Literature review of the costs of infrastructure provision for different development forms

iCity: Urban Informatics for Sustainable Metropolitan Growth
ORF-RE7 Project 2.4: *Integrated Urban Modelling & Economic Analysis*

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1. Introduction

Metropolitan areas worldwide are undergoing a dramatic transformation in terms of population and job growth, leading to rapid urbanization and social, economic and environmental consequences for the region. Many cities worldwide are facing rapid and unprecedented rates of population growth and increasing development pressure. Managing urban growth sustainably thus poses enormous challenges for local governments, wherein infrastructure provision for the needs of a fast-growing population is the most crucial and capital-intensive responsibility. Infrastructure investment is a driver of urbanization and supports the necessary conditions for economic growth by supplying key inputs like water, transport and energy. The Greater Toronto-Hamilton Area (GTHA) is a globalizing regional economy, which needs efficient intra-regional mobility and supporting community services and utilities' infrastructure to maintain competitiveness of business and continue attracting mobile skilled workers for its knowledge-based industries (Blais, 2018). The GTHA is the most populous contiguous urban area in Canada, with current population of 7.1 million and growing at an annual rate of 6.2% (2016 census). Servicing growing needs of vibrant metropolitan regions, while maintaining the existing stock of infrastructure and public facilities, can cause a strain on a city's fiscal capacity to pay for new infrastructure. As a result, financial sustainability has become a rising concern for many city governments.

Building hard infrastructure like roads, transit, water and wastewater facilities, requires large up-front capital investment and costly planning and execution efforts that result in long-term monetary and non-monetary implications for the society. Infrastructure assets once built, are almost irreversible, due to their high fixed and sunk costs coupled with high costs of maintenance/ replacement. The durability of linear infrastructure like transportation networks, water supply lines and sewerage networks, has long-lasting impacts on regional and local land use planning, urban growth and subsequently, public finance. Hence, it is critical for managing population growth and infrastructure investment that the factors affecting the costs of providing infrastructure are understood well. This will enable planning agencies to evaluate and compare the costs and benefits associated with alternative design and development settings, so that municipal capital and operating budgets can be allocated efficiently to retrofit/upgrade or build new infrastructure. Urban form or growth patterns, among other factors, is known to influence the costs of providing services and infrastructure in a city, which suggests that managing the physical growth of the city might have a role in delivering services in a cost-effective manner.

1.1. Aim and objectives

Planning decisions regarding infrastructure development impact the expenditure and revenues of cities for decades and have an indirect effect on the serviced areas, in terms of land use change and induced growth. Urban growth management is important for ensuring the sustainable growth of population and efficient delivery of services. There is limited information available on the long-term impact of urban growth patterns at the regional or city scale on infrastructure costs. The aim of this report is to review key literature investigating the impact of urban form and specifically, different patterns of growth, on the costs of infrastructure provision in a city or metropolitan region.

The objectives of the research are:

- Explore the determinants of costs of infrastructure provision for residential developments.
- Determine the variation in costs of infrastructure provision according to different urban forms/development patterns (e.g. greenfield versus infill/ brownfield site, or higher versus lower housing density).
- Develop a framework for a comprehensive investigation of infrastructure costs of different forms of development that can enable municipalities to understand the impact on their capital and operating budgets for urban infrastructure.

1.2. Scope and methodology

This research compares the upfront capital costs of construction and operational and maintenance (O&M) costs of urban infrastructure in different development settings. The analysis does not extend to indirect social and environmental costs of infrastructure provision. Finally, the focus is on costs to the municipality.

Infrastructure types include hard, linear infrastructure like transportations systems (roads, rail and bus transit network, stations and rolling stock), water supply systems (intake and filtration plant, pipeline network and reservoirs/ storage tanks), sewerage systems (pipeline network and sewage treatment plant), stormwater drainage (pipeline network and reservoirs); and community infrastructure like emergency services and parks and recreational facilities.

Literature reviewed includes academic papers published in peer-reviewed journals, non-academic publications and consultant reports on analyses of infrastructure costs for different development forms (infill or greenfield, compact or sprawling), contexts (developed or developing country) and scales (region, city or neighborhood).Most studies are based on infrastructure costs in American, Australian and Canadian metropolitan areas. Inferences of urban form studies conducted in developing countries may not be directly applicable to developed countries. Such examples have been kept to a minimum.

A database of papers and reports focussed on factors affecting infrastructure costs of residential developments was created, which was then filtered to select studies investigating the impact of urban form features on costs of infrastructure provision in alternative development patterns. All conceptual, theoretical and empirical studies have been considered as relevant literature. The municipal cost implications of individual characteristics of urban form were consolidated as findings. Broad conclusions and recommendations have been presented towards facilitating the efficient provision of public infrastructure and services in the most cost-effective development form, with the larger goal of supporting municipal fiscal health and sustainable urban growth

The remainder of the report is divided into three sections. Section 2 documents the urban context, data and indicators examined in all studies. The work focuses on capital and O&M costs of urban infrastructure outlined in Section 2.1, while renewal or replacement costs are considered out of scope in the analysis of individual services as they are more dependent on material specifications, usage, weather conditions etc. and less affected by urban form features. Different forms of development as described in Section 2.2, have been investigated to compare the impact on public expenditure. Section 3 reports and synthesizes the findings from various studies and Section 4 presents the conclusion and proposes a methodology for assessing development costs through a structured framework.

2. Literature Review

Assessment of the impact of different urban growth patterns on the cost of infrastructure provision, needs data on transportation, land use, housing typology, travel behaviour, energy consumption, and actual capital and operating costs of utilities for a long timeline to understand the effects of changing development settings. Land supply policies guiding urban containment/growth boundaries, land use zoning and development controls for density and building design in urban cores need appraisals to assess impacts on costs of development for a 15-20 year horizon (Gurran, Ruming, & Randolph, 2009). Currently, studies focus on shorter term (10-15 years) cost projections of infrastructure, but longer term (15+ years) costs of development are required to capture the effects of urban form characteristics. The review covers long-term studies on the implications of alternative growth patterns on infrastructure costs, the scale, scope and time horizon of studies is not constant.

2.1. Infrastructure components

Urban infrastructure typically consists of transportation, parks and open spaces, utility services like water, wastewater, stormwater and solid waste management, electricity and community services like emergency services, public health and social services. Since the focus of this literature review is on understanding the impact of urban growth patterns on infrastructure costs, infrastructure affected by the physical growth of a city has been identified and included for analysis.

All linear infrastructure like roads, transit, water and wastewater distribution and collection network and electricity distribution lines, needs to extend to service new areas as a city undergoes physical expansion. Most cities have response time goals for emergency services like ambulance or fire protection, which require additional medical centres/fire stations and vehicles to be located in new growth areas to be able to reach a target within the designated response time. The same is true for schools, which are planned based on maximum travel distances by walk and school bus for students to access the school safely, as well as standard teacher to student ratio. Police infrastructure is generally based on staffing ratio for police officers to residents as well as emergency response time goals, which relate the service planning to both population and city growth. Minimum population standards are set for providing parks and open spaces, which is related to population growth more, but they impact urban form as more land is converted to urban uses.

In general, though providing social infrastructure like social housing and health services and cultural facilities like art galleries and theatres have cost implications for city governments, they do not have a significant relationship with the physical form of the city(Sustainable Cities International, 2012).

2.2. Development settings

The most dominating development forms for managing growth discussed in all studies are the high-density centralized or clustered development and the low-density dispersed development. The former compact urban form is also referred to as 'Smart Growth' or 'Infill' development and the latter is referred to as 'Sprawl' or 'Greenfield' development. This report discusses the impact of the individual features (like density and dispersion) of these two alternative development settings on infrastructure and development costs. The basic four dimensions of sprawl and their related urban characteristics (see Table 1), have been defined in a seminal report (Ewing, Pendall, & Chen, 2002). These urban form features are the most critical factors defining alternative development settings.

Table 1. Urban form factors of sprawl. Source: Ewing et al. (2002)

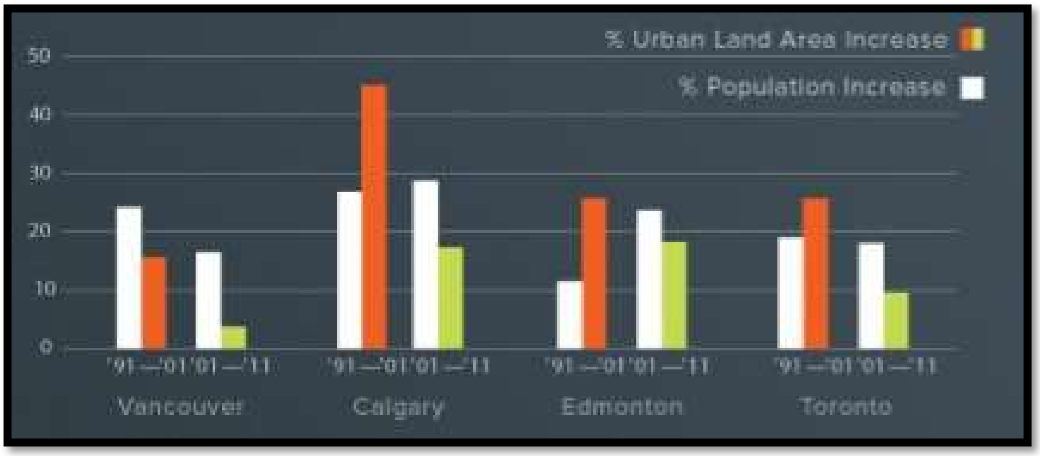
Sprawl dimension	Urban form factors
A population that is widely dispersed in low-density development	Residential density
Rigidly separated homes, shops, and workplaces	Neighborhood mix of homes, jobs, and services
A network of roads marked by huge blocks and poor access;	Accessibility of the street network
A lack of well-defined, thriving activity centers, such as downtowns and town centers	Strength of activity centers and downtowns

Despite the commuting benefits from living in proximity to job opportunities and enjoying easy access to commercial and recreational amenities in inner/middle city areas, there seems to be an undeniable demand for low-density development at the city fringe in North American metropolitan regions. A central city's suburbs offer several attractions that may include: lower housing costs, lower tax rates, more flexible and comfortable auto-dependent lifestyles, lower crime rates, better air quality, access to a variety of open spaces and preferred separation of residences from commercial and industrial zones (Gordon & Richardson, 1997; Heimlich & Anderson, 2001).

The urban expansion and land use change trends over the past century, triggered by the advent of the automobile and extension of highways, have resulted in the current settlement patterns, where people from rural areas have migrated to urban areas and residents in dense metropolitan centres have relocated to the suburbs, particularly in North American cities. The advancement in information and communication technologies have enabled the dispersion of firms and households, such that retail and office centres have followed the housing expansion in the urban fringe. This has changed commuting patterns and provided added locational benefits such as access to employment in knowledge-based companies, thereby fuelling further sprawl or greenfield developments. While most Canadian cities have maintained strong central cores containing both employment and residential population, they have simultaneously experienced significant growth in suburban employment and population as well (SGS, 2009). Such developments impose direct and indirect costs on individuals, society and the environment, but the primary implication for municipalities of supporting low-density expansion oriented and car dependent urban growth is the increase in per capita cost of land development and new infrastructure provision and its maintenance (Litman, 2015).

Urban sprawl in Canadian cities, measured by comparing rates of population increase and rate of increase in urban land over a 20-year period, shows that most major Canadian cities sprawled between 1991 to 2001 (Neptis, 2015). Consistent growth-management efforts have resulted in compact and efficient development in Vancouver, relative to Calgary, Edmonton and Toronto (see Figure 1) as the population of Vancouver kept increasing but land area has not expanded, thereby indicating densification.

Figure 1: Comparing urban sprawl in four Canadian cities. Source: Neptis, 2015.



Infill developments are hence, a means to control sprawl and densify urban centres, reduce commuting distances and vehicle-kilometers travelled, and mitigate the negative externalities of sprawl developments.

3. Findings

Development cost is a function of land costs, infrastructure costs and structure costs, which eventually influence the final cost of dwelling units. Out of these, infrastructure costs are of the highest concern to local governments and authorities. However, analyzing costs of infrastructure provision for different development settings is challenging due to variations in urban contexts of cities, socio-demographic differences as well as varying record keeping and accounting practices (Hamilton & Kellett, 2017). For example, infill locations might have more apartment dwelling types, while suburban fringe developments may attract demand for detached housing, in which case the construction and infrastructure costs will be substantially different and difficult to compare. Some municipalities record cost databases in per capita terms and some in terms of per dwelling unit, thereby changing the unit of analysis.

The following sections document the cost factors of infrastructure provision as outlined in the literature and discuss the influence of various urban form characteristics on development costs.

3.1. Factors affecting costs of infrastructure provision

Many factors have been investigated in various studies to determine the capital cost per dwelling unit of providing public services and infrastructure for new residential development.

Project costs vary for each infrastructure project and individual factors affect the direct (equipment, material and labour costs of construction) and indirect costs (field and administrative expenses, contractor fees, insurance, taxes) of infrastructure differently (Ellsworth, 2010).

The major common factors influencing infrastructure asset project costs and service delivery costs are listed and described briefly below.

3.1.1. Cost factors affected by the development setting;

- Urban form: population size, density, lot size and shape, location of development, dispersion of development, housing typology, and street network pattern.
- Site conditions/ topography: geographical location, space availability and transportation access, slope.
- Utility capacity utilization: catchment of existing infrastructure and the level of augmentation required is an important location specific factor affecting costs, especially in infill areas.
- Proximity to service areas: distance of the new development from existing utility plants and trunk infrastructure.

3.1.2. Other cost factors:

- Technological change: Infrastructure materials, construction methods and service delivery technology have largely been the same for decades, but there have been design and efficiency improvements in capacity planning and equipment specifications. It is difficult to account for these differences when comparing cost estimates.
- Factor price measures: costs for design and engineering, technical specifications, vertical construction, equipment redundancy, price premiums, market demands, labor factors and many other local area market factors.
- Demographics: age distribution, household size, etc.
- Service delivery standards: per capita service level goal

The following section explores specifically the different urban form features affecting the costs of public infrastructure and service provision. Table 2 gives a summary of the relevant academic and non-academic papers/ reports that present a quantitative infrastructure cost analysis.

Table 2. Summary of the quantitative studies

Author(s), Year	Study area	Infrastructure	Urban form indicator
Adaku, 2016	Ghana, Africa	Roads, water distribution, electricity	Street pattern - radial, grid, tributary
Burchell and Mukherji, 2003	U.S. metropolitan areas	Undeveloped land, roads, public services, housing	Location - infill vs. fringe
CMHC, 1995	Ottawa-Carleton	Linear infrastructure and community services	Location - infill vs. fringe
CMHC, 2007	6 Ottawa neighbourhoods	Transportation	Street pattern - grid and fused
De Duren and Guerrero Compeán, 2015	8,600 cities in Brazil, Chile, Ecuador and Mexico,	water, sewage, and waste collection	Density
Ford, 2009	2 U.S. neighborhoods	Roads, parking, linear infrastructure	Neighborhood design - compact vs. sprawl
Fox and Gurley, 2006	European, American and African cities	Municipal and community services	Population size
Gurran et al., 2009	15 Australian cities	Housing, on-site infrastructure	Location - infill vs. fringe
Halifax Regional Municipality, 2005	Halifax, Canada	Roads, public transport, water, waste services, emergency services, parks and library	Density, distance, dispersion, diversity
Hamilton and Kellett, 2017	Adelaide, Australia	Roads, public transport, municipal services, emergency services, health, education	Location - infill vs. fringe
Heimlich and Anderson, 2001	U.S. metropolitan areas	Rural land	Location - infill vs. fringe
Hortas-Rico et al., 2010	2500 Spanish municipalities	Public services, housing and community services	Location - infill vs. fringe
IBI Group, 2008	Calgary, Canada	Roads, public transport, water, wastewater, fire, schools	Location - infill vs. greenfield
Lieske et al., 2015	Wyoming, U.S.	Water and sewerage	Location - infill vs. fringe
Litman, 2004	Greater Toronto and Hamilton Area, Canada	Roads, water, sewage, garbage collection, school transport and mail delivery	Location - infill vs. fringe
Miller et al., 2004	Greater Toronto Area	Transportation and housing	Location - city centre vs. suburbs
Mohamed, 2009	Kingstown, U.S.	On-site infrastructure	Lot size
Parsons Brinckerhoff, 1998	U.S. cities	Transport, water, sewerage, schools, safety, parks, electricity	Location - infill vs. fringe
Rutgers University, 2000	New Jersey state, U.S.	Roads, water, sewerage and housing	Location - infill vs. fringe

SGS, 2016	Victoria, Canada	Roads, transit, water, wastewater and parks	Location - brownfield, greenfield, greyfield
Sustainable Cities International, 2012	Calgary and Los Cabos	Roads, public transport, water, wastewater, fire, schools	Location - infill vs. fringe
Teng at al., 2016	Nevada, U.S.	Road pavement maintenance	Topography
Trubka et al., 2010	Australian cities	Municipal and community services	Location - infill vs. fringe

3.2. Variation in infrastructure costs due to urban form

Various studies highlight the significance of a number of urban form characteristics that influence the demand for infrastructure and public services in a city. These urban form characteristics are drivers of infrastructure costs and can be manipulated as means to manage costs of infrastructure provision. The effects of urban features on development costs are discussed below based on conceptual and empirical analyses.

3.2.1. Population size

Larger populations both need and support a greater number of and more specialized community services (Slack, 2011). More personnel with advanced training for emergency services like police and fire-fighters, having access to modern vehicles and equipment to negotiate narrow back streets in dense downtowns. Big cities encounter higher crime rates, poverty, homelessness, new immigrants with special needs (training, language education, etc.), which means higher expenditures on social housing, shelters, public health and social services. To stay competitive on the global front and attract skilled international workers, metropolises need efficient transportation systems, especially high capacity public transit systems, mixed-use public spaces, parks, recreational and cultural facilities. Small cities may not have the demand or required urban densities to sustain subways and light-rail transit systems. Thus, it can be inferred that large high-density developments need more community services and have greater public service costs. Hard municipal infrastructure costs for transportation, water and sewerage also increase as the city needs a larger fleet size for bus transit, higher capacity treatment plants for water supply and wastewater, larger diameter mains and a greater number of garbage collection trucks along with bigger landfill sites. All this infrastructure has long-term maintenance and replacement costs. For this reason, municipal per-capita costs for central core cities in a metropolitan area are higher than its smaller suburban cities. City of Toronto's per-capita spending in 2008 was 50 percent higher than the average for both the Greater Toronto Area and the Province of Ontario on account of community services and transit operations (Kitchen 2010).

3.2.2. Population density

Population density is an important service delivery factor that affects the cost structure and quality of delivery, according to population size and land area. The most common measure of performance of an infrastructure service production and distribution system is efficiency, which refers to providing the maximum amount of service at a given level of resources. Serving large populations may offer a cost advantage from economies of scale, although empirical evidence is mixed about whether scale economies in infrastructure delivery exist, and suggests that it depends on the type of infrastructure service (Fox & Gurley, 2006). Generally, services with large capital inputs capture economies of scale in production, like a treatment plant of a given capacity can treat additional water at low marginal costs, allowing for periodic increases in serviced population. However, low per unit costs of treatment may be offset by the higher per capita cost of water distribution, if the population is distributed over a large geographic area. Increasing distance from the source of raw water increases the cost of distribution (extensive pipeline network and numerous water storage towers) as well as the operational costs of pumping water through the system. Residential density and distance to treatment plants have a significant impact on the costs of 'hard' infrastructure-based services (Halifax Regional Municipality, 2005). Distribution infrastructure is much more compact for a dense development consisting of high-rise towers built in a small area, producing cost savings. In other words, low density developments are spread over a large area, resulting in high capital costs for linear infrastructure for all capital-intensive hard infrastructure like water, sewerage and stormwater drainage as well as roads and rail transit systems. Similarly, each additional kilometer of road or pipeline results in additional maintenance costs.

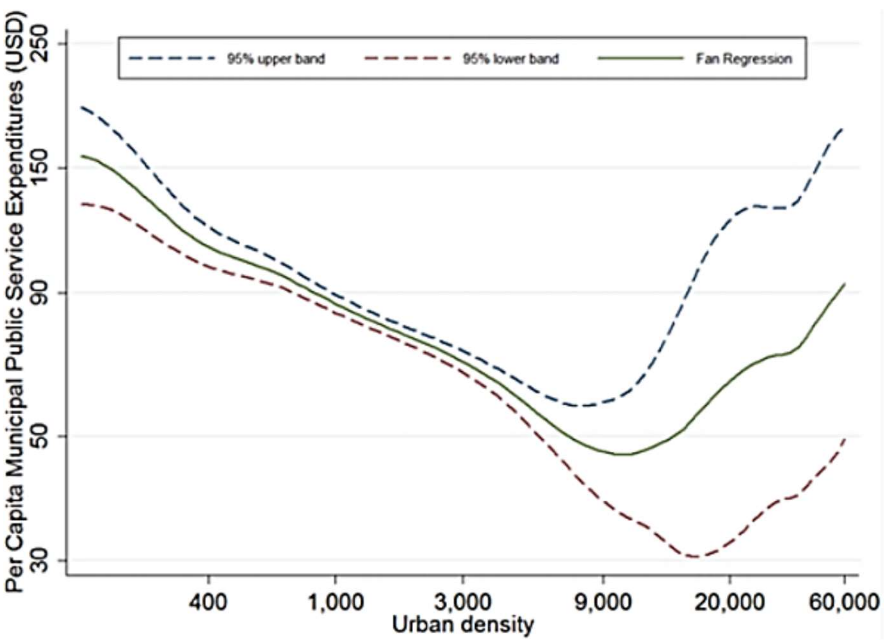


Figure 2.Municipal service costs by urban density (De Duren & Guerrero Compeán, 2015).

Community service delivery costs are also lower in densely populated areas, where fewer service locations may be needed for police and fire-fighting services relative to a sparsely developed area containing the same population, because of short response times. More service centres will be required to cover a larger urban area, irrespective of the population size, if the same response time has to be achieved. For example, the annual per capita service delivery costs for water (see Figure 2), wastewater and garbage collection by municipal governments in Brazil, Chile, Ecuador, and Mexico range from more than $150 in very low-density suburban areas to about $50 in dense urban areas (De Duren & Guerrero Compeán, 2015). The delivery costs increase sharply in very high-density downtown areas or city centres due to negative effects of congestion and possibly higher demand.

However, costs for labour-intensive services like fire-fighting and education (number of schools/ classrooms/ teachers) tend to increase with population size and density, because these have a fixed ratio of personnel to serviced population (De Duren & Guerrero Compeán, 2015). On one hand, high density development reduces the cost of producing services, on the other hand, it increases the overall cost due to increase in demand for services. Thus, effects of density on costs of providing community services cannot be generalized as scale economies are service-specific. Researchers, discussed below, have suggested designing separate cost-minimizing service-specific districts for say, water, sewerage, fire protection and schools to capture scale and size economies for a given residential population and density. This strategy, though logical, may not be a practical solution due to differing size jurisdictions for different services. For instance, authors of a study of urban water service in the Seoul metropolitan region, conclude that designing the optimum-sized water district in relation to population density and distance from the water source and the means of service delivery ensures the provision of water services to the widest population base at the lowest per capita cost (Kim & Lee, 1998). Lieske et al. (2015) used geographic information science-based planning support systems to develop urban service areas containing residential clusters, that were fiscally efficient for water and policing service provision (Lieske, McLeod, & Coupal, 2015).

Another noteworthy finding is that the majority of cost savings associated with high-density compact developments are made in the user-pay component of infrastructure, that is, service delivery charges (Kinhill Engineers, 1995). For example, existing rail stations are excellent opportunities for infill transit-oriented developments (TOD) with shared public-private infrastructure costs. TODs create dense, mixed-use centers of activity and are an essential smart growth strategy (Ewing et al., 2002).

3.2.3. Topography

Costs for sewerage and water infrastructure can vary immensely depending on terrain and soil conditions of the site, such as mountainous areas may require different service methods, infrastructure and costs than plains or along the shore (Fox & Gurley, 2006; Trubka, Newman, & Bilsborough, 2010). Roadways at high elevation have to be constructed with special safety features, such as guard rails, or need special structures like retaining walls, which would produce high maintenance costs and higher capital costs(Teng, Hagood, Yatheepan, Fu, & Li, 2016). Similarly, distribution costs are heavily dependent on terrain and slope. Stormwater management infrastructure is solely dependent on topography as it mimics a site's natural hydrology to design runoff infiltration systems (Ford, 2009). However, topography cannot be manipulated much and is not a significant variable in controlling development costs.

3.2.4. Location and dispersion of development

The primary development settings for urban growth include high-density, clustered infill development (Figure 3.b. Smart Growth) within inner city areas and low-density, dispersed greenfield developments (Figure 3.a. Sprawl) in fringe areas. Compact growth through infill developments instead of fringe growth reduces per-capita land consumption and saves on costs of new land development, building new roads and extending underground linear utilities. Compact growth 30-year scenarios (till 2040) identified savings of 33% for Calgary, Canada for the capital cost of roads, transit, water, emergency response, schools and recreation services and savings of 14% on operational costs(IBI Group, 2009). In a similar study for Los Cabos, Mexico, savings on capital costs were 38% and operational cost savings were 60% (Sustainable Cities International, 2012).Growth simulations for the U.S. using mathematical impact models suggest that sprawl developments increase local road lane-miles by 10%, annual public service costs by 10%, and housing development costs by 8%, increasing total development costs by about $550 per dwelling unit per annum (Burchell & Mukherji, 2003).

Fig. 3.a. Fig. 3.b.

Figure 3.a-b. Comparison of alternative development forms (Conventional suburban development or Sprawl vs. Traditional neighborhood development or Smart Growth). Source: Ford, 2009.

Infill is generally recognised as having low infrastructure costs due to the opportunity for developers to tap into spare capacity within existing government-provided services and infrastructure systems, provided spare capacity exists within these systems. Several studies have established that municipal infrastructure and service delivery costs tend to decline with increased density achieved by infill developments relative to greenfield expansion (Burchell & Mukherji, 2003; Ford, 2009; Hamilton & Kellett, 2017; Hortas-Rico & Solé-Ollé, 2010; Litman, 2004, 2019; Parsons Brinckerhoff, 1998; SGS, 2016; Slack, 2002; Trubka et al., 2010; UC Berkeley School of Law, 2017). Based on three comparative case studies in metropolitan Adelaide, Hamilton & Kellett (2017) state that the cost of infill development is one-third of greenfield or renewal developments on the urban fringe. A study investigating the cost of infrastructure materials and construction for the two hypothetical development scenarios with alternative housing mix and density levels for the infill scenario, found that infrastructure costs for the smart growth scenarios were consistently less than the greenfield sprawl scenarios, the difference ranging between 32% to 47% (Ford, 2009). In a comparative evaluation of infrastructure costs in different development settings in Victoria, greenfield lots were found to cost 2-4 times more than infill, depending on the capacity of existing infrastructure (SGS, 2016). A study comparing development costs in major cities of Australia, the U.S. and Canada suggests that, excluding land and construction costs from the analysis, the initial capital costs of a non-contiguous fringe development with no existing infrastructure can be 3.2-4.2 times higher than a contiguous infill development with existing infrastructure (Western Australian Planning Commission, 2001). If development charges are location-specific and reflect the full costs and benefits (private and social) of a sprawl development, then developers will be incentivized to make more efficient location choices (Donnan, 2008).

Some transportation costs for the government may be high in core city areas due to the demand for high-capacity rapid transit systems, but high parking provision costs, in addition to provisioning for road construction, are associated with fringe development. More parking spaces are required for fringe residents than those in inner cities, due to a higher proportion of car trips in low-density areas, resulting in more dispersed residential subdivisions and an increase in total vehicle kilometers travelled. Transportation infrastructure shapes cities by guiding urban growth and has the most significant operational costs, in both inner-city and fringe areas. Nonetheless, it accounts for almost 50% of the cost difference between the two development forms (SGS, 2016). Both private and public transport operational costs for greenfield development are more than that for infill or urban redevelopment, by approximately $18,000 per household per year for Australian cities, which are indirectly subsidized by various levels of government (Trubka et al., 2010).A study assessed public water and sewer costs associated with alternative development patterns using an engineering cost model and found costs increased with more dispersed housing (Speir & Stephenson, 2002). Conventional suburban development often requires additional pavement, walks, driveways, and other impervious surfaces, which result in additional material cost for construction of impervious surfaces and more stormwater runoff volume. As a result, higher public investments are needed for more extensive and high-capacity stormwater management systems. Development charges are a useful tool for encouraging compact land use and efficient infrastructure provision. Developers, however, tend to consider only their own costs, not the impact of the development on the city's costs of providing services, unless development charges are calculated to reflect the different costs associate with different types of development (Slack, 2002).

However, there is some evidence to suggest that developer's construction costs can be higher in very high-density infill situations, due to congestion, friction with neighbouring sites or very high land costs which may get offset by reduced transportation costs (Litman, 2004). There are a few studies, which suggest that infrastructure costs in urban core areas are higher due to vertical buildings and space and access constraints (Gordon & Richardson, 1997, 2000; Windsor, 2007). It is suggested that sprawl developments have flourished due to residential preference and technological changes and that, if it is an uneconomical form of development, market forces will take care of it. A counter-argument suggests that if the housing market has a demand for low-density fringe developments, then there is probably a market distortion that is preventing the allocation of true location-related costs to the beneficiaries of greenfield infrastructure in terms of development charges, utility fees and local taxes (Litman, 2004; Rutgers University, 2000). Similarly, user charges for residents in low-density fringes should reflect the true costs of public services such as school busing, road maintenance, water and sewer lines, or garbage collection for recovery of actual O&M costs (Slack, 2002), Another argument in support of suburban expansions is provided through an econometric analysis of actual municipality data that indicates that there is no significant difference in expenditures per capita between the more sprawling and less sprawling communities (Cox & Utt, 2004). This study has been criticized by Litman (2004) stating that the assumption that municipal expenditures reflect the costs of providing per capita public services is fundamentally wrong and also that the Cox and Utt study did not consider all cost saving infrastructure components of Smart Growth, among other issues.

3.2.5. Street pattern

Street patterns directly influence linear infrastructure costs, but very few studies have examined this critical urban feature. The costs of roads, sidewalks and underground utilities infrastructure for the traditional grid street pattern have been found to be significantly higher when compared with the conventional curvilinear suburban street pattern (Dillon Consulting Ltd., 2010). A study of costs per dwelling of water distribution systems, electricity distribution systems and road networks in Ghana influenced by tributary, grid, radial, and hybrid street patterns in four hypothetical 1.1 km^2 residential neighborhoods of 5000 inhabitants and average household size of 5, shows that the tributary street pattern has the lowest linear infrastructure costs, while the grid pattern has the highest costs (Adaku, 2014).These studies suggest that street configurations provide an opportunity for cost optimization.

Fig.4.a. Fig.4.b.

Figure 4.a-b. Comparison of alternative street layouts (conventional suburban vs. fused grid). Source: CMHC, 2007.

The fused grid pattern (Figure 4.b.) is an evolution of the traditional gridiron pattern and the conventional suburban pattern (Figure 4.a.) found in most residential subdivisions, that overlays two independent hierarchical street networks, one each for pedestrians and cars. This pattern gives priority to walking and cycling at the block level, and restricts high-speed automobile movement to the neighbourhood and district scale (CMHC, 2007). The Dockside Green in Victoria, BC, and Emerald Hills in Strathcona, Alberta are the most popular and awarded examples of neighborhood designs based on the fused grid concept.

The fused grid gives the best traffic performance recording least delays because its major collectors are designed as one-way couplets, that reduce the number of signalized intersections required and streamline traffic signal cycle timings. This saves on future costs of road infrastructure. In terms of land development costs, the traditional grid requires 10% more land for roads and lanes due to 28% more road length, 18% more road pavement, that amounts to a 64% increase in total lifecycle costs, when compared to fused grid(CMHC, 1995). Another research report found a 42% increase in infrastructure cost, 14% increase in maintenance and renewal costs and 14% decrease in taxable property frontage for traditional grid-based neighborhoods in Winnipeg, Canada (Dillon Consulting Ltd., 2010). A similar comparative study also reported 23% decrease in land under roads and a 30% decrease in infrastructure costs and lifecycle costs (IBI Group, 2008). These studies demonstrate the development efficiency of fused grid road patterns.

3.2.6. Parcel lot size

It is known that the developers' on-site costs for sewer and water services and road construction vary with parcel lot size, but there is insufficient evidence available to understand the cost relationship. A few researchers claim that infrastructure costs increase with increasing lot sizes (Najafi et al., 2007; Speir & Stephenson, 2002). One study found that on-site costs per lot decrease as lot sizes increase (Mohamed, 2009). There are serious implications of this finding as it suggests that if on-site infrastructure costs influence the decisions of single-family residential land developers, they may prefer larger exurban lots and continue supplying low-density dispersed housing. Large-lot developments consume much more land per unit of housing than the typical suburb, which has led to loss of rural amenities, open space, and environmental goods(Heimlich & Anderson, 2001).

3.2.7. Housing typology

Small-lot single-family housing favours low-density, automobile-oriented sprawl developments, while multi-family housing fosters compact, dense and transit-oriented communities (Litman, 2017). The prevalent sprawling development patterns, supplying single family attached and detached houses, have encouraged car ownership and use, leading to increases in congestion and commute times. A study of travel and housing markets in the Greater Toronto Area showed that average annual transportation costs exceed average annual housing costs for residents in the suburbs of Toronto, and combined housing plus travel costs have increased over time within the region (Miller, Roorda, Haider, & Mohammadian, 2004). Providing compact, affordable housing in job and transit rich city cores as part of infill redevelopments is not easy for the government, as high land and building costs incurred by the developers are eventually transferred to the potential owners and tenants, resulting in very high housing costs in downtown areas. A study of Californian cities points out that local land use policies have made developable land in core areas more costly through zoning restrictions, off-street parking requirements, preservation regulations, and unnecessarily slow permitting processes, among other factors (UC Berkeley School of Law, 2017).

A study of 8 patterns of greenfield development in Australia for 100,000 persons over a 20-year period shows that the least costly form of development considering overall infrastructure costs is at 15 dwellings per hectare, where reducing the density to 10 dwellings per hectare increases utility costs by 3% (Kinhill Engineers, 1995). Different studies propose different person and housing density numbers, based on local conditions.

4. Conclusions and recommendations

There is limited research available on how costs of infrastructure provision change with urban form in North American cities and other western countries, but most are based on theoretical assumptions rather than real cost data. Comparing infrastructure costs for different development settings and locations in a metropolitan region can be complex, due to lack of long-term data availability, variable units of analysis, cost components, recording methods and their interpretations, and different local contexts. Despite these challenges, the common significant cost factors for infrastructure provision have been identified and some conclusions can be drawn about the effects of two principal alternative development forms (high-density infill redevelopment vs. low-density sprawl greenfield development) on infrastructure costs. Based on the findings of the literature review, structured recommendations have been made towards achieving cost-efficient and sustainable management of urban growth.

Important urban form factors that influence infrastructure costs were considered in this study: population size, density, lot size, location of development, dispersion of development, housing typology, and street network pattern. These findings indicate that density and location are the major determinants of infrastructure costs in a metropolitan region. Infrastructure costs are found to be inversely related to density. But, density-related savings from economies of scale are service-specific, that is, scale economies may be captured in production (example, a water treatment plant) but additional demand may or may not result in water distribution savings as distribution infrastructure depends on the development form (example, compact or dispersed). Another important trend observed in infrastructure costs varying by urban density is that cost savings may decline at very high densities in urban cores due to negative effects of crowding, access constraints and saturation of existing infrastructure capacity in the area.. Hence, density benefits need to be combined with locational factors (distance from city centre and from existing infrastructure) to capture cost savings in capital sunk costs of infrastructure. Scale and size economies can be exploited by creating separate cost-minimizing service districts for different infrastructure services. It is recommended that cost analysis may be conducted for a single infrastructure service at a given time, as it is easier to determine appropriate input and output measures for designing optimum-sized service districts.

Location of the development is critical, mainly because of its direct impact on costs of service provision in relation to distance from and capacity of existing trunk infrastructure. Infill infrastructure cost estimates have low reliability, because the capacity of surrounding infrastructure varies over short distances between blocks. The costs of servicing infrastructure in greenfield areas are comparatively straightforward to measure on a per unit basis. Nonetheless, initial capital costs of infrastructure provision are lower in contiguous infill redevelopment locations in comparison to capital costs for non-contiguous fringe development due to spare capacity in existing underground trunk infrastructure in infill locations, lower parking space requirements and low public transport operational costs. Since, suburban residents are not paying true costs of development, location-specific development charges and true user-charges are needed to incentivize a reduction in supply as well as demand for detached or attached single family housing in sprawl developments.. The findings suggest that even though infrastructure costs in dense infill sites may be low, the land development and structure costs are high due to restrictive zoning policies or space and access constraints, resulting in expensive high-rise apartments in city centres, pushing residents to move to low-density suburban developments, where housing costs are comparatively less, but transportation costs increase steeply. Residential relocation to suburban and ex-urban locations fosters unsustainable sprawling urban growth patterns and creates financial stress for municipal governments and agencies responsible for infrastructure provision. Similarly, neighbourhood design and street patterns affect the costs of linear infrastructure. Mixed housing neighbourhoods based on the fused grid street pattern, which combines the benefits of the traditional gridiron pattern and the conventional suburban pattern, are the most efficient and cost effective for infrastructure service delivery.

. One of the primary goals of land use regulations is to provide efficient and economical infrastructure and service provision, but they need appraisals every 15-20 years, based on their impact on development costs. Policies supporting recycling of land in inner urban areas in the form of infill redevelopments, are needed as providing new infrastructure for greenfield developments is fiscally challenging for local governments, especially in the absence of true pricing of infrastructure costs of sprawl developments. (Moreover, smart growth savings from compact, mixed-use and more accessible land use patterns extend beyond municipal government annual accounts and reduced fiscal deficits, to savings for other stakeholders like private sector utilities, school districts, state governments, businesses and consumers.

4.1. Framework for determining infrastructure costs

The following method could be used to project future costs of infrastructure provision in differing development settings. The focus of the framework is on assessing the impact of the urban form, while keeping socio-demographic and topographical impacts constant. Steps in the proposed framework are as follows.

4.1.1. Estimate the spare capacity of existing surrounding infrastructure at alternative development locations.
4.1.2. Define the population size and average density to make assumptions about the demand for transportation, water supply and sewerage.
4.1.3. Undertake an appraisal of development locations (infill or fringe) to compare initial capital costs and operational costs of public infrastructure and community services.
4.1.4. Compare alternatives for neighborhood design, street network pattern and lot sizes to estimate costs for linear infrastructure.
4.1.5. Compare alternative mixes for housing typology and related dwelling density to achieve the desired population density.
4.1.6. Develop cost-effective service-specific distribution districts based on existing infrastructure capacity and demand.
4.1.7. Estimate development charges, user fees and tax revenues for financial viability.

4.2. Suggested research

Long-term infrastructure costs of urban growth are influenced by a set of interacting socio-economic behaviours of which we have limited knowledge. We need more longitudinal research in order to fill in gaps in our understanding of the impacts of alternative development patterns. More panel surveys to document changes in travel behaviour arising from shifts in a household’s income/ residential location/ job location would help in quantifying value of time for residents. Value of travel time is the largest cost in the full-cost planning framework and is essential to reliable cost-benefit analysis for transportation investments, estimating development charges and full costs of alternative development patterns (Parsons Brinckerhoff, 1998).

Similar long-term studies are required to understand the effects of housing typology, lot sizes and street patterns on residential/ commercial transportation needs, water and energy consumption and open space needs, and the resulting costs of development patterns (compact urban form and sprawl). Other than cross-sectional datasets on transportation, land use and urban form aspects, longitudinal data on actual capital and operating costs of utilities in consistent units, is necessary for full-cost models to analyze the costs of development in different settings.

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