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The Morphological Effect of Public Transportation Systems on Cities: Urban Analysis of Transit-Oriented Development (TOD) in Swedish Cities  
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Introduction
Transit, a shortening from mass transit, is an American catchall for public transportation (Cervero, 1998) and Transit-Oriented Development (TOD) is a policy to design and develop dense, attractive and walkable urban environments that enhance the use of public transportation. In a broader perspective, it deals with synchronizing the urban life, its everyday activities and mobility patterns, the development and growth of the city with public transportation (Stojanovski et al., 2014).

The public transportation and its integration with cities has been a leitmotif of urban design in the European compact city and American TOD since the 1990s (EC, 1990; Calthorpe, 1993). The sustainable mobility challenge in European cities is to break the dependence on oil without compromising the mobility (EC, 2011, p.5). The ambition is to create integrated, multimodal transportation systems that fully exploit the potential of public transportation (EC, 1997, pp.11-2) where greater numbers of passengers are carried jointly to their destination by the most efficient (combination of) modes (EC, 2011, p.5).

The sprawling of cities often acts as an obstacle to sustainable mobility and TOD which is always associated with walkability that assists access to public transportation (Cervero et al. 2004; Currie 2005) is conceived as a solution. The walking distances determine the size of the TOD and there are rules of the thumb about proximity to public transportation: 400 m or quarter mile walk to the bus (5 min) and 800 m or half mile to the train (10 min). These distances were used by architects and urban designers as urban boundaries for neighborhoods in Sweden from the mid-20th century (Markelius, 1944) and they are still used in the TOD guidelines (Calthorpe, 1993). But the heuristics of proximity to public transportation are never questioned: Do people really walk these distances to the bus or train? What makes people to walk further in urban environments? How the effect of public transportation influences urban form and spreads in the urban environments?

Urban morphology of public transportation and Transit-Oriented Development (TOD)
Urban form implies either design or emergence of form, in two or three dimensions, from the scale of courtyards to conurbations (Marshall, 2005, pp.15). Traditionally, the urban form is defined through form and process. The city is a “mosaic of small worlds” (Park et al., 1929, pp.40), where the pieces of the mosaic develop their own particular character and personality as individuals (Reclus, 1905), grow, evolve, degrade and die. There is ongoing historical layering of urban patterns: 1) street layouts, 2) plots and their aggregation in blocks, and 3) buildings in blocks (Conzen, 1960); and land utilization (Birkhamshaw and Whitehand, 2012), on small scale; and creation of fringe belts from different urbanization periods on medium scale (Conzen, 1960; Whitehand, 1967).

In another urban discourse the cities are conceived “extraordinary agglomerations of flows” of people on the move, information, capital (Ash and Thrift, 2002, pp.42). There is a hierarchy of world cities (Friedman, 1986; Sassen 1994). Each place in the city is a node in a glocal urban network, with a network capital (Urry, 2007) which contributes in the struggle for global distinction. The network capital equally revolves around connectivity as well as around the quality of place: Why to go there? What to do there? What is there? Who is there? What is going on there? (Florida, 2008) The urban lives are mobile and experienced as sequences of more or less attractive fixed places and vehicles on the move (buildings, streets, squares, cars, buses, trains, airplanes, etc.).

There is much research on urban design and form in a context of mobility and flow, but this morphological discourse shifted gradually towards the large scale of urban systems from adapted spaces and flow system
(Lynch and Rodwin, 1958); paths, edges, nodes and districts (Lynch, 1961); activities, spaces, channels and communications (McLoughlin, 1969); to transportation systems in urban environments as a feedback cycle of land use, activities, accessibility and transportation (Wegener, 1994).

The interplay between urban form and public transportation systems is multileveled and multifaceted. In a context of mix of traditional and “cities on the move” urban morphology, architecture and urban design interface with transportation systems, produce frontages, getaways and affordances (Gibson, 1986; behavioral settings in Barker, 1969) and create network capital that hinder or stimulate movement and mobility. The effect of public transportation systems on cities is multileveled. It is visible in the proximity of stops and stations on a small scale and in establishment of urban networks on medium and large scale, regionally and globally. There is not much focus on interfaces between urban form and flow. The urban form and transportation systems can be conceived though two perspectives: top vs. within. The two perspectives are consequence of two modes of thinking: hot vs. cold, fast vs. slow, emotional vs. cognitive, reflexive vs. reflective (Metcalfe & Mischel, 1999; Kahneman, 2011). The top perspective is reflective and generalizing, whereas the within perspective is reflexive and responsive to environmental stimuli. There are three focuses that also has to merge: the urban form, transportation systems and the interfaces in between (Table 1).

Table 1: The interplay between urban form and transportation systems (urban flows) from two perspectives

<table>
<thead>
<tr>
<th>Urban form</th>
<th>Interfaces</th>
<th>Transportation systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top perspective (reflective)</td>
<td>Urban patterns (mosaics of places or elements, networks of places or elements)</td>
<td>Interfaces between places (exits and entrances between cityscapes, entering or exiting urban flows, etc.)</td>
</tr>
<tr>
<td>Within perspective (reflexive)</td>
<td>Cityscapes (observing and responding to environmental stimuli)</td>
<td>Being in an urban flow</td>
</tr>
</tbody>
</table>

For TOD there must be a fusion between the scales. Peter Calthorpe argues that TOD has two scales (the urban design and regional city scale) (Calthorpe, 1993), but there are also finer psychological levels within these scales tangling interfaces between places and entering or exiting urban flows. The interfaces between urban form and public transportation systems are both physical (stations or stops) and psychological (change between the modes of thinking by entering or exiting urban flows). The complexity of perceiving an urban environment or being in a flow combined with the cognition of urban environments and generalization about urban form and mobility can be described and structured with the PATTERN LANGUAGE which tangles both URBAN and MOBILITY PATTERNS.

**PATTERN LANGUAGE of URBAN and MOBILITY PATTERNS**

Within urban morphology, the PATTERN LANGUAGE (Alexander et al., 1977; Alexander, 1979) is one way of looking the cities, their physical form and the urban life within cities. Christopher Alexander argues that each building, neighborhood and town has a particular morphological character marked by patterns underlying it: patterns of events and physical spaces. Each URBAN PATTERN consists of underlying elements and relationships between elements that can be formulated as:

\[ X = r(A, B, C, \text{etc.}) \]

\[ X \quad \text{type} \]

\[ r \quad \text{relationships between elements A, B, C, etc.} \]

The urban design is a morphogenetic process (Alexander, 2002, pp.508), where the number of generic URBAN PATTERNS is not terribly high, but there are many variations and replication of few genotypes. Each city has its own distinctive set of URBAN PATTERNS, either unique or recurring across the city, which exist on different scales. Each pattern is connected to certain larger patterns (for example MAIN STREET is part of URBAN CORE where URBAN CORE = r (MAIN STREET, etc.) which come above; and to certain smaller patterns which come below (MAIN STREET = r (COMMERCIAL FRONTAGES, STROLLING, CORNER CAFÉ, BUS STOP, CROWD OF PEDESTRIANS, etc.). Some URBAN PATTERNS are interdependent. There is no URBAN CORE without a MAIN STREET or COMMERCIAL FRONTAGES.
There is a hierarchy between elements in traditional urban morphology described with relationships. The streets are most rigid element that influences patterns of plots and plot division of the blocks. The urban blocks are created by combination of plots and streets. The urban block is seen from a street (Italian school) perspective, one street with aligning plots, or from a plot (German and British school) perspective, a block is all the plots surrounded by streets (Kropf, 2014). The urban blocks via plot sizes and street patterns influence the buildings. BIG BOX BUILDINGS need LARGE PLOTS and MOTORWAYS. In the end the land utilization often depends on the type of buildings. These relationships are formulated the traditional elements of URBAN FORM:

\[ \text{URBAN FORM} = r(\text{LAND UTILIZATION (INCLUDING BUILDING UTILIZATION)} = r(\text{BUILDINGS} = r(\text{URBAN BLOCK} = r(\text{PLOTS} = r(\text{STREETS}))))). \]

The PATTERN LANGUAGE is applicable for public transportation. There are underlying and overlaying URBAN and MOBILITY PATTERNS in public transportation. Different PUBLIC TRANSPORTATION NETWORKS AND SERVICES exist on different scales. The TRUNK-FEEDER SYSTEM is common as regional pattern in a context of European public transportation planning. The TRUNK and FEEDER LINES are often completed with DIRECT LINE services, direct connections between important origins and destinations. There are also COMMUTER SYSTEMS only, for example in Brisbane. A set of PATTERNS including PUBLIC TRANSPORTATION NETWORKS AND SERVICES can be summarized by the planning genotypes:

\[ \text{TRUNK-FEEDER SYSTEM} = r(\text{TRUNK LINES, FEEDER LINES, DIRECT LINES, etc.}); \]
\[ \text{COMMUTER SYSTEM} = r(\text{DIRECT LINES}). \]

Within the overlaying URBAN PATTERNS of PUBLIC TRANSPORTATION NETWORKS AND SERVICES each BUS LINE or TRAIN LINE has its own morphological character. There are MOBILITY PATTERNS that include WEEKDAY COMMUTING, HOLIDAY JOURNEY, HIGH SPEED, etc. If we consider the blue BUS LINE 1 in Stockholm it has distinctive elements:

\[ \text{BUS LINE 1} = r(\text{BLUE BUSES, 15 MIN MINIMUM FREQUENCY, SERVICE AROUND THE CLOCK, LOW SPEED, URBAN PROSPECT, BUS ON STREET, etc.}). \]

**The PATTERN LANGUAGE of public transportation and TOD**

TOD was introduced by Peter Calthorpe (1993) as design or development of moderate or high density mixed use urban environments at strategic points along a regional public transportation system. Calthorpe differentiates two URBAN PATTERNS: urban and neighborhood TOD that are described though preferred mix of functions (residential, commercial and public spaces), street layouts, mix of housing types, etc. The two scales can be formulated through LOCATION AND CONNECTIVITY and WALKABILITY AND INTEGRATION as:

\[ \text{TOD} = r(\text{LOCATION AND CONNECTIVITY} = r(\text{PUBLIC TRANSPORTATION NETWORKS AND SERVICES, NETWORK CAPITAL})); (\text{WALKABILITY AND INTEGRATION} = r(\text{URBAN FORM, PUBLIC TRANSPORTATION INFRASTRUCTURE, INTERFACE BETWEEN URBAN FORM AND PUBLIC TRANSPORTATION INFRASTRUCTURE})). \]

The development of PUBLIC TRANSPORTATION NETWORKS AND SERVICES results in a certain hierarchy and uneven NETWORK CAPITAL in the urban mosaic of one region. The NETWORK CAPITAL of each place depends on the centrality within the network. At the large scale the TOD urban patterns exist in a context of the location of the neighborhood in the public transportation network and its connectivity. Ditmar and Poticha (2004) has developed a typology of places and preferred PUBLIC TRANSPORTATION NETWORKS AND SERVICES in respect to the different urban fringe belts in American cities. More generally the fusion of PLACE and PUBLIC TRANSPORTATION NETWORK LOCATION AND CONNECTIVITY can be conceived though a typology on its own:
1. REGIONAL NEXUS (URBAN CORE WITH REGIONAL IMPORTANCE) (a transfer point between trunk lines)
2. REGIONAL CORE (PART OF AN URBAN CORRIDOR WITH REGIONAL IMPORTANCE) (on a trunk line)
3. LOCAL URBAN NEXUS (a transfer point between trunk lines)
4. LOCAL URBAN CORE (PART OF AN URBAN CORRIDOR) (on a trunk line)
5. TRANSPORTATION NODE (TRANSFER POINT) (a transfer point between trunk lines or terminal where feeder lines branch)
6. WELL-CONNECTED PLACE (on a trunk line)
7. POORLY-CONNECTED PLACE (on a feeder line)
8. OFF-GRID PLACE (no public transportation service)

The regional scale tangles motorized mobility and accessibility throughout the urban network of one region. The urban scale revolves around integration of public transportation infrastructure in the urban form that allows for easy walking access. At urban scale there is interplay between PUBLIC TRANSPORTATION INFRASTRUCTURES and the traditional URBAN FORM elements. There are four principal PUBLIC TRANSPORTATION INFRASTRUCTURES in a context of the street as traditional morphological element (Stojanovski, 2013a):

1. PUBLIC TRANSPORTATION ON STREETS (bus lines and tramways, bus stops and tram platforms);
2. COMPLETELY SEGREGATED PUBLIC TRANSPORTATION, either elevated or on the ground (buses or trains on heavy railways or busways, completely segregated train or bus stations on the ground or elevated);
3. PUBLIC TRANSPORTATION UNDERGROUND (railway or bus tunnels);
4. PARTIALLY SEPARATED PUBLIC TRANSPORTATION ON GROUND (light railways or busways, bus stops and tram platforms).

The level of segregation or integration by PUBLIC TRANSPORTATION INFRASTRUCTURES shapes zones for TOD as URBAN PATTERNS:

1. TOD CORE (100 m default or 1-2 min walk, but they can extend depending on the urban design, zone that generates maximum number of passengers)
2. ZONE IN WALKING DISTANCE (100 to 400-600 m or 2 to 5-7 minute walk) the number of passengers roughly halves
3. ZONE OF ACCESS (up to 2 km or 30 minute walk)
4. BUS FEEDER ZONE (5-15 minute ride)
5. CYCLING FEEDER ZONE (5-15 minute ride)
6. KISS and RIDE /PARK and RIDE ZONE (5-15 minute drive)

The argument here is that there are different zones within walking distance to a stop or station. There is a desirability core (Stojanovski 2013a), the most desirable TOD zone in the center. The morphological effect on architecture and cityscapes is visible firstly in the TOD CORE zone. The TOD CORE zones are tentative and question the traditional urban design heuristics about walking distances.

The hypothesis and morphological method to analyze TOD CORES as interfaces between URBAN FORM and PUBLIC TRANSPORTATION

Even though the coinage TOD was introduced by Peter Calthorpe in the 1990s, the TOD is nothing new. Urban cores or corridors created during in different periods of urbanization, especially during the European industrialization and the age of railroads, stayed until today as relics of that era. Historically, many European cities developed as compact cities along public transportation systems, mainly railroads throughout the 19th and the beginning of the 20th century (Stojanovski et al., 2012).

The hypothesis is that the URBAN PATTERNS of PUBLIC TRANSPORTATION INFRASTRUCTURES have a consistent morphological effect historically on the TOD CORES (Stojanovski, 2013) in respect of direct effect on architecture and cityscapes around stations. The hypothesis of the TOD CORES can be
represented and analyzed graphically (Figure 1). Thus morphological methods are applicable to analyze the URBAN PATTERNS of public transportation and TOD in existing cities. The proposed method involves theory on orientation and perception in urban environments through the concept of affordances in environmental psychology. The broad concept of URBAN PATTERNS allows awareness of the scale of the analysis in the TOD PATTERN:

The first preposition is that a person in the urban environment orients itself differently as an individual and a group. The urban environment is directly perceived through the visual field. The visual field is the area within the fields of view of the both eyes. It is clear in the center (foveal vision field) and vague in the periphery. It extends 180° from side to side and 140° up to down and it is oval in shape (Figure 2, A). The environmental stimuli come though the visual world that is like a sphere around a person and clear everywhere (Gibson, 1986, pp.206). The visual world is represented by isovist with affordances. An isovist is the set of all points visible from a given vantage point in space with respect to the obstacles and voids in the line of sight in one environment (Benedikt, 1979). Affordances show what the urban environments offer to the observer either for good or ill. The environment has a meaning and value to the observer (Gibson, 1986, pp.127) and determines, presupposes behavior (Rapoport, 1977).

There are different ways to analyze cityscapes (see serial vision in Cullen, 1961; paths, nodes, edges, districts and landmarks in Lynch, 1960). The method of representation includes a fusion of plan and perspective representation (see Stojanovski, 2013b) to grasp the within and top view. The façades as cityscape frontages are interfaces between streets and buildings and they are represented on the plan by skewed top perspective (Figure 2, B). The skewed perspective allows representing a wider region of the isovist as sphere of environmental stimuli.

When observing, the environmental stimuli come as isovists, a set of affordances (people to talk to, shops to look at, exits to other urban spaces, etc.) towards the vantage point. There are blind regions in the isovist (Figure 2, C1). The routine is either to turn the head rapidly to grasp the sphere of the visual world or choosing vantage points in the urban environment to minimize the blind fields and maximize looks on affordances (Figure 2, C2). The second preposition is that there is a difference in perception between individuals and groups. The group creates a “collective perception” where the entire isovist is either jointly perceived by different members of the group or the group becomes “blind” to environmental stimuli and enters a joint “flow mode” of conversation (Figure 2, C3). “Flow” is engaged mode of thinking described by Csikszentmihalyi (1990) that is presumed to subordinate the processes of observing environments and responding to environmental stimuli.

The urban sense of a place tangles activity, image and physical form (Canter, 1977; Montgomery, 1998). The physical settings for an “urban feeling” are anthropomorphically straightforward. An average person “feels” other people emotions and distinguishes facial expression (anger, happiness, etc.) at a distance between 20 to 25 m (60 to 80 ft.), “hears” to a distance to 30 m (100 ft.) and “sees” to 100 m (325 ft.). The line of sight is much longer, but at a distance between 70 and 100 m (250 and 325 ft.) the human figures become individuals and it is possible to notice the person’s sex, approximate age and what a person is doing. It is called a “social field of vision” (Gehl, 1987). The streets and squares form enclosures (urban spaces) which are designed according to the anthropomorphic measure to “feel” and “hear”. No square or street designed “to human scale” is wider than 30 m. Beyond the 30 m urban enclosure threshold the square or street works as open space. It will be a border, an urban edge, between two neighborhoods. The neighborhoods are seldom beyond Gehl’s “social field of vision” (Gans, 1968; Canter, 1977; Bosselmann et al., 1999)

The TOD CORE extends 100 m from a public transportation stop or a station and corresponds to the “social field of vision”. It has fluidity properties and stretchy borders depending on the creation of groups of pedestrians that jointly walk, design of the urban environment and interaction with other desirability cores. The exit door of a bus, tram or train is an initial vantage point in the space of a desirability core, but they can elongate in amoebic shape. If a person steps out alone or for the first time (Figure 2, D1), reflective mode of observing space plugs in. In a group, the crowd of people triggers subconscious movement of a person. The mode of observing space plugs in later and the desirability core is elongated in amoebic shape that includes
several vantage points. This feeling of “being in a flow” can be triggered by urban design and attractive inviting frontages (shops, services, etc.) around the public transportation stop or station. The desirability core of TOD can be considered as flows of pedestrians in dispersal (Figure 2, D2) and thought occurrence and arrangement of inviting frontages in urban environments (Figure 2, D3). Both aspects are somewhat related. The inviting frontages create flows of pedestrians through activity.

**Urban analysis of TOD CORE zones in Swedish Cities**

Cases of principal PUBLIC TRANSPORTATION INFRASTRUCTURES were chosen and analyzed in different Swedish cities. The effect of principal PUBLIC TRANSPORTATION INFRASTRUCTURES on the urban environments in three Swedish cities was analyzed with comparison of the arrangement of inviting frontages in urban environments.

The first row (Figure 3) shows the desirability cores defined by inviting frontages (shops, services, etc.) along tramways on streets in Norrkoping (A1) and Gothenburg (A2). The inviting frontages along the tram lines continue between the stations creating elongated TOD cores that are highly walkable. The frontages and public transportation create lively main streets. The inviting frontages continue sometimes on the side streets, usually where the public transportation stops are. The disadvantage of public transportation on street is the low speed.

The desirability cores along completely segregated railways and busways in Stockholm (B1, B2) show dislocated TOD cores as hypothesized. The desirability cores for train or bus stations on completely segregated railways and busways start when a person exits the station. The completely segregated railways and busways act as barriers in urban space. The desirability cores have amoebic shape and exist on one or two sides depending on the number of exits. Not always a desirability core is created (B2) depending predominantly on the population density around the station. The advantage of completely segregated public transportation is the high speed. The analysis includes only commercial frontages in the historical core around the station in Ålvsjö (B1). The area around the station is currently under development and the core will expand in the other direction too.

The subways produce no barriers in urban space (C1, C2). The desirability cores have amoebic shape and start and depend on the number of exits. The advantage of the subways as completely segregated public transportation is the high speed, but the cost are high.

The desirability cores along the (partially segregated railways and busways) LRT in Stockholm (D1, D3), BRT in Gothenburg (D3) are elongated and are in different levels of evolution. The partially segregated railways and busways act as permeable barriers in urban space, but they. LRT and BRT are usually medians on wide main streets and multimodal boulevards. The research shows that the neighbors do not communicate over wide boulevards (ref). The public transportation is speedier than on streets. The tramway in Enskede, Stockholm does not exist today, but the commercial frontages are there. Their location corresponds with the desirability cores of the historical stations that were positioned with help of photographs from Stockholmskällan (accessible via the web address http://www.stockholmskallan.se/).

**Discussions and conclusions**

The analysis show somewhat correspondence between the hypothetical URBAN PATTERNS about the TOD CORES represented graphically (Figure 1) and the desirability cores produced by the arrangement of inviting frontages in the building and cityscapes around the public transportation stops and stations in Swedish cities (Figure 3). Some TOD CORES are fully formed (A1, A2, D1) even when the public transportation is defunct (D3) while others are developing gradually (B1, D2).

There is also much research about walking distances from travel surveys. The empirical research of walking distances to public transportation shows that people walk up to 2 km and there are different zones. The number of passengers boarding buses is highest within 100 m from the bus stop in Sydney. In the next zone of walking distances between 100 to 400 m, the number of passengers drops to 60% of the maximum. In the same study the walking distances to the train are always longer than 400 m and the peak is 500 m. The buses...
serve areas with low uniform density in Sydney, whereas the trains create large transportation nodes with park and ride facilities that are difficult to access by walking (Daniels and Mulley, 2011). It additionally drops to 30% in distances between 400 and 800 m. The drop in passengers after distances of 400 and 700 m were documented in Copenhagen (Hartoft-Nielsen, P., 2002).

There are accustomed ways to design cities. Architects and urban designers have predominantly used established heuristics about public transportation (walking distances to bus, tram or train) neglecting the mobility and flow aspect of urban life. A bus stop can be within 400 m, but there might be 1 bus each hour going to a wrong destination. The connectivity by public transportation to the urban network is very poor. The transportation planners on the other hand often neglect the architecture and urban design, and the interfaces with the urban form. Urban design and transportation planning evolved differently over the past century: urban design focusing on the street, frontages, place, neighbors and experiential qualities of urban environments, generally at small to medium scale; and transportation planning on function and efficiency, particularly for the motorist, at the large scale of cities and regions (Southworth, 2005). The broad view of URBAN PATTERN as generic codes and on TOD CORES as focus on the interface between form and flow can be understood in a way to mix different urban forms and transportation infrastructures to create larger diversity of urban design solutions.

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Bus or tram stops or train station and subway exits

Bus lines or tramways on streets

Partially segregated railways or busways on the ground or elevated

Completely segregated railways or busways on the ground or elevated

Subways

1 2 3 4

Desirability cores
A. VISUAL PERCEPTION AND ENVIRONMENTAL STIMULI

- Visual field
  - Visual field
  - Binocular vision
  - Foveal vision
- Visual world
- Isovist (environmental stimuli)

B. GRAPHICAL REPRESENTATIONS OF URBAN SPACE
(Storatorget, Stockholm)

- Within view (image/perspective)
- Top view (plan)
- "Top-within" view (top skewed perspective to reveal frontages and getaways in urban space)

C. VISUAL PERCEPTION OF URBAN SPACE (INDIVIDUAL AND COLLECTIVE)

D. DESIRABILITY CORES FOR TOD (ELONGATION BY COLLECTIVE "VISION" AND URBAN DESIGN)

- Blind part of the isovist
- Visible part of the isovist
- Collective "vision" or "blindness" (complete isovist or visual void in conversation)
- Frontages in the foveal plane of the isovist
- Inviting frontages (shops, services, etc)
- Affordances (exits/entrances, people to communicate, inviting frontages, etc.)

- Bus, tram or train
- Desirability core
- Inviting frontages in top perspective (affordances)