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# The impact of light rail transit station area development on residential property values in Calgary, Canada: Focus on land use diversity and activity opportunities

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## ABSTRACT

Although many studies have examined the effects of transit accessibility on housing prices, fewer studies have looked more closely at the implications of transit station area development on the urban housing market. Employing a multi-level hedonic price model, we examined the effect of light rail transit (LRT) station area development on residential property values in Calgary, Canada. Station area development is measured by 1) land use diversity index, also known as land use entropy, and 2) activity opportunity count (i.e., the number of selected business licenses) within the 400m-buffers of station. In the case of Calgary, land use diversity is not associated with property values, which is counter to the existing knowledge. However, our findings suggest that activity opportunities around stations are positively related, particularly to the value of apartment properties. We also observed that a lack of activity opportunities for pedestrians and transit users and a poorly designed station area can partially explain the unexpected outcomes.

## 1. Introduction

The benefits of transit-oriented development (TOD), which generally refers to dense, mixed-use, and walkable development oriented to rapid transit, are abundant (Cervero, 2004; Topalovic et al., 2012). As a walkable sub-center, TOD can play a role in increasing pedestrian activities in and around stations. Additionally, better transit accessibility attracts people to live near transit stations and encourages trips by transit (Crowley et al., 2009; Olaru et al., 2011). Moreover, diverse land use around transit stations can make it easy for transit users to be involved in different activities due to various activity types produced in proximate distances from one land use type to another and higher accessibility connected to active modes of transportation, such as walking and biking (Grant, 2002). Another benefit of TOD is that such areas can function as a core of urban development guidance that encourages compact and mixed-use development close to transit stations or along transit routes, which would be able to curb urban sprawl and, therefore, significantly reduce costs associated with outward growth (Cervero and Dai, 2014; Handy, 2005; Ratner and Goetz, 2013).

Real estate appreciation is another way that TOD can provide its

residents or those in adjacent neighborhoods with economic benefits. Previous research has shown a strong correlation between the value of residential properties and the accessibility or the proximity to rapid transit (e.g., distance to the closest transit station) (Hess and Almeida, 2007; Kay et al., 2014; Mathur, 2020). Some studies have examined the relationship between station area characteristics (e.g., land use mixture or other TOD features) and residential property value (Shen et al., 2018; Zhang et al., 2021). However, less attention has been given to activity opportunities (e.g., grocery stores, restaurants, etc.) in and around stations and their impact on home values (Zheng et al., 2016). Hence, in this study, we aim to comprehensively investigate the economic impacts of station area development of light rail transit (LRT) on the urban housing market. To this end, we measured station area development by 1) the degree of land use mix, which is the most widely used metric in the planning literature and 2) the number of potential activity opportunities, which was derived from selected business licenses within buffer areas of stations. Then, we quantified the impact of each measure on two types of residential property—attached houses and apartment properties—in Calgary, Canada. This study contributes to the literature related to the impact of transit station area features on the urban housing

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market.

## 2. Literature review

In addition to the societal and environmental benefits previously stated, the improvement of transit accessibility and transit-oriented land use planning can influence the urban real estate market, particularly properties adjacent to rapid transit service facilities and those in and close to mixed-use development according to such land use planning (Bartholomew and Ewing, 2011; Hess and Almeida, 2007; Knaap et al., 2001). A large body of previous studies has focused on residential property value in adjacent areas to rail-based stations (Weinberger, 2001), while others have evaluated the economic impact of rapid transit on commercial and industrial properties (Cervero and Duncan, 2002; Ko and Cao, 2013). Despite variance in magnitude, most studies have demonstrated that the proximity to rail transit is likely to increase average property values, and therefore houses located within a certain radius of stations can earn a premium (Debrezion et al., 2011; Hess and Almeida, 2007; Kay et al., 2014). However, residential properties situated too close to rail stations (e.g., within one-quarter of a mile) might experience depreciation in home values (Pan, 2013). Similarly, as in residential properties, substantial economic benefits are also expected for commercial properties when they are situated in the immediate proximity to rapid transit infrastructure, LRT in particular (Cervero and Duncan, 2002). Rapid transit investments may benefit the urban real estate market and draw new developments to areas near proposed stations even in the planning stages. Knaap et al. (2001) investigated whether the plans for light rail investments impact land values in proposed station areas in Washington County, Oregon. They found that the plans are likely to increase the value of the vacant land nearby and even upscale future development density (Knaap et al., 2001). Cao and Porter-Nelson (2016) studied the plan for the new Green Line LRT and its impact on the number of building activities in St. Paul, Minnesota. Their findings demonstrate that LRT investment accelerates development in the proposed corridors when financial concerns are fully addressed (Cao and Porter-Nelson, 2016).

As the impact of proximity to transit on residential property values and future land development has been well studied, many previous studies have attempted to understand the impact of land development in and around station areas on the urban housing market (Higgins and Kanaroglou, 2018). Duncan (2011a) provided empirical evidence that home prices can be appreciated or depreciated depending on land use regulation and rail proximity. Another study by Duncan (2011b) suggests that the effect of accessibility to rail transit on the condominium market in San Diego, California, can become stronger when stations provide a pedestrian-oriented environment, characterized mainly by the density of employees in food, entertainment, sales, retail, and service industries. Some studies consider TOD as a factor influencing housing price. Focusing on the Dallas-Fort Worth (DFW) metropolitan area, AlQuhtani and Anjomani (2019) studied the impacts of transit accessibility and TOD development on the housing market. Their findings suggest the block groups developed as TOD experienced the appreciation in median housing value over the study period (2000–2014). They also found proximity to shopping areas could have positive externality (AlQuhtani and Anjomani, 2019). Moreover, properties in TOD could be resilient during the economic downturn even when compared to those along the transit corridor (Zhang et al., 2021). However, TOD features do not always increase nearby property values, and the effect can vary by the context of the catchment areas. For example, the premium for proximity to rail transit can be discounted by park-and-ride facilities (Zhong and Li, 2016), while station areas with more pedestrian-oriented amenities can increase housing prices nearby (Atkinson-Palombo, 2010).

In the previous studies, the economic effects of transit station area features on the housing price has been addressed by the development type (i.e., TOD or non-TOD) (Zhang et al., 2021), the accessibility to

other land uses (AlQuhtani and Anjomani, 2019; Shen et al., 2018), or the density of employment (Duncan, 2011b). However, fewer studies have discussed the impact of activity opportunities from the user perspective. Zheng et al. (2016) studied how a new subway station contributed to new openings of restaurant in the market, and how the growth of the local food destinations (both in the number and diversity) attributes to the rental housing market. They found that a new subway station could induce more openings and increase the diversity of local restaurants. Consequently, renters nearby are willing to pay more for housing services in the area (Zheng et al., 2016). To the best of our knowledge, there is a limited number of studies focusing on activity opportunities in and around station areas and their impact on housing prices.

## 3. Study area

Since the permanent settlement of Calgary began in 1875, the city has grown concentrically, limited only by the Tsuut'ina Nation, an Indian reserve, to the west and the Calgary International airport in the northeast (Sandalack and Nicolai, 2006). Most of the city's growth has been low density characterized by single-family homes with most employment opportunities located in the commercial/office downtown business district. This translates into a monocentric city where people commute from the outside and where the center of activity resides within inner-city neighborhoods. The Bow and Elbow River valleys' topographic features and its proneness to flooding also present limitations to the city's growth and have impacted its built form. These valleys limit the building of infrastructure and particularly influence the layout of transportation systems with limited river crossings.

The current LRT system or CTrain was first introduced in the early 1980s. It began operating in 1981 with a short north-south line (11 km) and has grown to close to 60 km with 46 stations along two lines, the original northwest-south line (Red) and a newer northeast-west line (Blue). Because of Calgary's centralized allocation of jobs and dispersed residential neighborhoods, most of the CTrain traffic is one-directional, morning commute from the edges to the center and in the opposite direction at the end of the working day. This presents challenges but also relatively high ridership numbers for a Canadian city. In 2019, the CTrain had a ridership of 91,604,600, or about 313,800 per weekday in the fourth quarter of 2019 (American Public Transportation Association, 2020). Fig. 1 illustrates the city of Calgary and LRT stations as well as several city's landmarks.

Since the early 2000s, The City of Calgary has begun to emphasize the need to abandon the curvilinear, auto-dependent pattern and adopt higher densities and more diverse land use practices. This is, however, a process that will take time to see tangible results in Calgary's built form. As part of that process, the areas around CTrain stations have become a priority for the potential densification of housing and jobs. A new type of land use and development instrument was created to address these areas (The City of Calgary, 2021), Station Area Redevelopment Plans (SARP), where the focus was creating TODs around some priority inner-city neighborhood stations. These plans have encouraged some development, but the slowing of the economy has also slowed the redevelopment of these areas.

## 4. Methodology

### 4.1. Data and variables

The Calgary Real Estate Board (CREB) provided the data on sales transactions that occurred within the city from January to December in 2017. The original dataset contains detailed information about individual transactions, including sold prices, properties' structural features, and geographical locations, which enabled us to identify spatial information. In this study, we primarily focused on non-detached residential properties that are located within 1500 m of the 46 existing LRT stations.

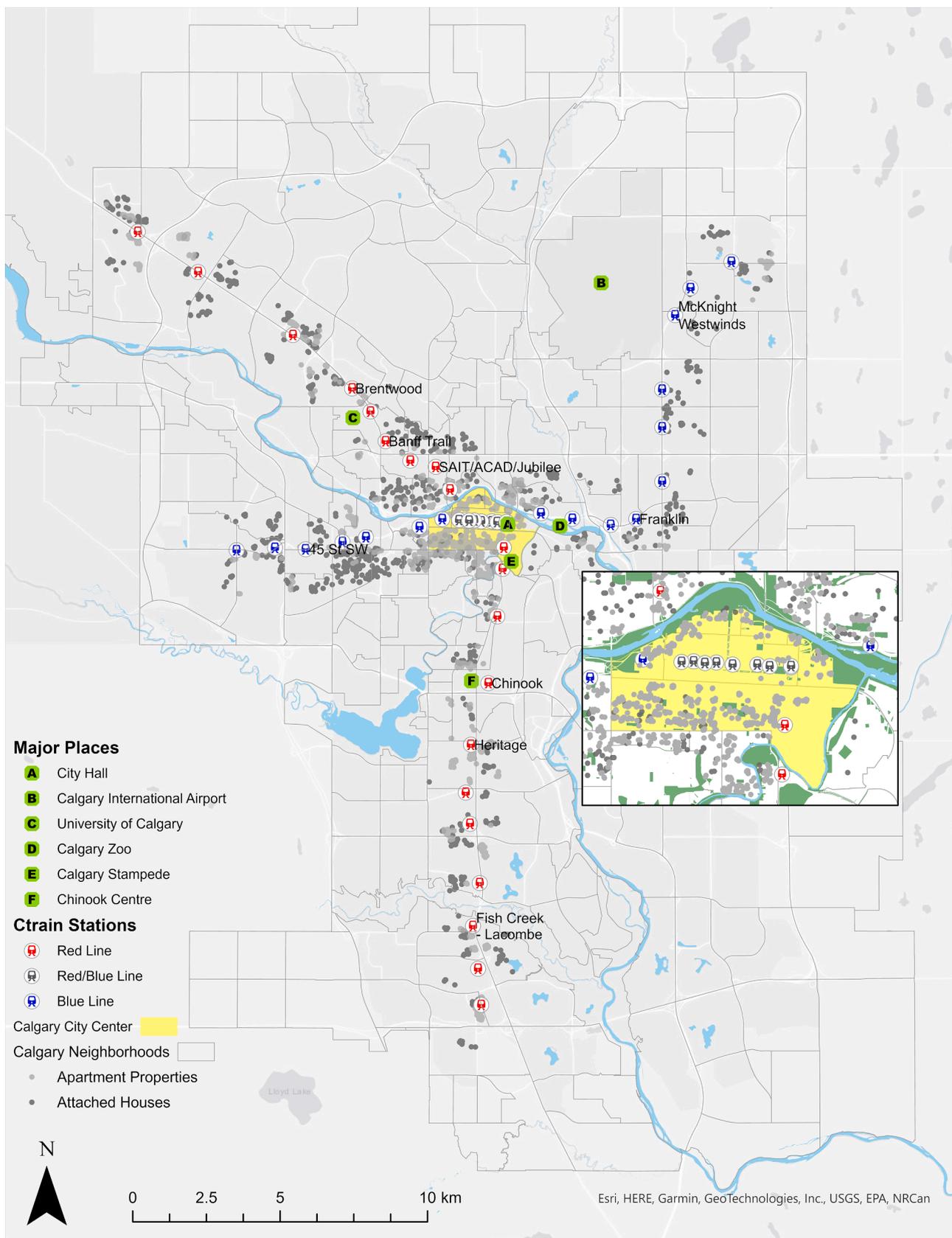


Fig. 1. Study Area.

This distance cutoff was determined based on the finding from the case study of Montreal, Canada, in which the authors found that regardless of transit mode, the maximum walking distance to transit is near 1500 m, which is also equivalent to approximately 20-minute walking (El-Genaidy et al., 2014). As a result, our study sample includes 1054 attached houses (e.g., semi-detached or row houses) and 1770 apartment properties. Table 1 summarizes the characteristics of residential properties by housing type in this study.

Along with the structural characteristics of individual properties that were readily available in the original dataset we obtained, we derived geographic features for individual properties, including location within the city (i.e., Distance to City Hall) and accessibility to the LRT service (i.e., Distance to the nearest LRT station). As seen in Fig. 1, Calgary consists of many neighborhoods, and they vary greatly from one another. Thus, we also measured five neighborhood characteristics by using the demographic and economic information from the Statistics Canada (<https://www.statcan.gc.ca>) and the community crime statistics from the city’s open data portal (<https://data.calgary.ca>). In the Canadian Census, a visible minority is defined as “persons, other than aboriginal peoples, who are non-Caucasian in race or non-white in colour. (Statistics Canada, 2018, p. 150)” The crime count refers to all violent crime offences as defined by the Centre for Canadian Justice Statistics, which are reported to the Calgary Police Service. We also assigned a walk score to each neighborhood, which was originally available from Walkscore.com®. The Walk Score measures walkability on a scale from 0 to 100 based on the walking environment (e.g., walking routes to nearby amenities and pedestrian friendliness). The higher the walk score, the more walkable the neighborhood is.

Besides the structural, transit accessibility, and neighborhood characteristics, we included the dummy variable of city center location. If a property is in the city center (see Fig. 1), we assigned the value of 1 to the property, otherwise we assigned the value of 0. In general, high sales prices for properties, particularly apartment properties, are observed in the central area of city, where homogenous land use is dominant due to a substantial amount of land used as commercial. Since the Calgary case is

**Table 1**  
Summary Statistics.

Variables	Attached Houses		Apartments	
	Mean	SD	Mean	SD
<b>Dependent variable</b>				
Sold price (1,000 CAD)	481.24	250.46	317.90	208.54
<b>Independent variables</b>				
<b>Structural characteristics</b>				
Total floor area (ft <sup>2</sup> )	1374.17	448.59	879.82	319.10
Building age (in 2017)	23.26	16.96	21.17	17.63
Number of bedrooms	2.96	0.91	1.64	0.52
Number of bathrooms	2.44	0.96	1.50	0.52
Number of garaged parking	1.06	0.87	0.01	0.16
Distance to City Hall (km)	7.51	4.46	4.69	4.67
<b>Transit accessibility characteristics</b>				
Distance to the nearest LRT station (m)	868.54	353.56	655.42	342.62
<b>Neighborhood characteristics</b>				
Population density (persons/km <sup>2</sup> )	4165.17	2133.72	8498.51	5673.05
Percent of visible minority (%)	29.83	16.67	29.41	13.71
Median household income (1,000 CAD)	99.36	26.39	86.36	25.50
Crime count (per year)	834.87	992.28	2805.78	3305.89
Walk score (0–100)	56.50	17.54	72.39	19.29
<b>City center location</b>				
If a property is in the city center, 1, otherwise 0	0.02	0.14	0.35	0.48
<b>Station area characteristics</b>				
Land use entropy (0–100): 400 m	43.26	15.41	34.65	18.23
Activity opportunity count (0–700), 400 m	52.34	63.96	117.01	147.28
N =	1054		1770	

not far from the norm of many other cities, we attempted to control the effect of central location on housing price by this dummy variable. We found 35 % and 2 % of the apartment properties and the attached houses, respectively, are in the city center.

We measured station area development by 1) the degree of land use mix and 2) the number of potential activity opportunities. First, the land use diversity index, also known as land use entropy, is the most widely accepted and commonly used index for representing the degree of land use mix (Bordoloi et al., 2013). We computed the land use entropy for 400-meter buffers of individual stations because 400 m is deemed the distance for which walking is the most convenient means of transportation (Utterman, 1984). In other words, an average person can reach anywhere inside the buffer within 10 minutes on foot. The index quantifies the level of heterogeneity of land uses in a given area. A typical land use entropy is expressed as follows:

$$Entropy_{LU} = - \sum_j \frac{P_j \times \ln(P_j)}{\ln(j)}$$

where,  $P_j$  is the proportion of  $j^{\text{th}}$  land use category of the total land area found in the station area being analyzed;  $j$  is the total number of land uses considered in this study. As shown in the equation, the entropy is normalized using the natural logarithm of the number of land uses. Its value lies between zero and one, where zero represents the completely homogenous land use, and one indicates the tract of land being equally distributed across all the land use types. We considered the following five land uses: (1) commercial, (2) industrial, (3) institutional, (4) parks and recreational, and (5) residential. Additionally, we accounted for other land uses that were not defined previously, such as the infrastructure land use (e.g., roads and surface parking lots) and other unclassified land uses (e.g., undeveloped areas). The value zero was assigned to these types of land use, which is collectively  $Entropy_{OTHERS}$ . Another aspect of the traditional land use codes that we have is the mixed land use. The value one was assigned to the mixed land use type, which is  $Entropy_{MIX}$ . We assigned the full score to areas coded as mixed-use based on the assumption that mixed land use itself in their lots could impact the housing price to the fullest extent. The final entropy index formula in this study is expressed as follows:

$$100 \times \sum_k Entropy_k \times R_k$$

where  $k = 1, 2,$  and  $3$ ; 1 indicates  $LU$ , or Regular Land Use; 2 is  $OTHERS$ ; and 3 is  $MIX$ ; and  $R_k$  is a ratio of the  $k^{\text{th}}$  area to the total area of the 400-meter buffer. For our final land use index, we multiplied the combined entropy index by 100 to allow a more intuitive interpretation of the outcomes on a 0–100 scale. The final entropy score of the closest LRT station to each property was assigned to all properties in our study.

We also counted the number of activity opportunities that can be performed within the station buffers. We utilized the Calgary Business License (CBL) dataset from the Open Calgary. The CBL dataset was particularly useful for this study because it contains not only types of places (e.g., retail, restaurant, etc.) but also the number of possible activities of individual places (e.g., eating, drinking, playing, etc.). Hence, we were able to weigh places differently based on the number of possible activities. For instance, some restaurants can simultaneously have three licenses, including food service, alcohol beverage sales, and outdoor patio. For this study, we primarily considered non-work-related licenses that can provide activity opportunities within the station catchment areas. The types of business licenses considered in this study include alcohol manufacturer/sales, amusement arcade, spa/massage center, cinema, entertainment establishment, food service, market, outdoor patio, personal service, and retail dealer.

#### 4.2. Hedonic price model

The hedonic pricing method estimates the implicit value of attributes

of differentiated goods (Lancaster, 1966; Rosen, 1974), and the hedonic price models generally take the following form:

$$P_i = f(\mathbf{H}, \mathbf{T}, \mathbf{N}, \mathbf{S})$$

where  $P_i$  is the estimated price of property  $i$ ;  $\mathbf{H}$  is the vector of structural characteristics;  $\mathbf{T}$  is the vector that measures proximity to rapid transit facilities;  $\mathbf{N}$  is the vector of neighborhood characteristics; and  $\mathbf{S}$  is the vector of station area characteristics (Higgins and Kanaroglou, 2016).

Because many properties share the characteristics of a given neighborhood and/or the nearest station area, we developed multi-level hedonic price models to estimate factors influencing property values. Multi-level models can account for the fact that properties from the same neighborhood and/or station area share common attributes (i.e., population density, percent of the visible minority population, household median income, crime rate, walkability, station area land use diversity, and the number of activities). Our multi-level models incorporate both fixed and random effects. Fixed effects represent variable coefficients that are constant across upper-level (i.e., neighborhoods and stations) units, while random effects include error terms that vary across upper-level units. Estimated multi-level hedonic price models take the following forms:

$$\text{Level 1: } Y_{ij} = \pi_{0j} + \pi_{1j}H_{ij} + \pi_{2j}T_{ij} + e_{ij}$$

$$\text{Level 2: } \pi_{0j} = \rho_{00} + \gamma_{0m}N_j + \delta_{0n}S_j + u_{0j}$$

$$\pi_{1j} = \alpha_{k0}$$

$$\pi_{2j} = \beta_{l0}$$

$$\text{Mixed Model: } Y_{ij} = \rho_{00} + \alpha_{k0}H_{ij} + \beta_{l0}T_{ij} + \gamma_{0m}N_j + \delta_{0n}S_j + u_{0j} + e_{ij}$$

where  $Y_{ij}$  is sold price of property  $i$  (Level 1) in neighborhood/station area  $j$  (Level 2);  $\rho_{00}$  is the model constant (intercept);  $\alpha_{k0}$ ,  $\beta_{l0}$ ,  $\gamma_{0m}$ , and  $\delta_{0n}$  are fixed effects of structural, transit accessibility, neighborhood,

and station area characteristics, respectively ( $k, l, m, n = 1, 2, 3, \dots, p$ ;  $p$  = number of variables in each category).  $H_{ij}$  is a vector of structural characteristics of property  $i$  (Level 1);  $T_{ij}$  is a vector of transportation accessibility for property  $i$  (Level 1);  $N_j$  is a vector of neighborhood characteristics (Level 2);  $S_j$  is a vector of station area characteristics (Level 2); and  $u_{0j}$  and  $e_{ij}$  are the residual error terms of Level 2 and Level 1, respectively.

## 5. Results

### 5.1. Statistical models

In many respects, attached houses and apartment properties were distinct. Thus, we ran separate models for each property type. Table 2 reports the results for both attached houses and apartment properties. We tested the land use entropy of station area in Models (1) and (4) and the count of activity opportunities within the station catchment area in Models (2) and (5) while controlling the characteristics of structure and neighborhood as well as the proximity to LRT station. Models (3) and (6) consider both station area features. In all models, the log-transformed sold price in Canadian dollars was regressed on the listed predictors in the left column in Table 2.

Most variables for structural and neighborhood characteristics are in line with our initial expectation. The findings suggest that garaged parking seems to have a strong influence on property values, which can be explained by the auto-dependent mobility patterns of Calgary, the result of its low density and sprawling built forms, and potentially severe winters in Canada. The negative effect of the distance to city hall may reflect the monocentric feature of Calgary. The coefficients for the

**Table 2**  
Multi-level Model Results (DV = log-transformed sold prices in Canadian dollars).

Parameter	Attached Houses			Apartment Properties		
	(1)	(2)	(3)	(4)	(5)	(6)
<b>Fixed</b>						
Intercept	9.7090 (0.2069) **	9.6910 (0.2059)***	9.6983 (0.2072)***	7.3052 (0.2035)***	7.3179 (0.1969)***	7.3184 (0.2009)***
<b>Structural Characteristics (H)</b>						
Total Floor Area (ft <sup>2</sup> ) (log-transformed)	0.4200 (0.0240)***	0.4203 (0.0240)***	0.4207 (0.0241)***	0.7820 (0.0194)***	0.7823 (0.0194)***	0.7823 (0.0194)***
Building Age	-0.0152 (0.0013)***	-0.0151 (0.0013)***	-0.0151 (0.0013)***	-0.0230 (0.0006)***	-0.0229 (0.0006)***	-0.0229 (0.0006)***
Building Age (squared)	0.0002 (2.20E-5)***	0.0002 (2.20E-5)***	0.0002 (2.20E-5)***	0.0002 (8.13E-6)***	0.0002 (8.15E-6)***	0.0002 (8.15E-6)***
Number of Bedrooms	0.0495 (0.0069)***	0.0495 (0.0069)***	0.0495 (0.0069)***	-0.0331 (0.0108)***	-0.0332 (0.0108)***	-0.0332 (0.0108)***
Number of Bathrooms	0.0470 (0.0083)***	0.0471 (0.0083)***	0.0470 (0.0083)***	0.0612 (0.0122)***	0.0611 (0.0122)***	0.0611 (0.0122)***
Number of Garaged Parking	0.1119 (0.0083)***	0.1119 (0.0083)***	0.1118 (0.0083)***	0.1153 (0.0227)***	0.1154 (0.0227)***	0.1154 (0.0227)***
Distance to City Hall (km)	-0.0279 (0.0046)***	-0.0278 (0.0045)***	-0.0280 (0.0046)***	-0.0170 (0.0055)***	-0.0172 (0.0054)***	-0.0172 (0.0054)***
<b>Transit Accessibility (T)</b>						
Distance to the nearest LRT station (m)	3.46E-5 (1.73E-5)**	3.47E-5 (1.73E-5)**	3.47E-5 (1.73E-5)**	1.71E-6 (1.98E-5)	1.19E-7 (1.97E-5)	1.02E-7 (1.97E-5)
<b>Neighborhood Characteristics (N)</b>						
Population Density (persons/km <sup>2</sup> )	0.0018 (0.0010)*	0.0019 (0.0010)**	0.0019 (0.0010)*	7.47E-5 (0.0006)	0.0004 (0.0006)	0.0004 (0.0006)
Percent of Visible Minority (%)	-0.0044 (0.0011)***	-0.0044 (0.0011)***	-0.0043 (0.0011)***	-0.0031 (0.0013)**	-0.0038 (0.0013)***	-0.0038 (0.0013)***
Median Household Income (1,000 CAD)	0.0025 (0.0005)***	0.0025 (0.0005)***	0.0025 (0.0005)***	0.0017 (0.0006)***	0.0017 (0.0006)***	0.0017 (0.0006)***
Crime Count (per year)	-0.0069 (0.0017)***	-0.0074 (0.0017)***	-0.0073 (0.0017)***	-0.0019 (0.0009)**	-0.0020 (0.0009)**	-0.0020 (0.0009)**
Walk Score (0–100)	0.0017 (0.0013)	0.0019 (0.0013)	0.0019 (0.0013)	0.0047 (0.0017)***	0.0037 (0.0017)**	0.0037 (0.0017)**
<b>City Center Location (Dummy)</b>	0.3723 (0.1290)***	0.4164 (0.1359)***	0.4083 (0.1383)***	0.1361 (0.0703)*	0.1038 (0.0706)	0.1037 (0.0714)
<b>Station Area Characteristics (S)</b>						
Land use entropy (0–100)	-0.0003 (0.0009)		-0.0003 (0.0009)	-0.0010 (0.0009)		-1.27E-5 (0.0010)
Activity opportunity count (0–700)		-0.0002 (0.0002)	-0.0002 (0.0002)		0.0002 (0.0001)**	0.0002 (0.0001)*
<b>Random</b>						
Residual (within group)	0.0204 (0.0009)***	0.0204 (0.0009)***	0.0204 (0.0009)***	0.0228 (0.0008)***	0.0228 (0.0008)	0.0228 (0.0008)
Intercept (between group)	0.0162 (0.0029)***	0.0161 (0.0029)***	0.0161 (0.0029)***	0.0178 (0.0031)***	0.0170 (0.0030)	0.0170 (0.0030)
-2 Log Likelihood	-900.880	-901.285	-901.386	-1429.570	-1432.467	-1432.467
Akaike's Information Criterion (AIC)	-864.880	-864.285	-863.389	-1393.570	-1396.467	-1394.467

Note: Values in parentheses are standard errors; \*\*\*  $p < 0.01$ ; \*\*  $p < 0.05$ ; \*  $p < 0.1$ .

building age and its quadratic term suggest property value tends to diminish with the building age up to a certain age of the building, but it increases at a slower rate afterwards. In terms of neighborhood characteristics, while the percentage of visible minority and the crime count tend to have negative impacts on the property values, the affluence of a neighborhood is likely to increase home values. While neighborhood walkability does not affect attached housing prices, the residents of apartments are likely to place value to the ease of walking around and within their neighborhoods. This could be one reason for the less significant coefficient for the city center dummy in Models for the apartment properties.

Interestingly, the distance to the nearest LRT station is positively associated with housing price for the attached houses. This indicates that attached houses located further from LRT stations may expect higher but marginal appreciation. Two explanations can be suggested. First, the residents of attached houses may use their automobile more frequently than the LRT because it is still the case in Calgary that the use of automobile is generally more convenient than the LRT, regarding travel time. Second, this is partly because of the nuisance generated near transit stations. Frequent transit services would increase pedestrian and vehicular traffic in the station areas, which can be perceived adversely by the residents. Hence, the attached houses too close to stations could see some depreciation. The distance to the nearest LRT station for the apartment properties, however, is not statistically significant in our models. This is partly due to that all apartment properties in our sample are located within the walkable distance (i.e., 1500 m).

The outcomes of station area characteristics are more interesting and contradictory to the existing knowledge. Both the land use entropy and the activity opportunity count for the attached houses appear to negatively relate to housing price although the coefficients are insignificant. The outcomes of the economic impacts of station area features are mixed for the apartment properties. While the land use entropy tends to affect the value of apartment properties negatively (but insignificant), the

activity opportunity count seems to influence positively the value of apartment properties nearby. In other words, the diverse land use around station areas does not appreciate the property value nearby, but the apartment properties within the proximity of a station with more activity opportunities could expect some appreciation in the case of Calgary. The insignificance and the directions of the impact of the station land use entropy are counter-intuitive, which requires further investigation. In the following sub-sections, we explore possible reasons for these outcomes and discuss the results of the statistical models from a different angle.

5.2. Land use entropy and activity opportunities around Calgary's stations

To further investigate the statistical outcomes that are not in line with the existing findings from other cities, we first examined land use entropy of individual stations. Table 3 lists the five most diverse and the five least diverse station areas in terms of land use diversity after excluding the downtown stations. Calgary's downtown, similarly, as seen in other cities, is primarily composed of commercial land use or mixed-use. Table 3 also provides land use maps of those stations and information about the proportions for individual land uses. Station areas with higher entropy exhibit heterogeneous land use, and those with lower entropy exhibit homogeneous land use. For instance, the Franklin station shows the highest land use entropy with well-balanced land uses that include commercial (12.8%), industrial (26.0%), institutional (4.8%), parks/recreational (12.9%), and residential (21.1%) uses. In contrast, 86% of the 45 St. SW Station area is residential use, and the remaining area is commercial and parks/recreational land.

Then, we listed stations by the number of activity opportunities in the respective 400-meter station buffers to see whether the rankings of stations by the land use entropy and the activity opportunity count show a similar trend. We also excluded the downtown stations because they

Table 3 Station Land Use Entropy (Top 5 & Bottom 5).

5 Most Diverse Stations				
Franklin	Lions Park	Banff Trail	39 Avenue	Marlborough
Commercial (12.8%); Industrial (26.0%); Institutional (4.8%); Parks and Recreational (12.9%); Residential (21.1%); Others (22.4%) – Entropy (71.76)	Commercial (30.6%); Industrial (0%); Institutional (2.8%); Parks and Recreational (16.0%); Residential (49.6%); Others (1.1%) – Entropy (67.84)	Commercial (25.1%); Industrial (0%); Institutional (0.6%); Parks and Recreational (23.0%); Residential (47.4%); Others (4.0%) – Entropy (63.89)	Commercial (17.5%); Industrial (53.9%); Institutional (0%); Parks and Recreational (3.9%); Residential (17.8%); Others (7.0%) – Entropy (62.46)	Commercial (47.7%); Industrial (23.9%); Institutional (0%); Parks and Recreational (0%); Residential (24.8%); Others (3.7%) – Entropy (62.43)
5 Least Diverse Stations				
Tuscany	McKnight Westwinds	45 St SW	Victoria Park/Stampede	SAIT/ACAD/Jubilee
Commercial (0.9%); Industrial (0%); Institutional (0%); Parks and Recreational (9.0%); Residential (29.1%); Others (61.0%) – Entropy (15.70)	Commercial (8.2%); Industrial (43.1%); Institutional (0%); Parks and Recreational (0%); Residential (1.3%); Others (47.5%) – Entropy (17.67)	Commercial (6.5%); Industrial (0%); Institutional (0%); Parks and Recreational (4.1%); Residential (86.1%); Others (3.3%) – Entropy (25.16)	Commercial (63.0%); Industrial (0%); Institutional (0%); Parks and Recreational (1.9%); Residential (11.8%); Others (22.2%); Mixed-use (1.0%) – Entropy (26.91)	Commercial (1.2%); Industrial (0%); Institutional (80.1%); Parks and Recreational (2.5%); Residential (9.3%); Others (7.0%) – Entropy (29.48)

Commercial Industrial Institutional Residential Parks and Recreation

have a much greater number of activity opportunities than the other stations. A substantially different list was generated and presented in Table 4. The ranks indicate an actual order within the 46 stations. Interestingly, the five stations with the highest land use entropy in Table 3 are ranked at relatively lower places with respect to the number of activity opportunities, suggesting that diverse land use is not necessarily a clear indication of a higher number of activity opportunities.

### 5.3. Examples of station area development in Calgary

To supplement the quantitative results discussed in the preceding sections, we observed selected stations. Although the land use entropy shows a great degree of mixed land use, the real practice may not work as anticipated. According to the entropy score, Franklin station has the most diverse land use, which means different land uses are well-balanced within the 400-meter radius of the station. However, we found that this station area does not provide many activities for pedestrians and transit users. As seen in Fig. 2, a church is located on the southwest side of the station and surrounded by a huge parking lot that is also used as a park-*n*-ride. The church can attract people during weekends, but it does not play a role as a destination for activity during weekdays. Furthermore, the commercial area on the northeast side of the station seems to be dominated by big franchise restaurants, which also offer a huge parking lot, and the northwest side of the station is mainly industrial that may not attract the public in a way to produce additional benefits on this land that could eventually impact the housing price in adjacent neighborhoods.

The Banff Trail station is another example of a station with diverse land use, but the area seems to be neither pedestrian-friendly nor desirable to walk around for several reasons. Motels dominate in the commercial area, and the small area on the northwest side of the station is utilized as a car dealership. The area designated as Parks and Recreational is mainly used for parking for those who visit the University's stadium (Fig. 3). Based on this observation, we found these station areas do not play a role as a community hub, although the station provides good accessibility to transit.

**Table 4**  
Number of Activity Opportunities around Station.

Rank	Station Name	Activity Count	Rank	Station Name	Act Count
8	<b>Marlborough</b>	229	29	Sunalta	29
9	Rundle	173	30	McKnight	26
10	Chinook	136	31	Westwinds	25
11	Sunnyside	130	31	Fish Creek – Lacombe Canyon	25
14	<b>Lions Park</b>	111	31	Meadows	25
15	Westbrook	103	34	Shawnessy	24
16	Victoria Park / Stampede	95	35	Saddletown	23
17	Downtown West – Kerby Station	81	36	Bridgeland / Memorial	14
18	Southland	78	37	Whitehorn	12
19	Dalhousie	76	38	SAIT/ACAD/ Jubilee	6
20	<b>39 Avenue</b>	73	39	Erlton / Stampede	4
21	Sirocco	57	40	Barlow / Max Bell	3
22	Somerset-Bridlewood	51	40	69 St SW	3
23	<b>Banff Trail</b>	46	41	45 St SW	1
24	Heritage	45	42	Shaganappi Point	0
25	Brentwood	44	42	Martindale	0
26	<b>Franklin</b>	37	42	Zoo	0
27	Anderson	33	42	University	0
28	Crowfoot	30	42	Tuscany	0

Another possible reason that made the diverse land use of station area inefficient could be the location of the station. Many of Calgary's LRT stations were built on expressways (or highways), which are illustrated in Fig. 4. Since these stations are in the middle of highways, transit users or pedestrians are required to use a pedestrian overpass to take a train or visit the other side of the station area. These elevated pedestrian bridges not only impair walkability within the area from the transportation perspective but also separate structures and levels and become a barrier from the land use perspective.

These stations were built without taking into consideration the activity in the public realm, and in many cases, the pedestrian experience is not welcoming and tends to feel isolated and unsafe. While in some cases there is a diversity of land uses, many of these land uses continue to be auto oriented with little to no contribution to a high-quality pedestrian environment.

## 6. Conclusions

In this study, we investigated the effect of LRT station area development on residential property values in Calgary, Canada, with a focus on land use diversity and activity opportunities. These indicators could appropriately capture the economic impact of station area features on housing prices by considering the aspects of potential commercial activities as well as land use diversity. Our results demonstrate that the higher land use entropy of station area is not necessarily associated with the higher value of non-detached residential properties nearby (i.e., attached houses and apartment properties) in the case of Calgary. We found that the lack of activity opportunities for pedestrians and transit users in the station catchment areas as well as poorly developed station areas could be reasons for the insignificant association between land use diversity and home value. However, more activity opportunities in and around LRT stations are likely to appreciate apartment properties nearby.

Based on our findings, we can draw several implications for TOD projects. In practice, land use is a key element of the built environment, which the planning profession uses extensively to regulate and structure cities. However, diverse land use is not a sufficient condition but rather a necessary condition for TODs to be successful. Our findings suggest that commercial activities associated with basic needs, social interaction, and recreation are ideal in proximity to LRT stations in the case of Calgary. To this end, station area land use should support a frequent and steady flow of customers, such as for grocery stores, coffee shops, pharmacies/drug stores, bakeries, flower shops, and food and drink establishment. Our findings are in line with the findings from the study of effective American TOD projects for an urban design where the authors argue that providing places for both permanent and occasional activities would be important in and around TOD areas (Jacobson and Forsyth, 2008). We believe that the findings of this study are applicable to TOD projects in other cities.

This study could also contribute to the literature in two respects. First, we used the business license data to measure activity opportunities within the vicinity of stations. This indicator could be an alternative or a complement to the traditional land use entropy, which has the inherent problem that ignores the fact that a certain land use (e.g., commercial) may have vertically denser usage with more activity opportunities than other land uses. Secondly, we modified the traditional land use entropy by assigning the full score to mixed land use, which is a diverse land use type by itself, and zero to other land uses (e.g., infrastructure, parking lots, or undeveloped areas) that are not likely to contribute to the diversity of land uses. We believe that the measures of station area features used in this study were able to consider both the macro (land use metrics) and micro (pedestrian experience) scale of the built environment to some degree.

Despite the contributions of our study, there are several limitations that need to be addressed in future research. First, we did not consider pedestrian facilities such as connections between places, sidewalks, and



Fig. 2. Franklin Station Note: Church (Left), Commercial (Middle), Parking Lot (Right).



Fig. 3. Banff Trail Station. Note: Motels (Left), Car dealership (Middle), Pedestrian overpass to the stadium (Right).



Fig. 4. Grade-separated Stations. Note: Franklin Station (Left) and Brentwood Station (Right).

crosswalks of station areas as well as activities possibly happening in public spaces near stations such as wandering, sitting, and gathering. Second, we only accounted for land use from broad categories. Future research would benefit from a further breakdown of subcategories and necessarily to look at a finer grain scale of land use. For example, commercial land use could be broken into retail, fast food, restaurant/café, groceries, fitness services, professional services, to name a few. Third, the impact of the proximity to the rail station may vary depending on the property type. We did not include single-family homes because of insufficient single-family home samples within the defined TOD areas in Calgary. However, other cities with a statistically meaningful number of single-family houses located close to light rail stations could complement our research by showing the influence of station area development on single-family homes, which is one of the most common housing types in North America. Finally, the sale transaction data were from the pre-pandemic period, and so different results might be obtained from the same analysis using data collected during the post-pandemic period.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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#### Authorship contributions

**Kwangyul Choi:** Conception and design of study, Acquisition of data, Drafting the manuscript, Revising the manuscript critically for important intellectual content, Approval of version of the manuscript to be submitted.

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