Application of an evidence-based tool to evaluate health impacts of changes to the built environment

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ABSTRACT

OBJECTIVES: To create and apply an empirically based health and greenhouse gas (GHG) impact assessment tool linking detailed measures of walkability and regional accessibility with travel, physical activity, health indicators and GHG emissions.

METHODS: Parcel land use and transportation system characteristics were calculated within a kilometre network buffer around each Toronto postal code. Built environment measures were linked with health and demographic characteristics from the Canadian Community Health Survey and travel behaviour from the Transportation Tomorrow Survey. Results were incorporated into an existing software tool and used to predict health-related indicators and GHG emissions for the Toronto West Don Lands Redevelopment.

RESULTS: Walkability, regional accessibility, sidewalks, bike facilities and recreation facility access were positively associated with physical activity and negatively related to body weight, high blood pressure and transportation impacts. When applied to the West Don Lands, the software tool predicted a substantial shift from automobile use to walking, biking and transit. Walking and biking trips more than doubled, and transit trips increased by one third. Per capita automobile trips decreased by half, and vehicle kilometres travelled and GHG emissions decreased by 15% and 29%, respectively.

CONCLUSION: The results presented are novel and among the first to link health outcomes with detailed built environment features in Canada. The resulting tool is the first of its kind in Canada. This tool can help policy-makers, land use and transportation planners, and health practitioners to evaluate built environment influences on health-related indicators and GHG emissions resulting from contrasting land use and transportation policies and actions.

KEY WORDS: Environment and public health; decision support techniques; city planning; geographic information systems; health impact assessment; spatial analysis

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The current obesity epidemic is well documented.[1,2] In Canada, the prevalence of overweight increased from 28% to 34% between 1985 and 2003, and obesity increased from 7% to 16% over the same time period.[3] Commonly cited societal factors include a shift from active to sedentary occupations, the current dominance of the automobile as the primary mode of transportation, an increase in sedentary leisure time, inadequate leisure-time physical activity and easy access to inexpensive, calorie-dense foods.[4,5] Inadequate physical activity and excess weight or obesity are risk factors for multiple chronic diseases (e.g., cardiovascular disease, type 2 diabetes), which are also on the rise.[6-8] These conditions have an increasingly detrimental impact on individual quality of life and repercussions for both individual and public spending on health care.[9,10]

Reversing the upward trends in body weight and chronic disease will require both individual and population-level approaches in multiple settings.[11] To date, published evidence indicates that the built environment has a small but significant impact on physical activity, obesity and chronic disease.[12] The evidence identifies features of the built environment that are associated with greater levels of active transportation (e.g., mixed land use), recreational physical activity (e.g., access to park and recreational facilities) and healthy food consumption (e.g., access to stores selling fresh produce).[13-15] Studies have also identified features that discourage physical activity (e.g., heavy traffic) or are associated with unhealthy food consumption (e.g., access to fast food restaurants).[16,17]

Recent Canadian studies have begun to confirm these findings in both adults and children.[18] Glazier et al. found higher neighbourhood walkability for Toronto adults to be significantly associated with more active travel, less automobile travel, lower prevalence of being overweight or obese, and lower prevalence of

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diabetes mellitus.[19] Pouliou and Elliott reported that higher residential density was associated with lower body mass index (BMI) for Toronto adults and that higher land-use mix, residential density, street connectivity and a walkability index were all associated with lower BMI for Vancouver adults.[20] In a study of 10-14 year olds in London, Ontario, Gilliland et al. found better residential access to recreational opportunities to be associated with lower BMI and better school access to fast food outlets to be associated with higher BMI.[21]

At the individual level, the effect size of built environment interventions is likely to be small, but these benefits are important because they are experienced by many people, which creates a population-level exposure to structural changes to the environment that is sustained over time. Changes to the built environment are a lasting form of prevention and should be one of many complementary strategies utilized to improve public health. Structural changes to the built environment are often required for other programmatic changes to be effective. For example, promoting walking and active travel is not effective without adequate infrastructure. Current cost-benefit tools used to prioritize major transportation investments do not consider the full array of health impacts that research suggests would result from changes to the built environment. Evidence from the current study along with the growing body of research in this area suggests that these tools should include costs associated with a wider range of health outcomes.

Health impact assessments (HIAs) are increasingly being incorporated into local practice to provide stakeholders and decision-makers with health-related information. HIAs can be applied to proposed laws, policies, programs, plans, development projects or investment priorities to evaluate potential impacts on human health. The use of HIAs has gained popularity in North America in recent years, though they most often rely on non-quantitative assessment measures based on translation of limited published evidence about a given decision or project. Recent reviews found that quantitative assessment measures were provided in only 11 of 27 HIAs in the United States and 17 of 98 in Europe.[22,23] The specificity and defensibility of HIAs can be substantially strengthened by the incorporation of quantitative data based on local evidence.[24,25] This is particularly important when interventions to major land development and transportation proposals to improve health and environmental outcomes can have large-scale fiscal consequences and will likely be challenged. Qualitative data are less likely to hold up under legal challenge.

The current study provides an overview of the model development and case study application of an evidence-based, quantitative HIA tool created and applied within the City of Toronto. The tool was developed for Toronto Public Health as a part of the Healthy Canada by Design's Coalitions Linking Action and Science for Prevention (CLASP) initiative funded by the Canadian Partnership Against Cancer.[26] It has already been applied elsewhere in Canada and was designed to predict levels of physical activity, health-related indicators and GHG emissions associated with proposed land use and transportation developments.

METHODS

Development of the CLASP tool involved two major steps: fitting predictive models associating built environment characteristics to health behaviours/indicators using local Toronto cross-sectional data, and modifying an existing software tool (CommunityViz, developed by Placeways, LLC, Boulder, CO) to predict changes in health behaviours/indicators in response to user-defined changes in built environment characteristics. The tool was then applied to the West Don Lands Redevelopment in Toronto as a case study to demonstrate the functionality.

CommunityViz (CViz) is a commercially available extension to ArcMap (ESRI, Redlands, CA) software. CViz was selected for implementation of the CLASP tool because it is already widely used by urban planners for evaluating basic impacts (e.g., on transportation, environmental, school) of future land development and transportation investment scenarios, and could be customized to include health impact models. CViz provides a user-friendly geographical information system interface that can be used by planners and stakeholders to analyze existing built environment conditions, modify future conditions and receive feedback on their impacts. CViz users manipulate future conditions in two basic ways to generate information on the health impacts: develop/redevelop land uses and modify transportation infrastructure. CViz feedback is presented through a combination of maps, numbers and charts that compare base conditions and future scenarios on the metrics of interest.

Dependent variables

Dependent variables were derived from two data sources: the 2007/2008 wave of the Canadian Community Health Survey (CCHS) and the 2006 Transportation Tomorrow Survey (TTS). Dependent variables considered for model building consisted of (from the CCHS) walking and biking for exercise, walking and biking to work/school, body mass index, daily energy expenditure and the likelihood of having high blood pressure; and (from the TTS) walk/bike trips/day, transit trips/day, automobile trips/day, kilometres of travel/day and estimated vehicular emissions of CO_2/day. The CCHS sample contained 4,077 participants within the City of Toronto who were geocoded to postal codes. The TTS sample contained 22,091 participants within the City of Toronto geocoded to postal codes. It was not possible to obtain records for each TTS participant; rather, the data represent postal code-level averages.

Independent variables

Built environment variables were measured for all 47,246 postal codes in the City of Toronto using spatially registered local parcel, transportation network (transit, roadway, pedestrian and bike) and destination (food outlet, park and school) data. The area within a 1 kilometre network buffer surrounding each postal code was included in the calculation of built environment variables. Buffers were created to encompass the area that can be traveled from the centre of the postal code, in all directions, for a kilometre along the street network (excluding limited-access roadways). This approach has been validated repeatedly in other peer-reviewed research.[27-29] The built environment variables included the length of roads; bicycle and sidewalk facilities; distance to nearest major arterial, school and transit stop/station; accessibility to major regional destinations; several density vectors, including net-residential, intersection, schools, transit stop and type of each food location (sit down and fast food,

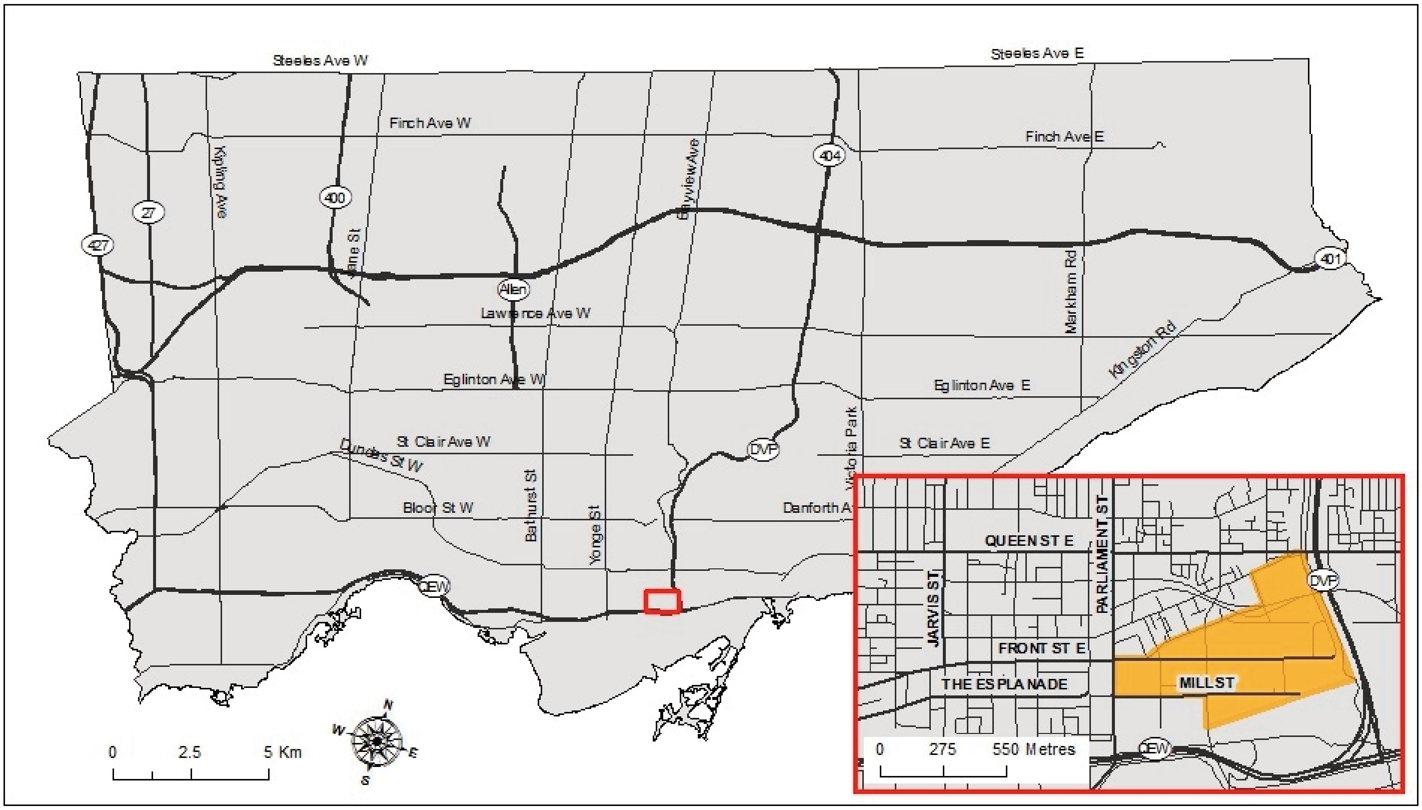

Figure 1. West Don Lands site overview (area shaded in orange represents boundaries of the development site)

grocery and convenience stores); and measures of land use, including an entropy-based measure of mix, retail floor-to-land area and park area.

Demographic and socio-economic covariates were also included as independent control variables in the models. The covariates were derived directly from the CCHS and TTS surveys when available. When critical covariates were not provided from these survey sources, covariate values for each participant were imputed from the 2006 Census in Canada. These data were available only at the level of the dissemination area (DA). DA values were assigned to all postal codes falling within the DA, and then assigned to the survey participants falling within each postal code. Demographic variables used in the predictive modelling included those of the survey participants as well as Census based variables. These variables included age, sex, household income, household size, vehicle ownership, education level, employment status and DA minority population percentage.

Analytical methods

Data were joined at the postal code level, the smallest common geographic unit. Multivariate regression models were used to predict the value of each health outcome/behaviour based on each participant's built environment and demographic/socio-economic characteristics. Four different types of regression model were used, depending on the type and distribution of the outcome variable: linear, log-linear, binary logistic and two-stage (zero-inflated). In each case, a base model was first built to include any statistically significant ($p<0.05$) demographic/socio-economic variables.

Next, built environment variables were added to the model until the combination of variables providing the highest predictive fit (r-squared) to the outcome was found. The modelling process was constrained by the fact that resulting variable formulations needed to be usable within the modelling software and applicable to real-world scenario testing. Therefore, predictive modelling (not hypothesis testing) was the ultimate goal of the analyses. In addition, built environment variables were included in a few instances in which they were not significantly associated with the outcome of interest because they improved the predictive fit of the model. As shown in the past, built environment variables were found to be multicollinear and were combined into an index. Log transformations were used for variables with extreme positive skew.

Some practical limitations related to the need to apply these models in a scenario-planning software tool constrained the selection of independent variables. For example, all model variables needed to be available for every Toronto postal code for the base scenario and modifiable for future scenarios. Similarly, all measurements required for calculating each variable must be technically possible within the software tool and able to be calculated in less than an hour (as the software tool is intended for use in real time at public meetings). CViz is more constrained in this manner than other software platforms that access external computing capacity through the Internet.

Case study area selection and model application

The West Don Lands (WDL), indicated in Figure 1, was selected for the test case study for the CLASP tool. The test scenario is based on the WDL Precinct Plan redevelopment of this underutilized, waterfront industrial land. It defines the location, scale, character and function of all public spaces, streets, buildings and facilities to be provided and developed within the

Table 1. Demographic characteristics of residents of the West Don Lands (WDL) study area and impact area, the City of Toronto, and CCHS and TTS participants

Variable	WDL study area (postal code level, *n*=15)*	WDL impact area (postal code level, *n*=350)*	City of Toronto†	CCHS (participant level, unless otherwise noted), mean (*N*)	TTS (average survey participant at the postal code level, unless otherwise indicated), mean (*N*)
Median age	45.2	38.4	38.4	46.6 (4077)	42.4 (22,102)
% female	53.0	48.3	51.9	54.0 (4077)	56.2 (21,028)
Average no. per household	2.6	2.6	2.5	2.5 (4077)	2.7 (22,113)
% with university degree	47.8	38.5	37.3	32.3 (3926)	30.0 (21,828)*
Median household income ($)	61,078	76,082	52,833	77,049 (3127)‡	83,988 (21,828)*

* Statistics Canada, 2006 Census dissemination area values assigned to participants/postal code centroids.
† Statistics Canada, 2006 Census Community Profile.
‡ Household income 2006.
CCHS=Canadian Community Health Survey; TTS=Transportation Tomorrow Survey.

Table 2. Study area built environment measures

Variable	Existing conditions	Future: WDL Precinct Plan	% change from existing
Net residential density (residential units per residential acres)	72.4	119.0	64.4%
Land-use mix (0-1)	0.5	0.5	0.0%
Retail floor-to-land area ratio	0.8	1.2	50.0%
Schools	12.0	13.0	8.3%
Food locations	159.0	193.0	21.4%
Intersection density (count/sq km)	134.8	152.0	12.8%
Transit density (count/sq km)	40.4	42.0	4.0%
Pedestrian-accessible roads (km)	58.4	62.2	6.5%
Bicycle facilities (km)	11.8	18.5	56.8%

Table 3. Estimated outcome values for West Don Lands (WDL) study and impact area

Outcome	Study area (15 postal codes)			Impact area (350 postal codes)		
	WDL existing conditions	WDL plan	% change from existing	WDL existing conditions	WDL plan	% change from existing
Active trips/person per day	0.23	0.48	108.7%	0.37	0.42	13.5%
Transit trips/person per day	0.60	0.79	31.7%	0.74	0.77	4.1%
Automobile trips/person per day	1.00	0.52	-48.0%	0.64	0.55	-14.1%
Trip kilometres/person per day	18.17	15.43	-15.1%	14.58	14.18	-2.7%
Vehicular CO_2 emissions (kg/household per day)	3.38	2.39	-29.3%	2.34	2.28	-2.6%
Leisure walking episodes per month	13.63	14.40	5.7%	11.80	12.06	2.2%
Walk trips to work/school per month	7.79	10.94	40.4%	10.84	11.54	6.5%
Leisure biking episodes per month	1.08	1.53	41.7%	1.15	1.26	9.6%
Bike trips to work/school per month	0.80	2.71	238.8%	0.98	1.47	50.0%
Daily energy expenditure (kcal/kg per day)*	2.28	2.73	19.7%	2.44	2.51	2.9%
Body mass index	24.31	24.14	-0.7%	24.03	23.99	-0.2%
Likelihood of high blood pressure	9.63%	9.19%	-4.6%	5.55%	5.48%	-1.3%

* Daily energy expenditure, expressed in kcal/kg/day (PACDTLE), was derived by Statistics Canada on the basis of participant responses to several activity questions. It was calculated by combining the time each participant spent engaging in leisure (e.g., walking, cycling, sports) and transportation (e.g., walking/cycling to work) activities in the previous three months. The total number of calories burned during all activities was calculated and converted into a daily value based on the participant's weight. Respondents are classified as follows: 3.0 kcal/kg/day or more=physically active; 1.5 to 2.9 kcal/kg/day=moderately active; less than 1.5 kcal/kg/day=inactive.
Source: Canadian Community Health Survey (CCHS): 2008 (Annual component) and 2007-2008, Derived Variable (DV) Specifications, Master and share file. http://www.statcan.gc.ca/imdb-bmdi/document/3226_D2_T9_V6-eng.pdf

WDL community. Significant changes are planned for this east of downtown, 80 acre site:

- 6,000 to 6,500 housing units, 1,300 of which will be affordable rental housing
- Residences in a mix of housing types from townhouses to mid-rise buildings and towers
- 1 million square feet of office and retail space
- New streets improving connectivity
- New parks, including an 18-acre park immediately adjacent to the Don River
- A new streetcar line
- A new school

Changes to the built environment within the study area are expected to have an impact not only on the behaviour of people in that area but also on those living in the area immediately surrounding it. For example, new retail, employment or transit that is built within the study area will offer new destination choices for people nearby. For this reason, models were applied to both the study area (*n*=15 postal codes) and the "impact area", defined as the study area plus any postal code that has its 1 kilometre buffer intersecting the study area (*n*=350 postal codes).

Demographic and socio-economic characteristics for the case study were derived from Census (2006) DA data. Table 1 provides average values of demographic characteristics at the postal code level for the study and impact areas, overall for the City of Toronto, and at the individual level for the CCHS and TTS participants whose data were used to create the regression models. Residents of study area postal codes are older, more educated and have a higher income than in the City as a whole. Residents of the impact area are more similar to those of the City

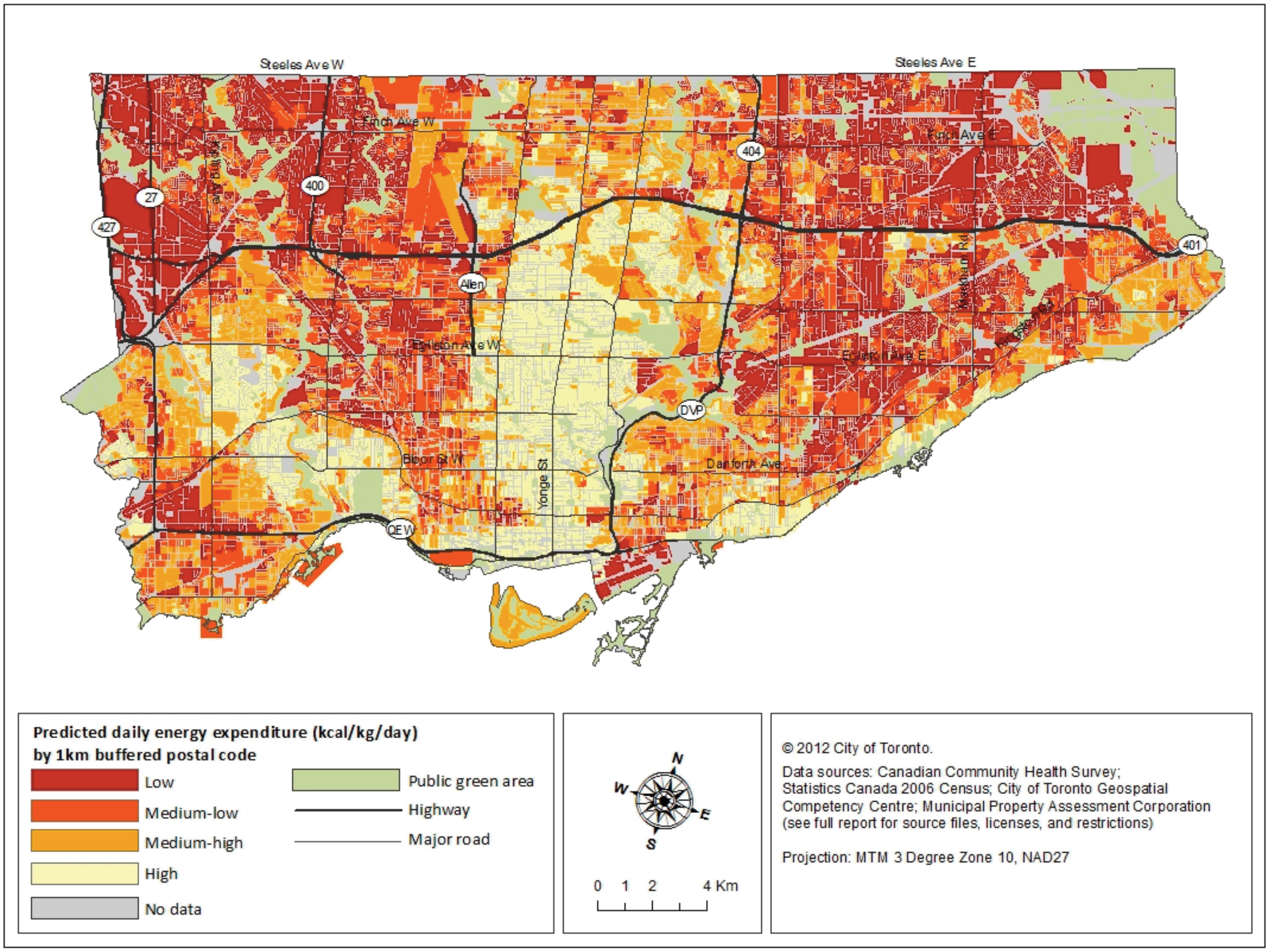

Figure 2. Daily energy expenditure (kcal/kg/day/person) – calculated values*
* Quartile range values: low=0.57-1.70, medium-low=1.70-1.94, medium-high=1.94-2.34, high=2.34-7.56

as a whole, with the exception of a lower proportion of female residents and much higher household income.

The final regression models were then applied at the postal code level for each outcome of interest for both base conditions and the future development scenario. For ease of interpretation, demographic and socio-economic profiles for each postal code were held constant between the two scenarios. Outcome estimates were generated for both the study area and the impact area.

RESULTS

Regression results are summarized as follows. Characteristics that were most commonly associated with more physical activity, lower body weight, better health and reduced vehicular impacts were higher land-use mix, intersection density, retail floor-to-area ratio, residential density, transit stop/station density and retail food store density. Greater access to parks and to trails was associated with walking for exercise, while greater sidewalk coverage and bike facility access were associated with more walking or bicycling for transportation. Better regional accessibility was associated with more walking, bicycling and transit trips, fewer/shorter vehicle trips and reduced GHG emissions.

Table 2 provides values for a subset of the built environment values used by the regression models and calculated for the study area's existing and planned future conditions. These values are based on the area encompassed by the buffered study area postal codes. Under the WDL Plan the area is expected to become denser with more destinations, and while the mix of residential and non-residential land uses is unchanged, the amount and density of new retail are increased. The transportation network is expected to expand for walkers, bicyclists and transit users.

Table 3 shows the predicted results for each outcome and the percent change between future and baseline conditions. The left half of the table indicates the results for people living only inside the study area, and the right half of the table indicates the results for people living within the impact area. Only the study area results will be discussed in detail below. In all cases, those living outside the study area experienced similar positive impacts at a lower magnitude than those living within the study area.

Upon implementation of the Precinct Plan for redevelopment, it is anticipated that there will be a substantial shift from automobile use to active modes (walking and biking) and transit.

For residents living within the study area, active mode trips are expected to more than double and transit trips to increase by one third. In contrast, automobile trips are expected to decrease almost by half. Concurrent with the reduction in automobile trips would be a 15% decline in vehicle kilometres travelled per person and a 29% reduction in vehicle-related GHG emissions per household.

Study area residents are projected to walk or bike to work or school with far greater frequency upon implementation of the Precinct Plan, increasing walking by 40% and biking by 238%. Smaller increases in recreational walking and biking are anticipated, a 5.7% projected increase for walking and 42% increase for biking. This increased walking and biking leads to a 20% projected increase in daily energy expenditure for study area residents upon implementation of the Precinct Plan, from 2.3 to 2.7 kcal per person per day.

The health benefits for study area residents of the shift to active transportation modes and the increase in recreational physical activity upon implementation of the Precinct Plan are demonstrated by the decrease in projected BMI and reduced likelihood of having high blood pressure. Average BMI is projected to decrease by 0.17 points, while the prevalence of high blood pressure is projected to decrease from 9.6% of the population to 9.2%.

Application of the model results can also be used to create city-wide, postal code-level thematic maps for the outcomes. Figure 2 shows results by quartile for one selected outcome, daily energy expenditure. It is clearly seen that the central downtown and areas to the west and north, represented in yellow, indicate higher activity, with less activity estimated away from these areas.

DISCUSSION

This study reports on the development and application of an evidence-based software tool to predict the health impacts of built environment changes. The West Don Lands application of the tool demonstrated the potential to predict how proposed changes to the built environment can improve human health by increasing levels of physical activity. The implementation of a development plan to infill the WDL with additional housing, retail opportunities and improved transportation infrastructure was predicted to increase walking, cycling and transit use among residents, particularly for utilitarian purposes but also in terms of leisure activity. The predicted increase in active transportation and leisure physical activity resulted in increased total daily energy expenditure. While not conclusive based on cross-sectional data alone, it is logical that increased energy expenditure would lead to lower body weight and improved health over time. The case study results are consistent with these causal relationships, as WDL residents are also predicted to have lower BMI and reduced likelihood of high blood pressure.

Although not measured for the case study, the health benefits are also anticipated to reduce the health care costs related to obesity.[30] In addition to the physical activity and health benefits, the results also demonstrated important transportation and environmental co-benefits, including a reduction in vehicular trips, vehicle kilometres travelled and GHG emissions. Although the magnitude of change was relatively small for many of the outcomes, the number of people affected by the Plan (not to mention the co-benefits) suggests that built environment changes merit consideration as one of many complementary strategies that can be used to combat rising rates of obesity and chronic disease.

Regression model development and case study development suffered from a few limitations. First, the data used to build the regression models were cross-sectional. While the predictive modelling application implies a cause-and-effect relationship, it is important to recognize that causality cannot be determined from these data. Second, variable selection and modelling methods were constrained by sample (CCHS and TTS) and population-wide data availability and the limitations of the CViz application tool. Thus we were unable to adjust for variables in the final models known to be associated with the outcomes of interest, such as diet, attitudinal factors and genetics. Third, demographic and socio-economic characteristics were held constant between base and future scenarios. This decision was made purely for ease of interpretation. Arriving at an agreed-upon predicted future demographic mix of a given location is one of the most difficult parts of scenario planning. Modifying only the built environment characteristics allowed us to isolate the impact of built environment changes disentangled from potential impacts related to change in individual-level characteristics. The resulting software tool is fully capable of simultaneously modelling both individual-level and built environment changes, and doing so is recommended for real-world applications.

Despite these limitations, the regression modelling and case study results were intuitive and consistent with other published findings. Greater local accessibility and access to walking/biking/transit infrastructure have been associated with more transportation-related and total physical activity, reduced body weight and reduced blood pressure.[31-33] Better access to park and recreation facilities has been associated with more leisure physical activity.[15,34] Both local and regional accessibility have been associated with reduced vehicle kilometres of travel and GHG emissions.[13,35]

The development of a quantitative health impact assessment tool and its pilot testing in Toronto are important contributions to the field, as they demonstrate the value of using local data sources to generate evidence-based health predictions in response to proposed changes in the built environment. The tool was also successfully applied in the rapidly growing City of Surrey in British Columbia, showing considerable health benefits of the adopted downtown redevelopment plan.[26] Rather than being a one-off analysis, this tool can be used by the City of Toronto to routinely evaluate development proposals and inform plan updates and infrastructure funding prioritization decisions. Conducting routine health impact analyses helps to elevate the importance of health as a key consideration in urban planning, increasing the likelihood that "healthy living" is ingrained more generally into both government and private sector culture. The ability to quantify health impacts has the added benefit over non-quantitative assessments of providing measurable and defensible metrics that can be compared against competing proposals or plans.

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