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High-rise apartment quality evaluation and related demographic factors: lesson from RentSafeTO programme

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ABSTRACT

With the rapid increase in urbanization and the number of residents living in high-rise apartment buildings, the quality of living environments in terms of the facility, safety and hygiene of high-rise housing has become an important topic. Although numerous studies have investigated occupant satisfaction through subjective assessment, only few studies have used objective assessment methods, such as expert evaluation, to elucidate the quality of high-rise apartments and the related occupancy factors. According to the dataset from Toronto's RentSafeTO programme, which provides the results for 9928 high-rise apartments evaluated using 20 quality indicators, this study conducted a factor analysis and identified two main factors for assessing high-rise housing: building structure and building facilities. Furthermore, this study used multiple regression models and census data to analyse the housing quality at the regional level. The results of social housing and private housing differed. Labour force attributes, education, immigration and ethnic origin significantly affected the quality of private housing. The results provide important directions for the post-occupancy evaluation of high-rise apartments. In addition, demographic factors significantly affected residential quality. This study provides a basis for the government to formulate equal and unbiased support for high-rise building maintenance and management.

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KEYWORDS
High-rise apartment; post-occupancy evaluation; facility management; demographic factors; maintenance policy

Introduction

Research background

Housing is a critical issue in building healthy and attractive communities; it fulfils vital individual needs, thereby affecting the quality of life, and it is relevant to ensuring human rights (Maliene & Malys, 2009). Suitable housing is more than a shelter, as it includes adequate living conditions; fair housing; safe, stable, reliable buildings and infrastructure; and a comfortable environment. It also includes proper maintenance, security, safety and several other factors that determine the suitability of a home for tenants (Zavadskas & Vilutienė, 2006). For a rapidly growing population, housing is also a significant challenge; rapid urbanization has led to housing shortage, and the standard solution is to construct high-rise buildings in metropolitan areas. For example, to accommodate 6.7 million people on 1102 km^2 of land, Hong Kong has developed a highly compact living environment characterized by high-rise apartment buildings, and new residential buildings of 50 or more stories are commonplace (Ho et al., 2008). Tall buildings account for 30% of residences currently under construction in London (New London Architecture, 2017). Between the 1950s and the early 1980s, several high-rise residential buildings were built in the inner city of Toronto, accounting for approximately 30% of Toronto's housing stock and 48% of Toronto's total rental housing stock (Poppe & Young, 2015).

The Council on Tall Buildings and Urban Habitat (CTBUH, 2022) defines a high-rise building as 14 stories or more, i.e. buildings taller than 50 m. The definition of a tall or high-rise building measured in metres or stories also varies by region or country (Mostafavi et al., 2021). For example, in Hong Kong, the standard defines a high-rise residential building whose upper story floor is more than 30 m above the stair discharge point at the ground level (Hong Kong Fire Services Department, 2005); in the UK, it is seven stories and above or 18 m and above (GOV.UK, 2022), and in Australia, it is higher than or equal to 8 stories (NSW Department of Planning, 2022). The literature suggests that high-rise buildings are less satisfactory than other forms of housing in terms of residents' experiences, satisfaction, preferences, social behaviour and mental health (Gifford, 2007). Residents of high-rise buildings are under more stress than residents of low-rise buildings owing to

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noise, lift accidents, crime, a feeling of isolation from the ground and anxiety regarding protection from accidents (Je & Lee, 2010).

To clarify the housing issues related to dense living, post-occupancy evaluation (POE) has been frequently used to systematically evaluate residential buildings (Carthey, 2006). POE has been used to evaluate built projects to improve their current conditions and guide the design of future buildings (Meir et al., 2009). Given the global trend of rural–urban migration and the development of urban residential construction, residential high-rise buildings have been the largest category of high-rise buildings studied via POE (Kalantari & Shepley, 2020). Table 1 summarizes recent studies on POE for high-rise housing, including the primary data analysis methods, research subjects, setting variables and research purpose and results. Of the eight studies included, four focused on sites in Asia and three focused on sites in Europe. Approximately half of the studies explored the relationship between variables using regression analysis, with three using logistic regression analysis and one using multiple regression analysis. Most of the studies ($n = 7$) used self-administered interview surveys and half ($n = 4$) of the studies identified similar indicators, such as satisfaction with living conditions, as key factors.

Residential satisfaction is an essential topic in the housing field. The term refers to a person's evaluation of the conditions of their living environment in terms of their needs, expectations and achievements; it has been identified as a critical indicator of how people view their overall housing and quality of life (Abdullah et al., 2020). Previous studies have shown that housing satisfaction is influenced by several housing, neighbourhood and personal attributes. Based on the American Housing Survey, it was found that public housing residents are more satisfied with their housing units than unsubsidized renters in a similar location (James, 2008). The residents' educational background, employment sector, gender and age were predictive of housing satisfaction (Ibem & Amole, 2012). A survey of immigrant satisfaction with public housing communities using a random sample of Wuhan renters showed that gender, age, education, occupation, income and household size all had adverse and significant effects on renters' satisfaction with their homes (Li et al., 2019). A surveyed in Amman city, Jordan found that high income and education levels were strongly associated with high satisfaction with housing quality attributes (Al-Betawi et al., 2021). Baker (2002) examined the results of the forced relocation of public housing tenants from metropolitan Adelaide and found that location characteristics were related to the residential satisfaction of public housing tenants. Therefore, we make the following hypothesis: private housing and social housing differ in living environment and the local demographic characteristics such as age, income, education level and ethnicity affect the quality of high-rise housing.

Although several studies have focused on the POE of high-rise residential buildings, they had some common limitations: First, most of the samples studied were based on a survey of selected residents, and large-scale data were rarely used. Second, the regional problems associated with high-rise residential buildings and the related facilities were not analysed. Third, most of them were based on data obtained via subjective methods such as questionnaires or interviews, which might be biased by sample selection, while studies using objective evaluation methods, such as expert scoring, are few. Therefore, it is necessary to broaden the knowledge of the quality of high-rise housing, considering the impact of regional factors in a more objective way using big data. This paper builds on the previous shortcomings by using Toronto as an example and analysing its high-rise apartment evaluation system to extract the key components of assessment system whilst also looking for the socioeconomic influences behind the assessment scores.

RentSafeTO building evaluation in Toronto

Housing stock is one of the most important real assets in any economy, and therefore, the allocation and pricing of the stock is an important determinant of both economic performance and consumer welfare (Halket et al., 2020). The rental housing stock can provide safe, secure and affordable housing for families who cannot afford or choose not to purchase houses. The number of high-rise buildings for rent in the Toronto Census Metropolitan Area (CMA) is staggering. Five or more stories are the norm for high-rise apartment buildings in Canada (Government of Canada, 2019). The CMA contains more than 1000 high-rise homes, accounting for ~27% of the total housing stock (Statistics Canada, 2011). Toronto's public and private rental accommodations are primarily in high-rise buildings. More than 30% of Toronto residents are renters, and this number continues to grow as many families, newcomers, older adults and vulnerable individuals reside in apartment buildings. The City of Toronto recognizes that access to quality, safe housing is an essential determinant of health and can improve an individual's social and economic status (RentSafeTO Program, 2021).

In Toronto, the removal of both the government and private sector from the production of rental housing and vacancy decontrol has created an enduring crisis

Table 1. Literature related to the POE of residential high-rise buildings in recent years.

Reference	Region	Method	Data	Variable	Purpose	Results
Brown (2015)	Toronto	Comparative analysis	Questionnaire survey of 165 residents of four high-rise residential buildings in Toronto	Indoor environmental quality, occupant comfort	Produced feedback on how occupants experience and behave in high-rise buildings	The air-conditioning system, envelope, balcony, hot water delivery system and noise control strategies are complementary strategies to improve the satisfaction
Jung et al. (2021)	Dubai	T-test and comparative analysis	Questionnaire survey of 573 residents of the Princess Tower, a high-rise residential building in Dubai	The health evaluation data from residents, the number of living floors and the indoor temperature and humidity condition	Evaluated the health of the residents of high-rise residential buildings in Dubai	The residence floor is irrelevant to overall health, changes in health status relative to the previous year and the daily assessment of illness health by the Todai Health Index
Bond et al. (2012)	Glasgow	Multivariate multinomial logistic regressions analyses	Questionnaire survey of 3911 residents in 15 deprived areas in Glasgow.	Socio-demographic factors, self-reported health and perceived housing and neighbourhood quality	Examined the relationship between the positive mental well-being and housing and neighbourhoods	For people living in deprived areas, the quality and aesthetics of housing and neighbourhoods were associated with mental well-being
Verhaeghe et al. (2016)	Belgium	Multilevel, binary logistic regression analyses	Used data from the Belgian Census of 2001, merged with the National Register of Belgium	Self-rated health, demographic characteristics, socioeconomic status, household composition, housing conditions and place of residence	Examined the relationship between living in high-rise buildings and self-rated health in Belgium	People living in high-rise buildings were significantly less likely to have good self-reported health than those living in low-rise buildings, but after the results were adjusted for socioeconomic and demographic variables, the negative relationship disappeared
Kearns et al. (2012)	Glasgow	Logistic regression analyses	Questionnaires and interviews with randomly selected 5151 cases from 14 social housing areas	Housing satisfaction and ratings of space, noise, security and condition; safety in the area at night-time; community cohesion; social aspects	Examined the impacts of living in high-rise buildings in comparison to other dwelling types	Living satisfaction was more likely to be poorer in high-rise apartments than in other apartments or houses. On average, high-rise residents had a weaker sense of community, higher rates of serious anti-social behaviour and lower levels of trust in their neighbours
Siu and Xiao (2015)	Hong Kong	Correlations and multiple regression	Questionnaire survey and interviews with 505 residents of two old districts in Hong Kong	The physical settings, the socio-demographic variables and the respondents' attitudes on recycling and living environments	Examined the quality of life in high-rise buildings in relation to sustainability	People's recycling behaviour was highly correlated with their perceived quality of life
Dwijendra et al. (2021)	Tehran	DEMATEL method	Questionnaire survey of 230 residents of the high-rise residential buildings of District 22 of Tehran	The most significant social impacts, the level of influence that each variable exerts on others	Examined the social effects of high-rise buildings on their inhabitants	Anti-social behaviour, lack of social cohesion and lack of social contact with neighbours were the most critical and influential impacts
Khoo et al. (2022)	Hong Kong	Analysis of variance and Ordinary least squares regression	Questionnaire survey of 400 occupants from two pairs of high-rise public rental housing estates	Electricity and water-saving behaviours, awareness of green fixtures/technologies and built environment satisfaction	Examined whether attaining green building certification has positive effects on awareness, behaviours and satisfaction	There was no significant impact of certified green buildings on occupant environmental behaviours and satisfaction

in housing affordability. Vacancy liberalization has resulted in significant rent increases in Toronto, with 43.5% of rental households paying more than they can afford (i.e. more than 30% of their income) as of 2015 (August & Walks, 2018). Many low income, mostly racialized, immigrant and lone-mother-headed families were evicted because they could not afford to pay rent. They might have no choice but to move into ageing high-rise buildings in Toronto's postwar suburbs (Paradis et al., 2014). In 2015, more than 80,000 households were waiting for social housing, with an average waiting period of 8.4 years (ONPHA, 2016). With housing

affordability rapidly deteriorating and a shortage of social housing, the Toronto administration is under pressure to provide more affordable housing (Zhang, 2019).

Most studies on Toronto's housing focused on affordability, while the quality of the housing, especially the living condition of the high-rise apartments is missing. According to the HousingTO 2020–2030 Consultations report, the ageing of numerous Toronto's high-rise buildings is a significant concern for renters and landlords. More than 1000 high-rise rental towers were built between the 1950s and the 1980s, with a growing risk of building system failures and pest infestations. Participants observed that poor maintenance and cleanliness standards could affect tenants' health and exacerbate accessibility issues. The conditions of the ageing buildings are further worsened by climate change. Under hot summers and more extreme weather conditions, tower residents are at risk of heat waves and power outages occur. The poor resilience of tower blocks can result in considerable costs to house owners, residents and the city; moreover, it can result in the displacement of hundreds of residents for over a year, thereby affecting their physical and mental health. In Toronto, the tight rental market reflects a vacancy rate below 1% and limited construction of new rental housing. To address the resilience challenges of high-rise rental towers and prevent system failures, Toronto has been implementing the RentSafeTO: Apartment Building Standards Program since 2017 (HousingTO, 2020–2030 Action Plan, 2018). Through assessment initiatives, RentSafeTO ensures that apartment building owners and operators meet building maintenance standards. The programme objective is to prevent the deterioration of critical housing stock, ensuring that tenants live in safe, well-maintained buildings and promoting the active maintenance of apartment buildings. The programme applies to all apartment buildings with three or more stories and 10 or more units, which make up 30% of Toronto's residents living in ~3500 apartment buildings across the city (RentSafeTO Program, 2021).

The City Council evaluates apartment buildings registered in the RentSafeTO service at least once every three years. A bylaw enforcement officer is assigned as zoning inspector to evaluate each building, and the officer notifies the owner/operator when a building requires evaluation. The zoning inspectors and zoning enforcement officers are expected to have a college degree as a civil engineer or architectural technologist or technician and several years of experience in law enforcement and/or construction of buildings or a related field (Government of Canada, 2022). During building evaluation, staff inspects common areas, mechanical and security systems, parking lots and external sites. The final evaluation score (from 0 to 100%) determines the subsequent evaluation date and whether the building must be audited. The apartment building evaluation results are available online. Landlords or operators should provide information and the evaluation results to prospective renters and tenants of the RentSafeTO programme (Toronto, 2018). Over the years, as more buildings have improved their evaluation scores and met the maintenance requirements, the number of audits per year has decreased. In 2021, the RentSafeTO team completed 1149 building evaluations, with an average building evaluation score of 77.6% (RentSafeTO Program, 2021).

Although several studies have applied the RentSafeTO programme to improve tenant satisfaction, only a few studies have analysed the scores corresponding to the quality of high-rise apartment buildings. The present study analysed the expert rating evaluation index of high-rise residential quality and explored the demographic and economic influencing factors. This study provides the basis for designing and managing high-rise residential buildings and their evaluation system. The objectives of this study are as follows:

(1) To examine the major components of the high-rise housing evaluation system.
(2) To explore the differences between the qualities of high-rise social housing and privately owned high-rise residential housing in Toronto.
(3) To identify the regional demographic factors influencing the quality of high-rise housing.

Methodology

Data source

Data of apartment building evaluation

The data for Toronto's apartment building evaluation were obtained from the City of Toronto's Open Data Portal (*Open Data Dataset*, n.d.). The dataset used in this research contained building evaluation scores for buildings registered with RentSafeTO. During the evaluation, bylaw enforcement officers inspected common areas, mechanical and safety systems, parking lots and exterior sites. Each item was inspected and assigned a score from one to five, with one being the lowest and five being the highest. An item that did not apply to the building at the evaluation time was not scored. There were 20 scoring items, namely entrance lobby, entrance doors, windows, security, stairwells, laundry rooms, internal guards handrails, garbage chute rooms, garbage bin storage area, elevators, storage

areas lockers, interior wall ceiling floor, interior lighting levels, graffiti, exterior cladding, exterior grounds, exterior walkways, balcony guards, parking area and other facilities. Furthermore, the dataset also provided basic information about the building, such as construction year, property type, ward and site address (*Open Data Dataset*, n.d.).

The data were categorized according to each building's ownership properties to identify variability in RentSafeTO evaluation scores for buildings with different properties. The buildings evaluated were classified into three categories according to their ownership status: owned privately, owned by the Toronto Community Housing Corporation (TCHC) or another assisted housing provider, and social or supportive housing provider. According to City Guidelines for Social Housing Providers in Toronto, TCHC is a category under social housing (*City Guidelines for Social Housing Providers*, 2017). Therefore, this study combined TCHC and an assisted, social, or supportive housing provider in the data into the social housing category. Through preliminary processing of the data, invalid data with missing information were removed and finally 9928 samples were obtained for analysis.

Table 2 provides an overview of the apartment building evaluation. Eighty-four per cent of the rated buildings were private housing, and 16% were social housing. The variation in the data range for each score was pronounced, but for some items, the variation in score was so little that more statistical methods were needed to determine the variability. The average score for private housing (72.5) was higher than that of social housing (72.1). The highest score for private housing was found for graffiti, with 4.65 points, and the lowest was for parking area, with 3.32 points. The highest score in social housing found on graffiti was slightly lower (4.25) than that for private housing, while the lowest score was 3.30, for stairwells. The variance in the overall score for social housing was lower than that of private housing and the variance of the total score for social housing was lower than that of private housing. Notably, the parking lot is the item with the lowest overall score, which indicates the poorer quality of parking spaces in high-rise condominiums.

Data of Toronto census

To correlate the evaluation scores of the apartment buildings and their demographic conditions, this study used Ward Profiles that included information from Statistics Canada's 2016 census using the 25-Ward model. Each Ward Profile provided a demographic and household profile, which included demographic information on population by age, households and dwelling types, families, language group, household tenure and period of construction; immigration, mobility, ethnic origin and visible minorities; education and labour force; income and shelter cost. Census consists of two questionnaires per year; a short questionnaire addressed to all households and a long questionnaire addressed to a sample of households containing more detailed questions. The figures in the tables were subjected to a confidentiality procedure known as 'random rounding' by Statistics Canada. Therefore, the number is randomly rounded to the nearest 5 or 10. This procedure is done to prevent the possibility of linking the data to any individual. The total for each table is the sum of

Table 2. Apartment building evaluation descriptive statistics.

Item	Total (n = 9927)				Private housing (n = 8335)				Social housing (n = 1592)			
	Mean	Sd.	Min	Max	Mean	Sd.	Min	Max	Mean	Sd.	Min	Max
SCORE	72.43	10.08	20	100	72.51	10.13	20	100	72.05	9.78	39	99
ENTRANCE_LOBBY	3.64	0.75	1	5	3.67	0.75	1	5	3.52	0.72	1	5
ENTRANCE_DOORS_WINDOWS	3.59	0.73	1	5	3.60	0.73	1	5	3.53	0.69	1	5
SECURITY	4.02	0.87	1	5	4.02	0.88	1	5	4.03	0.83	1	5
STAIRWELLS	3.40	0.76	1	5	3.42	0.76	1	5	3.30	0.79	1	5
LAUNDRY_ROOMS	3.51	0.76	1	5	3.51	0.77	1	5	3.53	0.72	1	5
INTERNAL_GUARDS_HANDRAILS	3.54	0.80	1	5	3.52	0.80	1	5	3.69	0.73	1	5
GARBAGE_CHUTE_ROOMS	3.49	0.81	1	5	3.53	0.80	1	5	3.40	0.81	1	5
GARBAGE_BIN_STORAGE_AREA	3.51	0.74	1	5	3.52	0.74	1	5	3.47	0.75	1	5
ELEVATORS	3.76	0.79	1	5	3.80	0.80	1	5	3.61	0.73	1	5
STORAGE_AREAS_LOCKERS	3.54	0.75	1	5	3.54	0.75	1	5	3.56	0.75	1	5
INTERIOR_WALL_CEILING_FLOOR	3.45	0.74	1	5	3.46	0.75	1	5	3.35	0.72	1	5
INTERIOR_LIGHTING_LEVELS	3.57	0.85	1	5	3.55	0.87	1	5	3.66	0.72	2	5
GRAFFITI	4.58	0.77	1	5	4.65	0.71	1	5	4.25	0.97	1	5
EXTERIOR_CLADDING	3.49	0.69	1	5	3.47	0.69	1	5	3.58	0.69	1	5
EXTERIOR_GROUNDS	3.56	0.70	1	5	3.58	0.71	1	5	3.49	0.67	1	5
EXTERIOR_WALKWAYS	3.57	0.71	1	5	3.57	0.72	1	5	3.61	0.65	1	5
BALCONY_GUARDS	3.68	0.80	1	5	3.70	0.81	1	5	3.60	0.75	1	5
WATER_PEN_EXT_BLDG_ELEMENTS	3.61	0.73	1	5	3.60	0.73	1	5	3.68	0.70	2	5
PARKING_AREA	3.34	0.73	1	5	3.32	0.74	1	5	3.41	0.69	1	5
OTHER_FACILITIES	3.92	0.78	1	5	3.99	0.81	1	5	3.83	0.74	1	5

SD. means standard deviation.

the various demographic characteristics in the table provided by Statistics Canada, each of which may be randomly rounded. Therefore, owing to random rounding, the totals in any table may differ from the region's total population reported by Statistics Canada (*Ward Profiles*, 2018).

There was significant variation in total population between wards. Hence, the data for each demographic characteristic were divided by the total population for that indicator, then the proportion of the total population within each ward was obtained. The data were initially processed to eliminate very small demographics from the sample and filter out demographics suitable for describing the constituency population. Finally, 291 demographic factors were compiled for the survey.

Pearson correlation coefficient was used to calculate the correlation coefficients between the mean apartment evaluation score and 291 demographic factors in each region. The top 23 demographic factors with the highest correlation coefficients were selected and classified into six broad categories according to the classification of population indicators in Canada: labour force, education, income and housing costs, migration, mobility and languages. Ethnocultural and Dwellings, with the number of factors being 4, 2, 2, 10, 2 and 3, respectively. Details of the selected factors are provided in Table 3.

Statistical analysis

As shown in Figure 1, there were several main steps in this study. In stage one (i.e. the data preparation phase), outliers and empty values were deleted, evaluation data were classified according to building ownership attributes, and census data were converted to the percentage of the total population of the indicator for each demographic feature. In stage two (i.e. the exploratory analysis phase), the data were assessed via descriptive statistics, and one-way analysis of variance (ANOVA) was used to determine whether any difference existed in the private and social housing assessment results. Afterward, an exploratory factor analysis of the rating items in the RentSafeTO apartment evaluation was performed to determine the potential structure of the rating indicators. The census data were correlated with the average rating of each ward to filter out less relevant factors. In stage three (i.e. the correlation analysis phase), after the extraction of the demographic factors, the evaluation data were used as dependent variables, and the screened demographic factors were used as independent variables for multiple linear regression (MLR). The demographic factors were screened out using the Akaike information criterion (AIC) to solve the multicollinearity problem. In stage four (i.e. the knowledge discovery phase), the

Table 3. Demographic factors selected.

Factors	Census variables
Labour Force	
Occupations	1 Business, finance and administration occupations
	2 Natural and applied sciences and related occupations
	8 Natural resources, agriculture and related production occupations
Place of work status for the employed labour force aged 15 years and over in private households	Worked outside Canada
Ethnocultural	
Ethnic origin for the population in private households	Latin, Central and South American origins
	Asian origins
Education	
Highest certificate, diploma, or degree for the population aged 15 years and over in private households	Certificate of Apprenticeship or Certificate of Qualification
	University certificate or diploma below bachelor level
Income and Shelter Costs	
Household total income groups in 2015 for private households	$20,000 to $24,999
Total income groups in 2015 for the population aged 15 years and over in private households	$40,000 to $49,999
Migration, Mobility & Languages	
Mother tongue for the population in private households	Non-Aboriginal languages
	English
Selected places of birth for the immigrant population in private households	Asia
	Americas
	Europe
Selected places of birth for the recent immigrant population in private households	Asia
	Americas
	Africa
Dwellings	
Tenure (includes band housing)	Owned
	Part of a condominium
	Rented
	Not part of a condominium
Occupied private dwellings by period of construction	1960 or before

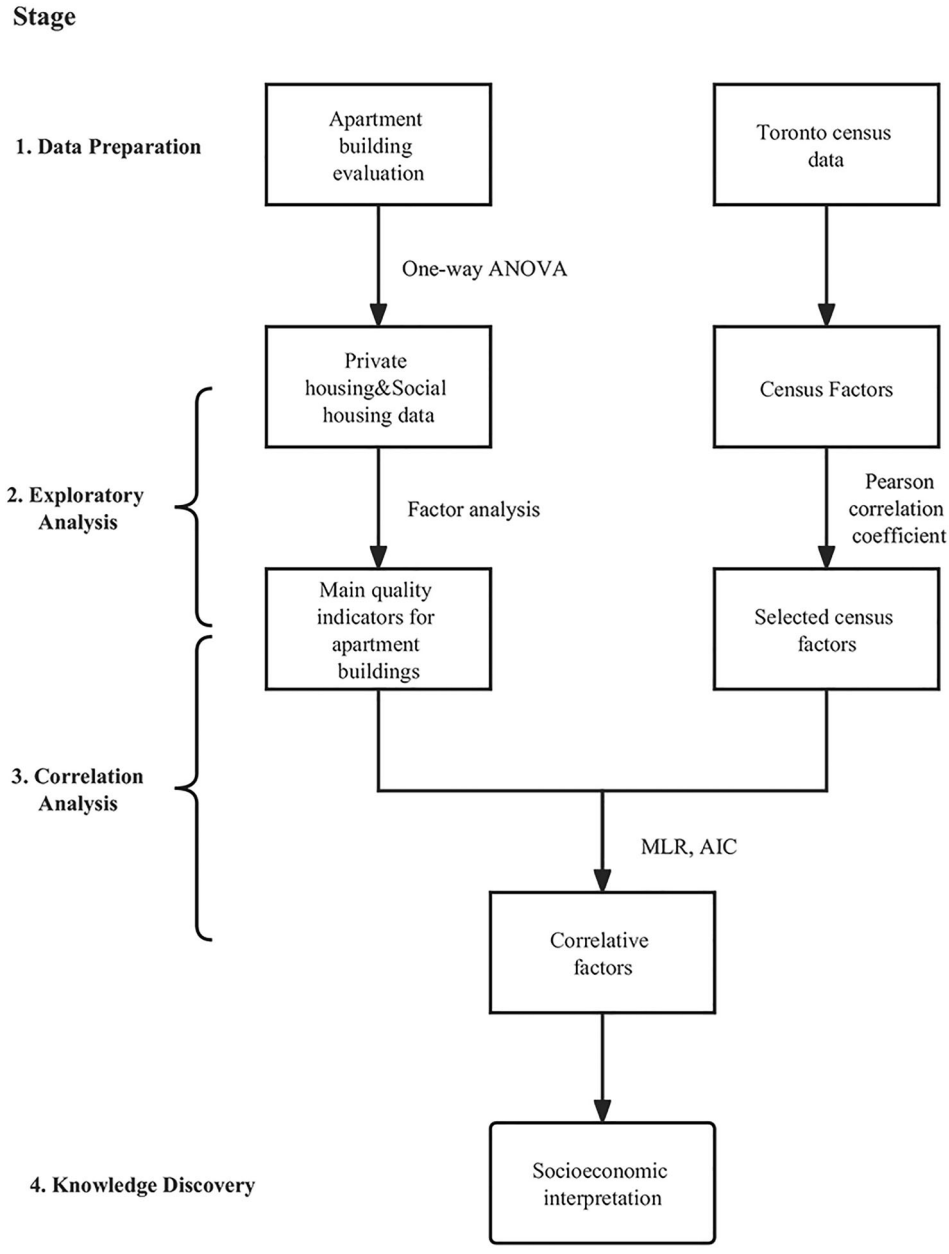

Figure 1. Analytic framework.

socioeconomic interpretations of previous studies were reviewed, the data analysis results were discussed, and the relevant conclusions were drawn. The analytical techniques are detailed in the following sections.

Factor analysis

The RentSafeTO building evaluation system has 20 scoring items, which are difficult to analyse as variables owing to the large number of combinations required. Consequently, this study used exploratory factor analysis and adopted the factanal() function in the package 'psych' in Rstudio (a programming language for statistical computing and graphics) to determine the number of extraction factors via the maximum likelihood estimation method. Then, the factanal() function was used to rotate the extracted factors using varimax rotation to reduce the number of factors (Beaujean, 2013). Exploratory factor analysis (EFA) can analyse the data sets, summarize their salient features, reduce the multicollinearities and condense the variables into conceptually related and statistically related groups (Sant'Anna et al., 2018). EFA can be used to develop a scale to measure satisfaction with the residential environment (Adriaanse, 2007), and to extract the essential sub-domains that affect satisfaction (Bougouffa & Permana, 2017). The objective was to explore the hidden structure in the RentSafeTO building evaluation system.

Factor analysis is an interdependence statistical technique designed to determine the number and nature of latent variables or factors that explain the variation and covariance in a set of practical measures (Brown, 2015). There are two types of common factor analysis: confirmatory factor analysis and explanatory factor analysis (EFA). EFA is used when researchers have no clear or relatively complete expectations of the relationship structures (Rogers, 2022). There are several commonly used methods for quantifying EFA factors: the Kaiser–Guttman rule, the scree test and the parallel analysis (Fabrigar et al., 1999). Since no method is fail-safe, it seems reasonable to apply multiple criteria. Fabrigar et al. (1999) recommended the combination of the scree test and parallel analysis to identify the appropriate number of factors. If the common factors are extracted via the maximum likelihood method, the number of potential variables can be determined more naturally using model test results and additional fitting indicators(Fabrigar et al., 1999; Schulze et al., 2015).

One-way ANOVA

ANOVA is a statistical method that is used to compare the differences between the mean value of two or more groups (St»hle & Wold, 1989). It uses a probability distribution to measure the variance. In statistics, the *p*-value refers to the probability, assuming the null hypothesis (H_0) is correct, that the test statistic equals the observed value or a value even more extreme in the direction predicted by the alternative hypothesis (H_1). H_0 proposes that there is no difference between the groups studied, while H_1 proposes that a difference exists. The *p*-value is used as an indicator for rejection according to the significance level of the results. The significance level (α) is the probability of rejecting the null hypothesis when it is true. For example, an α of 0.05 indicates a 5% risk of inferring that a difference exists when there is no actual difference. Thus, a smaller *p*-value implies that there is stronger evidence to support H_1 (Alassaf & Qamar, 2020). ANOVA can be used to test for between-group differences in residential satisfaction (Chen, 2012). The study used one-way ANOVA to determine if a difference existed between private and social housing scores. *P*-values less than 0.05 were considered statistically significant.

Demographic factors screening

Since there are numerous demographic factors, screening out those with little impact is essential. To calculate the correlation coefficient between the building evaluation score and the demographic factors, Eq. (1) is used (Yuan & Tao, 2016):

$$\mathrm{Correl}(X, Y) = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \quad (1)$$

where Correl(x,y) = −1, 1 indicates completely negative and positive correlation, respectively; and Correl(x,y) = 0 indicates no correlation at all. In addition, the larger the value of $r(x,y)$, the more the similarity between x and y. (Zhang et al., 2020).

Since the total number of variables (wards) was 25, the number of independent variables cannot exceed 23 for multivariate linear regression analysis. Therefore, we selected the top 23 demographic factors with the most significant correlation coefficients. The second-round screening was conducted using the 'step' function in Rstudio. The 'step' function selected factors through the AIC, which was also used for model or factor selection. In the comparison of models fitted via maximum likelihood, a smaller AIC corresponds to a better fit. The AIC equation is as follows (Mao & Shang, 2018):

$$\mathrm{AIC} = k \cdot \log(\mathrm{var}(x(1, k))) + (N - k - 1) \cdot \log(\mathrm{var}(x(k + 1, N))) \quad (2)$$

where k is an index equal to 1 to N, N is the total length of the time series and var(x) denotes the variance function. The value AIC (k) has a global minimum (Gui et al., 2020).

MLR

MLR is a generalization of the simple linear regression model. It explains the mutual effects of dependent variables on independent variables. MLR analysis is widely applied to assumptions in economics, finance, behavioural science and business administration (Flores-Sosa et al., 2022). Several prior studies have used the MLR to examine the association of socio-demographic variables with residential satisfaction (Fernández-Carro et al., 2015; Mohit et al., 2010; Potter & Cantarero, 2006; Rojo Perez et al., 2001). This study used MLR to explore the demographic factors determining regional rental housing quality. A series of demographic factors with the smallest AIC were selected as independent variables. The multivariate linear regression method was used to determine the main demographic factors affecting the score based on the average apartment evaluation score and factors extracted after factor analysis in each ward. The relationship between the selected demographic factors and apartment evaluation scores was established via MLR in Rstudio. With the assumption that k factors are selected, the MLR model can be

expressed as

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n + \varepsilon \quad (3)$$

The output of the MLR model between demographic factors and apartment evaluation scores showed the regression coefficients. 'β' in the above equation denotes the parameter 'Estimate' and it means the impact each factor has on the score. The p-value represents the significance of the MLR model. The regression model is statistically significant at a p-value less than 0.05. R-squared represents the proportion of the variance of the dependent variable that is explained by a linear model. The closer the R-squared to 1, the more the model matches the data (Gui et al., 2020).

Results

Apartment building evaluation system

Figure 2 shows box plots and the results of variance tests for each apartment evaluation item score and construction year of private housing and social housing. A significant difference exists between the scores of private housing and social housing for the different items, except for laundry rooms, security and storage area rockers, whose scores are not significantly different ($p > 0.05$). The statistically significant difference confirms that the private and social housing scores differ. These results suggest that analysing buildings according to private and social housing ownership attributes is reasonable. The following items exhibit the most significant differences: construction year, entrance lobby, entrance door windows, stairwells, internal guard handrails, garbage chute rooms, storage areas lockers, interior wall ceiling floor, interior lighting levels, graffiti, exterior cladding, exterior grounds, balcony guards, parking area and other facilities ($p < 0.001$). The difference in 'storage area rockers' is the least significant. No statistically significant differences exist between the 'security' of social housing and private housing.

Exploring scoring items through factor analysis

Factor analyses of the apartment building evaluation system with 20 scoring items were conducted using tilt rotation (direct tilt). The Kaiser–Meyer–Olkin (KMO) criterion confirms that factor analysis is applicable to the sample. The KMO value used for analysis is 0.76, which is regarded as mediocre, and all KMO values for individual variables are >0.54, above the 0.5 limit. The Barteltt sphericity test χ 2 (66) = 622.667, $p < 0.01$, indicates that the correlations between variables are sufficiently large to allow for factor analysis. First, the analysis was performed using the fa.parallel() function in Rstudio to generate eigenvalues for each component of the data and a scree plot (Figure 2) Two components based on the scree plot were combined with the actual selection. The two extracted components account for 74% of the variance. Table 4 shows the factor loadings after rotation using the factanal() function in R studio (Below et al., 2012).

The variables with high loading on the same components indicate that component one represents the building main structural factors, including entrance lobby, entrance doors, windows, security, stairwells, laundry rooms, internal guard handrails, interior wall ceiling floor, interior lighting levels, exterior cladding, exterior grounds, exterior walkways, balcony guards and water penetration of external elements. Component two represents the building facility factors, including garbage chute rooms, garbage bin storage area, elevators, graffiti, parking area and other facilities. Each factor loading shows positive coefficients. The average sum of the scores of items with the same components was used as the new dependent variable. Thus, we obtained two main public factors to explain the scoring indicators.

Factor 1: Building main structure, or primary features of the building, such as entrances, security, stairs, interior finishes, exterior facades and other significant parts of the building.

Factor 2: Building facility, such as elevators, trash chute rooms, exterior graffiti, parking and other building amenities (Figure 3).

Regression analysis results

The scores of building main structure and building facility were used as dependent variables, while 23 screened demographic factors as independent variables. The MLR result for each factor filter is shown in Tables 5 and 6. The p-values of the regression models for each score of private housing evaluation and the demographic factors are< 0.05, and the R-squared ~0.95, suggesting that these regression models fit the data well. However, the regression models of social housing evaluation scores with demographic factors have p-values >0.05 and the R-squared ~0.5, suggesting that the regression models do not match the data well. In Toronto, applying for social housing requires several conditions; for example, at least one family member must be over 16 years, be able to live independently without parental supervision, and have legal status in Canada. The applicant's household income should be below a certain threshold, and the applicant should pass income verification and rent payability assessment

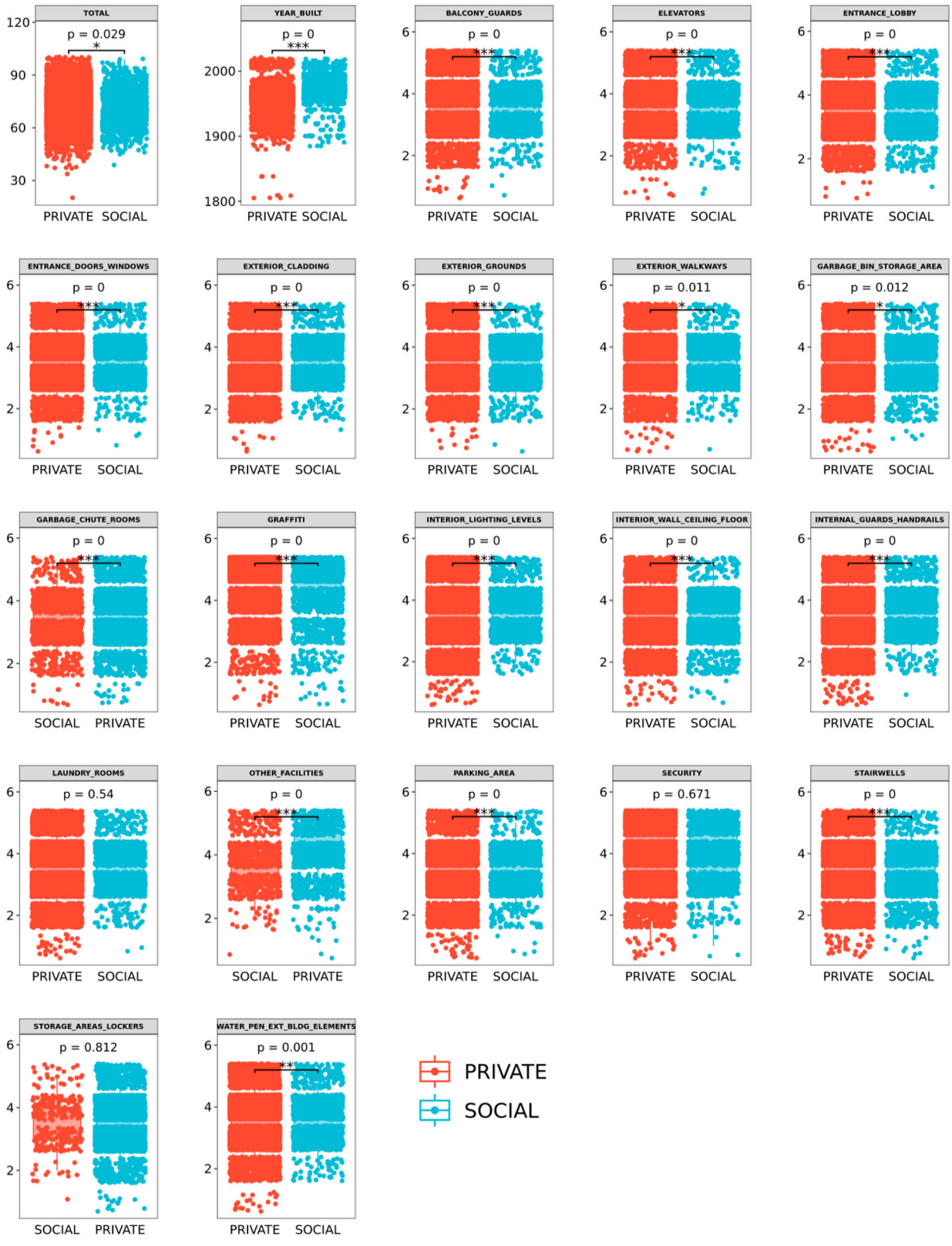

Figure 2. Variance test of evaluation score (Each box-plot illustrates the statistical distribution of the apartment building evaluation results).

(*Market Rent*, n.d.). Thus, the demographic characteristics of social housing residents do not considerably differ between wards compared with those of private housing residents, leading to little correlation between the evaluation scores of social housing and the demographic factors of each ward.

Table 4. Pattern matrix.

Variable	Rotated factor loadings	
	Building	Facilities
ENTRANCE_LOBBY	**0.837087825**	0.504275066
ENTRANCE_DOORS_WINDOWS	**0.73499072**	0.546289932
SECURITY	**0.598869127**	0.575706624
STAIRWELLS	**0.704631605**	0.629475599
LAUNDRY_ROOMS	**0.784992004**	0.398140388
INTERNAL_GUARDS_HANDRAILS	**0.815702501**	0.315042022
INTERIOR_WALL_CEILING_FLOOR	**0.675399572**	0.583258707
INTERIOR_LIGHTING_LEVELS	**0.829627573**	0.408886338
EXTERIOR_CLADDING	**0.809275214**	0.247174765
EXTERIOR_GROUNDS	**0.705965612**	0.591367765
EXTERIOR_WALKWAYS	**0.809633677**	0.442295454
BALCONY_GUARDS	**0.718328593**	0.46729358
WATER_PEN_EXT_BLDG_ELEMENTS	**0.800856373**	0.182351617
GARBAGE_CHUTE_ROOMS	0.198670535	**0.977517447**
GARBAGE_BIN_STORAGE_AREA	0.462418136	**0.650600495**
ELEVATORS	0.522066156	**0.71096091**
GRAFFITI	0.194925486	**0.550729453**
PARKING_AREA	0.496737186	**0.509033026**
OTHER_FACILITIES	0.261098561	**0.572508031**

Regarding private housing, labour force and education exhibited the most significant overall impact on grades, with 'resource and agriculture' and 'Place of work status for the employed labour force: working outside Canada' having the most negative impact. Having an apprenticeship certificate has the most significant positive impact on scores. For each 1% increase in the number of people working in natural resources, agriculture and related production occupations, there is a 15.5-point decrease in the total building evaluation score, a 27.8-point decrease in the building principal part structure score and a 49.0-point decrease in the building facility score. The results indicate that the building evaluation scores are generally lower in blue-collar neighbourhoods. For each 1% increase in the number of people working outside Canada, the total building evaluation score decreases by 16.3 points, the building principal part structure score decreases by 15.2 points and the building facility score decreases by 8.6 points. People who work outside Canada are more likely not to use and maintain their homes for a long time, leading to lower scores.

Most of the factors screened out are related to migration, mobility and languages and ethnocultural characteristics. The proportions of second-generation immigrants and new immigrants in the overall population are negatively correlated with the scores, possibly because recent immigrants have much lower income and home-ownership ratios than non-immigrants (Edmonston, 2016). The proportion of immigrants, such as those from Asia and Europe, is positively correlated with the score, as the proportion of native speakers of English. According to the 2016 census data from Toronto, 46% of residents in the city have an unofficial language as their first language, 47% are immigrants and 48% are economic migrants. Consequently, most migrants have sufficient economic means to sustain

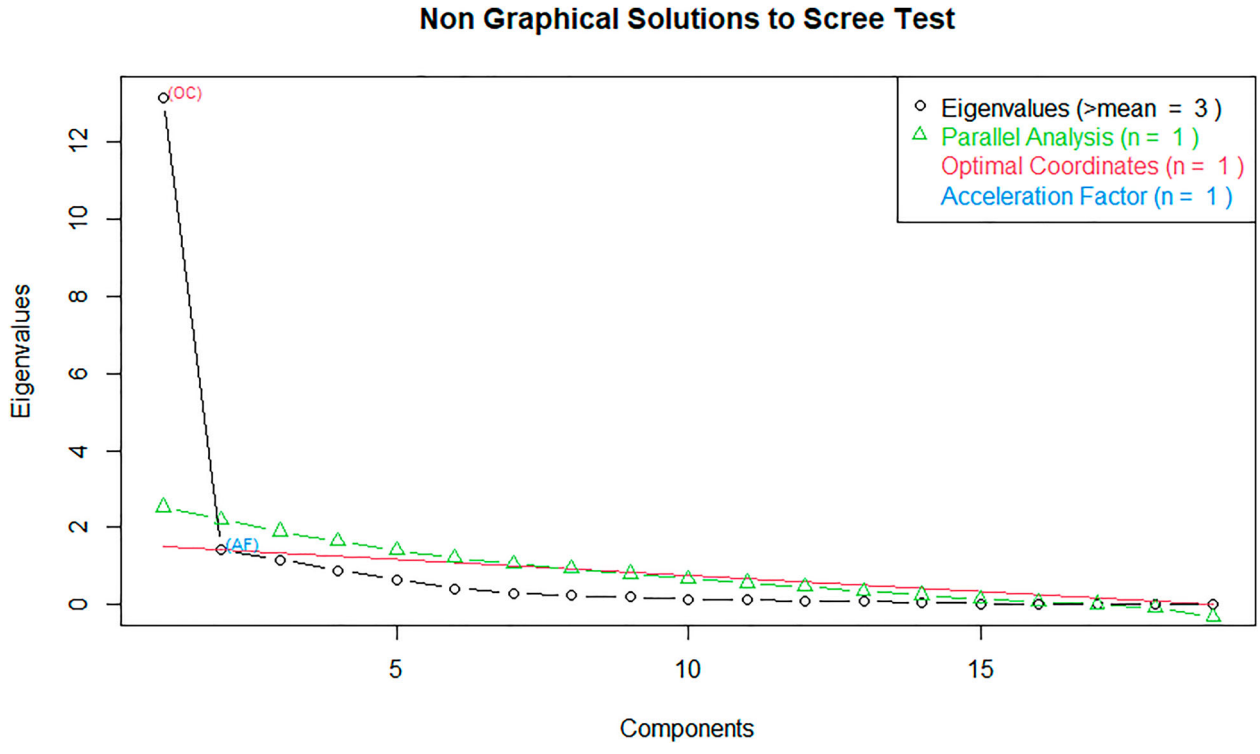

Figure 3. Non-graphical solutions to the scree test.

Table 5. Regression results: the demographic factors (with their coefficients) with the greatest influence on private housing.

Model 1 (Y = total score)	Model 2 (Y = building principal part structure score)	Model 3 (Y = building facility score)
Worked outside Canada (−1631.76 **)	Natural resources, agriculture and related production occupations (−2782.61*)	Natural resources, agriculture and related production occupations (−4907.67*)
Natural resources, agriculture and related production occupations (−1553.26)	Worked outside Canada (−1525.81**)	Certificate of apprenticeship or certificate of qualification (1481.81*)
Certificate of apprenticeship or certificate of qualification (1006.15)	Certificate of apprenticeship or certificate of qualification (1342.03*)	Worked outside Canada (−826.92*)
Household total income of $20,000 to $24,999 (−864.50*)	Household total income of $20,000 to $24,999 (−952.01*)	Mother tongue non-aboriginal languages (793.79*)
Mother tongue non−aboriginal languages (664.78*)	Mother tongue non−aboriginal languages (820.96*)	Mother tongue English (771.53*)
Mother tongue English (583.43*)	Mother tongue English (778.33*)	Household total income of $20,000 to $24,999 (−597.87*)
Business, finance and administration occupations (202.23*)	Groups with total income of $40,000 to $49,999 (−184.52*)	Business, finance and administration occupations (288.97**)
Natural and applied sciences and related occupations (197.19*)	Business, finance and administration occupations* (173.26)	Immigrant population from Asia (96.70*)
Groups with total income of $40,000 to $49,999 (−111.56)	Natural and applied sciences and related occupations (155.67*)	Generation status: second generation (−93.43)
Generation status: second generation (−78.73)	Immigrant population from Asia (92.79*)	Recent immigrant population from Asia (−85.49*)
Immigrant population from Asia (52.59)	Generation status: second generation (−67.87)	Groups with total income of $40,000 to $49,999 (−57.05)
Recent immigrant population from Asia (−17.41)	Recent immigrant population from Asia (−53.19)	Natural and applied sciences and related occupations (28.01)
Period of construction 1960 or before (16.04 *)	Period of construction 1960 or before (22.63*)	Period of construction 1960 or before (8.59)
p value = 0.01*	*p* value = 0.01*	*p* value = 0.01*
adj.r.squared = 0.96	adj.r.squared = 0.99	adj.r.squared = 0.96

***significance < 0.001; **<0.01; *< 0.05.

their homes and are committed to improving their homes.

Discussion

The study identifies two major factors for assessing the high-rise housing: the building main structure and the building facility. The findings can guide the construction of evaluation systems for high-rise residences. The previous studies shown in Table 1 used subjective data such as satisfaction as variable indicators. The majority of studies used subjective and dispersed indicators, while this study used more objective and systematic indicators. The analysis supports the hypothesis setting in 1.1 by showing statistically significant differences between social housing and private housing in

Table 6. Regression results: the most influence demographic factors (with their coefficients) for social housing.

Model 1 (Y=Total score)	Model 2 (Y=Building principal part structure score)	Model 3 (Y=Building facility score)
Certificate of apprenticeship or Certificate of qualification (1344.68*)	Certificate of apprenticeship or Certificate of qualification (891.04*)	Natural resources, agriculture and related production occupations (−2042.90)
Groups with total income of $40,000 to $49,999 (−899.95**)	Groups with total income of $40,000 to $49,999 (−461.42)	Certificate of apprenticeship or Certificate of qualification (1796.98)
Business, finance and administration occupations (324.86**)	Mother tongue English (326.48)	Mother tongue English (579.87)
Natural and applied sciences and related occupations (−168.68)	Mother tongue non−aboriginal languages (273.17)	Mother tongue non−aboriginal languages (561.61)
Generation status: second generation (−160.28)	Business, finance and administration occupations (265.18**)	Household total income of $20,000 to $24,999 (−461.26)
Immigrant population from Asia* (−111.21*)	Generation status: second generation (−132.88)	Groups with total income of $40,000 to $49,999 (−359.65)
Mother tongue English (97.14*)	Natural and applied sciences and related occupations (−125.50)	Business, finance and administration occupations (223.31)
Recent immigrant population from Asia (−88.26*)	Recent immigrant population from Asia (−112.07*)	Generation status: second generation (−149.31)
Period of construction 1960 or before (12.51)	Immigrant population from Asia (−99.97*)	Recent immigrant population from Asia (−110.49)
	Period of construction 1960 or before (20.18)	Immigrant population from Asia (−68.51)
		Natural and applied sciences and related occupations (−43.80)
		Period of construction 1960 or before (16.77)
p value = 0.07	*p* value = 0.13	*p* value = 0.30
adj.r.squared = 0.52	adj.r.squared = 0.49	adj.r.squared = 0.48

***significance < 0.001; **<0.01; * < 0.05.

overall scores and most evaluation items. The overall score for social housing is low, but the distribution is more concentrated because governments tend to provide basic amenities, services and maintenance for social housing. In contrast, private homeowners are more financially buoyant and tend to improve the quality of their housing. But those with lower incomes are often unable to adequately maintain their homes (Elsinga & Hoekstra, 2005), leading to higher mean scores but more significant internal disparities in private housing.

According to the analysis results, immigrants' place of origin, immigration time and generation significantly affect building evaluation scores. The proportion of new immigrants in the population negatively affects building evaluation scores. Since the early 1990s, many new immigrants have been attracted to older, high-rise apartment buildings in downtown Toronto. The growing demand for low-cost rental units and a socially induced housing shortage have left many immigrants in vulnerable situations and prolonged their stay in older high-rise apartments (Ghosh, 2014), which are of lower quality.

The proportion of residents whose native language is not English in the total population significantly affects the residential evaluation scores. The overall immigrant populations from Asia and America are positively correlated with the scores. The findings of the present study differ from previous studies. In the United States, a higher proportion of Blacks and Latinos was associated with lower satisfaction (Swaroop & Krysan, 2011). In the Netherlands, the proportion of non-Western minorities in the neighbourhood was associated with a lower level of satisfaction with the neighbourhood (Dekker, 2012). Canada is characterized by a diverse immigrant population, including millionaire families and poor refugees. In cities in which the foreign-born population (i.e. children born to immigrants) exceeds one-third (e.g. Vancouver) or two-fifths (e.g. Toronto) of the total population, they are generally not regarded as immigrants. A study of immigrants who arrived in Canada from 1961 to 1971 revealed that the immigrants had a problematic decade during which they faced various forms of deprivation. In the second decade, they became indistinguishable from others; and twenty years later, they had achieved more than an average person (Ley & Smith, 2000). Therefore, low income and quality of life in Toronto cannot be linked directly to immigration.

The present study also reveals that occupation significantly affects building evaluation scores. Particularly, blue-collar occupations related to natural resources, agriculture and production negatively affect the evaluation scores. Skilled occupations in business, finance, and administration and natural and applied sciences are positively associated with scores. Blue-collar workers tend to earn low incomes and mainly live in deteriorating working-class residences. In contrast, skilled traders have higher incomes and can afford high-quality residential environments.

However, apparent income has little effect on residential ratings. Only two income groups are associated with the scores: household total income groups (from $20,000 to $24,999) and total income groups (from $40,000 to $49,999), and the effects are not as significant as expected. In 2019, in the Toronto area (CMA), the poverty line was calculated as $49,304 for a family of four. Although the household total income groups (from $20,000 to $24,999) fall below the poverty line, other income groups below the poverty level were not significantly correlated with the score. The study's results are inconsistent with previous analyses by Frank and Enkawa (2009) using data from Germany, which found a positive effect of total income on residential satisfaction (Frank & Enkawa, 2009). Additionally, housing age has a negligible effect on building evaluation scores; only privately occupied residences constructed before or in 1960 are correlated with the scores, and the correlation coefficient is low, which differs from James' conclusion that the decrease in the age of the housing structure has positive spillover results on occupancy satisfaction (James, 2008). Furthermore, the age of the regional population is not significantly correlated with the score, which is in contrast to the results of many previous studies (Al-Betawi et al., 2021; Ibem & Amole, 2012; Li et al., 2019); hence the hypothesis is rejected. However, from previous analyses, it can be inferred that other important effects, such as migration time and occupation, indirectly affect building evaluation scores by affecting income and construction age. Therefore, studying the relationship between housing quality and the income status and age of regional residents is vital.

Conclusion

We systematically analysed apartment building evaluation data published by the Toronto RentSafeTO programme to clarify the relationship between high-rise housing quality and demographic variables for regional-level analysis. The demographic factors were screened, and a multivariate linear regression model of the relationship between housing quality and regional demographic characteristics was established. The statistically significant models showed that the selected

demographic factors explained and predicted the quality of habitation in the region.

The findings of the study have important implications for both theory and practice. In theory, it offers insights into the need for POE research to pay attention to ownership attributes, enriching the study of POE systems for high-rise housing, especially for objective evaluations, such as expert ratings, and proposes two main factors that constitute a holistic evaluation system for high-rise apartment buildings. In practice, the study can help managers selectively supplement the maintenance of residential buildings under different population and economic conditions to improve residents' satisfaction and provide designers with information on the impact of regional characteristics on the quality of residential buildings. Regional demographic characteristics are not considered in the current management system, and managers may develop different management and repair methods and use different assessment systems depending on the type of occupants. Overall, public housing is of low quality, and the government needs to improve the maintenance of public housing, i.e. housing for the low-income population, to promote equity. In addition, the results show that the parking lot quality of high-rise buildings is relatively poor, affecting the overall quality of life. There is a need to use some technical solutions to ameliorate this problem, such as three-dimensional garages. Given the trend of human concentration in high-rise buildings, there is a need to focus on the liveability of residential high-rise buildings. Further research is needed on the POE systems in high-rise buildings.

This study is limited in terms of the insufficient number and refinement level of the study areas. The study was based on generalizations from the demographic and economic characteristics of a large number ($n = 9928$) of housing environments in 25 wards, which limits the interpretation of some findings. Future studies should comprehensively analyse the demographic characteristics of different areas. The criteria for dividing the area from ward to ward need to be further narrowed down to explore the correlation between regional socioeconomic factors and high-rise housing quality.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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