

# **A quantitative assessment of expert-rated Smart City Development on quality of life in the United States**

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Smart City Development (SCD) is one of the most prevalent paradigms in urban planning in the developed world, emerging as a response to post-industrial demographic transformations. In developed countries, including the United States (US), urban population declined from the 1930s until the 1990s, owing to the demographic decline of populations born in these cities and the loss of many jobs requiring physical presence in urban areas. But, unexpectedly, the Shrinking Cities transformation stopped about three decades ago and first-world urban populations are once again increasing (Baudet-Michel and Paulus (2021); Frey (2024); Ministerio de Transportes, Movilidad y Agenda Urbana, DG de Vivienda y Suelo (2022); National Records of Scotland Web Team (2021)). On the other hand, in developing countries, there are large demographic shifts from rural to urban environments, replicating the earlier population flow experienced by the developed world in the early 20th century (United Nations, Department of Economic and Social Affairs, Population Division (2018)).

There is concern that an increase in urban densities could lead to a loss of quality of life (QoL), as witnessed in the West in the early 20th century. Despite significant changes in city zoning and building codes, recent cross-sectional observational studies indicate an inverse correlation between subjective well-being and population density in US cities (Winters and Li (2016)). On the other hand, similar studies conducted in Western Europe (Mouratidis (2019)) or focused on specific age cohorts (Okulicz-Kozaryn and Valente (2019)) suggest that this inverse correlation is not universally present. Several attempts to explain this discrepancy start assume the inclusion of Type II statistical errors, or epoch-specific idiosyncrasies within each sample. A third hypothesis attributes the difference between American and European density - QoL relationship to cultural differences, as captured by the witticism “Americans live to work, while Europeans work to live.” (Okulicz-Kozaryn (2011)) This approach suggests that culture-specific social structures facilitate Europeans’ higher tolerance for increased demographic density. A relevant implication would be that policies allowing Americans to live similarly to Western Europeans could improve the formers’ perception of high urban density.

SCD can be seen as a practical application of this corollary. Experts from both sides of the Atlantic believe that cities with shorter distances between key locations, public spaces facilitating

social interactions, accessible public transport, and green spaces tend to provide a better QoL at the same objective level of demographic density, compared to cities developed around the personal automobile or gated communities. Furthermore, they argue that an active effort to reshape cities from an individualistic to a more community-focused model would enhance urban residents' QoL (Caragliu, Bo, and Nijkamp (2011); Nivola (1999)). This trend toward community-oriented urban development is generally linked to the belief that the introduction of novel technologies, such as real-time monitoring, may counter potential urban decline. Within this framework, the European Commission (EC) has defined the smart city as “a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business.” (European Commission (2016)) Among the goals set by the EC for developing smart cities are the efficient use of local resources, pollution minimization, improved availability of public transportation, safe drinking water and sanitation infrastructure, energy-efficient lighting and heating, and streamlined citizen-authority interactions. In short, the European understanding of SCD stresses QoL improvement.

By contrast, in the US, the National Institute of Standards and Technology (NIST) defines SCD as “the effective use of digital technologies to deliver prioritized services and benefits to achieve community goals.” (Serrano et al. (2022)) In addition to improved services, NIST criteria for a smart city include the alignment of metrics and budget priorities with citizens preferences, investment optimization, and rich information streams. While these gauges can be useful in evaluating cities or city governments' efforts, the cost-effective structure of NIST's goals is notable. It is indeed intuitive that SCD evaluation should include a metric of public investment efficiency, but it is unclear how this efficiency can be measured in a smart way. For example, it is unclear whether an urban highway is a smart amenity. A highway is superior in terms of speed to a bicycle lane, but, at the same time, urban highways degrades the well-being of the supposed beneficiaries, to the point that, even in the US, housing near the highway is sold at a discount (Samuels and Freemark (2022)). According to the NIST definition, US urban planners were the first in the world to apply intelligent city management techniques, in 1970, when they used aerial photographs to assess the quality of Los Angeles' housing stock (Stübinger and Schneider (2020)). Again, it is not immediately obvious how this approach improved the quality of life of the residents of the city surveyed in this hi-tech manner. Arguably, in the US understanding of the term “smart city”, the purpose is subordinated to the process.

Between the concept of the smart city as defined by the EC and the one defined by the NIST, there exists a broad spectrum of definitions, ranging from those centered on QoL to those focused on the novelty of development methods. According to a recent European review (Bolívar (2019)), the various definitions encompass, with varying emphasis, “smart economy, smart people, smart governance, smart mobility, smart environment, and smart living”. Unfortunately, almost all the articles cited in this review offer definitions without applying them to concrete data, and, therefore, without quantitative scaling for any of the criteria. Such an approach makes it impossible to compare cities based on SCD indices, or even to appreciate dynamics within the same city. We are aware of only one study that provides quantitative evidence supporting the correlation between QoL and a numeric composite metric of SCD using the previously mentioned six domains (Wang and Zhou (2023)), but it is limited to China. A quantitative assessment of SCD in the US and the EU is urgently needed, given that its theoretical foundation - the hypothesis that a communal way of life is superior to an individualistic one in terms of QoL - appears accepted solely on axiomatic grounds, and yet it guides the development of several first-order urban centers (New York and Vienna, among others reviewed in Choi and Caicedo (2023)).

In this study, we analyze quantitatively the correlation between the SCD and QoL. SCD metrics were obtained from two European academic centers, the International Institute for Management

Development (IMD) in Lausanne and the Instituto de Estudios Superiores de la Empresa (IESE) in Barcelona. Both institutions host expert groups, who publish periodic world SCD city rankings, based on published, well-defined SCD criteria. Additionally, both sets of rankings include domain metrics, allowing identification of stronger and weaker SCD domains in the assessed cities. For general QoL rankings, we use, as a starting point, the scores from the well-known US News & World (USNW) report ranking US cities, based on quantitative and survey data. For a deeper understanding of QoL components, we use the publicly-available data from Numbeo.com, an online platform where anonymous resident ratings and several well-published indicators are combined, through specified formulas, into domain indices. The analysis was limited to US cities, primarily because a narrower geographic focus reduces potential cultural confounders, such as language differences in questionnaires and intercultural axiological differences.

## 1. Research hypotheses

H1. SCD metrics from IESE and IMD have a strong degree of correlation, indicating that they measure similar concepts.

H2. Domain SCD metrics for a city are largely correlated, indicating that local authorities pursue systemic rather than domain-specific improvements.

H3. SCD metrics from the same group of experts are correlated over time, indicating that local authorities show a persistent interest (or lack of interest) in SCD.

H4. QoL metrics from USNW and Number.com have a strong degree of correlation, indicating that they measure similar concepts.

H5. QoL metrics and SCD metrics correlate in cross-sectional analysis, demonstrating an effect of SCD-oriented policies on QoL in US cities.

H6. The correlation between QoL metrics and SCD metrics is domain-specific, with certain SCD domains (for example, smart transportation) showing stronger associations with QoL than others.

H6. The correlation between QoL metrics and SCD metrics is domain-specific, with certain SCD domains (for example, leisure time) showing stronger associations with QoL than others.

## 2. Data acquisition and processing

Ten US cities were evaluated in the most recent wave of the IMD Smart Cities Index, in 2023 (Bris et al. (2023)). The IMD data include an estimate of the Human Development Index (HDI) at city level, a survey on the top five Concerns of the resident population, and a survey on the Structures and Technologies supporting SCD. The latter assesses five domains: governance, health and safety, mobility, professional development opportunities, and leisure activities (copied from Bris et al. (2023) in Supplemental Table 1). The IMD methodology has been significantly changed several times, thus limiting the usefulness of its stability across time. The number of respondents is not specified, but it is stated to be representative. IMD data were semi-automatically transcribed from the document available at [imd.org](http://imd.org).

The SCD indicators obtained from IESE include solely a score and a rank. However, correlation between IESE scores with IMD scores would be supportive for the notion of a relative agreement

among experts, with regards to SCD metrics. Moreover, IESE criteria have been rather invariable, making IESE rankings useful in evaluation of eventual chronologic trends with regards to expert-generated SCD rankings. In 2024, the IESE criteria covered nine domains, namely human capital, social cohesion, economy, governance, environment, mobility, international profile, urban planning, and technology (copied from Berrone et al. (2024) in Supplemental Table 2). The IESE overall rankings and scores data were transcribed semi-automatically from documents published at [iese.edu](http://iese.edu), and cover 8 US cities assessed in IESE Cities in Motion 2014 (Berrone et al. (2014)), as well as 19 US cities in IESE Cities in Motion 2024 (Berrone et al. (2024)).

For QoL, we used USNW rankings, compiled by experts for over fifty years and highly influential in shaping American public perception (Bloom (2024)). In the Best Places to Live 2023-2024 rankings, QoL scores comprise 36% of the overall desirability score of a city. QoL scores are computed from metrics of subjective well-being, crime rates, education quality, commute quality, environment quality, and quality of healthcare services, with weights derived from US surveys (copied from “How We Rank the Best Places to Live and Retire” (n.d.) in Supplemental Table 3). USNW does not publish domain-specific QoL metrics. The overall QoL score was manually extracted from the Best Places to Live and Retire 2023 ranking (“Best Places to Live for Quality of Life, Ranked” (2023)), available at [usnews.com](http://usnews.com).

Since 2009, Numbeo.com has hosted a web platform where self-selected, anonymous users, authenticating with their email address, may rate cities across the world, based on criteria such as cost of living, cost of housing as a proportion of income, safety, healthcare services, climate, pollution, and commute burden. Although there are concerns regarding data quality, as with any internet-based survey, each of the studied cities has over 200 reviews, which reduces the impact of malicious responses. Moreover, in addition to survey data, Numbeo also incorporates a few official public data in the calculation of its composite indices (detailed, based on, in Supplemental Table 4). Numbeo is considered the best available source, especially for local prices, by major media outlets such as The Economist (L.S. (2013)), Forbes (Barrett (2010)), and The New York Times (Kugel (2016)). We manually collected overall QoL scores, as well as scores for its eight dimensions, from [numbeo.com](http://numbeo.com), as displayed in April 2024.

Although USNW and Numbeo.com provide QoL ratings for hundreds and, respectively thousands of US cities, the number of cities ranked by IESE and IMD is typically around 100 across the world. For the most part we analyzed data for all the 19 US cities featured the IESE 2024 rankings, but only 4 US cities (New York, Los Angeles, Chicago and Philadelphia) were assessed in all three reports used for this study.

```
library(readxl)
library(dplyr)
```

Attaching package: 'dplyr'

The following objects are masked from 'package:stats':

`filter`, `lag`

The following objects are masked from 'package:base':

`intersect`, `setdiff`, `setequal`, `union`

```

library(stringr)
library(purrr)
library(tidyr)

# List only sheets ending in IMD
sheets <- excel_sheets("data/rawdata.xlsx")
imd_sheets <- sheets[str_ends(sheets, "IMD")]

# Function to extract last positive number from first column
extract_percents <- function(sheet) {
  df <- read_excel("data/rawdata.xlsx", sheet = sheet)
  first_col <- df[[1]] # Take the actual first column, whatever its name
  tibble(percent = str_extract(first_col, "\\d+\\.?\\d*$")) %>%
    mutate(percent = as.numeric(percent)) %>%
    pull(percent)
}

# Apply to each sheet
results <- map(imd_sheets, extract_percents)

```

New names:

\* `` -> `...2`

\* `` -> `...3`

New names:

New names:

New names:

New names:

New names:

New names:

New names:

New names:

New names:

\* `` -> `...2`

\* `` -> `...3`

```

# Bind all results into one dataframe

```

```

results_df <- results %>%

```

```

  set_names(imd_sheets) %>%

```

```

  bind_rows(.id = "City")

```

```

# Rename columns generically

```

```

colnames(results_df) <- c("City", paste0("column ", sprintf("%02d", 1:(ncol(results_d

```

```

results_df

```

```

# A tibble: 64 x 10

```

	City	`column 01 IMD`	`column 02 IMD`	`column 03 IMD`	`column 04 IMD`
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
1	NA	NA	NA	NA	NA
2	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA

# i 54 more rows

# i 5 more variables: `column 05 IMD` <dbl>, `column 06 IMD` <dbl>,  
# `column 07 IMD` <dbl>, `column 08 IMD` <dbl>, `column 09 IMD` <dbl>

### 3. Discussions

More notably, a number of indices used by IESE are actually sourced from Numbeo.

#### A. Supplemental data

##### A.1. Supplemental Table 1. IMD Smart Cities Index 2023 components (copied from Bris et al., 2023)

###### Structures

- Healthcare and safety
  - Basic sanitation meets the needs of the poorest areas
  - Recycling services are satisfactory
  - Public safety is not a problem
  - Air pollution is not a problem
  - Medical services provision is satisfactory
  - Finding housing with rent equal to 30% or less of a monthly salary is not a problem
- Mobility
  - Traffic congestion is not a problem
  - Public transport is satisfactory
- Leisure
  - Activități din timpul liber
  - Green spaces are satisfactory
  - Cultural activities (shows, bars, and museums) are satisfactory
- Professional development opportunities

- Employment finding services are readily available
- Most children have access to a good school
- Lifelong learning opportunities are provided by local institutions
- Businesses are creating new jobs
- Minorities feel welcome
- Governance
  - Information on local government decisions are easily accessible
  - Corruption of city officials is not an issue of concern
  - Residents contribute to decision making of local government
  - Residents provide feedback on local government project

## Technologies

- Healthcare and safety
  - Online reporting of city maintenance problems provides a speedy solution
  - A website or App allows residents to easily give away unwanted items
  - Free public wifi has improved access to city services
  - CCTV cameras has made residents feel safer
  - A website or App allows residents to effectively monitor air pollution
  - Arranging medical appointments online has improved access
- Mobility
  - Car-sharing Apps have reduced congestion
  - Apps that direct you to an available parking space have reduced journey time
  - Bicycle hiring has reduced congestion
  - Online scheduling and ticket sales has made public transport easier to use
  - The city provides information on traffic congestion through mobile phones
- Leisure
  - Online purchasing of tickets to shows and museums has made it easier to attend
- Personal development opportunities
  - Online access to job listings has made it easier to find work
  - IT skills are taught well in schools
  - Online services provided by the city has made it easier to start a new business
  - The current internet speed and reliability meet connectivity needs”
- Governance
  - Online public access to city finances has reduced corruption
  - Online voting has increased participation
  - An online platform where residents can propose ideas has improved city life
  - Processing Identification Documents online has reduced waiting times

## Concerns:

- affordable housing
- air pollution
- basic amenities
- citizen engagement

- corruption
- fulfilling employment
- green spaces
- health services
- public transport
- recycling
- road congestion
- school education
- security
- social mobility
- unemployment.

## **A.2. Supplemental Table 2. IESE Smart Cities 2024 components (copied from Berrone et al., 2024).**

### Human capital:

- Proportion of population with secondary and higher education
- Number of public and private schools in the city
- Number of business schools in the city included in the Financial Times TOP 100
- Expenditure on education
- Expenditure on leisure and recreation
- Expenditure on leisure and recreation per capita
- International flow of mobile students at the tertiary level
- Number of museums and art galleries in the city
- Number of TOP 500 universities
- Number of theaters in the city

### Social cohesion:

- Variable that indicates whether a city provides a friendly environment for women (on a scale of 1 to 5).
- Number of public and private hospitals in the city
- Estimation of the general level of crime in a city
- Variable representing the national government's response to situations of slavery in the country.
- Variable representing ... overall happiness
- Gini Index
- Index measuring the level of peace/violence in a country or region.
- Estimation of the overall quality of the health care system, health care professionals, equipment, costs
- Variable indicating whether a city provides a friendly environment for the LGBTQ+ community
- Property price as a percentage of income.
- Rate of female employment in the public sector.
- Death rate per 100,000 city inhabitants.
- Unemployment rate (number of unemployed/labor force).
- Murder rate per 100,000 city inhabitants.
- Suicide rate per 100,000 city inhabitants.



- Number of terrorist incidents in the city in the last three years.
- Index of racial tolerance in a city.

#### Economy:

- Number of unicorn companies in the city
- Index ... higher for cities that have a more favorable regulatory environment for setting up and operating a local business.
- Ranking of startup ecosystems.
- Mortgage as a percentage of income is the monthly mortgage cost as a proportion of household income (the lower the better).
- The percentage of opportunity-driven early-stage entrepreneurs divided by the percentage of necessity-driven early-stage entrepreneurs.
- Number of headquarters of publicly traded companies.
- Number of Fortune 500 companies present in the city.
- Gross domestic product in millions of US dollars.
- Projected growth in gross domestic product for the next year.
- Gross domestic product per capita.
- Purchasing power in buying goods and services in the city (based on the average salary), compared to that of New York City residents.
- Labor productivity calculated as GDP/employed population (in thousands).
- Hourly wage in the city in US dollars.
- Number of calendar days needed to complete the procedures to legally operate a business.

#### Governance:

- Whether or not Bitcoin is legal in the city.
- Whether or not the city has ISO 37120 certification. Certified cities are committed to improving urban services and quality of life.
- Number of government buildings and premises in the city.
- Number of embassies in the city.
- Percentage of employed population working in public administration and defense; education; health; community, social and personal service activities; and other activities.
- Index supplementing the E-Government Development Index (EGDI), which focuses on the use of online services to facilitate provision of information by governments to citizens (“e-information sharing”), interaction with stakeholders (“e-consultation”), and engagement in decision-making processes (“e-decision-making”).
- Variable that reflects the human capacity dimension, which is one of the three dimensions that make up the EGDI (online service, telecommunication connectivity, and human capacity).
- Index that measures the degree to which collateral and bankruptcy laws protect the rights of borrowers and lenders and thus facilitate access to loans.
- Variable that reflects the development status of telecommunication infrastructure, which is one of the three dimensions that make up the EGDI (online service, telecommunication connectivity, and human capacity).
- Corruption Perceptions Index
- Variable that reflects the scope and quality of online services, which is one of the three dimensions that make up the EGDI (online service, telecommunication connectivity, and human capacity).
- Number of research and technology offices in the city.
- Whether or not the city has an open data system.

- Democracy Index - The top-ranked countries are the ones considered most democratic.
- Total reserves in millions of current dollars. City-level estimate based on population.
- Reserves per capita in millions of current dollars.

#### Environment:

- Index of pollution.
- Index of carbon dioxide emissions.
- Carbon dioxide emissions from fossil fuel use and cement production.
- Methane emissions caused by human activities such as agriculture and industrial methane production.
- Environmental Performance Index
- PM10, PM2.5 - air particulate pollutants
- Percentage of the population with reasonable access to an appropriate quantity of water resulting from an improvement in the supply.
- Renewable water resources per capita.
- Average amount of municipal solid waste generated annually per person (kg/year).
- Risk to the city due to climate change.

#### Mobility:

- Whether or not the city has a bicycle, moped or scooter rental service.
- Number of shared bicycles in the city.
- Number of metro stations in the city. Number of metro lines in the city. Length of the metro system in the city
- Index estimating traffic inefficiencies.
- Index of traffic and congestion in the city.
- Index that is estimated by considering time spent in traffic. It is assumed that travel time dissatisfaction increases exponentially beyond 25 minutes.
- Percentage of households with bicycles.
- Variable that shows whether the city has a high-speed train or not.
- Number of commercial vehicles in the city.
- Number of inbound flights (air routes) in a city.

#### Urban planning:

- Number of bike-rental or bike-sharing points, based on docking stations where they can be picked up and dropped off.
- Whether or not the city has a bike-sharing system.
- The number of completed buildings in a city.
- Electric car charging points in the city.
- Percentage of the urban population that uses at least basic sanitation services—that is, improved sanitation facilities that are not shared with other households.
- Whether or not the city has AI projects.
- Percentage of buildings classified as high-rises. A high-rise is a multi-floored building of at least 12 stories or 35 m in height (115 feet).
- Number of deaths in traffic accidents per 100,000 inhabitants.

#### International profile:

- Annual number of passengers per airport in thousands.
- Number of hotels per capita.

- The Restaurant Price Index compares the price of meals and drinks in restaurants and bars in a city to prices in New York City.
- Number of McDonald's outlets in the city.
- Number of international congresses and meetings held in a city.

#### Technology:

- Active mobile broadband subscriptions.
- Innovation Cities Index
- Percentage of households with Internet access.
- Percentage of households with a personal computer.
- Number of mobile phones per 100 inhabitants.
- Registered X users in a city (in thousands of individuals) + number of registered LinkedIn members in the city.
- Broadband subscriptions per 100 inhabitants.
- Percentage of households with some kind of telephone service.
- Fixed-line Internet speed in megabytes per second by country.
- Mobile speed in megabytes per second (country).
- Number of options for connecting to the Internet in a city.

### **A.3. Supplemental Table 3. Components of USNW QoL Scores (copied from How we rank the Best Places to Live and Retire, U.S. News & World Report, as of April 2024)**

- Crime Rate index (25% of QoL score) is computed using murder, violent crime and property crime per-capita rates, from FBI's Uniform Crime Reports.
- Quality of Education index (19%) is computed using the average college readiness score from the US News Best High Schools rankings.
- Well-being (index 19%) use resident satisfaction scores regarding purpose, social, financial, community and physical We used the composite score, from Sharecare's Community Well-Being Index.
- Commuter Index (16%) uses time spent traveling door to door, whether by foot, public transit, car or bicycle, from US Census Bureau.
- Quality and Availability of Health Care (9%) uses the quantity of ranked facilities within 50, 100 and 250 miles of each metro area from US News Best Hospitals .
- Air Quality Index (7%) uses the homonymous index from the Environmental Protection Agency.
- National Risk Index (5%) uses risk to 18 types of natural hazards from Federal Emergency Management Agency, and community risk factors, including social vulnerability and community resilience.

### **A.4. Supplemental Table 4. Numero.com QoL score components (paraphrased from numbeo.com, as of April 2024)**

The Cost of Living Index is a weighted mean of readers' submitted prices for:

- Restaurants (such as McMeal at McDonalds, Meal at Inexpensive Restaurant, Meal at Mid-range Restaurant, Domestic Beer, Imported Beer and so on)

- Food Markets
- Transportation
- Utilities
- Sports And Leisure
- Childcare
- Clothing And Shoes.

The Purchasing Power Index is the ratio between:

- readers' submitted rents and Cost of Living prices (from the previous indicator)
- readers' submitted net salaries.

The Property Price to Income Ratio (sometimes referred to as Housing Affordability) estimates the number of years of family income required to purchase a typical apartment outright, without a mortgage.

- Family income is calculated as 1.5 times the net salaries submitted by readers.
- The typical apartment has 90 square meters, and is not located in downtown areas. Prices are submitted by readers.

The Safety Index (sometimes referred to by its inverse, Crime Index), based on readers' responses about:

- General perception of crime levels
- Perceived safety during daylight and nighttime
- Concerns about specific crimes (mugging, robbery, car theft, physical attacks, public harassment, and bias-motivated incidents)
- Property crime severity (burglary, theft, vandalism)
- Violent crime severity (assault, homicide, sexual offenses).

The Healthcare Quality uses readers' responses about healthcare providers, be they individuals or organizations, from the point of view of:

- skill and competency
- speed
- modern equipment
- accuracy and completeness
- friendliness and courtesy
- responsiveness waitings
- location
- cost.

The Climate Index is calculated from the temperature and dew point (unspecifid source).

The Pollution Index is calculated from data, from World Health Organization and from readers, about:

- Air and Water Pollution
- Garbage Disposal and Cleanliness
- Noise and Light Pollution
- Availability of Green Spaces
- Overall Pollution Comfort.

Traffic and Commute Times Index is calculated using reader's submitted estimates for:

- overall traffic system inefficiencies
- commute time
- dissatisfaction with time spent in traffic
- CO2 emissions (indirectly estimated from commute time).

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