

Shopping morphologies of urban transit station areas: A comparative study of central city station catchments in Toronto, San Francisco, and Melbourne

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ABSTRACT

Synergies between shopping and public transit have long been noted, with main streets emerging along tram lines and shopping malls attached to train stations. The shopping-transit synergy is also at the core of transit-oriented development (TOD), a widespread planning approach to urban sustainability. However, there is a lack of morphological research investigating how shopping clusters around transit stations at a fine-geographic scale. This paper explores the shopping morphologies of three central-city subway station areas in Toronto, San Francisco, and Melbourne, mapping and measuring the extent of public and quasi-public shopfronts relative to the station. The morphological analysis of 200, 300, 400, and 500 m walking catchments shows that as the distance from the station increases, the proportion of shopfronts in the total catchment declines. Quasi-public shopping space can enhance the walkable catchment and permeability of a station area and may contribute to urbanity as long as it adds to diversity of access options. The findings highlight the role walkable shopping environments can play within urban transit station areas and show the importance of nuanced consideration being given to morphologies in the analysis and planning of TODs.

1. Introduction

Shopping has long formed synergies with public transit capturing pedestrian traffic from/to the station and enabling multi-purpose trips. Main streets often emerged along tram lines, and many shopping malls were developed on top of or below train stations. These shopping-transit synergies do not only capitalise walkability and pedestrian mobility for retail development; they can also contribute to a more walkable, vibrant, and attractive urban space (Carmona, 2015). Shopping has therefore been considered an important part of transit-oriented development (TOD) where urban intensity concentrates towards the train station at walkable scales (Calthorpe, 1993).

TOD seeks to promote low-carbon commuting, healthy lifestyles, and urbanity; it has been widely adopted as a key approach for sustainable city (re)development (Bertolini and Spit, 1998; Cervero et al., 2004). Much TOD research is focused on the ways in which train stations – as transportation ‘nodes’ – can be arranged into a metropolitan transport network in cities around the globe (González et al., 2019; Lyu et al., 2016; Jeffrey et al., 2019; Papa and Bertolini, 2015). When modelling the walking catchment around stations, conventional methods assume a constant intensity of access across different distances up until an

arbitrary threshold, as can be seen through Ewing and Cervero’s (2010) meta-analysis of travel/built environment-related literature. These measurements are inconsistent with the actual practice of walking, which gradually decreases with distance. An exception is the work by Gutiérrez et al. (2011) that empirically tested the ‘distance-decay’ effect of train station attractiveness in Madrid; it quantified a gradually decreasing ridership in the living and working population with increasing walking distance to the station. Furthermore, TOD research often adopts metrics that largely reduce streets to centrelines, walkability to a singular index, and so forth (e.g., Jeffrey et al., 2019; Liu et al., 2020a; Lyu et al., 2016). Such reductions are difficult to avoid when examining a large number of case studies, but their limitations in capturing socio-spatial properties are often overlooked.

This raises a multiplicity of interlinked questions about the spatial clustering of walking-related activities around stations: how does the clustering of shopfronts vary as distance to the station increases? How does pedestrian access vary depending on proximity to the station? How do quasi-public access networks within shopping malls impact on station catchments? How do synergies between transit and shopping relate to urban form?

This paper examines the synergies of shopping and transit in central

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station areas at various walking distances, based on a morphological analysis (Moudon, 1994) and with a focus on quasi-public shopping spaces. Three subway stations are selected from central Toronto, San Francisco, and Melbourne – cities with similar socio-economic conditions and grid street networks, high urban density, and sufficient open data for detailed morphological analysis. The selected stations are nodes with high patronage within the public transit network of their respective cities, and their catchment areas include key parts of each central-city shopping district. A morphological analysis of these three cases is conducted at four walkable catchments (200, 300, 400, and 500 m to the station), measuring shopping frontages, permeability, and shopping floor area. Here a particular attention is given to how the quasi-public space of private shopping centres (e.g., shopping malls) is fostering walkability. The main goals of this research are twofold. One is to explore forms of transit-oriented shopping areas geared to walkability and urbanity in city centres. The other is to advance TOD research through detailed morphological analysis.

In what follows, the paper first proceeds with a brief overview of the literature on shopping-transit synergies, TOD research, and walkability. Then it introduces the research design, comprising the theoretical lens, case selection, data collection, and methods for morphological analysis. Next, the results and analysis are presented in three subsections dedicated to each case and a fourth subsection comparing the cases. Lastly, the paper concludes with a discussion of the key findings and implications for transit-oriented urban design, planning, and research.

2. Literature review

2.1. Shopping, transit, and walking

There is an abstract diagram at the base of all shopping: a pedestrian flow at a tangent to a shop; a customer sees or smells, hears, touches a product and a desire for it may be triggered (Rao et al., 2018). A key generator of pedestrian movements is public transit, and therefore shopping has long been clustering around various forms of public transit. Many main streets emerged radiating from tram or railway stations (Gruen, 1964).

While shopping malls are often car-dependent, in urban settings they can be attached to a bus or train station (Goss, 1993). Shopping malls were initially developed in low-density suburbs. In a typical suburban mall, an enclosed pedestrian-only space with a dumbbell arrangement of shops – two ‘anchor’ stores at the ends of an arcade – is surrounded by large car parks (Gruen and Smith, 1960). This car-based shopping morphology has been adapted to public transit in two key forms. One is to establish a pedestrian linkage between the mall and a nearby transit station (Zacharias et al., 2011). The other is the ‘vertical mall’ (Jewell, 2015) that is frequently established in city centres. In the vertical mall the top floor is occupied by an anchor attraction (e.g., cinema) while the bottom is often linked to an underground railway station.

Main streets have long acted as an important public space for commuting, gathering, and everyday socialisation, and this street-based urbanity can be bolstered by public transit (Carmona, 2015). Concerns have been frequently raised that the rise of the shopping mall has led to increasing privatisation of public space (Sorkin, 1992): while the suburban mall can be accessed by the majority of the public, it is subject to the control of the private developer. The suburban mall is often designed and branded to evoke a sense of publicness, hence is also often referred to as ‘quasi-public’ (Dovey, 2016). With mall development being increasingly mixed with public transit stations and many other civic spaces such as the public waterfront, museum, and library (Leong, 2001; Ford, 2003), the threat of private control over public life has further grown; Crawford (1992) termed it ‘the world in a shopping mall’ and Al (2016) called it the ‘mall city’.

While a transit station fosters pedestrian flows from and to the station and creates opportunities for retail development, shopping morphologies can in turn contribute to the walkability of the station area: a

more concentrated agglomeration of shops can lead to a larger number and frequency of walking trips. Also, the shopfront – a key form of ‘porous’ interfaces, enabling ‘eyes on the streets’ and ‘sidewalk ballet’ (Jacobs, 1961; Zukin et al., 2016; Benjamin, 1996) – is considered a core factor influencing people’s walking choice and experience. This has been empirically confirmed in studies conducted in New York, Hong Kong, Salt Lake City, and Tianjin: retail frontages assist to nurture pedestrian-friendly streets (Guo and Loo, 2013; Liu et al., 2020b; Park et al., 2019).

2.2. Transit-oriented development

The synergy of shopping and transit is also at the core of transit-oriented development (TOD), a widely-accepted strategy for sustainable city development (Cervero et al., 2004). The presence of various ground-floor shops is regarded as a typical feature of functional TODs (Ewing et al., 2017). The term TOD was originally coined by Calthorpe (1993), referring to a mode of city development that gravitates towards the transit station. There is, however, no universal definition of TOD. Two key conceptualisations have enriched the notion of TOD including the ‘D’ models and the ‘node/place’ theory. The ‘D’ models suggest that TOD should consider the synthesis of density, diversity (land use mix), design, distance to station, and destination accessibility (Cervero and Kockelman, 1997; Ewing and Cervero, 2010). The node/place theory conceptualises TODs as embodying dual properties, being a ‘node’ of the public transit network and a ‘place’ that can be conducive to everyday living, working, and visiting; the key lies in fostering a node/place balance while enhancing the capacity for ridership (Bertolini, 1999; Bertolini and Spit, 1998). Drawing on these TOD definitions above, this study broadly uses the term TOD as concentrating and intensifying density and functional mix towards the transit station through a pedestrian-friendly access network. The emphasis here is on the socio-spatial form of station areas. Thus, this research is open to the process through which TOD is generated in a station area, whether through planning mechanism or market-driven evolution.

Recent empirical studies of TOD mainly focus on the city or metropolitan transit network, exploring typologies for TOD stations (Kamruzzaman et al., 2014; Lyu et al., 2016; Vale, 2015; Higgins and Kanaroglou, 2016; Liu et al., 2020a) and the degrees to which TOD principles and criteria have been or could be implemented (Papa and Bertolini, 2015; González et al., 2019; Jeffrey et al., 2019; Li et al., 2020; Sung and Oh, 2011; Deboosere et al., 2018; Zhou et al., 2020). Less studies are concentrated on the station area (Renne et al., 2016; Liu et al., 2020b; Gutiérrez et al., 2011; Ewing et al., 2017). Empirical TOD studies tend to rely on measures and indexes of ridership, density, land use mix, and walkability (e.g., Kamruzzaman et al., 2014; Jeffrey et al., 2019). Based on such measurements, a central station area may be ranked among the top in terms of TOD intensity even if the station itself was poorly integrated with the surrounding urban fabric. Noticing this limitation, Sung and Oh (2011) and Pojani and Stead (2015) proposed that more design/form-based measures should be considered to examine the degree to which TOD is fostered in a station area with a high urban density.

The TOD studies mentioned above applied three key types of spatial unit for analysis. First is the ‘census tract’ with arbitrary boundaries (Renne et al., 2016; Deboosere et al., 2018). Second is the ‘square area’ (often at a walkable scale) serving as the cell of a spatial grid (often at the city scale) (Singh et al., 2014; Papa and Bertolini, 2015). Third is at the fine-geographic scale, including the cadastral parcel, building, address (with geographic coordinates) and point-of-interest (POI) (Jeffrey et al., 2019; Zhou et al., 2020). The emerging trend of TOD research is towards the last type of spatial unit, as more and more open ‘big data’ are becoming available.

Almost all current TOD studies considered the walkable catchment of a transit station to be an area within a fixed distance threshold, variously defined somewhere between 400 and 800 m. Such an approach,

however, is at odds with TOD theories which generally envisioned that the development intensity would diminish as the distance to the station increases (Calthorpe, 1993; Bertolini and Spit, 1998; Dittmar and Poticha, 2004). These conceived changes of TOD intensity by different walkable distances, what sometimes is called the ‘distance-decay effect’, are barely considered by many of the recent TOD studies, while the distance-decay effect had been widely discussed in many earlier literature on land value, willingness to walk, and other attributes that tend to decrease as the distance to the station grows (Iacono et al., 2008; Keijer and Rietveld, 2000; Renne, 2009; Zhao et al., 2003). One of the most methodologically-elaborate is Gutiérrez et al. (2011) who adopted a ‘distance-decay’ function to calculate walkable catchments of the train station at multiple scales and confirmed that the proportion of the ridership in the living/working population gradually decreases as the distance to the station rises. This phenomenon of distance-decay – what might be considered another D dimension for TOD – requires more empirical investigations.

2.3. Walkability

Walkability has been linked to a range of factors: natural, socio-economic, and spatial (Moudon et al., 2007). Of these the key factors that can be influenced through urban design at neighbourhood scale are density, functional mix, and access, or the ‘Urban DMA’ (Dovey, 2016). While there are many attempts to condense such attributes into a singular index (e.g., ‘walkscore’), these arithmetical approaches obscure key differences between various urban conditions, as if a high-density monofunctional area can be compared with a low-density mixed-use area (Dovey and Pafka, 2020). When comparing a large number of case studies, metrics can be useful when there are orders of magnitude between these cases. However, morphological attributes such as density, mix and access are spatial properties that are best captured through mapping (Dovey et al., 2017).

This research concentrates on ‘walkable access’ within high-density functionally mixed environments. One of the most common measures of walkable access adopted by current TOD research is ‘walkable catchment’, also known as ‘pedshed’, referring to the area that a pedestrian can walk from a train station (Vale, 2015; Higgins and Kanaroglou, 2016; Deboosere et al., 2018; Jeffrey et al., 2019; Liu et al., 2020a). There are four key limitations of such studies. First, while pedsheds are increasingly calculated based on ‘street-network distance’, it is still common to use ‘crow-fly radius’. With the now widespread use of GIS, the simplification to crow-fly radius is no longer justifiable, as it introduces significant ‘noise’ by ignoring impermeable morphologies. Second, pedsheds are traditionally measured up to an ‘average walking distance’, which is problematic because it is inconsistent with the phenomenology and practice of walking. People’s desire and capacity of walking gradually decrease with distance, rather than stopping abruptly at a predefined threshold. Third, in most studies, quasi-public shopping space is rarely recognised as part of the walkable access network. Fourth, the spatial analysis of the street network in GIS applications often generates walkable catchment areas within the most distant points that can be reached, while it ignores street width, open space, and block size. Yet these morphological attributes are linked to both capacities to walk through/to the urban fabric. To address this, ‘interface catchment’ (IC) – the total length of public/private interfaces within a given walking distance – has been proposed as a more useful measure that captures the morphological capacity for accommodating various attractors (e.g., retail frontage) within a catchment (Pafka and Dovey, 2017).

However, a measure of interface catchment alone is not sufficient. It needs to be supplemented by a measure of pedestrian permeability (Jacobs, 1961) that captures the ease of movement through the urban

fabric, as street networks incorporating many dead-ends may have high interface catchments but poor permeability. In TOD studies, pedestrian permeability – whether the term is directly mentioned or not – is often approximated through proxies such as ‘road density’, ‘intersection density’, or ‘average block size’ (Jeffrey et al., 2019; Liu et al., 2020a; Lyu et al., 2016; Kamruzzaman et al., 2014; González et al., 2019; Schlossberg, 2004). These metrics, however, hardly capture the effect of large impermeable areas (common in actual cities; e.g., freeway, car park) on permeability. Through a qualitative research of transit-oriented design, Pojani and Stead (2015) discussed the impact of actual morphologies (grid v.s. radial street network) on the permeability of train station areas yet there is a lack of measures. ‘Area-weighted average perimeter’ (*AwaP*) has been proposed as a more accurate measure of permeability (Pafka and Dovey, 2017). It considers both the perimeter and area of blocks, namely the actual morphology, so that the impact of a large impermeable block is not lost in the average. The algebraic function of *AwaP* is shown below,

$$AwaP = \sum_{i=1}^n P_i \times \frac{A_i}{A_T}$$

where n is the number of blocks, P_i and A_i are the perimeter and area of each block i , respectively, and A_T is the total area of all blocks. Low *AwaP* scores indicate high permeability.

3. Methodology

3.1. Comparative urbanism

Comparative urbanism is adopted as a key methodological framework of this research; it has become a significant approach in urban research since the beginning of the 21st century (Dear, 2005; Ward, 2008; McFarlane, 2010; Robinson, 2016), which intersects with ‘planetary’ theories that consider cities around the globe to be closely and increasingly interconnected (Brenner, 1999; Castells, 2004), ‘post-colonialism’ that emphasises the diversity and uniqueness of cities (Roy, 2011) and ‘assemblage’ thinking that focuses on the complexity and capacities of cities (Dovey et al., 2018). Comparative urbanism is anti-determinist, rejecting preconceived, fixed, and top-down superstructures. It also avoids particularism, resisting the tendency to portray generalisation as useless. Comparative urbanism is a ‘relational comparative approach’ (Ward, 2008: 408) that seeks to explore ‘*why separate places can be very similar in certain respects*’ (Nijman, 2007: 1). In other words, comparative urbanism does not consider a particular case an instance of the general; rather, generality emerges from various particular cases. Research of comparative urbanism, however, is difficult as it entails challenges to case selection (e.g., how to identify comparable cases in different contexts), data collection (e.g., how to retrieve reliable data in different contexts), and analysis (e.g., how to prepare rigorous criteria for interpreting such data) (Dear, 2005; Ward, 2008). These challenges in the context of this research are addressed in the following subsections.

3.2. Case selection

This research focuses on Toronto, San Francisco, and Melbourne, given their similarity of demography, economy, transport modal split, and city form (see Table 1). These three cosmopolitan cities are major urban centres with similar population size. They also have comparable industries, evidenced by comparable proportions of knowledge-based and creative jobs in the total employment. In these cities the dominant means of commuting is driving, with public transit used by less than a

Table 1
City profiles compared.

Metropolitan area ^a	Toronto metropolitan area	San Francisco-Oakland-Berkeley	Greater Melbourne
Demographics			
Population (million)	5.9	4.7	4.5
Age 65 and above (%)	14.5	15.2	14.1
Economy			
Knowledge/Creative jobs (%) ^b	63.2	70.2	62.8
Modal split			
Driving (%)	68.0	69.9	75.6
Public Transit (%)	24.3	20.4	14.7
Walking (%)	5.2	5.4	3.5

^a Data sources include *Census of Canada 2016*, *American Community Survey 2017 1-Year Estimates* and *Census of Australia 2016*.

^b In work-age population, 15 and above.

quarter of the total work-related travels and with walking accounting for less than 6%. These cities are often promoted as ‘pedestrian-friendly’ and ‘becoming transit-oriented’ in their respective countries, while at the metropolitan scale they are car-dependent compared to cities around the globe. Next, these cities were planned with regular grids: while morphological transformations have altered the original grids, the central areas of the selected cities remain grid-dominated. A final consideration was that, each city has an open data portal that includes building footprints, cadastral parcels, access networks (railway stations/lines), and ridership (per station).

Within each city one underground train station was selected in two steps. First, the primary nodes of the railway network were identified, defined as the top 10 stations in terms of station ridership as share of the total network ridership (Table 2). Second, among these most-used railway nodes in each city, the station having its walkable catchment most extensively overlaid with the city-centre shopping morphologies was selected. The selected subway stations are: *Dundas* (opened 1954) in Toronto, *Powell Street* (opened 1973) in San Francisco, and *Melbourne Central* (opened 1981). None of these stations is a subway interchange, while each is only within proximity of lower capacity bus or tram stops; thus the subway station acts as the core transit hub in its walkable catchment. Each station is intermingled with a hybrid of main streets and private shopping centres such as arcades, department stores, and shopping malls. In each case the largest shopping mall opened 10 to 20 years after the station and the mall is grafted onto or linked to the station in a clear attempt to capture the pedestrian traffic from/to the station. The three selected station areas are also regarded as established or

Table 2
Weekday entries per station as percentage of network total.

Data source	Toronto		San Francisco		Melbourne	
	Toronto Transit Commission 2017		Bay Area Rapid Transit 2019		Public Transport Victoria 2013	
Rank	Stations	Entries %	Stations	Entries %	Stations	Entries %
1	Bloor-Yonge ^a	14.7	Embarcadero	11.9	Flinders St ^a	12.3
2	St. George ^a	9.7	Montgomery St	11.1	Southern Cross ^a	8.0
3	Union ^a	5.3	Powell St	6.2	Central	7.3
4	Sheppard-Yonge ^a	4.9	Civic Centre	5.6	Parliament ^a	5.7
5	Kennedy ^a	3.7	12th St	3.4	Flagstaff ^a	2.6
6	Finch ^a	3.4	19th St	3.2	South Yarra ^a	1.8
7	Dundas	2.7	16th St	3.1	Footscray ^a	1.7
8	Eglinton	2.3	24th St	2.9	Caulfield ^a	1.5
9	St. Andrew	2.2	Berkeley	2.8	Box Hill	1.5
10	King	2.1	Balboa Park ^a	2.4	Glenferrie	1.5

^a Interchanges or route-end stations.

emerging examples of TOD in official guidelines or plans (BART (Bay Area Rapid Transit), 2017; City of Toronto, 2019; Victoria State Government, 2016). Building densities are high, with average gross floor area ratios within a 500-m catchment from the station ranging between 3.1 and 3.3.

3.3. Data collection

In this research two key spatial elements are focused on: the ‘shopfront’ and ‘shopping floor area’. The ‘shopfront’ includes two types: those on the public street and those inside of the quasi-public space (e.g., the shopping mall). The study of shopfront catchment could reveal the ways public and quasi-public shopping space are distributed and configured horizontally. The analysis of ‘shopping floor area’, on the other hand, could show the degrees to which retail activities are agglomerated vertically.

Among the three cities, the open data portals of San Francisco and Melbourne provide the required cadastral parcel data: boundary and shopping floor area. The floor plans of private shopping centres were derived from a combination of *Google Maps* and the websites of developers. For Toronto the entire floor area data were derived from *Google Maps* and *Street View*, as the public data lacked accuracy.

3.4. Morphological analysis

The morphological analysis at each walking distance was conducted in three steps. First, the shopfront and non-retail public/private interface that could be accessed at ground level were mapped. Second, QGIS plugins by Majic and Pafka (2019) were used to analyse the map and calculate total interface catchment (IC), shopfront catchment (SC), and area-weighted average perimeter (AwaP). Third, the intensity of vertical shopping development in each catchment was measured as the total shopping floor area divided by the total private land area, a measure that can be called the ‘net shopping floor area ratio’. Here as long as the property boundary of a parcel could be reached within a given walking distance from the station, the parcel was considered within the catchment and all of its floor areas were counted.

To explore the degrees to which shopping may decrease with increasing distance to the train station, the morphological analysis of the shopfront and shopping floor area was carried out at four walking distances: 200, 300, 400, and 500 m from the station. While 800 m is most frequently considered the walkable threshold of a train station in existing TOD literature, 500 m was adopted in this research as the top limit to avoid some of the overlap between adjacent train station areas. This still includes some overlapping catchments as the distance to the nearest station is around 450 m in Toronto, 600 m in Melbourne, and 700 m in San Francisco. The overlapping of the station catchments is

limited given that each selected station is only located on one railway line. The overlap for 500 m catchments is 13% in San Francisco, 16% in Melbourne, and 46% in Toronto, and decreases to 0 for 200 m catchments. Further, in order to identify the degrees to which quasi-public shopping space mediates walkability, the morphological analysis of interface and permeability were generated in two models: Model 1 merely explores the publicly owned space (e.g., streets, squares) while Model 2 considers both the public space and quasi-public shopping area (e.g., arcades, department stores, and shopping malls). Only the quasi-public spaces that connect two different streets were considered, as they are effective components of the access network during daytime.

In what follows, Figs. 1 to 3 present the morphological maps of the walkable catchments at the distances of 200, 300, 400, and 500 m to the station in Model 1 and 2 (in two columns) of the three selected cases, respectively. Fig. 4 shows the metrics of the morphological analysis, ordered as they appear in the following text.

4. Results

4.1. Toronto

The walkable catchment of the *Dundas* station in Toronto is well geared to shopping with more than 40% of the interface catchment shown as shopfronts at all the measured walking distances (Figs. 1 & 4). The distance-decay effect is strong in the net shopping floor area ratio, which drops from 1.4 to 0.7. The distance-decay effect of shopping is also noticed by measuring shopfront catchment: with walking distance increasing from 200 to 500 m the proportion of shopfronts in the total interface catchment drops from 66 to 45%. This distance-decay effect of shopping is further observed when the quasi-public shopfront length is removed from the distance of 200 to 500 m, the percentage of the public shopfront length in the total public interface catchment decreases from 54 to 40%.

The model-comparison of the Toronto case shows that quasi-public shopping paths contribute to the overall mobility of pedestrians in the city form, shown as an increase of the public interface catchment, yet at the two larger walking distances of 400 and 500 m (Figs. 1 & 4). Here the capacity of quasi-public shopping paths for expanding public interface catchment soars from the distance of 400 to 500 m. The ratio of additional public interface catchment to the length of quasi-public shopfront, increases from 0.19 to 0.55. Also, in these extended public interface catchments at the walking distances of 400 and 500 m, shopfronts on the street constitute 29% and 45% of the total, respectively. Further, quasi-public shopping paths enhance walkable permeability. The reduction of *AwaP* is significantly larger at the distance of 200, 300, and 400 m (between 107 and 247 m) than that of 500 m (68 m) and it peaks at the smallest distance of 200 m where *AwaP* decreases from 833 to 586 m.

4.2. San Francisco

The walkable catchment of the *Powell Street* station in San Francisco is strongly associated with shopping, indicated by a high percentage of shopfronts in the total interface catchment at each measurement scale (Figs. 2 & 4). In particular, as many as 70% of the interfaces within 200 m are shopfronts. The distance-decay effect of shopping is pronounced, with the net shopping floor area ratio diminishing from 0.9 to 0.5 as the walking distance to the station increases from 200 to 500 m. This distance-decay effect is also presented with the proportion of shopfronts declining to 59% within the 500 m catchment. The distance-decay effect of shopping is further noticed if the quasi-public shopfront length is removed. The percentage of the shopfronts on the street in the total public interface catchment drops from 65 to 56% as the walking distance grows from 200 to 500 m.

The model-comparison of the San Francisco case shows (Figs. 2 & 4)

that quasi-public shopping paths only increase the public interface catchment at the two larger distances of 400 and 500 m, and the magnitudes are relatively small: the ratios of additional public interface catchment to the quasi-public shopfront length are 0.1 and 0.05, respectively. Here shopfronts on the street are merely noticed in the added public interface at the walking distance of 400 m, accounting for 16% of the latter. On the other hand, quasi-public shopping paths significantly improve permeability with *AwaP* reductions between 109 and 212 m at the distance of 200, 300 and 400 m, while the *AwaP* reduction at 500 m distance is much smaller (25 m). At the smallest distance of 200 m the reduction of *AwaP* tops, with a decrease from 670 to 458 m.

4.3. Melbourne

The walkable catchment of the *Melbourne Central* station is well geared to shopping, as more than half of the interfaces are shopfronts at each measurement scale (Figs. 3 & 4). The net shopping floor area fluctuates around 0.4 from the distance of 200 to 500 m (0.3 to 0.5). The distance-decay effect of shopping is only revealed through measuring shopfront catchment, with the proportion of shopfronts in the total interface catchment decreasing from 67 to 54% as walking distance increases from 200 to 500 m. This distance-decay of shopping is also noticed when the quasi-public shopfront length is removed. The length of shopfronts on the street divided by the total public interface catchment decreases from 51% to 44% as the distance to the station rises from 200 to 500 m.

The comparison between the two models of the Melbourne case unveils the impact of quasi-public shopping space on the walkability of the station area (Figs. 3 & 4). Quasi-public shopping space significantly increases the walkable catchment of the station at each walking distance, and the increase of station catchment intensifies at a faster rate when the walking distance to the station grows: the ratio of additional public interface catchment to the length of quasi-public shopfront is 0.22 at the distance of 200 m, and the ratio rises to 0.47 at 500 m. Here shopfronts on the street are occupying more than 80% of the additional public interface catchment at all measured walking distances. Quasi-public shopping paths also promote the pedestrian permeability of the station area, most significantly at the smallest distance of 200 m with a 92 m reduction of *AwaP* from 616 to 524 m. At the other three measured distances the reduction of *AwaP* is only between 6 and 25 m.

4.4. Comparison

The distance-decay effect of shopping is identified in all three cases in Model 1 & 2, shown as a decreasing proportion of the shopfront length in the total interface catchment. This remains the case in Model 2 when the length of quasi-public shopfront is removed; there is a decreasing percentage of the public shopfront length in the total public interface catchment (Fig. 4). All the three stations are linked to private shopping malls in close proximity; in Melbourne the station is underneath a large vertical mall. The changes of the shopping floor area from the station to walkable threshold follow the distance-decay rule in Toronto and San Francisco as conventional TOD models often envisage. However, in Melbourne there are more retail spaces per private land area with an increasing distance to the station.

There are two ways to interpret this difference. First, the longer a station is established, the greater degree the station area may be captured by retail development. Aligning with the age of the station, the net shopping floor area ratio is most strongly clustered around the station in Toronto (1954), still strongly clustered in San Francisco (1973), and relatively even in Melbourne (1981). Second, in Melbourne Bourke Street Mall, the main pedestrian shopping street, is located 400 m south of the station. In between the station and traditional retail core – two

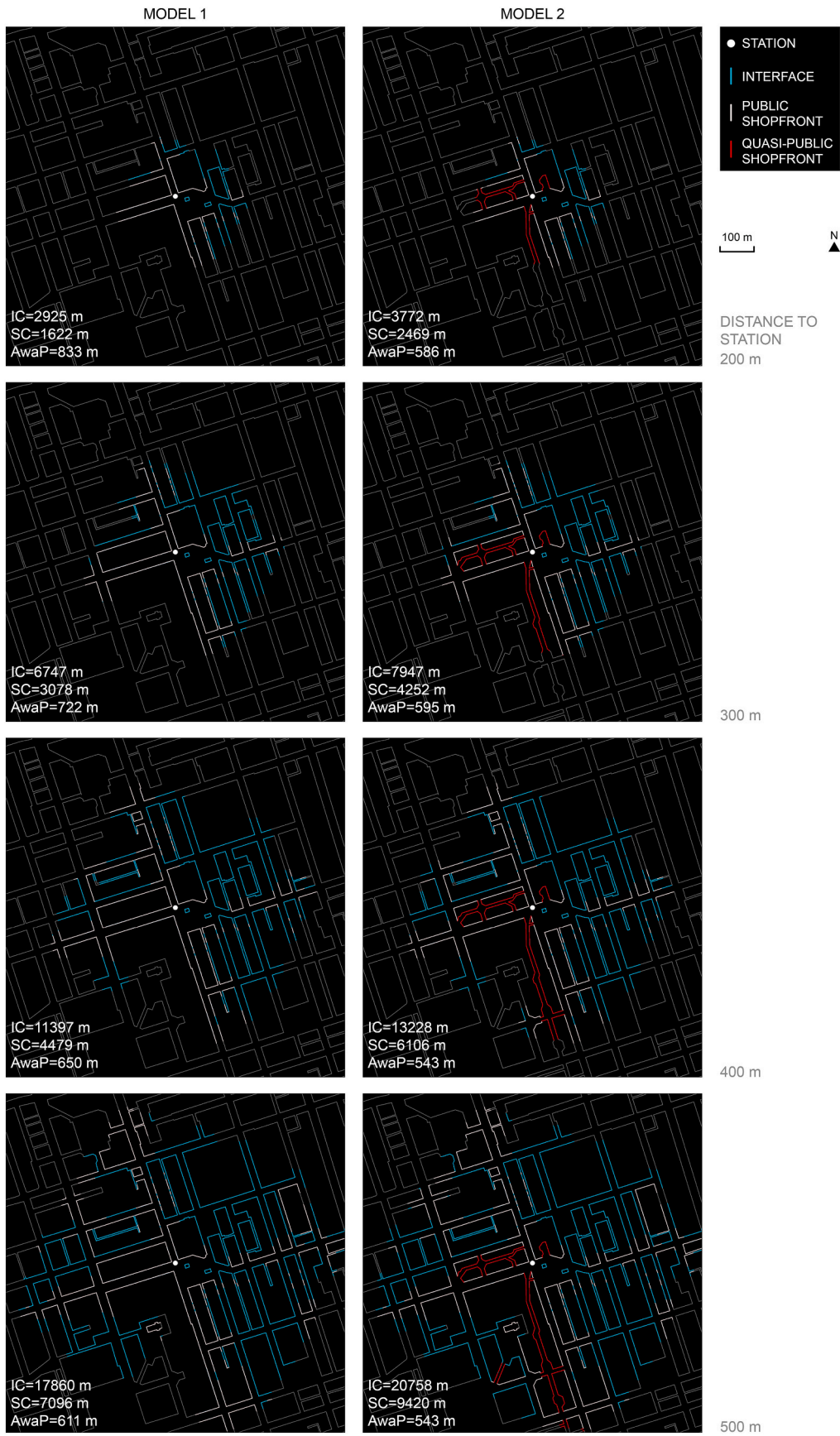


Fig. 1. Multi-scale morphological analysis of the Dundas station area in Toronto.

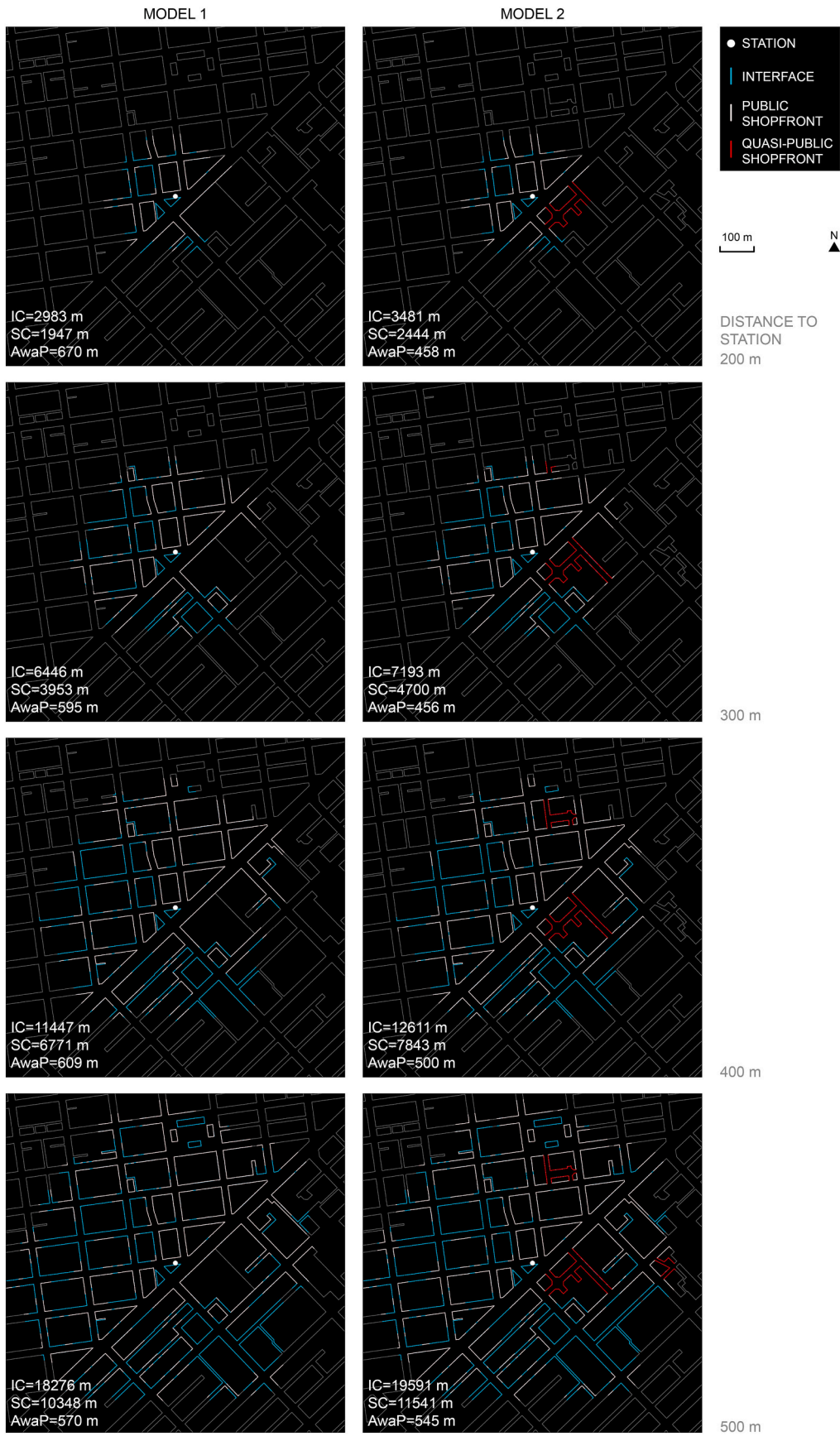


Fig. 2. Multi-scale morphological analysis of the Powell St station area in San Francisco.

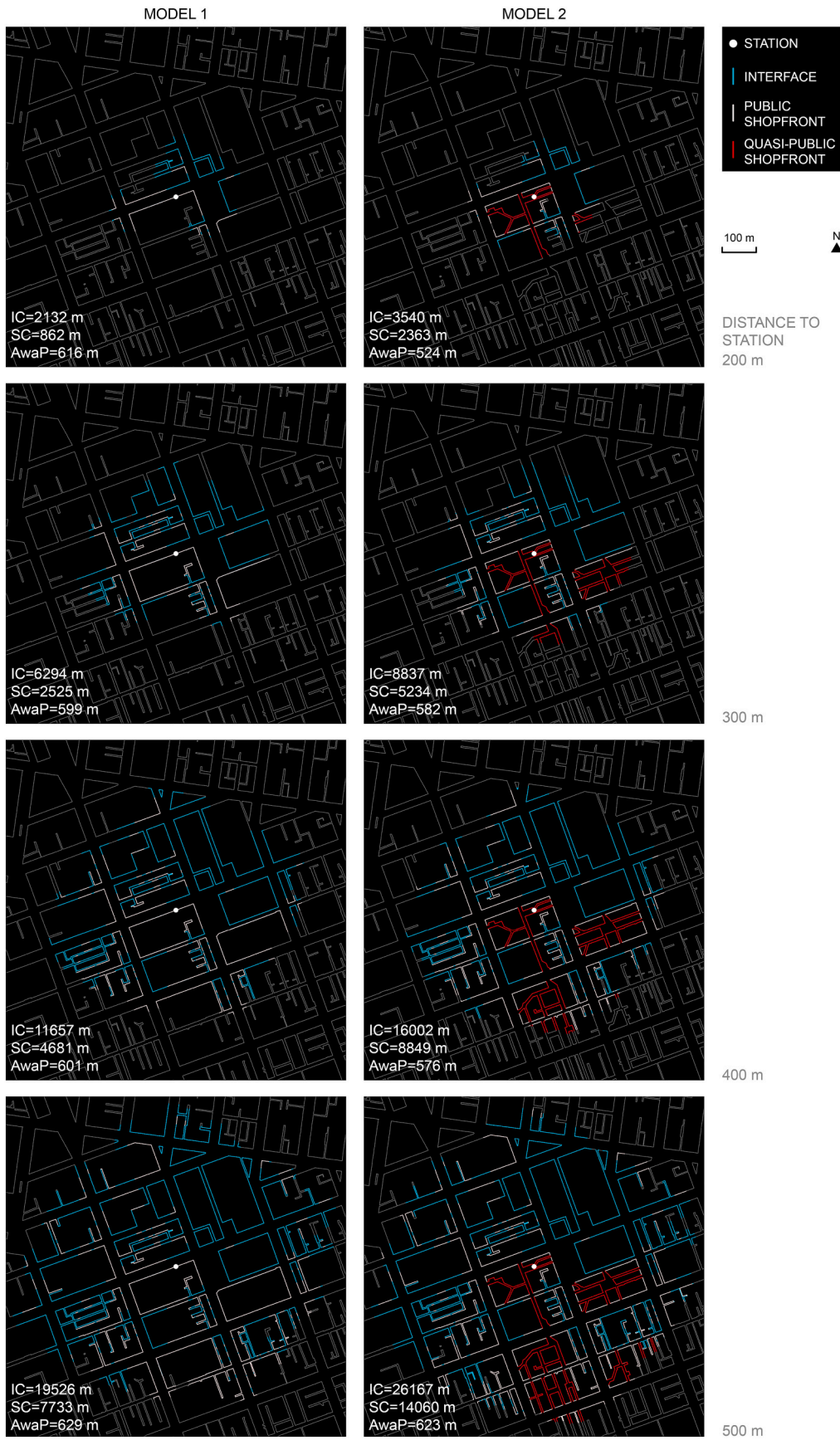


Fig. 3. Multi-scale morphological analysis of the Melbourne Central station area.

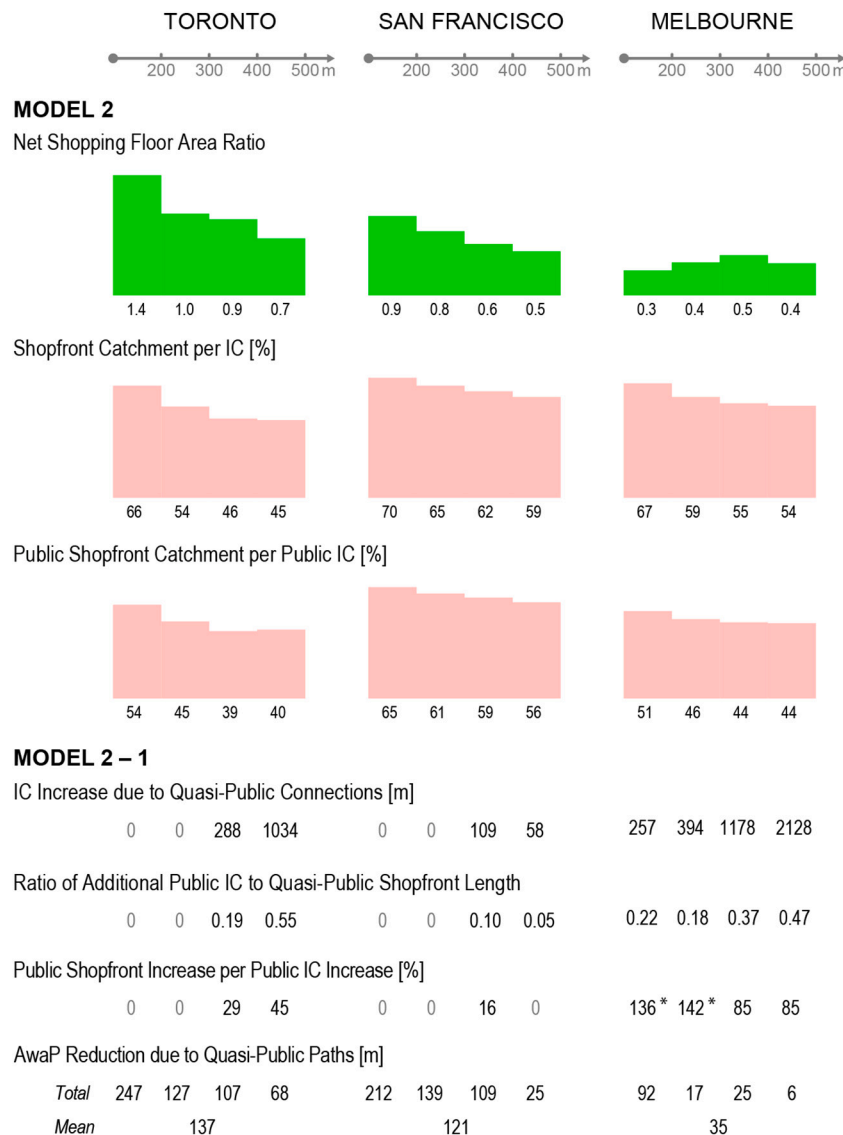
main generators of pedestrian traffic – several department stores and shopping malls collaboratively form a linkage, leading to a dumbbell agglomeration of shops. This might be considered a ‘peculiar’ transit-oriented morphology compared to conventional TOD models, while it has been a common shopping centre development practice geared towards the privatisation of public transit station and the malling of the city centre.

The quasi-public shopping space of private shopping centres, while privatising public space near the station, can enhance the walkable catchment and permeability of the station area. Here the increase of the public interface catchment is more frequently observed at the larger scales of 400 and 500 m, while the growth of permeability is most significant at the smallest scale of 200 m (Fig. 4). However, the degrees of these transformations in the three cases are different, largely influenced by the shopping and city morphology.

The spatial form of private shopping centres has a key impact on the capacity of quasi-public shopping space to increase the public interface catchment. The total increase of the public interface catchment by quasi-public shopping paths is different in the three cases, in particular at the

distance of 500 m: 2128 m of the added public interface catchment in Melbourne, 1034 m in Toronto and merely 58 m in San Francisco (Fig. 4). This is associated with the variations of quasi-public shopping morphologies in these three cases. In Melbourne there is a complex network of quasi-public shopping paths (Fig. 3). Most of these paths foster pedestrian through-traffic in the original fine-grained blocks, and many are diagonal with one end pointing to the station. Such shopping morphologies can effectively increase the walkable catchment of a station, while they are significantly less developed in Toronto and San Francisco (Figs. 1 & 2).

The capacity of private shopping centres to extend the walkable catchment of shopfronts on the street is influenced by the degree to which quasi-public shopping paths are integrated with main streets. In Melbourne, quasi-public shopping paths are often seamlessly grafted onto a main street or a main-street intersection (Fig. 3). In this way, more than 80% of the added public interfaces are shopfronts on the street at all measured walking distances. However, in the other two cities such integrations of quasi-public and public shopping spaces are mostly at the larger walking distances of 400 and 500 m (Figs. 1 & 2).



* The percentage here is larger than 1 while this can be explained. In Melbourne the locations of the subway station in M1 & M2 are slightly different. In M2 the station is inside of the mall while in M1 the station is on the north mall boundary. M2 stimulates a significantly faster increase in the shopfront catchment than that of the non-shopfront interface in M1. Thus, the shopfront catchment increase can be larger than the total interface catchment gap between the two models.

Fig. 4. Three cases compared: shopping and walkable access.

The additional public interface catchment only contributes to shopfronts on the street at the distance of 400 and 500 m in Toronto and 400 m in San Francisco; all with much smaller intensities than that of the station area in Melbourne (Fig. 4).

Next, the city form of the station area influences how well quasi-public shopping space could increase the area's walkable permeability. All the three cases emerged from grids of rectangular blocks. In Toronto and San Francisco there are larger blocks derived from the amalgamation of several original blocks around the selected station, leading to obstacles for walking from/to the station (Figs. 1 & 2). Therefore, when quasi-public shopping paths, many of which run through these large blocks, were considered in the model-comparison, the Toronto and San Francisco cases were revealed to receive significant improvement of walkable permeability. In Melbourne, however, the original city layout has already been subdivided by various laneways into a more permeable form (Fig. 3). That is why quasi-public shopping paths in Melbourne contribute less to walkable permeability than in the other cases. The average reduction of *AwaP* across the four catchments (when quasi-public shopping paths were considered) is merely 35 m in Melbourne, compared to 121 m in San Francisco and 137 m in Toronto (Fig. 4).

5. Discussion

This research examined to what degree shopping may be geared to the station catchment, based on a morphological analysis of three urban subway stations in Toronto, San Francisco, and Melbourne at four walking distances (200 to 500 m to the station). The shopping floor areas within the selected station catchments did not present a uniform distance-decay pattern as the walking distance to the station increases, while all these three station areas feature shopping/transit-oriented morphologies if the focus is shifted from the shopping 'area' to shopfront 'interface'. There is a diminishing proportion of the shopfront length in the total interface catchment as the walking distance to the station rises. This finding is in line with the original concept of TOD proposed by Calthorpe (1993) and subsequent research that regarded shopfront as one of the most important indicators for TOD (Guo and Loo, 2013; Park et al., 2019; Liu et al., 2020b). Shopfront catchment can also reflect the control by private shopping centres such as shopping malls. While many earlier criticisms of 'privatisation of public space' predominantly revolve around the 'area' of shopping space (Crawford, 1992; Sorkin, 1992; Al, 2016); there is a lack of discussions on interfaces in the public and quasi-public space.

This research, on the other hand, showed how the quasi-public space of private shopping centres often enhances walkability at the neighbourhood scale. While occupying key locations within the walkable catchment of the station, quasi-public shopping spaces often lead to shortcuts in the urban fabric. They can thus generate benefits for walkability – increasing permeability in the station area while also enlarging the interface catchment within a given walking distance, leading to more urban TOD stations. However, shopping malls can also monopolise large parts of the station area manipulating or reducing diversity of connections, such as it happens with the long shopping mall extending 500 m to the southwest of the Dundas station in Toronto.

This research further suggested that 'shopfront catchment', as a measure and morphological map, captures an important design attribute of TOD station areas in response to what Sung and Oh (2011) and Pojani and Stead (2015) called for. The measure of shopfront catchment is particularly useful in investigating the ways shopping and walkability are interlinked and examining their synergistic impact on urban public life in TOD station areas.

The findings may also have direct implications for practice. First, the street-level urban design should be an essential part of planning for TOD. Second, urban planning codes could harness shopping-transit synergies by encouraging private shopping (re)development to adopt a morphology that is geared to pedestrian movements from/to the nearby

station, such as a network of through and diagonal (orientating towards the station) shopping paths with frequent intersections. Third, urban planning codes could promote a better morphological integration between quasi-public and public shopping spaces as a means to incorporate more shops on the street within the walkable station catchment, leading to enhanced street vibrancy. Fourth, TOD planning should pay attention to multi-scale benefits of private shopping morphologies on pedestrian-friendly neighbourhoods.

There are two key lessons for research. First, distance-decay effects around railway stations can be significant, and therefore using a single arbitrary catchment threshold can distort results. Second, there is a strong impact of morphologies on the permeability and shopfront catchment of station areas, and therefore using conventional proxies – often featuring a reduction of city forms – to examine TOD at the walkable scale may generate misinterpretations. For future studies there are several key opportunities. This research only tested the distance-decay effect in city-centre station areas. Similar empirical investigations could be conducted in other contexts, such as for stations in regional centres and newly-established neighbourhoods. Next, this research only explored the distance-decay effect at the ground-level in city centres of car-dependent metropolises, while in more densely-populated and pedestrian-oriented cities (e.g., Hong Kong) the access network centred on the station largely operates at multiple levels and is more intricate. Lastly, this research unveiled the interrelationship between shopping and walkability of transit station areas, yet it did not cover other urban functions (e.g., living, working, non-shopping visit). Future studies could tackle to what degree these functions other than shopping and the mix between different functions can enhance or diminish the walkability of station areas.

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References

- Al, S., 2016. Introduction. In: Al, S. (Ed.), *Mall City: Hong Kong's Dreamworlds of Consumption*. Hong Kong University Press, Hong Kong, pp. 1–22.
- BART (Bay Area Rapid Transit), 2017. Transit-Oriented Development Guidelines. BART. Retrieved from: <https://www.bart.gov/about/business/tod/guidelines>. Accessed on 23 March 2021.
- Benjamin, W., 1996. *Selected Writings Volume 1: 1913–1926*. Harvard University Press, London.
- Bertolini, L., 1999. Spatial development patterns and public transport: the application of an analytical model in the Netherlands. *Plan. Pract. Res.* 14, 199–210.
- Bertolini, L., Spit, T., 1998. *Cities on Rails: The Redevelopment of Railway Stations and their Surroundings*. Routledge, London.
- Brenner, N., 1999. Globalisation as Reteritorialisation: the re-scaling of urban governance in the European Union. *Urban Stud.* 36, 431–451.
- Calthorpe, P., 1993. *The Next American Metropolis: Ecology, Community, and the American Dream*. Princeton Architectural Press.
- Carmona, M., 2015. London's local high streets: the problems, potential and complexities of mixed street corridors. *Prog. Plan.* 100, 1–84.
- Castells, M., 2004. *The Network Society: A Cross-Cultural Perspective*. Edward Elgar, Cheltenham.
- Cervero, R., Kockelman, K., 1997. Travel demand and the 3Ds: density, diversity, and design. *Transp. Res. Part D: Transp. Environ.* 2, 199–219.
- Cervero, R., Murphy, S., Ferrell, C., et al., 2004. *Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects*. The National Academies Press, Washington, DC.
- City of Toronto, 2019. *Toronto Official Plan*. City of Toronto. Retrieved from: <https://www.toronto.ca/city-government/planning-development/official-plan-guidelines/official-plan/chapters-1-5/>. Accessed on 23 March 2021.
- Crawford, M., 1992. The world in a shopping mall. In: Sorkin, M. (Ed.), *Variations on a Theme Park: The New American City and the End of Public Space*. Hill and Wang, New York, pp. 3–30.
- Dear, M., 2005. Comparative urbanism. *Urban Geogr.* 26, 247–251.
- Deboosere, R., El-Geneidy, A.M., Levinson, D., 2018. Accessibility-oriented development. *J. Transp. Geogr.* 70, 11–20.

- Dittmar, H., Poticha, S., 2004. Defining transit-oriented development: The new regional building block. In: Dittmar, H., Ohland, G. (Eds.), *The New Transit Town: Best Practices in Transit-Oriented Development*. Island Press, Washington.
- Dovey, K., 2016. *Urban Design Thinking: A Conceptual Toolkit*. Bloomsbury, London.
- Dovey, K., Pafka, E., 2020. What is walkability? The urban DMA. *Urban Stud.* 57 (1), 93–108.
- Dovey, K., Ristic, M., Pafka, E., 2017. Mapping as spatial knowledge. In: Dovey, K., Pafka, E., Ristic, M. (Eds.), *Mapping Urbanities: Morphologies, Flows, Possibilities*. Routledge, New York, pp. 1–16.
- Dovey, K., Rao, F., Pafka, E., 2018. Agglomeration and assemblage: deterritorialising urban theory. *Urban Stud* 55 (2), 263–273.
- Ewing, R., Certero, R., 2010. Travel and the built environment. *J. Am. Plan. Assoc.* 76, 265–294.
- Ewing, R., Tian, G., Lyons, T., et al., 2017. Trip and parking generation at transit-oriented developments: five US case studies. *Landsc. Urban Plan.* 160, 69–78.
- Ford, L., 2003. *America's New Downtowns: Revitalization or Reinvention*. Johns Hopkins University Press, Baltimore.
- González, S.R., Loukaitou-Sideris, A., Chapple, K., 2019. Transit neighborhoods, commercial gentrification, and traffic crashes: exploring the linkages in Los Angeles and the Bay Area. *J. Transp. Geogr.* 77, 79–89.
- Goss, J., 1993. The “magic of the mall”: an analysis of form, function, and meaning in the contemporary retail built environment. *Ann. Assoc. Am. Geogr.* 83, 18–47.
- Gruen, V., 1964. *The Heart of our Cities: The Urban Crisis, Diagnosis and Cure*. Simon and Schuster, New York.
- Gruen, V., Smith, L., 1960. *Shopping Towns USA: The Planning of Shopping Centers*. Reinhold, New York.
- Guo, Z., Loo, B.P.Y., 2013. Pedestrian environment and route choice: evidence from New York City and Hong Kong. *J. Transp. Geogr.* 28, 124–136.
- Gutiérrez, J., Cardozo, O.D., García-Palomares, J.C., 2011. Transit ridership forecasting at station level: an approach based on distance-decay weighted regression. *J. Transp. Geogr.* 19, 1081–1092.
- Higgins, C.D., Kanaroglou, P.S., 2016. A latent class method for classifying and evaluating the performance of station area transit-oriented development in the Toronto region. *J. Transp. Geogr.* 52, 61–72.
- Iacono, M., Krizek, K., El-Geneidy, A.M., 2008. Access to Destinations: How Close Is Close Enough? Estimating Accurate Distance Decay Functions for Multiple Modes and Different Purposes. Minnesota Department of Transportation.
- Jacobs, J., 1961. *The Death and Life of Great American Cities*. Random House, New York.
- Jeffrey, D., Boulangé, C., Giles-Corti, B., et al., 2019. Using walkability measures to identify train stations with the potential to become transit oriented developments located in walkable neighbourhoods. *J. Transp. Geogr.* 76, 221–231.
- Jewell, N., 2015. *Shopping Malls and Public Space in Modern China*. Ashgate, Burlington.
- Kamruzzaman, M., Baker, D., Washington, S., et al., 2014. Advance transit oriented development typology: case study in Brisbane, Australia. *J. Transp. Geogr.* 34, 54–70.
- Keijer, M.J.N., Rietveld, P., 2000. How do people get to the railway station? The dutch experience. *Transp. Plan. Technol.* 23, 215–235.
- Leong, S.T., 2001. And then there was shopping: The last remaining form of public life. In: Koolhaas, R., Chung, C.J., Inaba, J. (Eds.), *Harvard Design School Guide to Shopping*. Taschen, Cambridge, pp. 129–156.
- Li, S., Lyu, D., Huang, G., et al., 2020. Spatially varying impacts of built environment factors on rail transit ridership at station level: a case study in Guangzhou, China. *J. Transp. Geogr.* 82, 102631.
- Liu, Y., Singleton, A., Arribas-Bel, D., 2020a. Considering context and dynamics: a classification of transit-orientated development for New York City. *J. Transp. Geogr.* 85, 102711.
- Liu, Y., Yang, D., Timmermans, H.J.P., et al., 2020b. Analysis of the impact of street-scale built environment design near metro stations on pedestrian and cyclist road segment choice: a stated choice experiment. *J. Transp. Geogr.* 82, 102570.
- Lyu, G., Bertolini, L., Pfeffer, K., 2016. Developing a TOD typology for Beijing metro station areas. *J. Transp. Geogr.* 55, 40–50.
- Majic, I., Pafka, E., 2019. AwaP-IC—an open-source GIS tool for measuring walkable access. *Urban Sci* 3 (2), 48.
- McFarlane, C., 2010. The comparative city: knowledge, learning, urbanism. *Int. J. Urban Reg. Res.* 34, 725–742.
- Moudon, A.V., 1994. Getting to know the built landscape: Typomorphology. In: Franck, K.A., Schneekloth, L.H. (Eds.), *Ordering Space: Types in Architecture and Design*. Van Nostrand Reinhold, New York, pp. 289–311.
- Moudon, A.V., Lee, C., Cheadle, A.D., et al., 2007. Attributes of environments supporting walking. *Am. J. Health Promot.* 21 (5), 448–459.
- Nijman, J., 2007. Introduction - comparative urbanism. *Urban Geogr.* 28, 1–6.
- Pafka, E., Dovey, K., 2017. Permeability and interface catchment: measuring and mapping walkable access. *J. Urbanism* 10 (2), 150–162.
- Papa, E., Bertolini, L., 2015. Accessibility and Transit-oriented development in European metropolitan areas. *J. Transp. Geogr.* 47, 70–83.
- Park, K., Ewing, R., Sabouri, S., et al., 2019. Street life and the built environment in an auto-oriented US region. *Cities* 88, 243–251.
- Pojani, D., Stead, D., 2015. Transit-oriented design in the Netherlands. *J. Plan. Educ. Res.* 35 (2), 131–144.
- Rao, F., Dovey, K., Pafka, E., 2018. Towards a genealogy of urban shopping: types, adaptations and resilience. *J. Urban Des.* 23 (4), 544–557.
- Renne, J.L., 2009. Measuring the success of Transit oriented development. In: Curtis, C., Renne, J.L., Bertolini, L. (Eds.), *Transit Oriented Development: Making it Happen*. Ashgate, Burlington.
- Renne, J.L., Hamidi, S., Ewing, R., 2016. Transit commuting, the network accessibility effect, and the built environment in station areas across the United States. *Res. Transp. Econ.* 60, 35–43.
- Robinson, J., 2016. Comparative urbanism: new geographies and cultures of theorizing the urban. *Int. J. Urban Reg. Res.* 40, 187–199.
- Roy, A., 2011. Slumdog cities: rethinking subaltern urbanism. *Int. J. Urban Reg. Res.* 35, 223–238.
- Schlossberg, M., 2004. Comparing transit-oriented development sites by walkability indicators. *Transp. Res. Rec.* 34.
- Singh, Y.J., Fard, P., Zuidgeest, M., et al., 2014. Measuring transit oriented development: a spatial multi criteria assessment approach for the City region Arnhem and Nijmegen. *J. Transp. Geogr.* 35, 130–143.
- Sorkin, M., 1992. Introduction. In: Sorkin, M. (Ed.), *Variations on a Theme Park: The New American City and the End of Public Space*. Hill and Wang, New York.
- Sung, H., Oh, J.-T., 2011. Transit-oriented development in a high-density city: identifying its association with transit ridership in Seoul, Korea. *Cities* 28, 70–82.
- Vale, D.S., 2015. Transit-oriented development, integration of land use and transport, and pedestrian accessibility: combining node-place model with pedestrian shed ratio to evaluate and classify station areas in Lisbon. *J. Transp. Geogr.* 45, 70–80.
- Victoria State Government, 2016. *Plan Melbourne 2017–2050*. Victoria State Government. Retrieved from: <https://www.planmelbourne.vic.gov.au/the-plan>.
- Ward, K., 2008. Editorial - toward a comparative (re)turn in urban studies? Some reflections. *Urban Geogr.* 29, 405–410.
- Zacharias, J., Zhang, T., Nakajima, N., 2011. Tokyo Station City: the railway station as urban place. *Urban Des. Int.* 16, 242–251.
- Zhao, F., Chow, L.-F., Li, M.-T., et al., 2003. Forecasting Transit walk accessibility: regression model alternative to buffer method. *Transp. Res. Rec.* 1835, 34–41.
- Zhou, J., Yang, Y., Webster, C., 2020. Using big and open data to analyze Transit-oriented development. *J. Am. Plan. Assoc.* 86, 364–376.
- Zukin, S., Kasinitz, P., Chen, X., 2016. *Global Cities, Local Streets: Everyday Diversity from New York to Shanghai*. Routledge, New York.