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Research Paper

# Initiate Planning principles for Green Transit-oriented Development Using Green Infrastructure as a Core Principle.

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## Abstract

*The paper establishes a linking framework for green infrastructure (GI) and green transit-oriented development (green TOD), which is the combination of green urbanism principles and transit-oriented development (TOD) principles. Green infrastructure links other infrastructural developments with nature, which is also the role of green TOD. Thus, the first objective of this article is to explore green infrastructure measures and benefits that indicate its involvement in green TOD. The concept of green TOD lacks the planning model to implement it on the ground; Thus, as a second objective, from reviewed literature, this paper will try to develop planning principles to implement green TOD on the ground considering green infrastructure as one element. Finally, the study proposes a green TOD planning strategy for the urban regeneration of the St. Estifanos light rail transit (LRT) neighborhood. The paper advocates green infrastructure benefits based on a green TOD design strategy for environmental sustainability.*

## Keywords

*green infrastructure, TOD, green urbanism, green TOD, environmental sustainability, Addis-Ababa*

## 1. Introduction

TOD attains a compact neighbourhood, varied activities, and walking/cycling, and public transit uses. Hence, this strategy can also control the overall urban sprawl of a city to assist the use of land more efficiently. Even if TOD is a sustainable planning tool on its way to mitigate environmental pollution more excellently and to consume less of the energy resources and for environmental sustainability, the concept of "Green TOD" comes into practice. (Cervero and Sullivan 2010) proposed Green TOD, which is the combination of both TOD and Green Urbanism. Rather than implemented individually, the synergy between these two concepts can bring more environmental benefits (Cervero and Sullivan 2010). Green TOD is an environmentally friendly urban form, embeds sustainable and ecological features in planning TOD. Addis Ababa is facing the need for planning TOD aiming at sustainable, vibrant, livable, and functional transit nodes. The city is investing in LRT/BRT projects and green infrastructures, LRT development currently has two lines, but the projects have future proposals to add LRT lines and address the significant transit node developments and stations. Thus, to support the redevelopment of transit-oriented development in a more sustainable way, it should address green infrastructure, clustering housing, jobs, and services together, encouraging public transits as well walking and cycling, promoting

green areas, using sustainable materials, consuming less energy practices, and enhancing the productivity of renewal energy. By realizing the advantages of environmentally, socially, and economically, this paper will introduce Green infrastructure's many functions, services, and benefits needed for green urbanism development of urban areas and analyse numerous research studies. Furthermore, this paper introduces the Green TOD framework on the Addis Ababa LRT.

## 2. Theoretical framework

### 2.1. Green infrastructure in green TOD

TOD, as well as Green urbanism, have their principles of creating a neighborhood. However, their interlinked framework brings the best practice of transit-oriented development and environmentally sustainability around the transit corridor. Calthorpe's concept of providing green infrastructure elements like green spaces and public spaces within walking distance of TOD can support protecting the environment. With the ecology and habitat of TOD, Calthorpe emphasizes, "Natural features provide a visual relief and establish a unique character for a community, whenever possible open space resources should incorporate into the design of TODs" (Calthorpe 1993,72). Thus, natural features integrating with the new developments are the first step of Green TOD as it results in both nature protection and public green access.

Similarly, the central concept of green infrastructure focuses on environmental sustainability linking development with nature and nature with development "the main thought of green infrastructure is to link human and nature" (Naumann et al., 2011 ); he describes green infrastructure as an integrated service delivery for both ecology and humans. However, GI has been used and defined depending on the benefits it gives and the places used. Though there is no, single definition of green infrastructure, there are shared definitions based on its benefits. For example (Naumann et al. 2011), (Benedict and McMahon 2006), (Charles E. Little 1990) see GI from the area of connecting community use and nature; (Briony A. 2014 ) (Setala, H et al. 2013 ) from its impact on air quality; (Ulrich et al. 1991),(Nordh, H et al., 2009) from indicative of good health, and so on. Similarly, (Beatley 2000) emphasizes that nature in cities is essential to livability.

On the other hand, green urbanism also focuses on creating environmentally sustainable city by providing a healthy community, both environmentally and socially (Lehmann 2010). Green urbanism introduces 15 principles in creating a sustainable city. These are (1) understanding climate and context, (2) renewable energy, (3) zero waste, (4) water management and quality, (5) biodiversity, (6) sustainable modes of transportation and compact polycentric cities, (7) the use of local materials, (8) densifying existing districts with mixed-use developments, (9) development of green buildings and neighborhoods, (10) focusing on livability and quality of life, (11) local food production and supply, (12) fostering the identity and sense of place through balancing conservation and new developments, (13) the urban governance and leadership concerned with policies and decision making, (14) education and knowledge, and (15) developing countries strategies (Lehmann, 2010; Roggema 2017). Therefore, Green TOD presumes the connection between nature and new development. Natural habitats and sensitive environments need preservation, and at the same time, facilitate accessibility because the link between these creates a more significant public establishment that supports social, economic, and environmental benefits(Calthorpe 1993). In the same way, Green infrastructure development provides services that deliver environmental, economic, and social benefits at the same time. Furthermore, multiply those benefits by connecting to a broader network of spaces (Farnham 2010). green infrastructure benefits can help to value and enhance the built environment (Samuel M. et al. 2020).

Listed reviews on the benefits that GI development can deliver for environmental sustainability (Samuel M. et al. 2020). The link with green urbanism and measure indicators that support the 15 green urbanism principles.

Table 1: Multiple GI benefits

Benefits that GI can deliver.	
A. Create attractive links between community facilities that are safe. ( <a href="#">Burley</a> ,B.A 2018), (Suppakittpaisarn,P.et al. 2017),(Benedict and McMahon 2006)	M. Provide environmental resource for education & skills development  (Elliott et al. 2019),(Cole,Laura et al. 2017)
B. Tender Social interaction  (Mohd Hisyam et al. 2012),(Tzoulas et al. 2007),( <a href="#">Marusic</a> ,B.G. 2015), (Cohen, D. A et al. 2008)	N. Provide attractive places for tourism:  (Mekala, G.D et al. 2015), (Valánszki et al. 2018), (Berte E and Panagopoulos T 2014)
C. Support physical activity and improve health  (Tzoulas et al. 2007),(Forest Research, 2010),( <a href="#">Mick Lennon</a> 2017),(Mekala, G.D et al. 2015), (Hartig, T et al. 2014)(Jennings, V et al. 2016 ),(Kondo, M.C et al. 2015)	O. Carbon sequestration  (Mekala, G.D et al. 2015), (Greg Mcpherson et al. 2005), (Gil et al. 2007)
D. Improves Mental health  (Benedict and McMahon 2006), (Tzoulas et al. 2007),(Mekala, G.D et al. 2015),(Ulrich, R.S et al. 1991),(Tsai, W. et al. 2018),(Shanahan, D. et al. 2015)	P. Offer a habitat/habitat for fish, wildlife species  (Benedict and McMahon 2006), (Briony A. 2014), (Mekala, G.D et al. 2015)
E. Generate attractive living places  (Mohd Hisyam et al. 2012) (Benedict and McMahon 2006),(Krekel, C. et al. 2016)	Q. It secures inward Investment by providing attractive places  (Forest Research 2010), (NENW 2008 )
F. Creates appealing working/studying place  (Forest Research 2010),(Valánszki et al. 2018)	R. Creates wildlife corridors  (Charles E. Little 1990)
G. Enhance and create Recreation routes  (Benedict and McMahon 2006),(Charles E. Little 1990),(M'Ikiugu et al. 2012)	S.facilitate energy production and local food production  (Elliott et al. 2019), (Alessio Russo and Giuseppe T. Cirella 2020)
H. Improving land/property values & demand  ( Burley, B.A 2018),(Benedict and McMahon 2006),(Forest Research 2010),(Mekala, G.D et al. 2015),(NENW 2008 )	T. Plays a role in the financial and Economic developments  (Forest Research 2010), (Carter, J 1995)
I. Manage urban run-off,  (Suppakittpaisarn, P. et al. 2017) (Benedict and McMahon 2006),(Forest Research 2010),(Greg Mcpherson et al. 2005 ),(Krause B et al. 2011),(Dixon, K et al. 2007),(Gil et al. 2007),(Cotner et al. 2010).	U. Help to reduce traffic accidents  (Coffin, A. 2007), (Dixon, K et al. 2007), (Naderi et al. 2008)
J. Urban cooling  (Briony A et al. 2019),(Forest Research, 2010),(Dixon, K et al. 2007),(Gil et al. 2007)	V. Creates a buffer against drought  (Singh, V.S. et al. 2010)
K. Improve air quality	W. Reduce sound pollution

(Mekala, G.D et al. 2015),(Briony A et al. 2019),(Forest Research 2010),(Dixon, K et al. 2007),(Gil et al. 2007)	(Coffin, A. 2007), (Dzhambov Angel & Dimitrova, Donka 2015)
L. provide an attractive setting for townscape / cultural heritage assets:  (Forest Research 2010),(NENW 2008 )	X. forms a watersheds /water resources  (Benedict and McMahon 2006),(Cotner et al. 2010)

This review shows that there is much existing evidence of the benefits derived from green infrastructure and their ecosystem services and the benefits needed for compact cities' sustainability. Stresses the importance of green infrastructure assets from becoming undervalued and therefore over-exploited in planning processes (Jansson 2014). Strategic planning, design, and management of green infrastructure assets can increase their potentials and, thereby, their services and benefits in green TOD projects. The relationship between the 15 Green urbanism principles in creating environmentally sustainable city with the A-X mentioned green infrastructure measure indicators. The listed area of use shares common objectives, to provide a multifunctional infrastructure that is connected to the environment.

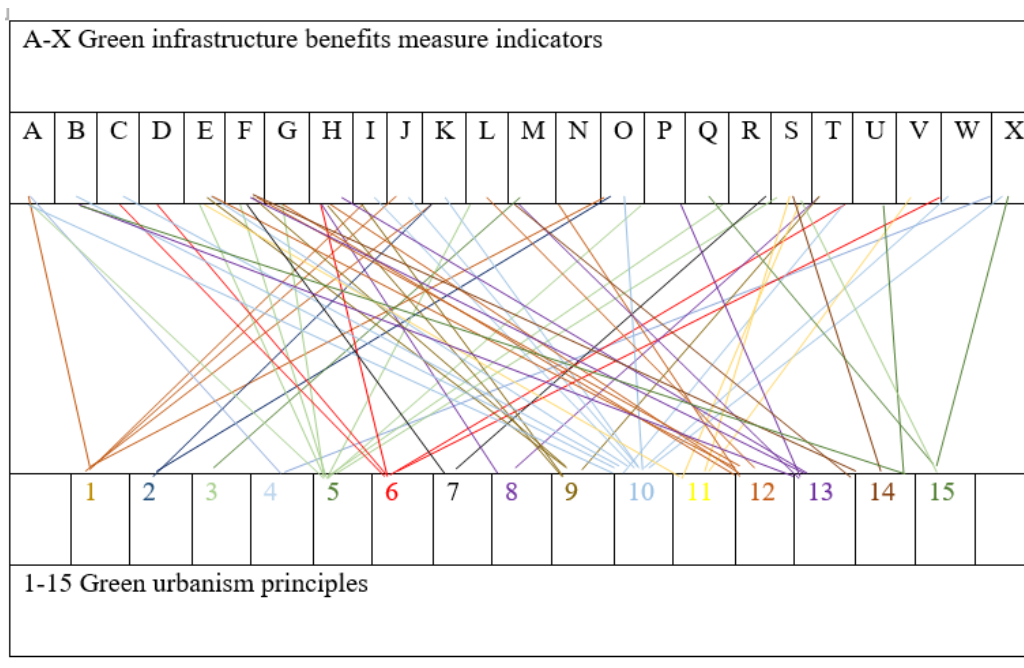


Figure 1. Use green infrastructure benefits measure indicators relation with green urbanism. Source: own compilation from publications.

As shown in numerous research studies, Green infrastructure elements provide many functions, services, and benefits that help green urbanism development of urban areas; thus, the development of green infrastructure plays a role in the concept of green TOD, which green urbanism and TOD gave birth to the concept of it.

The concept of "Green TOD" yields the benefits of social ,economic and environmental sustainability is empathized by (Cervero and Sullivan 2010). The authors registered that Green TOD "reduces the Vehicle Kilometer Traveled (VKT) by shrinking the city's environmental footprint and by encouraging using walking, cycling, and public transit system" (Cervero and Sullivan, 2010 p. 4). Thus, this will give an advantage in reducing the greenhouse gas emission that comes out of vehicles. (Newman et al. 2009)

emphasized that introducing a resilient city can reduce emissions from its primary sources. According to (Beatley 2000), the goals of green urbanism are to reduce the footprints of cities and enhance the relationship between the connection between nature and cities for environmental sustainability. Likewise, (Naumann et al. 2011) identify GI as a link to humans and nature; it creates the foundation for green urbanism's role in green TOD. For example, green roof architecture in Parkroyal, Singapore, and surface parking converted to a green kid's playground in Rieselfeld, Germany.

Another best practice of Green Urbanism is converting surface parking into kid's playgrounds and green spaces for the community in Rieselfeld, Germany. Such a method protects rainwater seeping into the ground to replenish groundwater, Thus working in green infrastructure strategies helps Green urbanism "reduce energy waste and increase energy efficiency, and they move in the direction of satisfying energy needs through renewable sources" (Beatley 2000, 258). Environmental sustainability is the target of green TOD and green urbanism can "deliver sustainable, zero-waste living and energy self-sufficiency" (Cervero and Sullivan 2010, 4).

## 2.2. Benefits of TOD with Green Urbanism (Green TOD)

As mentioned above, TOD principles combine with green urbanism create the new theme, called Green TOD. Both TOD and green urbanism combined to enhance a transit node and the environment. Accordingly, green TOD can mark up to a 35% decrease in the carbon emission than the normal TOD development (Robert Cervero and Sullivan 2011). These benefits are:

1. Higher Densities: Whenever the environmental footprint decreases, the travel demand will also decrease. Thus, in a higher community, densities encourage trains and buses to create transits more conveniently to encourage ridership.
2. Mixed land use: Diversity of uses such as housing, shops, restaurants, workplaces, and other activities, when placed together, invites more walking and cycling to reach a destination. Green TOD might also help to grow small-industries electric vehicles around the transit node. This practice can swap in creating a green community around central transit stations.
3. Reduce surface parking and impervious surfaces: Replacing paved surface parking into green areas and playgrounds can lower urban heat island, reduce the surrounding air pollution and decrease water pollution from the stormwater runoff increases groundwater recharge. Green TOD can also be a "kids-friendly TOD" (Cervero and Sullivan 2010, 4) that uses the shared spaces as a playground area. Rather than having a private space, the playground help to socialize, gather and congregate.
4. Solar energy production at the stations: Solar energy around transit stations can power light-rail cars and charge shared electric bikes and cars. The energy that comes from solar can further enhance green TODs. To sum up, the benefits of Green TOD is to establish a green city, promote walking, cycling, and public transit, use renewable source of energy, and manage stormwater runoff (Cervero and Sullivan 2010).

Nevertheless, the concept of Green TOD yet focuses on defining the concept and establishing the framework. It lacks the planning model to implement it on the ground. Therefore, this paper will try to develop planning principles for the Addis Ababa LRT corridor derived from TOD and Green Urbanism principles that regulate city planning.

### 2.3. Green TOD principles

Planning factors of Green TOD derived from both concepts. Each concept has its criteria and indicator for local development. All aspects of the review of urban design, planning, landscape design, and environmental elements are categorized.

Table 2. Green TOD principles planning factors and principles

GREEN TOD	Planning Factors	Aspects	LAND USE AND URBAN DESIGN
	Urban growth boundary	Definition of an area that can be developed	
	Density development	Medium or high-density development	
	Diversity of land use	Compatible and related land use mixing	
	Small blocks	Blocks should be small to promote non-motorized transit.	
	Public transit	Prioritize development around transit	SUSTAINABLE TRANSPORT
	Non-motorized transit	Promote non-motorized transit through a well-developed pedestrian path	
	Car control	Put in place measures to control cars, limit parking lot.	
	Public green space	Well distributed access to green spaces	ENVIRONMENTALLY SUSTAINABLE DEVELOPMENT
	Green Infrastructure and green buildings (Ecological)	Construct high-quality resource-efficient building and streets	
	Renewable energy district	Expand the opportunities to use the local source of renewable energy	
	Waste management	Classify waste for its be reuse	
	Water efficiency	Avoid water waste & conserve water.	

A quantitative spatial index developed in the above table based on several indicators related to TOD and Green urbanism concepts. However, these essential factors that feature in Green TOD stress more on TOD principles yet tend to incorporate the strategies of Green Urbanism. These are the critical principles developed from some European cities that successfully achieved in applying Green TOD around transit. Nevertheless, the performance of each principle may differ according to the condition, law regulation of the city. For instance, in the case of Addis Ababa heating cooling system of the building may not be applicable since the city is a tropical area. Understanding the local climate context and using local material for development is essential. Therefore, Green TOD is a complete planning approach in line with those guidelines. Nevertheless, to implement Green TOD in an urban area is supported by its quantification.

### 3. Study Area

The study area of this research is in Addis Ababa, the capital city of Ethiopia. Addis Ababa is known as the home to the Africa Union (AU) and Africa's diplomatic capital. The city-regional government launched the

first Light Rail Transit (LRT) system on September 20, 2015, and is planning for Bus Rapid Transit (BRT). The full extent of the railway network is 31 kilometers and comprises 39 stations.

Furthermore, after the development of the LRT, the City Government of Addis Ababa approved a new Structure Plan in 2017 to guide polycentric development connected by efficient use of the transportation system. Thus, TOD proposed to approach safe and reliable movement of people while maximizing land use potential by mixing and diversifying functions. However, some of the biggest challenges to approaches the sustainable developments are:

1. Land-use Zoning: lack of integration of residences with work, services, infrastructure, which creates high traffic congestion in peak hours
2. Transportation: lack of mass public transportation system and quality of its services, depending on the private vehicles and mini-bus taxis.
3. Materials: use unsustainable building materials and designs, which adapt to Western developments and weak environmental control mechanisms.
4. Density: low rise developments on the city's outskirts, fragmentation due to vacant land parcels.
5. Quality: inner-city deterioration
6. Green infrastructure: lack of a strong GI development strategy

Therefore, the introduction of green TOD can contribute to solving the problem mentioned above. These the strategy can enhance the benefits of the TOD by creating a sustainable transit node.

Namely, the first phase of Addis Ababa's LRT is known as E-W and N-S lines (Green and Blue) (Fig. 1). The E-W line is 17 kilometers long connects the Ayat neighborhood to Torhailoch, passing through the city's main centers, Megenagna, Meskel Square, Leghar, and Mexico square. The N-S line with a total length of 16.9 kilometers passes through Merkato, Lideta, Leghar, Meskel Square, and Gotera connecting Menelik II square to Kality. The full extent of the railway network is 31 kilometers and comprises 39 stations see figure2.

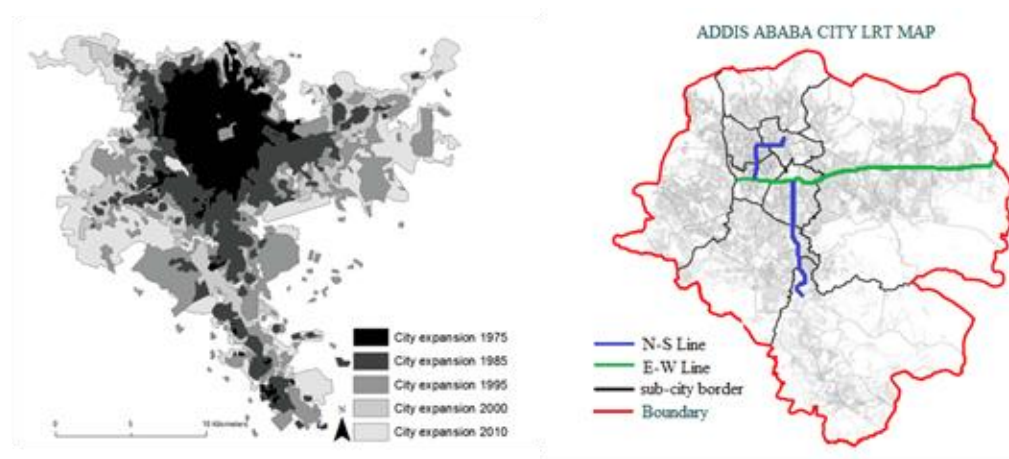


Figure 2. Addis Ababa city expansion from 1975 to 2010 E.C (Left), Addis Ababa LRT map (right) Source: Addis Ababa City Administration

### 3.1. Identification of indicators

The findings of the site, St. Estifanos station, are structured into site analysis, structure plan, and planning guidelines, based on the principles of integrating land use and transport system. Thus, TOD focuses on density, diversity, design, green space, pedestrian-friendly environment with better accessibility aspects,

while the transport system focuses on enhancing better public transit systems and increasing the transport demand.

### 3.2. Site analysis

St. Estifanos station is located along the major center of the city, located along the E-W line of the Addis Ababa LRT project. The station's location is in the Kirkos sub-city of the city, covering three zones see figure 2. The train station is on an elevated level with stairs. The buffer area for stations is 800 m, a comfortable walking distance (Schlossberg 2007). Within walking distance of the station, there is a public open square. The square has different activities throughout the day.

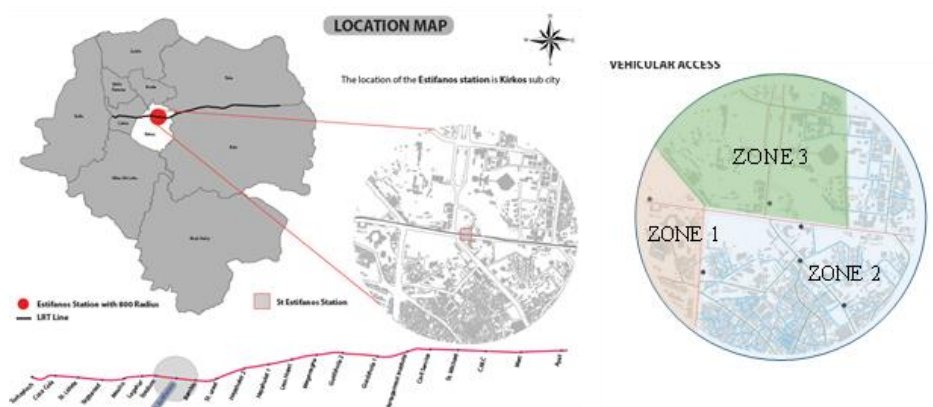


Figure3 Location map St. Estifanos station. Source: own compilation

The site covers an area of 2.01 km<sup>2</sup> within 800 m comfortable walking distance for the case of Addis Ababa. Therefore, the station is near the public square, to create a link between the public square and the surrounding area is very important. Moreover, the neighborhood includes a park within walking distance. The Park is not fully accessible (yet creating a link to the park is very significant) to the surrounding area. Another critical factor is the palace (residence), and UNECA (United Nations Economic Commissions for Africa) headquarter office is within walking distance of the station. The city planning strategy is to convert the palace into a national museum and park, which is open to the public. Therefore, proposed the palace to become a museum connecting with the park around it. The national stadium is located within this neighborhood too. Therefore, all these nodes of the land use are intended for future TOD development.

#### 1. Land use: density and diversity

The two major roads cross the site: Boles street, which connects to the airport area, and Menelik II street connects to 4 kilos. The east and west street connects the primary corridor of the city. The diversity of land use within the neighborhood showed in figure 3. The area's land use is more balanced, having schools, shopping malls, hotels, and office towers within 800 m walking distance from the station. The highest percentage of the land is related to residential use covering almost all the plots within zone 2. The mixed-use commercial frontage is very low in percentage comparing to other land use activities. Zone 3 mainly consists of green areas, and administration uses. Thus, the St. Estifanos station area has diverse land use such as residential, service, administration use, particular use, and green areas. However, the green area and the administration's domination within walking distance of the site limit the development around the area. Therefore, a more diverse commercial approach should be addressed, especially around the residential and prominent frontages of the street.



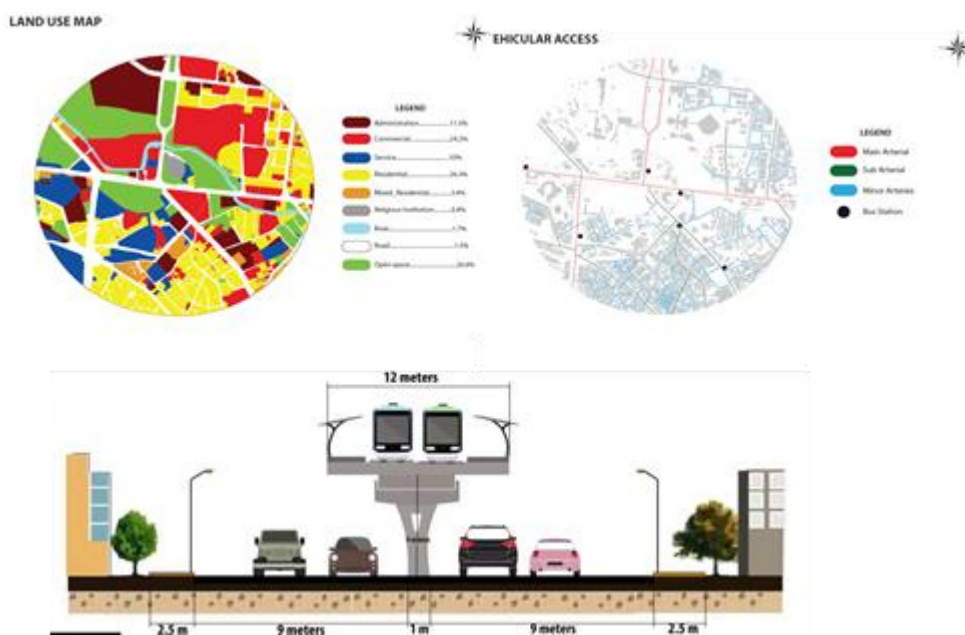


Figure 4 Land-use and vehicular access of St. Estifanos station. Source: own compilation

The density of the neighborhood varies according to the building height and the plot around the site. Even though most of the residential areas are G+0, the building height within site varies from G+10 to the lowest G+0. And some of the commercial buildings are G+5 and above; therefore, as TOD developments stress the high-density development, this concept also needed to be addressed, especially around the residential and administration area of the neighborhood.

2.Design: open spaces and Street patterns

The dominant public open space provided within walking distance is the 'Meskel Square,' used as a multi-activity space; Used as a running track in the morning, a social gathering, holiday celebrations, and kid's play. However, no significant visible consideration for the public realm as no pedestrian paths are available, and no public space amenities are visible. The connection is feeble from all the streets to the public square.

sometimes the public space is used as a parking space for cars. Connections of multiple nodes to the public square are available, but it shows a poor pedestrian path design because the streets designed are for cars at a high traffic level. There is no calming traffic system around the square; due to these reasons, the pedestrian feels unsafe around. This public can easily be developed into a green square to calm the surrounding commercial activity and high traffic speeds. Moreover, the main transportation system within the site is public and private vehicles. The street hierarchy within walking distance of the station ranges from the high traffic road into the local street around the residents. The main road has three lanes on each side, and the secondary street has two lanes on both sides. A transit connection with another transport system is not compatible.

3.Connectivity and public realm

The neighborhood street designed is for motor vehicle users. Thus, the site accommodates various road types, ranging from main arterial streets to the local streets giving priority to auto vehicles. The main arterial street has a three-lane on each side, where the sub arterial accommodates two lanes on each side and one lane on each of the minor arteries. Various bus stations are found in proximity to the LRT station, ranging from 50 m to 600 m, yet it is not enough to support the demand for transportation. The

availability of pedestrian sidewalks is seen in the main arterial and sub arterial streets, as seen in figure 3. Nevertheless, in most of the streets, it can be seen there is no consideration of the public realm for pedestrians—figure 4 shows the connection nodes visible around the neighborhood. However, in most of the nodes, it is poorly designed for pedestrians. Such nodes should be recognized and designed into open public green spaces.

## 4.Results and Discussions

### 4.1. Structure plan guidelines for green TOD

The structure plan guidelines for TOD were planned on the benefit and vision of livable transit nodes for Addis Ababa and done by focusing on the need of the people to utilize a polycentric pattern with a compact density connecting to essential services, getting easy access, and creating a high-quality life urban environment. Thus, the concept of TOD is led by the need to address: (1) a compact neighborhood with diverse land use (retail, services, employment, and civic spaces), (2) sustainable transportation access by reducing the dependence on private vehicle and encouraging NMT and public transit (3) environment and landscaping (green areas, open spaces, and parks).

### 4.2. Concept Principles Development

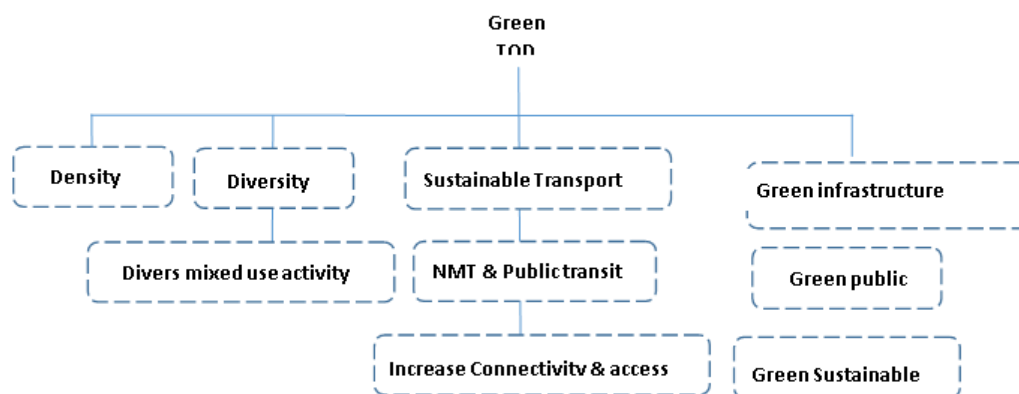


Figure 5 Conceptual principal development. Source: own compilation from publications

### 4.3 Framework components of green TOD

#### 4.3.1 Diverse neighbourhoods with efficient buildings

The area is mainly commercial offices and residential and administrative offices as shown on the existing land use. Thus, to enhance a livable neighborhood, the area can envision a diverse mixed-use development that includes all services and activities within walking distance of the transit station. The neighborhood is known as its main public square. Thus, the TOD proposal should include the center of cultural, tourist, and entertainment destinations. Active commercial frontages with better access to pedestrians are needed in the TOD planning concept

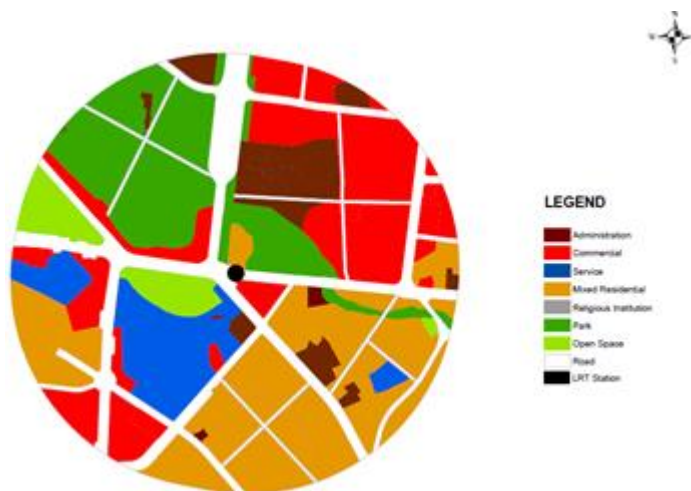


Figure 6 Proposed land-use. Source: own compilation

#### 4.3.2 Active Transport system

Designing TOD should first favor pedestrians as well as cyclists. The old trend of the city Addis Ababa planning system was dependent on designing for motorized trips. Thus, the connectivity of the TOD proposal will enhance the different transportation systems. Pedestrians should prioritize providing a safe and vibrant pedestrian street by providing better seating, shades, trees, and creating a green corridor. Connection of the transit station with another public transport system also needs a priority. Furthermore, a connection of pedestrian streets to public spaces and green areas (parks) also needs high-quality attention. Thus, the proposal is enhanced to build and encourage non-motorized transport holistically.

#### 4.3.3 Green Infrastructure

Assets of green infrastructure like Public spaces, civic spaces, street trees, institutional green spaces, Greenspace along rail corridor, Roadside green space, Amenity green spaces, Urban forest, Greenways, Greenbelts, Green roofs, community woodlands, Green walls, Wetlands, Groundwater recharge areas, sustainable drainage system SuDS schemes, Private gardens areas are places where the community’s gathering or social interactions create. Thus, the proposal should include green infrastructure assets to be enjoyed by the residents and visitors. Proposing Green infrastructure pocket spaces (green areas) and nodes of the street and connecting this node will also create a safe environment for pedestrians.

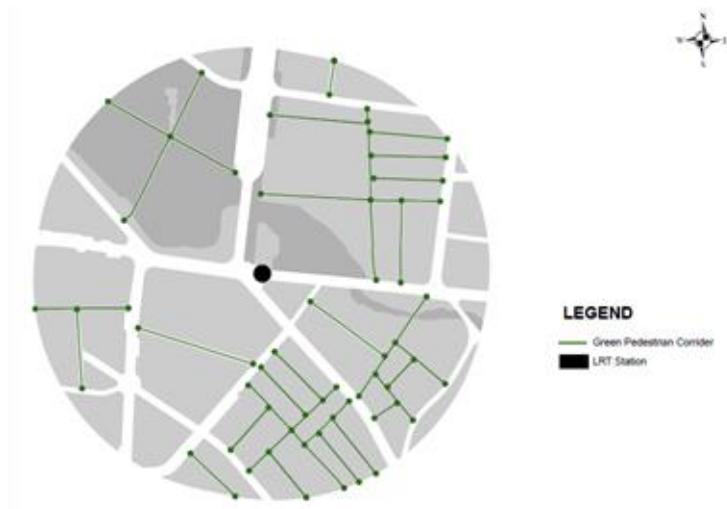


Figure 7 Green infrastructure Corridors . Source: own compilation

#### 4.4 Discussion

The shape of the built environment determines the characteristics of the neighborhood. The spatial form of the area has a significant impact on the livability and vibrant quality of life. However, neglecting how to create a green pedestrian-oriented development, livable/vibrant places, walkable neighborhood leads to lifeless development in social, environmental, and economic benefits. Despite all these, scholars argue that modern cities and urban settlements give priority to motor vehicles neglecting pedestrians and bicycle networks (Elsheshtawy 2004). Thus, St. Estifanos station proposed the strategy envisioned through the indicators mentioned in the table below.

Table 3. Dimension indicators and recommended guidelines

Dimensions/ Indicator	Recommended guidelines
Density/ diversity	<ul style="list-style-type: none"> <li>■ Provide high densities to enhance transit investment.</li> <li>■ Allow high-density development</li> <li>■ “Wedding cake” density development</li> <li>■ Ensure comfortable walking distances between points (i.e., 800 m)</li> <li>■ Intensify land uses</li> <li>■ Provide services within a radius of 800m ( at least six services )</li> </ul>
Walking and connectivity	<ul style="list-style-type: none"> <li>■ Creating more open spaces 20-40% by accommodating connected pedestrian network including shading, landscape design, and amenities,</li> <li>■ Enhance pedestrian accessibility</li> <li>■ Provide small blocks</li> <li>■ Ensure modal integration (i.e., connections between buses and trains).</li> </ul>
Public realms	<ul style="list-style-type: none"> <li>■ Provide pedestrian/cyclist-friendly streets that directly connect local destinations.</li> <li>■ Provide a continuous network of the sidewalk.</li> <li>■ Apply traffic calming devices (i.e., speed bumps, medians, lower speed, signal timing, and narrow roadways).</li> <li>■ Give priority for both pedestrian and cyclists on designing the project</li> </ul>
User-friendliness	<ul style="list-style-type: none"> <li>■ Ensure high quality of design of the main transit stop.</li> <li>■ Provide attractive, comfortable, informative, and sheltered transit stops.</li> <li>■ Ensure its accessibility and safety to all users (handicapped, children, elders).</li> </ul>

## Green Infrastructure

- Ensure modal integration (i.e., connections between buses and trains).
- Encourages active travel, jogging, walking, and cycling
- Space to play for children Restorative, uplifting and healing for both physical and mental health conditions
- Protect the distinctiveness and character of the district and its settlements
- Enhance an area's image
- Run-off reduction by increase in impervious surface, storing water in green structures like trees, green roofs, or walls
- Produces green link/corridor
- Provide opportunities for residents to interact with urban nature
- Ability to perform several functions
- Roof gardens and yards as a source of urban farming.
- Introduction of Green roofs , vertical gardens and permeable surfaces

The concept of Green TOD as a sustainable tool that enhances a city's environmental sustainability is becoming very important, and it is more viable to plan and implement in Addis Ababa. St. Estifanos station is the best example of a suitable neighborhood for residents and visitors. That people dominate the streets and public spaces. Due to many reasons people feel comfortable walking and do some sports activities around the public square. Thus, St. Estifanos station emphasizes a higher quality of life for residents and visitors and mobility systems. However, this article proposes introducing Green TOD to set an example to all the neighborhoods around the city. These, to promote Green TOD, the principles mentioned below aimed at creating a foundation for smart cities that is an integration of TOD and Green Urbanism. Thus:

4.4.1 Green Infrastructure assets: provide recreational areas for the residents and enhance the environmental quality and beauty of the space. Thus, in the St. Estifanos station neighborhood, replacing the parking areas into a green area and playground lower the urban. Replacing asphalt paved streets with other sustainable pavement materials can also decrease water pollution from the stormwater runoff into the lake, and at the same time, it increases groundwater recharge.

4.4.2 Renewable Neighbourhood: PV is the primary source of solar energy installed for housing and other commercial buildings. These renewable energy strategies can fit the successful TOD projects in Ethiopia to create a sustainable neighborhood and city at large. Thus, declaring solar energy in Addis Ababa will address the agenda of Green TOD that has been successful in other cities. This concept enables the use of renewable energy that can lead to a healthier city.

4.4.3 Green Buildings: Green buildings for TOD means constructing high-quality and resource-efficient buildings. In this case, avoiding using glazes, using more environmentally friendly materials can

enhance the city's sustainability. Buildings should also incorporate many natural green features to enhance the weather inside the building outside the buildings. More emphasis should be given on awareness to convert the buildings into horizontal gardens to alleviate climate change. The parking surface should also be converted into a green surface area.

4.4.4 Water efficiency: Water efficiency is emerging as an integral component of Green TOD development. Indeed, the government must set a goal of water-sensitive urban design developments, which helps in reducing the ecological footprints by saving water and using recycled and stormwater. By incorporating such designs, TOD designers can bolster water efficiency and further enhance this efficiency by introducing awareness and other TOD development activities. Therefore, each person's water consumption should reduce through eco-cycle installations, low flush toilets, and air mixer taps. Furthermore, the government should put a limit on households to reduce consumption. Rainwater from the roofs and open spaces should be drained into a wastewater treatment plant. Stormwater from the paved streets should also be treated before it goes to the rivers around.

4.4.5 Waste Management: Waste management is another important variable for a successful Green TOD plan. The government should address an eco-friendly solution for waste, water, energy, and sewage for housing, commercial building, and offices. Mandatory waste sorting strategies to optimize the use of recycling and minimize waste should be planned. This scenario's recommendation is categorized according to a model that attempts a linear system that consumes inflowing waste and discards out flowing energies. These waste eco-cycle disposal bins should be introduced. Moreover, these wastes can be transported through the underground piping system and convert into energy. For sewage, a wastewater treatment plant should be built to treat the sewage for biogas and cab used into fertilizer.

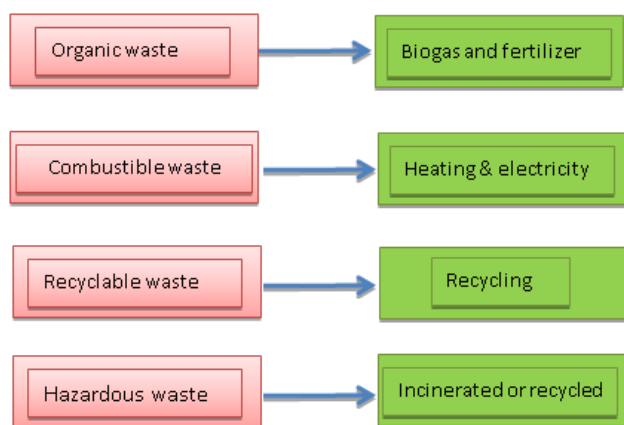


Figure 8 Waste to energy flows categorized into four types of waste. Source: own compilation

4.4.6 NMT : Sustainable transport strategies are one of the significant contributions to Green TOD. Addis Ababa has created a sustainable TOD by enhancing the quality transit stations and designing dense and diverse TODs. However, pedestrians' and bicycles' priority has not been a high priority; perhaps these TOD projects create tremendous congestion in the city. Thus, great emphasis should be given to the NMT users around TOD.

*Car control:* Various strategies and initiatives have been taken to reduce vehicle pollution; as the cities are overgrowing, the number of vehicles is increasing. Thus, some of the prevalent causes of congestion are still rooted in growing cities. Therefore, to pursue sustainable transport and create a safer and livable city, car control should be implemented around TOD. A strategy that prioritizes public transport, walking,

and bicycles should be introduced ahead of private car uses. Carpools should also be added to reduce the number of vehicles on the street. Another essential car control strategy is a parking system. On-street parking should be banned around transit stations. Support Ground-level public parking to minimize parking along the street. In a new development of TOD to reduce car use, a fully developed bus line and LRT line should be built.

Therefore, integrating land use and transport system is the primary approach to creating a vital and vibrant neighborhood within the transit node. It also enhances the economic development of the city. Thus, St. Estifanos station can be defined as a successful transit node and the area near the square. This article is significant to the urban planning in Addis Ababa because the structure plan of the city is envisioned to have a TOD approach to adopt the critical concepts of green urbanism and TOD in the selected node. Thus, this article can lead as an example of integrating rail transit and the city development approach following the approach of the structural plan of the city.

4.4.7 Connecting Green infrastructure; An environmental focus on the public realm is also one of the most important indicators in green TOD design. Professionals should advocate that parks and public plazas should fundamentally integrate into TOD. A compact and high-density building should focus on the public realm, such as public parks and plazas, as it effectively brings nature and multiple benefits back to the built environment. Therefore, more attention should be given to landscape aspects and green corridors drawing the natural surroundings back into developments.

4.4.8 Walkability; Designing the quality of the walking environment with proper shade and tree cover encourages people to move around comfortably, protected from rain and sun. Designers should also consider the climatic zone of the area to consider the plants that grow within the city. Developments should consider transit accessibility and safety and act as attractive destinations that work climatically by providing thermal comfort. Thus, both the transit node and area of accessibility must be considered when planning for TOD. Additionally, stations should also be aesthetically pleasing with lights and comfortable air breezes around.

4.4.9 Landscaping; Landscaping and planting are also emerging as indispensable components for TOD. People should feel comfortable when walking around transit nodes. The city Addis Ababa is found in the tropical zone, so the design should recognize the importance of 'deep planting' and suggest that 'green walls' should become integral components of tropical TOD. Planting trees that are essential for the tropical zone is a core component. As mentioned above, water management, such as harvesting rainwater and recycling greywater, is also emerging as an integral part of tropical design.

## 5. Conclusion

Green TOD is relatively becoming the new concept of TOD development in recent years. Most studies have been focused on TOD, while few studies and few countries applied this concept to conduct empirical studies. Therefore, this research emphasizes the literature review to illustrate Green TOD's underlying theory and concepts of Green TOD. Thus, combining the two concepts of TOD and Green Urbanism explores the criteria for developing Green TOD. This paper suggests further that Green infrastructure comes as one of the main strategies in achieving green urbanism. It holds connectivity and multifunctionality as its core; thus, the paper listed its benefits. How green infrastructure benefits integrated to green TOD, through the literature review, TOD identified land use density, land use mix, urban design, destination accessibility, and transit station identity; and green urbanism identified green building design, zero waste community, the recycling of water resources, the use of renewable energy, and urban open space. That showed the relation with green infrastructure. With several environmental, economic, and social advantages, Green TOD offers some goals by emphasizing more pedestrian and biking friendly with public transit over auto-mobility. St. Estifanos neighborhood, with its highly densified

building with its existing ground floor and mixed land uses, made destinations closer and creates a pedestrian-friendly environment. However, the city's environmental performance should be enhanced as fast as the present day of pollution emission. As the government strategy prioritizes public transport, private vehicles are still increasing with the increase in GDP in the city. For green urbanism, a more holistic view of planning should be implemented, which is Green TOD, introducing green infrastructure, minimal waste, low emission, and using renewable energy.

Integrating the elements of Green urbanism and TOD in this neighborhood can make it a simple design. Installing a renewable energy source, converting waste into energy, car control, water management, and reducing surface parking and impervious surfaces are all completely carbon neutral systems.

As mentioned, the advantage of Green TOD is highly impeccable. Even though the project may take more time and money, various departments starting from the government, private sector, and researchers, must be deeply involved in the planning and designing process. Green TOD offers highly walkable and transit-oriented neighborhoods. These can help people to travel from anywhere to everywhere, which results in a segregated community. Green TOD offers more choices on where to live and how to travel. Once green TOD has adopted, it becomes easy to adapt the principles and apply them in other local TOD developments.

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### REFERENCES

- Beatley, T. (2000) "Green Urbanism, learning from European cities." Washington, US: *Island Press*, 2000. <http://worldcat.org/isbn/1559636823>.
- Benedict, M. and McMahon, E. (2006) *Green infrastructure linking landscapes and communities*. Washington, DC: *Island Press*,
- Berte E, Panagopoulos T. (2014) "Enhancing city resilience to climate change by means of ecosystem services improvement: a SWOT analysis for the city of Faro, Portugal." *Intern J Urban Sustain, Dev* 6:241–253. <https://doi.org/10.1080/19463138.2014.953536>.
- Bradford city center GI study. (2014) [https://www.bradford.gov.uk/Documents/City\\_Centre\\_Action\\_Plan/Publication/draft/Evidence\\_base/Green\\_infrastructure\\_study](https://www.bradford.gov.uk/Documents/City_Centre_Action_Plan/Publication/draft/Evidence_base/Green_infrastructure_study).
- Briony A. Norton, Andrew M. Coutts, Stephen J. Livesley, Richard J. Harris, Annie M. Hunter, Nicholas S.G. (2014) "Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes." *Landscape and Urban Planning (Volume 134)*, pp 127-138).
- Burley, B.A. (2018) "Green infrastructure and violence: Do new street trees mitigate violent crime?" *Place* (pp 43-49). <https://doi.org/10.1016/j.healthplace.2018.08.015>.
- Calthorpe, P. (1993) "The next urban metropolis- Ecology, Community, and the American Dream." *New York: Princeton Architectural Press*.
- Carter, J. (1995) "The potential of urban forestry in developing countries: A concept paper." *FAO, Rome*.



Cervero, R., & Cathleen, S. (2011) "Green TODs: Marrying transit-oriented development and green urbanism." *The International Journal of Sustainable Development and World Ecology*, 18(3). Taylor & Francis, <https://doi.org/10.1080/13504509.2011>.

Cervero, R., Sullivan, C. (2010) "Toward Green TODs [Online]." *Berkeley Center for Future Urban Transport* (Working Paper: UCB-ITS-VWP-2010-7, UC 2010), <http://www.its.berkeley.edu/publications/>

Charles E. Little. (1990) *Greenways for America*. The Johns Hopkins University Press, Baltimore, and London.

Coffin, A. W. (2007) "From roadkill to road ecology: a review of the ecological effects of roads." *Journal of transport Geography*, 15(5), pp. 396–406. <https://doi.org/10.1016/j.jtrangeo.2006.11.006>.

Cohen, D. A., Inagami, S. and Finch, B. (2008) "The built environment and collective efficacy." *Health & Place* 14, 198–208. <https://doi.org/10.1016/j.healthplace.2007.06.001>.

Cole, Laura & McPhearson, Timon & Herzog, Cecilia & Russ, Alex. (2017) "Green infrastructure. Urban Environmental Education Review." *Cornell University*. <https://www.jstor.org/stable/10.7591/j.ctt1qv5qhq>.

Cotner, Lisa & Minor, Emily & Zellner, Moira & González-Meler, Miquel & Jaffe, Marty & Belaire, Amy & Johnston, Douglas. (2010) August. "The effectiveness of green infrastructure at improving water quality." A literature review. *95th ESA Annual Convention*.

Dixon, K. K., and K. L. Wolf. (2007) "Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response." *Proceedings of the 3rd Urban Street Symposium*, Seattle, WA. Washington D.C.

Dzhambov, Angel & Dimitrova, Donka. (2015) "Green spaces and environmental noise perception." *Urban Forestry & Urban Greening*. 14.1000-1008. <https://doi.org/10.1016/j.ufug.2015.09.006>.

Elliott, Robert & Motzny, Amy & Majd, Sudy & Viteri Chavez, Filiberto & Laimer, Daniel & Orlove, Benjamin & Culligan, Patricia. (2019) "Identifying linkages between urban green infrastructure and ecosystem services using an expert opinion methodology." *Ambio*. 49. 10.1007/s13280-019-01223-9.

Forest Research. (2010) "Benefits of green infrastructure." Report by Forest Research. *Forest Research*, Defra research contract number WC0807 Farnham.

Gill, Susannah & Handley, J.F. & Ennos, Roland & Pauleit, Stephan. (2007) "Adapting Cities for Climate Change: The Role of the Green Infrastructure." *Built Environment*. 33. 115-133. 10.2148/benv.33.1.115.

Greg Mcpherson, G., Simpson, J.R., Peper, P.J., Maco, S.E., and Xiao, Q. (2005) "municipal forest benefits and costs in five cities." *Journal of Forestry*. 411-416. <https://doi.org/10.1093/JOF/103.8.411>.

Hartig, T.; Mitchell, R.; de Vries, S.; Frumkin, H. (2014) "Nature and Health." *Annual Review of Public Health*. <https://doi.org/10.1146/annurev-publhealth-032013-182443>.

Jansson, Märit. (2014) "Green space in compact cities: the benefits and values of urban ecosystem services in planning." *Nordic Journal of Architectural Research*. 139-160.

Jennings, V.; Larson, L.; Yun, J. (2016) "Advancing Sustainability through Urban Green Space: Cultural Ecosystem Services, Equity, and Social Determinants of Health." *Int. J. Environ. Res. Public Health* 13, 196. <https://doi.org/10.3390/ijerph13020196>.

Kondo, M.C.; South, E.C.; Branas, C.C. (2015) "Nature-Based Strategies for Improving Urban Health and Safety." *J. Urban Health*. Volume 92, pp 800-814.

Krause B, Culmsee H, Wesche K, Bergmeyer E, Leuschner C. (2011) "habitat loss of floodplain meadows in north germany since the 1950s." *biodiversity and conservation*, 20:2347-2364 . <https://doi.org/10.1007/s10531-011-9988-0>.

Krekel, C.; Kolbe, J.; Wüstemann, H. (2016) "The greener, the happier? The effects of urban green and abandoned areas on residential well-being." *Ecological Economics*, 121: 117-121.

Landscape Institute. (2013) "Green Infrastructure, An Integrated Approach to Land Use." *LandscapeInstitutePositionStatement*. <https://www.landscapeinstitute.org/policy/green-infrastructure/>. accessed 8 Sept. 2019.

Lehmann, S. (2010) "The Principles of Green Urbanism: Transforming the City for Sustainability." *Routledge London: Earthscan Ltd, UK*. ISBN 9781844078349

Lehmann, Steffen. (2011) "What is Green Urbanism? Holistic Principles to Transform Cities for Sustainability." DOI 10.5772/23957.

M'ikiugu, Martin & Wang, Qianna & Kinoshita, Isami. (2012) "Green Infrastructure Gauge: A Tool for Evaluating Green Infrastructure Inclusion in Existing and Future Urban Areas." *Procedia Social and Behavioral Sciences*, 68, 815–825. 10.1016/j.sbspro.2012.12.269.

Mackenzie Schoonmaker and Fred Wagner. (2015) "Green Infrastructure in the Transportation Sector." Transportation Research Board Webinar. *TRB Webinar | Green Infrastructure in the Transportation Sector. Beveridge and Diamond* .

Marusic. (2015) "Social behavior as a basis for design and development of green infrastructure." *urbanizziv*, 10.5379, pp130-149. DOI: [10.5379/URBANI-IZZIV-EN-2015-26-SUPPLEMENT-009](https://doi.org/10.5379/URBANI-IZZIV-EN-2015-26-SUPPLEMENT-009).

Mekala, G.D.; Jones, R.N.; MacDonald, D.H. (2015) "Valuing the benefits of creek rehabilitation: Building a business case for public investments in urban green infrastructure." *Springer Science Business Media New York. Environmental Management* DOI 10.1007/s00267-015-0471-7.

Mick Lennon, Owen Douglas, Mark Scott. (2017) "Urban green space for health and well-being: developing an 'affordances' framework for planning and design." *Journal of Urban Design* DOI: [10.1080/13574809.2017.1336058](https://doi.org/10.1080/13574809.2017.1336058) Project: [Eco-Health](#).

Mohd Hisyam Rasidia\*, Nurzuliza Jamirsahb, Ismail Saidc. (2012) "Urban Green Space Design Affects Urban Residents' Social Interaction." *Cairo ASIA Pacific International. Conference on Environment-Behaviour Studies* Mercure Le Sphinx Cairo Hotel, Giza, Egypt.

Naderi, Jody & Kweon, Byoung-Suk & Maghelal, Praveen. (2008) "The street tree effect and driver safety." *ITE Journal on the Web*. 78. 69-73.

NENW. 2008. "The economic value of green infrastructure. Natural Economy Northwest (NENW)." <http://www.naturaleconomynorthwest.co.uk/resources+reports.php>

Newman, P., Beatley, T. and Boyer, H., (2009) "Resilient Cities: Responding to Peak Oil and Climate Change." *Island Press*, Washington DC. <https://www.ubcpres.ca/resilient-cities>

Roggema, R. (2017) "The future of sustainable urbanism: Society-based, complexity-led, and landscape-driven." *Sustainability*. 9. 1442. 10.3390/su9081442.

Samuel M., Zhongwei S., Gashaw A., & Amanuel W. (2020) "Green infrastructure benefits to value and enhance the built environment: the case of Addis Ababa, Ethiopia" *WIT Transactions on Ecology and the Environment*, Vol 241, WIT Press, 2020, ISSN 1743-3541.

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Schlossberg, Marc. (2006) "From TIGER to Audit Instruments: Measuring Neighborhood Walkability with Street Data Based on Geographic Information Systems." *Transportation Research Record: Journal of the Transportation Research Board*. 1982. 48-56. 10.1177/0361198106198200107.

Shanahan, D.; Lin, B.; Bush, R.; Gaston, K.; Dean, J.; Barber, E.; Fuller, R. (2015) "Toward improved public health outcomes from urban nature." *Am. J. Public Health* doi: [10.2105/AJPH.2014.302324](https://doi.org/10.2105/AJPH.2014.302324)

Singh, V.S.; Pandey, D. N.; Chaudhry, P. (2017) "Urban forests and open green spaces: lessons for Jaipur, Rajasthan, and India." IN: RSPCB Occasional Paper No. 1. Rajasthan State Pollution Control Board 4." *Jhalana Institutional Area, Jaipur 302017, Rajasthan, India*.

Suppakittpaisarn, Pongsakorn & Jiang, Xiangrong & Sullivan, William. (2017) "Green Infrastructure, Green Stormwater Infrastructure, and Human Health: A Review." *Current Landscape Ecology Reports*. 2. 10.1007/s40823-017-0028-y.

Tsai, Wei-Lun & McHale, Melissa & Jennings, Viniece & Marquet, Oriol & Hipp, Aaron & Leung, Yu-Fai & Floyd, Myron. (2018) Relationships between Characteristics of Urban Green Land Cover and Mental Health in U.S. Metropolitan Areas. *International Journal of Environmental Research and Public Health*. 15. 340. 10.3390/ijerph15020340.

Tzoulas, Konstantinos & Korpela, Kalevi & Venn, Stephen & Yli-Pelkonen, Vesa & Kazmierczak, Aleksandra & Niemelä, Jari & James, Philip. (2007) "Promoting Ecosystem and Human Health in Urban Areas Using Green Infrastructure: A Literature Review." *Landscape and Urban Planning*. 81. 167-178. 10.1016/j.landurbplan.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A. and Zelson, M. (199) "Stress recovery during exposure to natural and urban environments." *Journal of Environmental Psychology*, 11, 231–248, 1991b.

Valánszki, István & Dancsókné Fóris, Edina & Filepné Kovács, Krisztina. (2018) "Parallel Development of Green Infrastructure and Sustainable Tourism- Case Studies from Hungary." *Polish Journal of Natural Science*. 33. 625-647.