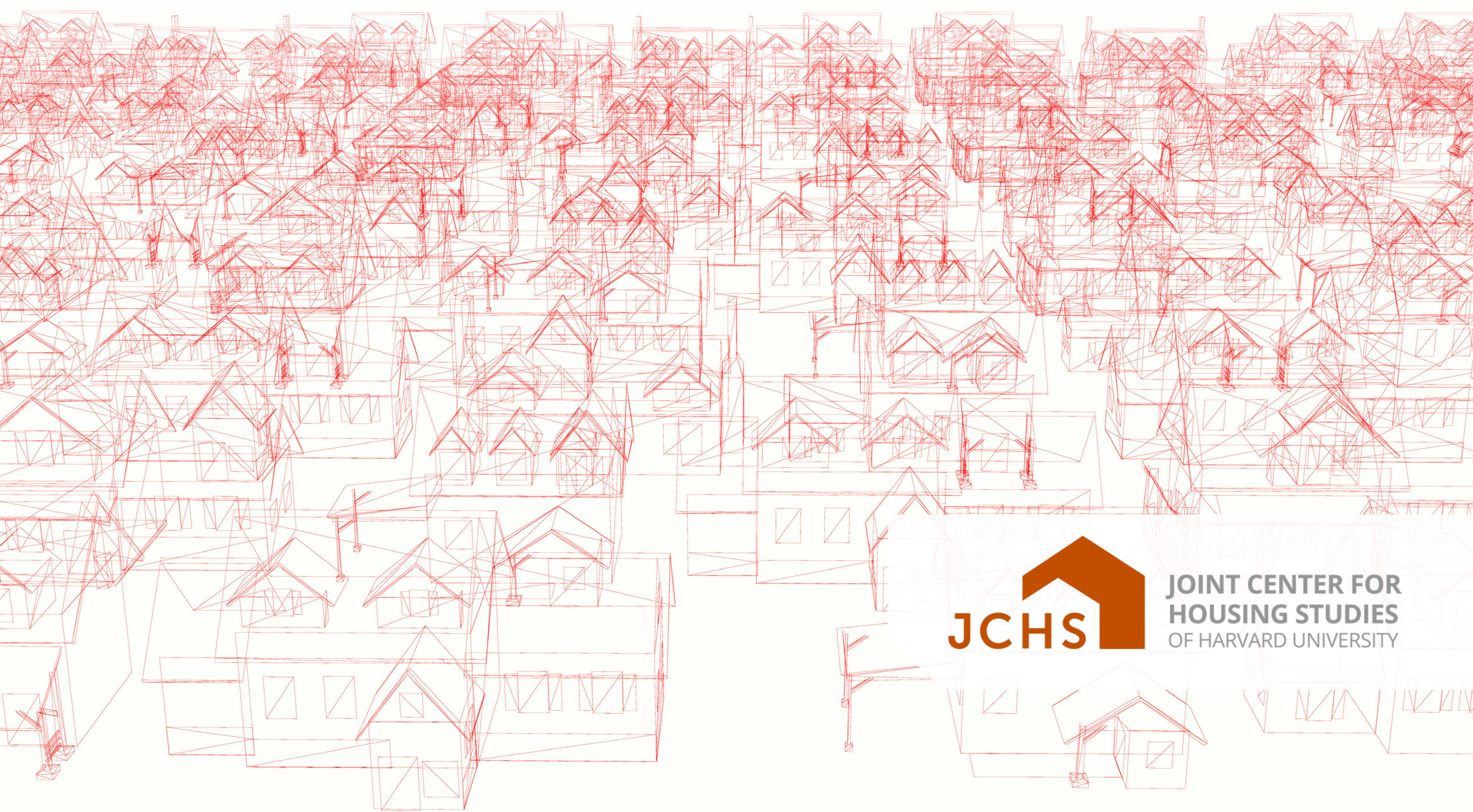
BRINGING DIGITALIZATION HOME SYMPOSIUM

Data-Driven Multi-Scale Planning for Housing Affordability

SEPTEMBER 2023 | PAUL WADDELL, AREZOO BESHARATI



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Data-Driven Multi-Scale Planning for Housing Affordability

Paul Waddell (University of California, Berkeley), Arezoo Besharati (UrbanSim)

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Introduction

Housing affordability was a chronic problem in many cities across North America and across the globe well before the global pandemic triggered an unprecedented surge in rents and prices. According to a survey conducted in October 2021 by the Pew Research Center, almost half (49 percent) of Americans responding indicated that housing affordability was a major problem in their local community, an increase of 10 percent since 2018. And it has only worsened since then, with interest rates doubling during 2022 as the Federal Reserve Bank tried to slow the pace of inflation.

In this paper, we explore the multiscale challenges of housing affordability and the need for coordinated efforts to undertake planning for meeting broad social goals of improving housing affordability within the United States and Canada. We focus on the Canadian context in this paper due to our ongoing engagement there and the emerging prospects of multilevel cooperation in implementing solutions. The overall objective of the paper is to explore how housing affordability as a broad challenge is beginning to reshape the information and analysis tools used for policy, planning, project design, and evaluation at every scale from the site to the nation. In the next section, we describe the current project to develop a nationwide data-driven planning strategy in Canada in partnership with the Canada Mortgage and Housing Corporation, followed by more detailed discussions of the data requirements and analytic components designed to support it.

Partnership with Canada Mortgage and Housing Corporation

The Canada Mortgage and Housing Corporation (CMHC) is a Canadian Crown corporation responsible to Parliament through a Minister and charged with addressing housing affordability in Canada. CMHC's stated objective is that "by 2030, everyone in Canada has a home they can afford and that meets their needs." CMHC uses the broadly used measure of less than 30 percent of pre-tax household income being spent on housing as the threshold for being affordable. It also captures in this goal a need to consider the size and type of housing when considering how well it meets the needs of diverse households. CMHC lists six activities through which it aims to achieve this ambitious goal:

- Canada's National Housing Strategy, a 10-year, $70+ billion plan;
- funds to create or improve rental units;
- mortgage loan insurance for buyers;
- data and research;
- development of First Nation housing;
- Creation of housing resources for newcomers (information in 8 languages on renting, buying, and getting a mortgage).

Within the data and research thrust, CMHC initiated a partnership with UrbanSim Inc. in late 2017 to begin building a data-driven planning platform to address housing affordability and related challenges across Canadian cities. The overarching objective of this initiative is to leverage data-driven planning technology to facilitate improved outcomes in meeting housing affordability goals through broader and more efficient coordination at multiple levels, including with:

- other federal entities such as Infrastructure Canada;
- provincial government entities such as Infrastructure Ontario, Ministry of Transportation Ontario, Ministry of Municipal Affairs and Housing in Ontario, and counterparts in other provinces;
- municipalities in each province and metropolitan area;
- academic scholars working on related research;
- non-profit housing developers;
- for-profit developers; and
- data providers and other stakeholders with interests in housing.

In short, the overarching goal is to achieve network effects that enable increasing the cumulative impact on challenges like housing affordability that can be effectively described as ”wicked problems.”

A Data-Driven Strategy

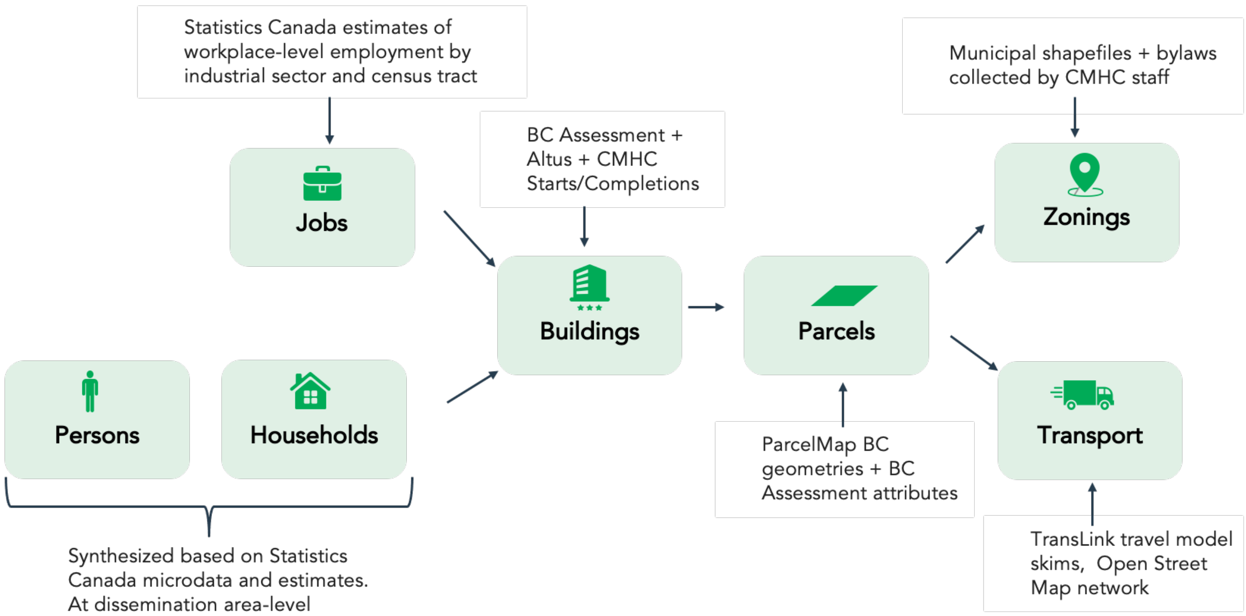
We turn next to the requirements for a coherent national data-driven planning strategy in Canada to analyze the factors influencing housing affordability, beginning with foundational data on parcels, buildings, and zoning. Data on land ownership and use, including boundaries and ownership and use attributes, sometimes referred to as the parcel fabric, is neither universally accessible nor standardized. Some provinces in Canada have embraced open data approaches and make parcel geometry and attributes readily available through interactive maps and downloadable files ready to load into a GIS platform. Other provinces, like Ontario, have privatized the parcel fabric, making access to it for planning purposes and research exceptionally difficult and expensive. The same pattern plays out in the US in varying degrees, though there appears to be more rapid movement towards open data accessible by download or application programming interfaces (APIs) among larger cities.

Besides parcel geometry and attributes, data is needed on the existing building stock and on new building projects in the pipeline. While CMHC maintains a database on housing starts, there is still remarkably sparse data on the details of development projects in the early stages of planning and approval and no unified way to track development proposals through the review and approvals process. Finally, zoning and other land use plans present an exceptionally difficult challenge to integrate into a data-driven planning approach. It is ironic to describe zoning as being extremely standardized: in fact, every city has its own standard. A single zoning label can mean something different in each municipality, and the specific measures used vary tremendously: they can range from restricting allowed uses; to regulating building massing through form-based codes; to idiosyncratic constraints on building height, setback requirements, floor area ratios, units per acre, lot coverage, parking requirements, unit mix requirements; inclusionary zoning for affordable units; minimum lot sizes for single family units; restrictions on accessory dwelling units; design standards such as angular planes (protect nearby sites from overshadowing); and more – all vary city by city.

Further complicating zoning is that base zoning is often overridden by one or more levels of overlay districts such as secondary plans that may relax or further constrain development in nuanced ways. And the level of digitization of the data and its accessibility varies even more than is the case for parcel data. One would be fortunate to find an interactive map of zoning and a corresponding PDF document containing the detailed bylaws that provide the basis for inferring what can be built on a parcel. Even in the best of these cases, there are broad gaps where the zoning is unspecified. We have yet to encounter a city that digitizes its zoning in a way that is analytically usable to determine what can be built on a site – consolidating information and logic from the base zoning and any overlays that amend it.

Making matters yet worse, in many cases, the zoning on the books is often out of sync with the projects that get approved and built. It is not unusual in Canadian cities to see projects that far exceed the zoning constraints get approved and constructed. This could arise because the zoning has not been updated, or in some cases, it may provide negotiating leverage during the extensive review and approval process. In contrast, there are many cities in the US and in Canada that need economic development and will quickly approve almost any development proposal brought by a developer. The state of zoning and land use plan digitization to support more data-driven planning is, in short, a complicated mess.
The project began with the assimilation of data from numerous sources for the purpose of developing a realistic simulation model of the real estate market in the Vancouver metropolitan area. Figure 1 summarizes the sources of core datasets integrated into the data system to support this model development effort, with collaboration from multiple federal, provincial and municipal entities as well as private sector data. The data development process included generating a synthetic representation of all households and persons within the metropolitan areas [1].

Figure 1: Sources for Core Datasets Assembled for Vancouver Parcel-level Model System



Following the initial development of the Vancouver region parcel-level model, the project was extended to the Greater Golden Horseshoe (GGH) region that includes Toronto. Due to much more limited access to parcel-level data in Ontario, the data system and models for this region initially used Statistics Canada census geographies called dissemination areas (DAs) as the smallest unit of analysis. Eventually, to support more fine-grained analysis, parcel-level data from the City of Toronto was integrated into the GGH model. These models represent digital twins of the real estate markets and built environments in each metropolitan area. The simulation models and harmonized data on which they operate provide the foundation for a data-driven planning infrastructure for urban development in Canadian cities and metropolitan regions.

Complementing the nationwide model development activity for multiple metropolitan areas, UrbanSim has also been developing tools to facilitate site-scale multi-family housing development feasibility and has been testing this tool with CMHC partners such as Infrastructure Ontario, HousingNowTO, Habitat for Humanity, and municipalities like Halton Hills. Both of these initiatives are aimed at helping CMHC and other stakeholders gain new insights into how macroeconomic and credit conditions interact with development regulations and infrastructure investments to influence the supply of housing and its effects on housing affordability.

Data-driven models can inform regional planning, urban policy making, and the local decisions of businesses and citizens. Having spatially detailed models of the real estate markets in metropolitan areas across Canada can expedite and strengthen the ability of governments, businesses, and citizens nationwide to make informed decisions in an ever-changing urban environment. This project's goal is to develop data-driven decision support planning tools for every metro area in the country to help actors in urban areas to better plan for the future and forecast possible consequences of their decisions. In order to achieve this goal, the data supporting the project needs to be timely and sufficiently detailed and accurate, and the analysis of these data needs to be sufficiently accurate and policy sensitive.

Aside from forecasting and analysis capabilities, local data extracted from the national model building initiative is useful in its own right. Many urban planners operate in a context where they need to collect their own data and do their own data processing, work that is often manual and time consuming. Limited access to analysis-ready datasets hinders local policymakers in their effort to make informed choices, especially in contexts where urban dynamics are evolving quickly. Small-area data and longitudinal data are often especially lacking or contain gaps. The nationwide urban models are paired with a national data viewer that can help increase local data access. National data also benefits smaller metropolitan areas from a model development point of view, in the sense that models derived from national data and cities nationwide can be fine-tuned on local slices of data. Fitting models on local data alone can be challenging in less populous areas due to sparsity and small sample sizes. But reasonable urban behavioral parameters can be learned based on large national datasets; then, the nationally fit urban models can be tuned in light of observed local dynamics in smaller metro areas to quickly adapt the large-data model to a local context where data size is more limited. Modern urban models can be data hungry, but this project's focus on nationwide data enhances the model development prospects of smaller cities.

The Canadian urban models reflect the latest generation in urban simulation methodology, incorporating advancements in machine learning (ML) and cloud computing to provide a scalable tool for urban forecasting and scenario analysis. The models are built using a combination of statistical and ML techniques.

A Policy-Analytic Urban Model System

A key motivation for developing such a model system is that the urban environment is complex enough that it is not feasible to anticipate the effects of alternative courses of action without some form of analysis that reflects the cause-and-effect interactions that could have both intended and possibly unintended consequences. Alain Bertaud [2] advanced a similar thesis that urban planning should be better informed by understanding the interaction of markets and planning. UrbanSim was designed to attempt to reflect the interdependencies in dynamic urban systems. See [3] for additional background on the model system.

The model system is composed as a set of interacting submodels. All submodels operate as microsimulation models that update the state of individual agents and objects: households, jobs, and units. The state of the simulation is updated by each submodel, and results are tracked in annual steps from the base year of 2006 that the model uses as its initial year to the forecast year that is simulated to.

Fitting the parameters of the DA-level UrbanSim models involves both cross-sectional and longitudinal data. First, a specification is posited; then, the parameters are fit to cross-sectional data from the 2006 model base year. Next, parameters are fine-tuned (i.e., calibrated) on longitudinal data from the 2006-2016 period to ensure that the model can approximate observed geographic patterns of change over time.

Household location choice model explanatory variable categories include:

- price and/or direct measures of housing affordability;
- residential unit characteristics (e.g., year built);
- neighborhood characteristics;
- local and regional accessibility.

Employment location choice model explanatory variables include:

- non-residential price;
- non-residential supply characteristics;
- agglomeration/clustering (e.g., number of jobs within same sector within one km);
- neighborhood characteristics;
- local and regional accessibility;
- If retail-sector, population-seeking variables.

The model systems are simulated from the 2006 base-year to 2016, and then comparisons are made between simulated outcomes and observed outcomes in the 2006-2016 period. This helps to evaluate the model's ability to replicate observed patterns of urban change over time. Figures 2 and 3 show draft comparisons between simulated and observed outcomes along the employment, residential unit, and household dimensions.

Figure 2: Scatter Plots of Simulated vs. Observed Growth Shares by GGH CSD, 2006–2016

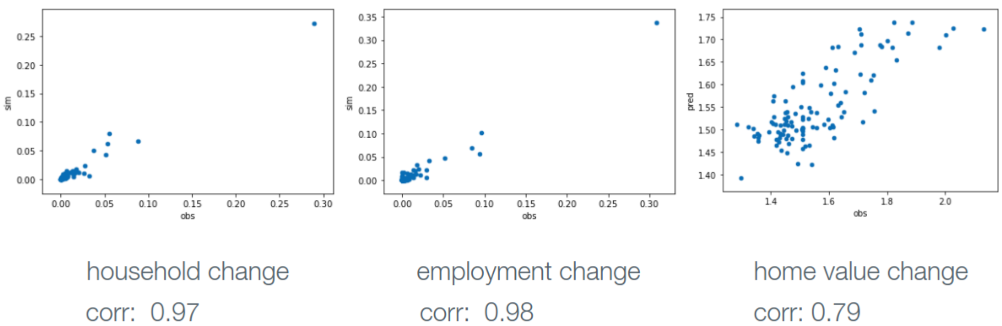
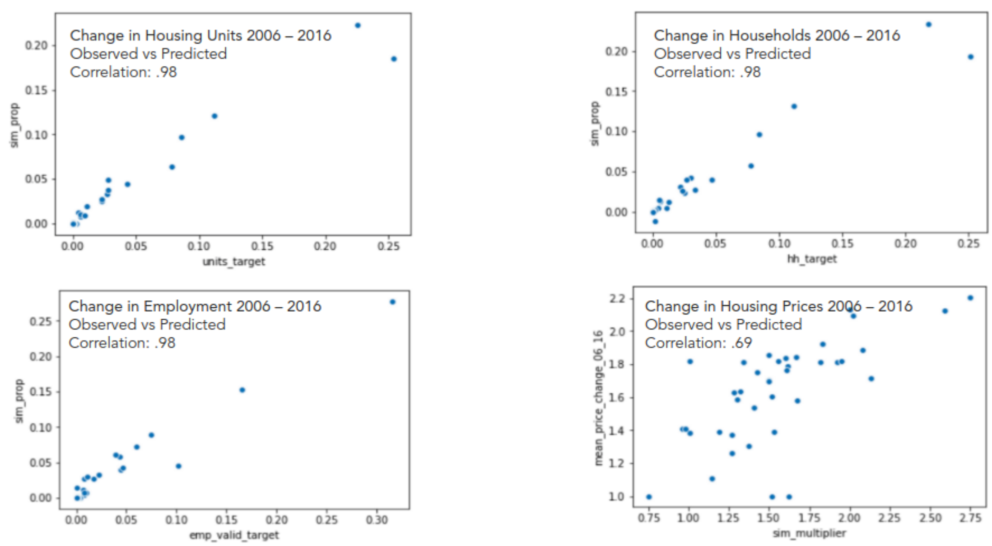


Figure 3: Scatter Plots of Simulated vs. Observed Growth Shares by Vancouver CSD, 2006–2016



Bessarion Station Area Case Study

A web-browser interface to the model system was created to improve accessibility and usability of the modeling suite and to make it much easier to create the scenarios being considered and to evaluate scenario simulation results. The user can create a new scenario or edit saved scenarios. An UrbanSim scenario is a set of land-use and transportation policies and other assumptions such as demographic and economic growth, which can be simulated over a forecasting period to understand their impact on a set of key housing, transportation, and socioeconomic indicators.

To create these scenarios, the user can edit several levers, in other words, the variables which can be flexed to generate these sets of assumptions. The currently available levers which can be shifted include:

- Residential capacity (i.e., changing the zoning regulations), by shifting the following types of levers:
- Maximum floor area ratio (i.e., the relationship between the building's floor area and the size of the lot/parcel that the building is located on)
- Maximum dwelling units per acre
- Maximum building height
- Employment capacity (i. e. , changing the zoning regulations)
- Household growth
- Travel accessibility
- Effects of constructing new metro station or line

Moreover, UrbanSim allows users to choose the geographies impacted by the levers. These can be applied at the DA level as well as to Toronto parcels (for instance, parcels within a buffer distance of a metro station or metro line).

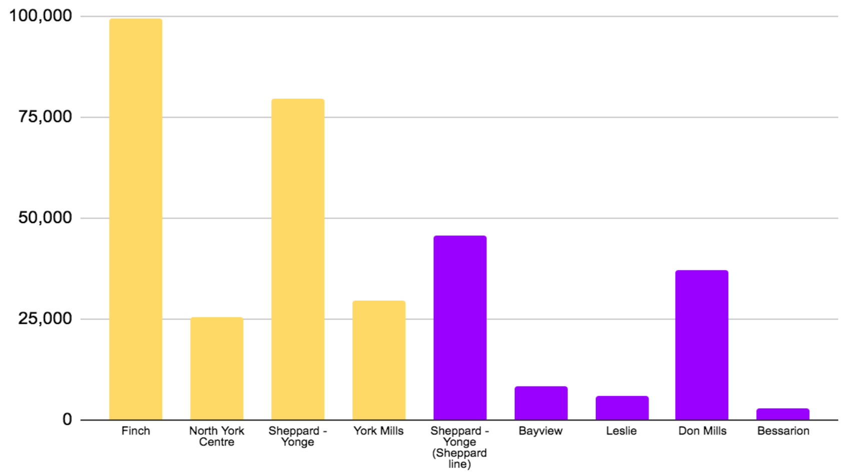
A case study using the Bessarion Station area is used to demonstrate the use of the model system to inform development policy. The Bessarion station is part of the Toronto Subway Sheppard line, which is operated by TTC (Toronto Transit Commission). The line is the newest in the system and serves the district of North York, a growing residential and commercial area north of Toronto (see Figure 4).

Figure 4: Toronto Subway Map

Source: TTC, 2021. Edited to highlight Bessarion.

As of 2018 Bessarion (rightmost bar in Figure 5) had the lowest ridership of all stations on the Sheppard line, and the had the third lowest ridership in the entire Toronto subway system.

Figure 5: Weekday Daily Passengers In and Out of North York's Stations in 2018



Source: UrbanSim Inc. from TTC data. Color depicts line as per Figure 4 (Toronto Subway Map).

Construction proposals for the Sheppard line date back to 1985 and faced several challenges over the years, including cost overruns. The Sheppard line runs 5.5 kilometers and contains 5 stations. It was constructed for just under $1 billion (Canadian dollars) over 8 years, opening in 2002 [4].
At the time Bessarion station opened, the surrounding area was principally zoned for single-family detached housing. However, changes in the Secondary Plans of the surrounding areas came into effect in 2016 [5], relaxing zoning constraints and allowing for higher density as well as mixed-use areas around the station, as illustrated in Figures 6-8.

Figure 6: Zoning Plan around Bessarion Station Prior to the 2016 Amendment

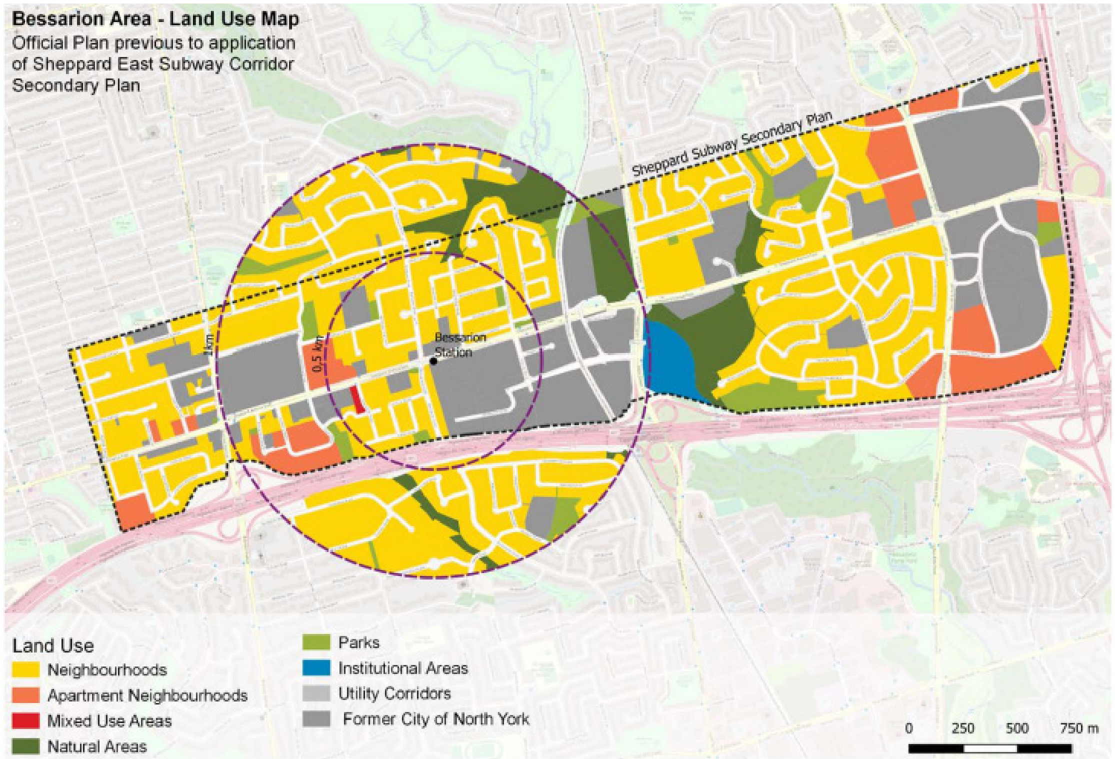


Figure 7: Zoning Plan around Bessarion Station After the 2016 Amendment

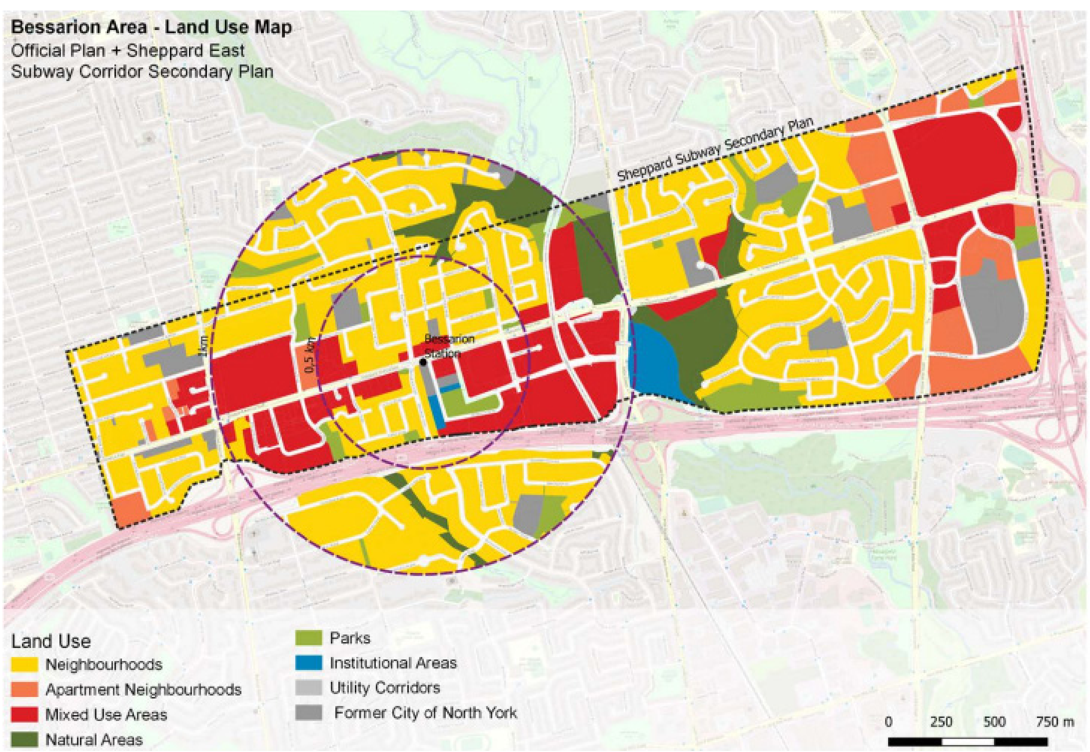
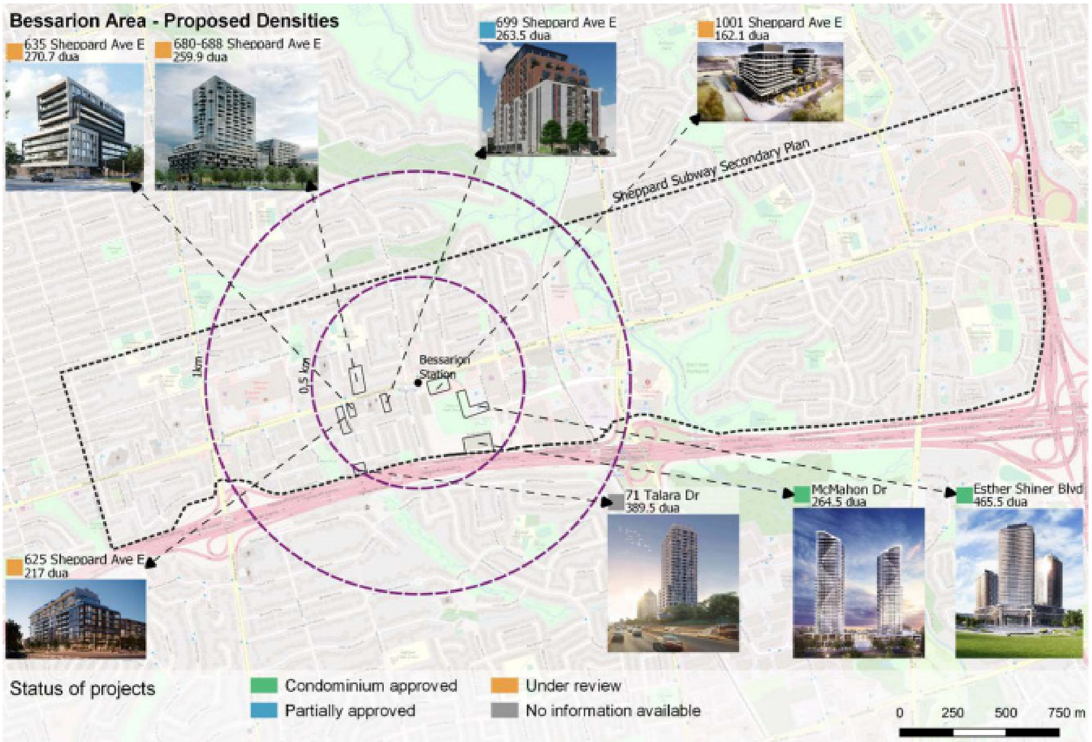


Figure 8: New High-Rise Developments around Bessarion Station



Since these changes, there has been a renewed interest in building transit-oriented schemes around the station, with several high-rise buildings already approved and many under review.

This proliferation of higher-density housing around the station would undoubtedly increase the potential addressable market of commuters served by Bessarion, hence, most likely increasing ridership. Moreover, the fact that development blossomed shortly after the change in zoning constraints indicates that the market conditions were adequate but the zoning system was too restrictive to let construction take place earlier.

This leads to the following questions: If upzoning had occurred much earlier, what would the current housing provision around Bessarion look like at present? What would it be like in the future? The levers present in UrbanSim allow us to design scenarios to explore these questions and visualize what the employment and housing provision in the area would have been in 2021 as well as the hypothetical market dynamics far into the future.

An UrbanSim scenario has been produced to investigate the effects of a hypothetical earlier upzone.

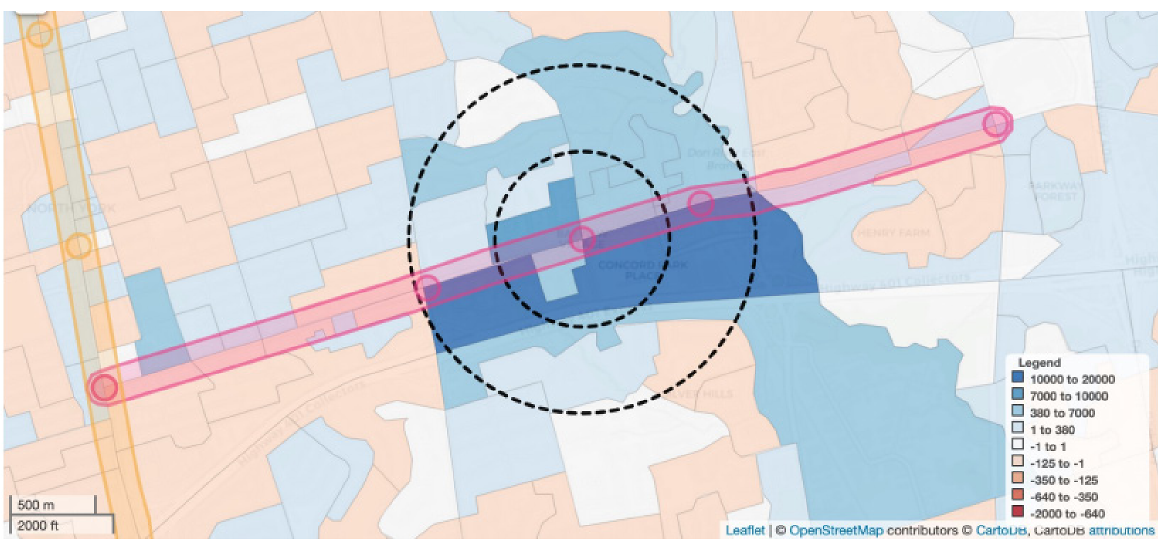
Scenario 1 - Bessarion Upzone from 2007

Table 1: Scenario Levers

Type	Lever	Geography
Residential	Max DUA = 150	Parcels within 1km of station
Residential	Max Height = 50	Parcels within 1km of station
Residential	Max FAR = 6	Parcels within 1km of station
Residential	Max DUA = 300	Parcels within 0.5km of station
Residential	Max Height = 100	Parcels within 0.5km of station
Residential	Max FAR = 12	Parcels within 0.5 km of station

Figure 9 shows the change in housing units, in 2045, by DA. The two circles correspond to the 0.5 km and 1km buffer zones used as reference for the levers. The pink and yellow lines correspond to the Sheppard and Yonge-University lines, respectively. Every circle designates a station along the line.

Figure 9: Change in Housing Units between Baseline and Scenario 1, by DA, 2045



As shown in the Table 2, the change in housing stock in the vicinity of Bessarion would be drastically different from the baseline scenario – almost 30,000 extra housing units by 2021 and 85,000 by 2045. Note that infrastructure capacity such as water and sewer has not been accounted for in these results – this is of interest in the further development of the model system.

Table 2: Summary of Scenario Results, by Year

Indicator	Year	Geography	Change
Housing units	2021	Affected DAs	27,000
Housing units	2045	Affected DAs	85,000

In order to help visualize the impact of these upzoning hypotheses, Figures 10 and 11 offer a comparison between the current layout of the residential units near the station as well as a representation, using UrbanSim's building generation tool, of what the resulting residential density would look like.

Figure 10: Current Housing Stock around Bessarion Station

Figure 11: UrbanSim's Approximate Representation of the Scenario's Resulting Housing Provision

Site Scale Development Feasibility

As noted at the outset of this paper, the problems of housing affordability require addressing multiple scales of analysis and planning. While the preceding analysis supports broad-brush analysis of policies such as upzoning around transit stations or allowing missing-middle housing at modest densities ranging from duplex to four-story neighborhood-scale multi-family development, it does not provide sufficient detail of analysis to support site-scale development planning and analysis. To address this scale, the specific circumstances of parcels matter. The shape and location and zoning on those sites matter. And the analysis of what can be built on a site requires two stages of analysis. The first is the testfit phase of the consideration of a development site, in which architects examine the size and shape of the site, its zoning, its surrounding context, and the desired building program, and then design a building form that attempts to meet the requirements of the desired building program while respecting the zoning constraints – unless they are asked to consider variances from the current zoning that might be negotiated with the city by the developer. This phase of analysis could be considered the regulatory feasibility stage. Architects use their expert knowledge and design skills to draft a rough massing and floorplan layout to determine the yield the site could generate in terms of units by size and bedroom count.

Once a testfit iteration has been completed on a site, a financial analyst takes the outputs from the testfit and enters the details along with other financial assumptions – such as the site acquisition cost, site remediation or demolition costs, construction costs, financing costs, equity investment, and expected revenues from leasing or selling the resulting project along with operating costs – to generate a discounted cash flow analysis commonly referred to as a proforma model. This financial analysis will generate insight into the financial viability of the project. If it is a 100% affordable housing project at below-market rent that is being considered on public land, the goal is not likely to be maximizing profit but rather maximizing the leverage of public investment on the production of affordable units targeted at specific household types and income levels. For-profit projects would attempt to maximize the return on investment while meeting local requirements, such as a minimum percentage of two or more bedroom units. And other projects would involve inclusionary zoning requirements to assign a certain percentage of the units built to below-market rent levels at a target percentage of area median income (in the US) or percentage of area median rent (in Canada). In the US context, projects might generate Low Income Housing Tax Credit (LIHTC) that would be also considered in the financial modeling.

Once the financial analysis is completed on a testfit, the results might indicate that the project is not viable financially or is, at least, not a very efficient use of scarce capital resources. The result might be so deficient that the project analysis ends immediately at this step. Or it might be close enough to viable that the testfit analysis is revisited with somewhat modified assumptions – such as changing the unit mix, the mix of affordable units, parking requirements, relaxing the zoned density if a density bonus might be negotiated, or any number of other changes. This triggers another iteration of the testfit analysis and another iteration of the financial analysis. Each of these iterations could take weeks. If the project is at a stage of requiring community input, each iteration could take far longer.

To address the complex requirements of this iterative testfit and proforma analysis that enables the design of projects on specific sites in ways that meet development objectives while respecting constraints, a combination of 3D building generative design algorithms and financial modeling algorithms is needed. We implemented a constrained optimization layout generator that uses an iterative approach to lay out corridors, units, and other space requirements in ways that respect the parcel geometry and zoning constraints; these include required setbacks on each side, floor area ratio and unit density constraints, height restrictions, lot coverage restrictions and parking requirements. It also must satisfy building code requirements for external light, open space, stair and elevator access, minimum widths for corridors, and others. Then, a user-provided building program is evaluated, with the optimization attempting to maximize the unit count while approaching the unit mix that the user has specified. It requires hundreds or even thousands of iterations to find floor layouts that satisfy all the requirements and maximize unit counts while closely matching the unit mix. Once the iterations are complete, the algorithm stores the building geometry and substantial metadata for that building option. This entire process generally requires only a few seconds of computer time to complete.

The pro forma analysis algorithm is designed to automatically draw on the unit count, residential square footage, and gross square footage of the building generated by the layout algorithm. While the pro forma analysis accommodates operating-period assumptions and funding sources that are specific to affordable housing development, it can also be used to evaluate market-rate or mixed-income developments. The pro forma analysis input form includes development costs, operating period assumptions, and sources of funds.

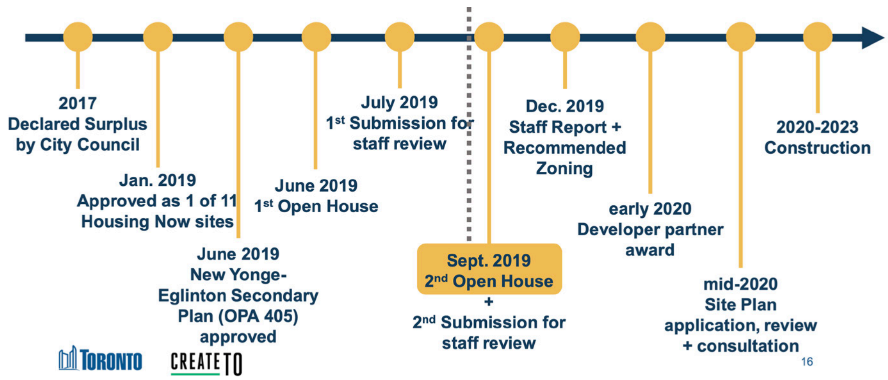
We have been testing this site feasibility tool with users in the US and Canada. One example of its application is included here as a case study, also in the Toronto context.

HousingNowTO in Toronto

The City of Toronto launched the HousingNowTO, a housing advocacy organization in Toronto, as an initiative in 2019, part of a multifaceted approach to address a full spectrum of housing issues in Toronto. This program spearheads the development of housing supply in mixed income, mixed use, and transit-oriented neighborhoods. Out of the estimated 12,350 units that will be added to the housing supply, approximately 4,920 will be developed into purpose-built, affordable rental homes. HousingNowTO, was created to demonstrate how housing can be built in unexpected places, propose viable development plans for the housing supply target set forth by their mandate, and achieve the vision of housing affordability imagined by the City of Toronto.

However, the process of designating sites and approving projects to be constructed is still relatively complex and lengthy. For example, 140 Merton is one of the sites which was designated for development in 2017, and construction is only now underway, with expected completion of an eighteen-story building in 2023 (see Figure 12).

Figure 12: Timeline for One 140 Merton Site Designated for Development by HousingNow



CMHC encouraged engagement with the Toronto housing process, and we collaborated with HousingNowTO to assist in evaluating alternative sites. One of those sites is described here as a case study to illustrate the complexities of local zoning regulations and permitting processes and how computational tools can be used to inform the planning process. The site is 405 Sherbourne Street in Toronto, which was a parking lot in 2020 (Figure 13).

Figure 13: 405 Sherbourne Street in 2020

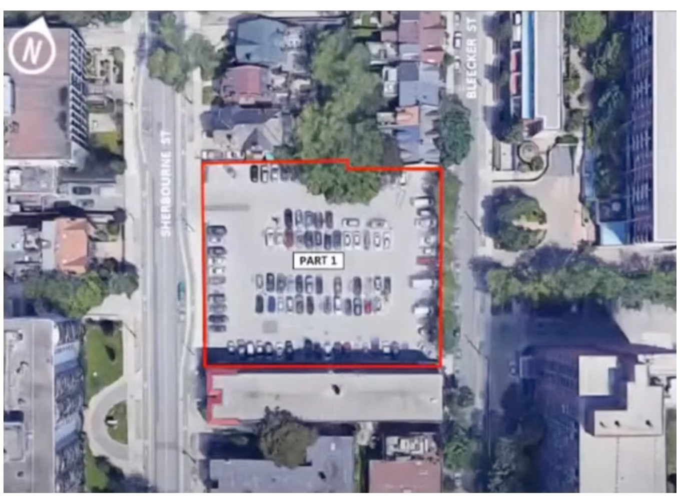
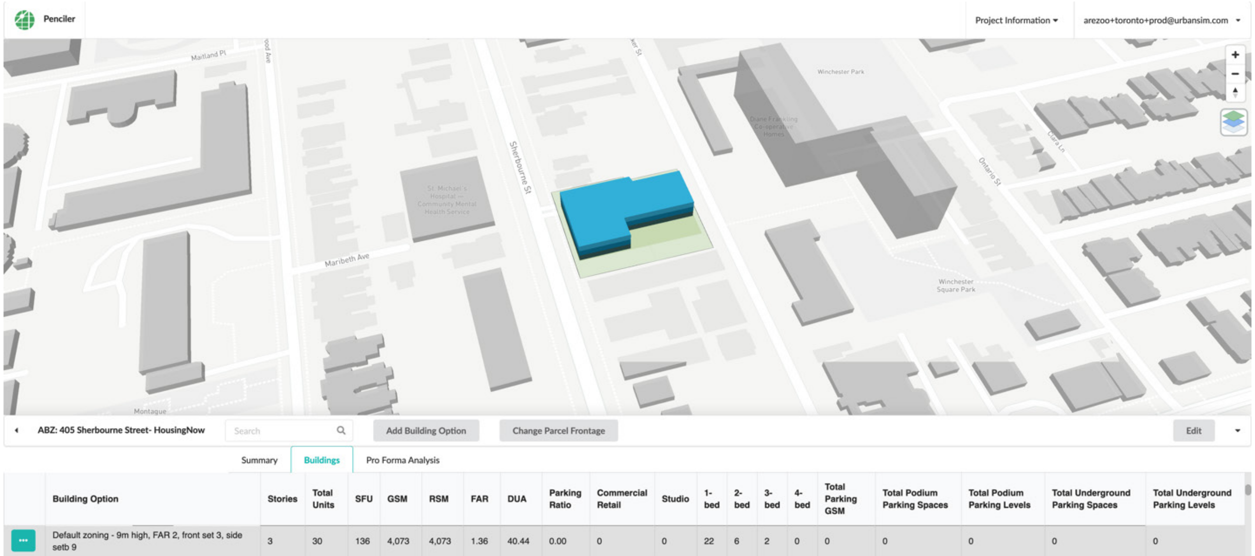


Figure 14 shows that the default zoning on the site only allowed three-story development, and it would not have been financially viable under current construction costs.

Figure 14: A Building Option Using Default Zoning on 405 Sherbourne Street



HousingNowTO collaborated in using our feasibility tool to assess several more-intense development options on this site, to engage with the city in altering the discussions about the density that should be considered on the site. After generating several options at mid-to-higher densities, up to twenty-seven stories, HousingNowTO provided proposals to the city for consideration, even before the city released its initial proposal on the site. Following consideration of the options generated by our tool, the city released an initial development proposal that was twenty-two stories and 216 units, of which half were affordable. After further experimentation with our tool and sharing the results with the city, the site was ultimately approved for twenty-five stories and 266 units, half of which were affordable (see Figure 15).

This was very close to the scale of development our tool had identified as being feasible on the site. While the exact building form and floorplan layout were not precisely what the city would ultimately approve, the tool enabled rapid iteration in the identification of the number of units of different unit types and levels of affordability that could be built on the site, under alternative assumptions on the zoning constraints being modified. It served that purpose and was a useful component in convincing the city to consider higher density options than planners had previously considered (see Figures 16 and 17).

Figure 15: A Twenty-Four Story Building Option on 405 Sherbourne with 277 units

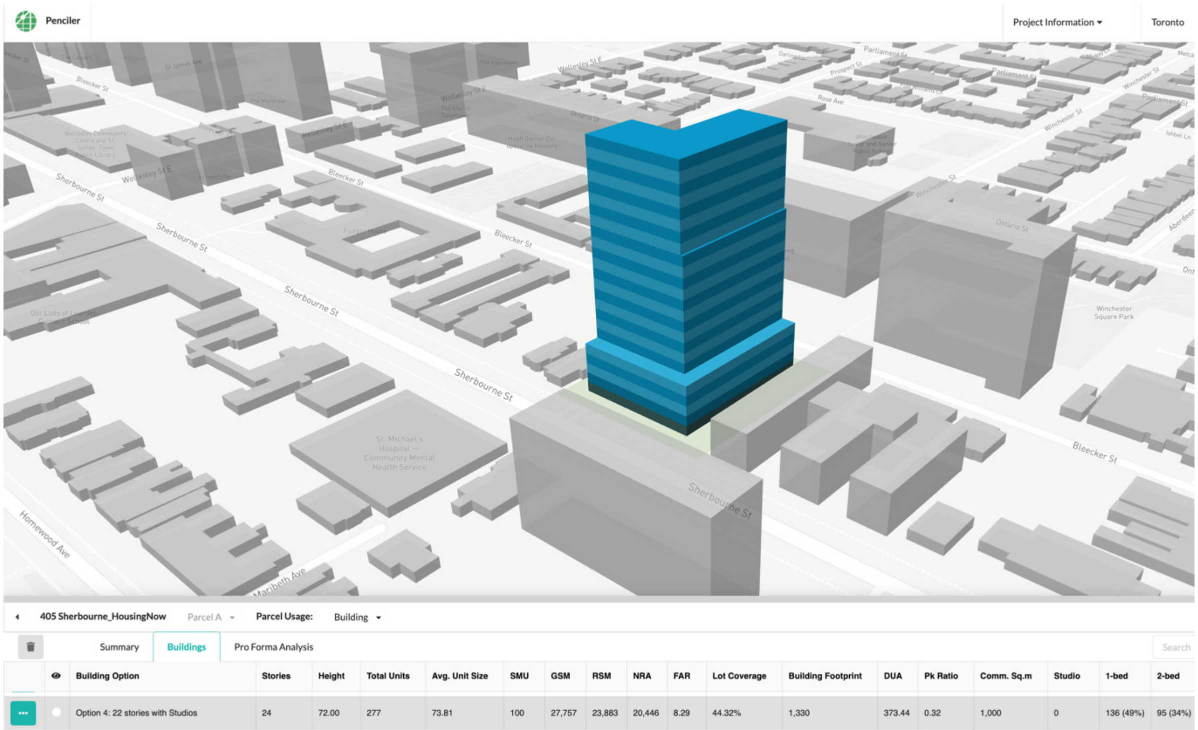


Figure 16: The Floorplans Generated for the Twenty-Four-Story Option on 405 Sherbourne

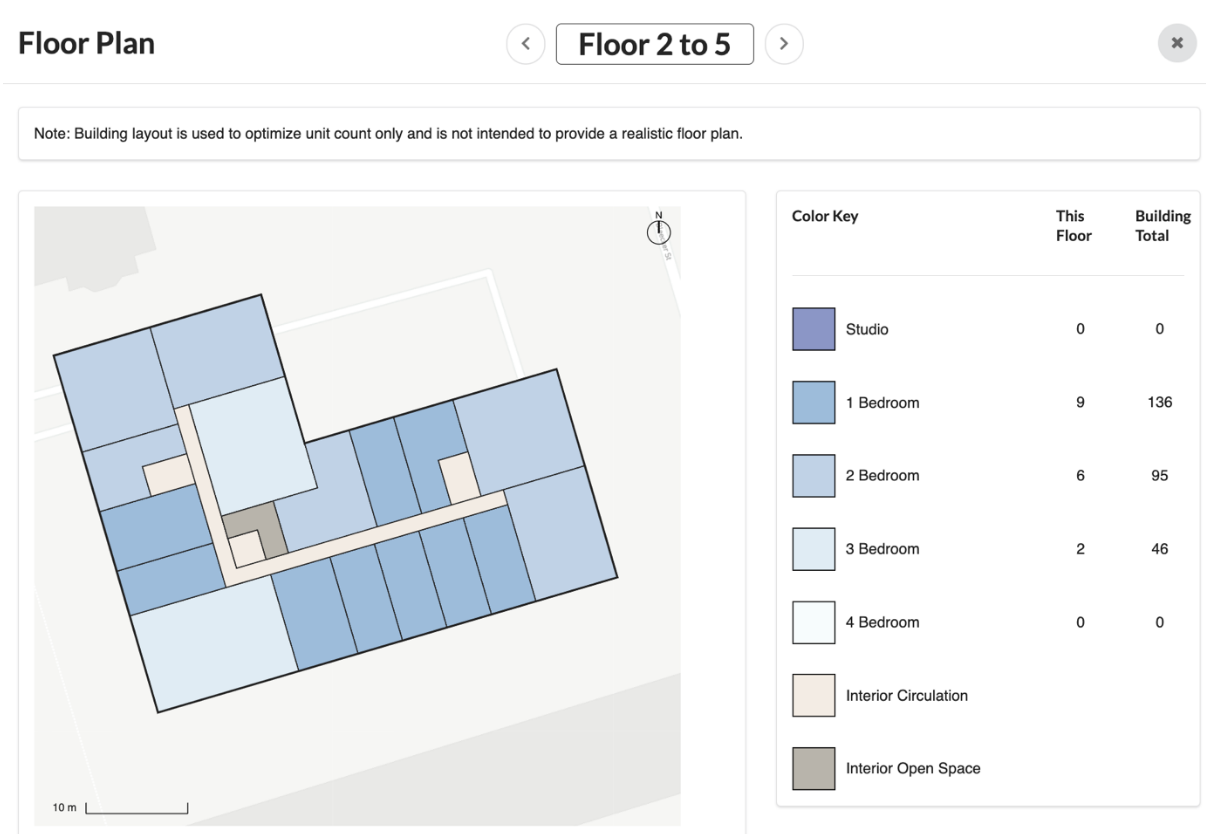


Figure 17: Final Proposal from the City on 405 Sherbourne, with Twenty-Five Stories, 266 units

In Conclusion

We have presented a description of a nationwide effort in Canada to use digitalization to advance the cause of addressing the housing affordability crisis plaguing its largest metro areas. Using novel techniques to integrate and synthesize data from municipal to national levels, and then leveraging a variety of simulation, machine learning, and optimization tools that have emerged in recent years, we demonstrate how these data and analytical tools can be combined to analyze housing affordability impacts of local zoning policies. Merging the best attributes of behavioral and statistical modeling with machine learning algorithms [4] has opened the door to more accurate predictions while supporting robust planning through assessment of alternative interventions. Doing this analysis at larger scales, such as the areas within walking distance of high-capacity transit, has helped to maximize the impact on transit ridership while also attending to the needs to generate sufficient housing supply within these areas and to decrease the potential for transit-oriented displacement [6]. At the site scale, these data and analytics can facilitate the optimization of housing supply on private or publicly owned lands, while accounting for neighborhood context and considerations such as light and scale.

The full potential of the data-driven planning paradigm outlined here will require deep integration of the data and analytics we have described into a unified platform with distributed access by participants across levels of government and the private nonprofit and for-profit stakeholders to maximize the potential network effects on improving housing affordability. The potential includes using a common framework to help national and provincial levels of government coordinate with municipalities to ensure that local zoning and other land use regulations are aligned with and supportive of meeting housing affordability goals.

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