EXPLORING THE RELATIONSHIP OF SOUND WITH THE URBAN ENVIRONMENT: A

STRATEGIC INQUIRY ON THE IMPACTS OF AND DESIGN AND PLANNING RESPONSES TO

SOUND IN TRANSIT-ORIENTED DEVELOPMENTS (TODs)

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**ABSTRACT:**

EXPLORING THE RELATIONSHIP OF SOUND WITH THE URBAN ENVIRONMENT: A STRATEGIC INQUIRY ON THE IMPACTS OF AND DESIGN AND PLANNING RESPONSES TO SOUND IN TRANSIT-ORIENTED DEVELOPMENTS (TODs)

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Over the last decades, Transit-Oriented Developments (TODs) have stimulated heated debates. Researchers have fully explored the TODs' quality-of-life characteristics; however, sound/noise impacts are under-explored in the field. This dissertation explores the planning and design implications of sounds in the Dallas-Fort Worth metropolitan area TODs. TODs include potentials to cover a broad range of sounds that improve the quality-of-life (QoL).

Since sound studies should not only rely on in-situ sound measurements and it should also examine the subjective aspects of the sound as the dissertation examines the perception of the individuals on sounds in TODs, the project required a certain number of participants for the validity concerns of the research efforts. To address these concerns, The author used a mixed-methods approach, where the qualitative aspect of the research focused on surveying with the TOD residents as they are the main "actors" in TODs. After defining the TOD stations, since not all train stations can be considered a TOD, the research also conducted a survey to get individuals' preferences on TODs in terms of sound implications. The findings of this research provide insights into how diverse sounds can create patterns and may affect people’s QoL based on their perception of sounds.

The dissertation also aims to understand the relationship between urban morphology and sound is an important undertaking for managing the adverse implications of noise. So, the dissertation also seeks to understand this nexus between urban morphological characteristics -namely buildings, plots, and streets in the Dallas-Fort Worth Metroplex- and sounds. While previous studies have examined TODs' amenities and disamenities, they have not investigated the intersection of sound and urban morphology within TODs. This dissertation probes the concept that sound heard within buildings is impacted affected by the plots and streets segments on which they are located.

Finally, the dissertation also concentrates on the train station-level of analysis to understand the effects of TODs on sound implications. So, the dissertation aims to examine sound levels and determine its contributors at the transit-oriented development (TOD) station and neighborhood levels by studying selected Dallas Area Rapid Transit (DART) stations. Various analyses were performed to model the likelihood of TOD stations and neighborhoods affecting sound levels, controlling for station amenities, socio-demographics, and built environment characteristics. The dissertation found that amenities, built environmental characteristics, and neighborhood features have significant implications on sound levels at both the TOD station and the neighborhood level, which affects the quality of life (QoL). TOD stations that include more amenities have a greater level of significance on sound levels. Additionally, neighborhoods with a pervasive street grid configuration, public facilities, and built environment densities are significantly associated with a likelihood of high sound levels. Conversely, higher population densities and intersection densities decrease the likelihood of a high sound level environment. These patterns provide an arena for transportation, urban, and environmental planning and policymaking to generate transformative solutions and policies.

# Contents

## List of Figures

**List of Tables**

# CHAPTER 1

# INTRODUCTION

Population growth, rapid urbanization, and technological advancements have transformed urban form and transportation services -including infrastructure, fleets, routes, park & ride systems- massively for decades. For instance, the industrial revolution was one of the milestones for these transformations. Following the industrial revolution, technology and mechanical equipment influenced both urban and rural parts of the cities. Such interventions also, directly and indirectly, influence the quality of life regarding economics, social life, and health. In particular, QoL of people who live nearby transportation facilities has become a preeminent problem, and numerous scholars (Steg and Gifford, 2005; Bieri and Dawkins, 2016; Lee and Sener, 2016) have contributed this nexus from several aspects, such as housing, environment, and urban design. While urban forms encounter many changes with many services, it also creates disservice for the city. Such disamenities can be considered air pollution and noise (Whiston, 1985; McCarty and Kaza, 2015). However, literature mainly lingers in undesirable sound levels rather than an extensive examination by including desirable and undesirable sounds. Very few studies (Renne, 2005; Seto et al., 2008; Loukaitou-Sideris and Schaffer 2014), if non-exist, have examined the association between sounds and urban form, particularly Transit-Oriented Developments (TODs). The literature mainly assessed the noise and transit vehicle intersections. This dissertation examines the relationship between sounds and the developments near transportation facilities, specifically TOD as a trending urban form in the United States, in the Dallas-Fort Worth Metroplex region. To do this, the research utilizes both quantitatively and qualitatively tests for the implications of the TODs on the soundscape perception and understandings.

The research introduces the scope of information on urban morphology concepts, in this context; eventually, examines the TODs. This section will be followed by quality of life (QoL), and soundscape is presented as the key theme.

**Background**

As a primary sensory quality, hearing captures a certain range and frequency of vibrations. However, sounds have experienced many transformations over time. The relationship between sound and urban life started quietly at the beginning of the recorded history (due to lack of industrial machinery and household appliances), and it has become noisier ever since, and it is forecasted to get even worse (Lee et al. 2014). Industrial Revolution played a significant role in increased noise levels, and it is a universal cornerstone of this transformation. The pre-modern world was quieter altogether, and there were not that many developments to generate noise. Before providing an in-depth context of the research, it is noteworthy that sound, noise, and soundscape are different terminologies. While noise generally represents the undesirable sounds, soundscape may include desirable and neutral sounds as well (Schafer, 1993). This differentiation is also one of the preeminent goals of this study. Modern civilization and technical advancements generated different sound and noise sources, and eventually, noisier environments. Thompson (2004) argues that natural and pleasant sounds are transformed both in direct and indirect ways. In order to capture attention to this "hidden issue," Schafer (1993, p. 71) claimed that the sound of nature is being lost or combined with industrial and technological invasions. However, what sources contribute to or create noise? How do they emerge? These questions call for answers for decades.

City facilities that affect the transformations of sounds and noise mainly emerged by the rapid developments of transportation, building, and construction industries, mass production, and machines.  Meanwhile, societies are expanding beyond their existing borders because of the demanding need to accommodate the increasing population. Expansion on population results in higher-density or greater dispersion of residential and industrial settings. Furthermore, new developments and people require mobility, delivery, and other services that can be fulfilled only by transportation facilities. The living environment at personal, communal and societal levels are the parts of the urbanization process, and it has implications on the inhabitants' (QoL), sense of place and place attachment (Ng et al., 2005).

To better tracking the QoL, built environments attempt to accommodate human needs. Meanwhile, continually transformed physical environments endeavor to evolve human needs. This two-way people and development relationship create an interface between physical form and human behavior, and Rapoport (1977) highlighted: “cities are designed to meet people’s environmental preferences and notions of environmental quality.” Similarly, Relph (1976, p.31) pointed out that any changes in places also result in changes in human behavior. So, prospective associations between human behavior and physical environment fulfill mutual well-being, and generally, this relationship occurs positively. When this relationship balanced, it promotes the life satisfaction of people.  As a contribution to the physical environment considering the QoL, TODs play significant roles in the U.S.

TODs become important urban forms in the United States, and they include the capability to address QoL considerations. TODs provide multiple dimensions of the QoL. For instance, TODs decrease the use of personal vehicles and bring their residents closer to transit facilities. Thereby, TODs enhance QoL by reducing personal vehicle use. They also increase transit ridership and promote the sense of community. Reducing private automobile use also reduces transportation costs, lowers vehicle emissions, and enhances the local amenities as well as promotes walking and biking activities. Furthermore, the mixed-use and compact urban form of TODs have cultural, recreational, educational, and health-related benefits (Curtis, Renne, and Bertolini 2009). For these reasons, TODs serve to increase the quality of life for the people with their characteristics.

Besides offering this array of public goods, soundscapes remain among TODs' under-explored features. Soundscapes cover a broad aural range and of sound sources from positive (desirable) to negative (less desirable or noise) (Schafer, 1993). Notwithstanding, few studies have explored the association between TODs and soundscapes as they pertain to QoL. Accordingly, this research seeks to examine the QoL aspect of TODs by distinguishing between desirable and undesirable sounds.

Given these, developments near transit stations and their rapidly changing physical conditions include importance for providing better QoL and satisfaction regarding sound context. This is also why this research concentrates on TODs.

**Problem Statement**

The noise that is caused by anthropologic effects is the most dominant factor of environmental elements with an estimated 125 million people affected (day-evening-night level, $L_{den}$ > 55 dBA defined by the Environmental Noise Directive) (European Communities, 2002; European Environment Agency, 2014).

The first federal attempt on regulating noise occurred in 1972 when Congress passed the Noise Control Act. However, several changes in technology and population appeared in the last decades since the first federal regulation and new developments target to provide higher QoL for residents. Currently, the sound is a QoL issue for the public in many urban areas, and it represents one of the challenging factors in urban design and planning. Although the literature has examined the relationship between transportation and noise (Seto et al., 2007; Loukaitou-Sideris and Schaffer, 2014; Noland et al., 2014), there is not sufficient research empirically proving the relationship between TODs and sounds.

Furthermore, the literature has not examined the positive and negative aspects of sound in TODs elaborately. The relationship between the soundscape and TOD is not well-defined and requires careful examination. Therefore, the implications of TODs on sounds call for an alternative and distinctive perspective.

This study addresses four fundamental questions: (1) explore the impacts of transit-oriented developments on soundscape; (2) clarify the positive and negative externalities of TODs in terms of soundscape on residents' QoL (3) collaborating between the "agents of TODs" for better perception of TODs (4) enrich the literature on the methodological aspects of soundscape, TOD, and QoL assessments (5) to examine the relationship between urban morphology and sound.

**Research Questions and Hypotheses**

To explore why TODs are essential and their relationships with soundscapes, as well as the interplay of TODs and soundscapes. This research seeks to respond to the following questions:

1. What is the relationship between TODs and soundscape?
2. What types and what extends of soundscapes TODs generate?
3. What are the perceptions of the "stakeholders of TODs" on soundscape?
4. Do urban morphology features, such as building, street, and neighborhood affect soundscapes of TODs?
5. Does train station of TODs matter on sound implications?

Accordingly, the research hypotheses can be stated as:

- TODs and their characteristics affect soundscapes.
- The perception of sound differs at different "stakeholders of TODs."
- The spatial configuration of TODs affects various soundscapes and QoL parameters.
- The train station level of TODs has implications on sound.

These hypotheses of the research will need a quantitative and a mixed-method analysis with both quantitative and qualitative techniques. Regarding the quantitative, the study will perform on-site sound pressure level measurements for further spatial and statistical analysis while the qualitative method will investigate the perception of the "agents" of TODs on soundscapes.

**Aims and Objectives**

The goals of the research are:

- To examine the interplay between soundscape of TODs and physical/social configurations.
- To develop a conceptual framework for the assessment of soundscape and its perception
- To understand expert and resident insights on sounds in TODs.
- To generate a comparative assessment of the soundscape perception through the operational definition of TODs at various spatial configurations, such as building, plot, street, and neighborhood.
- To investigate how TODs and surrounding development change soundscapes at those scales of assessments.

## Scope

The research attempts to shift the concentration of soundscape exploration from the undesirable sounds to versatile facets of the TODs as an urban morphology-adapted investigation. The study defines the operational definition of TODs and soundscape while identifying the study locations in Dallas-Fort Worth Metroplex.

## Research Design

This dissertation first sets up a theoretical and terminological background through the literature reviews on soundscape and TODs. The research reviewed the fundamental concepts and theories of soundscape and TODs, as well as their characteristics. Accordingly, various essays are produced for the soundscape, and the application of the framework in TODs.

## Overview of Dissertation Structure

This dissertation consists of 6 chapters. Following the introduction, Chapter 2 includes the overall background information on the dissertation. This section is followed by the three essays and the last chapter covers the conclusions and discussion chapter. The detailed content of each chapter is as follows:

Chapter 2 first reviews the concept of TODs and essential characteristics regarding the quality of life framework. First, it provides a brief review of the definitions by various sources regarding urban planning, urban design, and landscape architecture disciplines — next, characteristics of TODs regarding QoL as a critical determinant of subjective and objective QoL. Then, the chapter examines the approaches and methods of urban morphology. It emphasizes the three fundamentals of urban morphology, building, street, and plots. These concepts are defined and translated into urban form by defining its elements and types. The chapter also introduces the soundscape concept within the context of QoL research. To do this, the soundscape and its characteristics will be examined as well as revisiting the sound, noise, and soundscape basics.

Chapter 3-5 covers the essays to investigate the relationship between TODs and sounds at different scales and contexts. Chapter 3 examines the soundscapes of TODs, and it is followed by Chapter 4 that provides information on sound and urban morphology features. Finally, Chapter 5 focuses on the train station-related sound investigation of TODs.

Chapter 6 provides the conclusion and policy implications. The significance of the study is emphasized along with the various policy implications of several TOD phases.

# CHAPTER 2

# BACKGROUND AND TERMINOLOGY

## Transit-Oriented Developments (TODs) and Characteristics

TODs contribute to the multiple dimensions of QoL. Among other things, TODs decrease the use of personal vehicles and bring their residents closer to transit facilities, thereby improving the QoL by reducing personal vehicle use, but also increasing transit ridership, and promoting a sense of community. Reducing private automobile use reduces transportation costs, lowers vehicle emissions, and enhances neighborhood amenities and also promotes walking and biking activities. Furthermore, the mixed land use and compact urban form aspect of TODs have other cultural, recreational, educational, and health-related benefits across different age groups besides offering different types of public space, e.g., plazas, parks, gardens, and playgrounds (Curtis, Renne & Bertolini, 2009).

Recent TOD projects have already implemented a variety of urban planning and design strategies including multi-modal transportation, mixed-land use, public spaces, and several types of activities. Such projects place much emphasis on aesthetics as well, with the goal of promoting economic development. To do this, projects typically incorporate different transportation modes, e.g., walking, biking, public transit, and private vehicles with, mixed-use developments, and they incorporate public facilities such as parks, plazas, and gathering spaces for civic engagement. Even though the relationship between urban design and TODs has been explored, there still exists a significant gap in the literature about the nature of this relationship (Calthorpe, 1993; Ewing, 1996; Dittmar & Ohland, 2004; Ewing & Bartholomew 2013; Jacobson & Forsyth, 2008; TCRP, 2002).

Several initiatives have proposed to plan active TOD projects in the United States. In his groundbreaking research, The Next American Metropolis, Peter Calthorpe (1993) introduced a number of conceptual schemes and diagrams to describe TODs. The American Planning Association (APA), the Transit Cooperative Research Program (TCRP), and the Urban Land Institute (ULI) have generated urban design guidelines on TODs (Dunphy, Deborah & Michael, 2003; Ewing, 1996; TCRP, 1997; TCRP, 2002).

In addition to urban design related contributions, active living investigations promote QoL as well. Even though professional designers and controlled physically designate TODs, lobbied for, and regulated by experts, targeted social factors generally question TODs as people often disapprove of them in QoL grounds. Advocates of TOD, however, shed a positive light on these concerns by considering the QoL implications.

**QoL and Characteristics**

Transit-oriented developments (TODs) are rapidly gaining momentum in the United States with their ability to address the Quality of Life (QoL) concerns. This section revisits the fundamentals of some of those concerns while considering the attributes of TODs.

Before addressing the QoL aspects of TODs, offering an operational definition of QoL is warranted. QoL has been studied in many different disciplines, and primarily refers to people's satisfaction with their surrounding circumstances (Lee & Sener, 2015). Satisfaction, in this case, is typically understood to be a highly subjective phenomenon; in analyses of QoL, however, both subjective and objective measurements are considered (Rapley, 2003).

Since QoL includes various characteristics, it has been given many definitions and operational interpretations, such as health and wellbeing, the satisfaction of life, quality living environment, expectations from life –happiness, liveability- and so on (Kamp et al., 2003; Marans & Stimson, 2011; Paccione, 1986). Therefore, QoL definitions are operated for a broad context to explain the conditions of the living environment on human beings' lives, expectations, and factors (Philips, 2006).

Historically, the fields of public life and social sciences included QoL in their studies in the early 1900s and until the middle of the 20th Century. By the 1960s, QoL was added as its category to a growing list of social indicators. Also, by the 1970s, scholars had begun concentrating on the built environment-related measurement criteria in various fields with the effects of National Environment Policy Act (NEPA) and other environmental laws and awareness movements (Pacione, 2003; Sirgy et al., 2006). As of the 1980s, QoL studies changed their focus from merely having operational definitions to applying the concept through the indicators, and generating an interrelationship with parameters (Apparicio, Sequin, and Naud, 2008; Southworth 2003). Since many disciplines are involved in QoL assessments and indicators, this versatility also resulted in many overlaps for the QoL indicators. Nevertheless, the literature includes several QoL indicators (Table 1).

**Table 1:** QoL indicators

| **Quality of Life Indicators** | **Literature** |
|---|---|
| Economic and cultural vitality | Wish (1986), Shafer (2000) |
| Feeling of space and experience | Brock (1993), Apparicio et al., (2008) |
| Health | Pacione (2003), Kamp et al., (2003) |
| Pollution | Apparicio et al., (2008) |
| Security and safety | Kamp et al., (2003), Pacione (2003) |
| Lifestyle and identity | Mercer (2002), Kamp et al., (2003) |
| Natural access and scenic experience | Apparicio et al., (2008), Kamp et al., (2003) |
| Place belongings | Ng et al., (2005) |

In addition to these indicators, the contexts of QoL generally encompass four categories: "objective," "subjective," "combined objective and subjective," and "domain specific" (Lee & Sener, 2016). While objective measurements of QoL consider income and crime rate indicators, for example, they do not typically reflect personal experience (Felce & Perry, 1995; Sirgy et al., 2006); instead, indicators of personal experience wind up generating subjective evaluations, including perceptions of life satisfaction (Diener 2000). Some contend, however, that subjective indicators cannot solely interpret QoL regarding, for example, personal welfare – a key component of QoL – unless they reflect personal circumstances in their entirety (Felce & Perry, 1995). Researchers have also suggested QOL's aggregate form by including subjective and objective indicators (Atkinson, 2013; Bowling et al. 2003; Ferkany, 2012; Netuveli & Blane, 2008; Sarch 2012). The last classification of QoL dimensions falls within domain-specific dimensions. As a significant domain-specific dimension of QoL, public health and social science fields have investigated the relationship between housing, neighborhood facilities, and QoL (Sirgy & Cornwell, 2002; Nelson et al., 2007; Bize, Johnson & Plotnikoff, 2007).

Even though the literature in various fields have examined QoL, and from various points of view, the quality of physical and built environment studies on QoL are limited (Kamp et al., 2003). QoL research in urban planning, landscape architecture, and urban design fields is far less mature compared to the research in other disciplines such as biology, medicine, and public health. However, since the physical environment is a variable that is affected by numerous factors, there is a need for further QoL studies to examine this nexus. It is no wonder that QoL has been one of the burgeoning topics of interest to penetrate the urban planning and landscape architecture fields (Rinner, 2007). This proposed research will contribute to this growing field by examining transit-oriented developments (TODs) in the context of QoL.

How do TODs impact QoL? Several studies have attempted to address this question. The fundamental purpose of TODs is to create functional places for people by cooperating with transportation facilities. Research has shown that well-designed streetscapes could increase mobility and strengthen the connection to neighborhood facilities and natural amenities (Belzer & Autler 2002; Curtis et al., 2009), thus impacting QoL.

One of the main goals of TODs is to create a healthy environment that promotes quality of life (QoL) and livability for people, particularly as it relates to transportation facilities. Livability and QoL are closely connected to the direct and indirect elements of the built environment (Belzer & Autler, 2002). Since TODs aim to make a built environment work well for its residents, QoL has increasingly come to be seen as an essential connector of the environmental, social, and economic aspects of individuals' lives; in fact, QoL has emerged as a critical point of focus among multiple disciplines, including public health and urban planning (Bize, Johnson & Plotnikoff 2007; Diener, 2000; Ferkany 2012; Lee & Sener, 2016; Sarch, 2012).

Looking at the social aspects, TODs are well-balanced communities – i.e., communities with improved mobility that provide ample access to offices, retail stores, and other services – increase social relations between people. Additionally, TODs aim to provide more mixed-housing development types that target diverse age groups. TODs are expected to increase individuals' social relationships as a result of these features. Designating higher population density around TODs also provides more diverse outdoor spaces, potentially increasing the types of social relationships in which people can engage. Similarly, residents of TODs who have a choice of housing type, shopping venues, eateries, recreational outlets, and multi-modal transportation experience an increased QoL and overall livability. TODs also affect neighborhoods in the way that their residents engage with their community, an element referred to as social capital (Noland, Puniello & DiPetrillo, 2016). In Putnam’s (2010) words, social capital is a term that encompasses "social networks and the norms of reciprocity and trust to which those networks give rise”

(Putnam, 2010, p. 19). Another facet of TODs regarding social aspects is social equity. Even though some scholars question the benefits of TODs for social equity (Immergluck, 2009), others suggest that TODs might be positive for social equity through the opportunities of living and interaction that they offer: affordable housing, diverse housing types, proximity to transit services, access to transit services (offering commuters multiple transportation options), and access to education and experience opportunities (Cao & Lou, 2017; Dawkins & Moeckel, 2016).

There are also many other implications of TODs on QoL in terms of of demographics, social, and economic factors on TODs. In terms of demographics, household types – e.g., family/non-family, single/multiple-family – and household size have specific effects on TODs. Related, housing tenure circumstances (renting or owning a house) and car ownership have effects on TODs; it is expected that non-family or single-family households, renters, and people who do not own a car will be more likely to walk and use public transportation. Such travel behaviors are vital factors that affect TODs.

Similarly, socioeconomic characteristics, such as income, race, ethnicity, and education level are factors that affect TODs. The research acknowledges that individuals who have lower incomes positively influence walking and transit-ridership due to their inability to afford a personal vehicle. For example, Murakami and colleagues (1997) found that transit-use is generally higher in low-income households, with five percent of work trips taken by public transportation. Also, the authors highlighted that low-income households are two times more likely to commute to work on foot, also suggesting that more than half of their commutes are within a three-mile radius (Murakami et al. 1997). Directly or indirectly, minority populations, including those that are foreign-born, are more likely to live in these socioeconomic conditions of a TOD environment. Being under debate of minority population, whether or not the displacement of low-income and minority populations in TOD areas result in the gentrification of such communities, communities that also appeal to middle and upper-class residents of TODs (Bohl, 2000; O'Toole, 2001). Another feature is about the foreign-born population of TODs. This pattern was tested by several scholars. For instance, one study demonstrated that almost half of all transit users were born on foreign soil in California (CTOD 2005).

Finally, the economic impact of TODs in terms of QoL and livability is twofold. First, ideal TODs provide the appealing feature of location efficiency, thus making driving a choice – ideally the last choice – rather than a necessity. This can bring more financial options for the residents as the concept of location efficiency may incorporate a location-efficient mortgage program allowing residents to borrow more money; indeed, TODs with high-quality transit, mix-use land use, and various neighborhood amenities are capable of assisting such programs. Second, successful TODs offer various development projects around transit facilities which are expected to generate financial returns. Since both public and private stakeholders of TODs may ask to have a direct or indirect monetary return on investment, stakeholders would expect to have higher land, property, or business development because of the location that might utilize "the highest and best use" of TOD areas (Bossart et al., 2002). Compared to single-use developments, mixed-use land developments offer market volatility as well as a higher value of all types of developments. Thus, this return-on-investment concept has the potential to increase stakeholders' QoL expectations, particularly those of residents and business owners (Bossart et al., 2002). However, considering the construction cost as a drawback, some lenders are not willing to finance TODs – or if they are, only with higher interest – as the market of mixed-land use buildings is considered to be risky business compared to traditional developments. So, the developer should consider a sufficient supply of amenities among diverse population characteristics in TOD environment (U.S. Government Accountability Office, 2014). On the other hand, diverse favorable demographics, business owners, and various income levels increase the positive aspects of the TODs regarding economic factors. Also, by creating entertainment, commercial, retail, single and multi-family residential developments as well as secure lease, rent, or sales prices of developments, real estate experts attempt to absorb the adverse economic factors in TODs.

**Understanding Urban Morphology and Urban Form**

Since TODs are considered as urban form, this section aims to provide a general brief on the urban forms and morphology literature. The term morphology is one that was introduced into the scientific lexicon by German writer and polymath, Wolfgang von Goethe, in 1796. With interests ranging from poetry and drama to literature and philosophy and politics, Goethe's legacy is nowhere more prominent than in the field of biology. Defining morphology as "a science dealing with the very essences of forms" (Bullock, Stallybrass, and Trombley, 1988, p. 76), Goethe brought a new form of scientific inquiry into our world.

While commonly known as a branch of biology, general and abstract application of morphology as a science of form has allowed for the concept to be applied beyond biology. For instance, the fields of geology and geography apply this form of inquiry to natural landscapes; the field of linguistics, to elements and structure of language. In each case, morphology can be considered the study of form or structure. In the context of the built environment – the focus of this proposed research – urban morphology refers to the science of urban form and structure. Research in urban morphology, particularly in urban planning, geography, and landscape architecture, has expanded the definition and scope of the concept. For some, urban morphology provides a framework through which to investigate the change in the physical environment (Conzen, 1981; Oliveira, 2016), while others consider morphology studies as a human habitat (Moudon, 1997; Kropf, 2005). Table 2 below lists a collection of other definitions of urban morphology found in the literature.

**Table 2:** Compiled Definitions of Urban Morphology

| The Definitions of Urban Morphology | Scholars |
|---|---|
| The study of the evolution process of a particular place over time | Scheer & Scheer (2002) |
| The study of the physical fabric of urban form, and the people and processes shaping it | Larkham & Jones (1990) |
| A study indetifying "the repeating patterns in the structure, formation and transformation of the built environment to help comprehend how the elements work together. | Kropf (2014) |
| A method of urban and architectural analysis used to find out basic principles of urban and architectural formations and aiming to describe the process of urban formation | Mihcioglu (2010) |
| A method of analysis which is basic to finding out principles or rules of urban design or the study of the physical and spatial characteristics of the whole urban structure. | Cited in Oliveira (2016) |

Considering these definitions through an urban planning lens, a comprehensive definition of urban morphology can be developed as such: the study of urban forms and their agents, and their processes of transformations (Oliveira, 2016). Urban forms refer to the primary physical environments, including distinct elements of structure and the city. Such elements include urban tissues, streets, squares, urban plots, and buildings (Oliveira, 2016).

Structure emphasizes the built environment and spatial configuration of a city (Kropf 2005); it refers not only to the structural associations of the characteristics of physical form but as well, to the various effects in the emergence of different patterns in the physical environment. This more nuanced representation allows for a better understanding of the nature of the building process on many scales (Alexander, Ishikawa & Silverstein, 1977). The individual elements of structure, expanded upon below, should be considered in light of this dynamism.

Urban tissues are considered the core components of a city. Kropf (1996) defines urban tissues as the “organic backbones” of a city that contain various levels of resolution such as streets. According to him, the higher the level of resolution, the more detailed the urban morphology pattern. Moreover, these patterns are the outputs of smaller elements: buildings, streets, and urban plots. In other words, cities with various urban forms consist of these three main elements even though they may have a different configuration in each city structure. While these core elements can be observed in some cities, (e.g., Brasilia and Venice), they may not be distinguishable in others because of historical developments, and accompanying technological, social, and cultural influences of cities (e.g., New York City). Nevertheless, they exist, and here I lay out what those elements are, and how they function in a city.

**Buildings**

Even though buildings are less stable than streets and plots, they are one of the core components of the urban form, containing fundamental features that must be considered in any discussion of urban studies. There are two main categories of buildings: ordinary and exceptional (Oliveira, 2016). While many city buildings, namely residential and commercial buildings, are in the former category, smaller sets of buildings that are distinguishable are in the exceptional category (e.g., Dallas Observation Tower and Fort Worth Courthouse).

In addition to the building types, another factor is in the relationship with the urban morphology is the positioning of buildings within the streets and plots that also establishes the significance of the urban landscape. Up until the $19^{th}$ century, there was the only continuous alignment of building arrangements; however, discussions for alignment by city planners and theorists resulted in several variations in the positioning of buildings, which in turn devolved into the street, street layout, and building disputes. Other fundamental features of buildings are height, width, and their relationship with the streets (Oliveira, 2016). This is highly related to the sense of place and how people perceive and interact with a setting. For instance, if the height of the building is larger than the width of the street, people feel a lesser sense of enclosure, while if the reverse were the case, the sense of attachment would increase. In addition to dimension-related features, façade design is also an essential feature of buildings as it may consist of materials, colors, and configurations that influence the sense of place (Oliveira, 2016).

**Plots system**

A significant feature in the description of the physical form of the city is the element of its street blocks and, within these, its plots. The plots system is a critical factor of urbanization, tolerating lesser durability than the streets system, and having lower stability than the two previous elements, over time (Oliveira, 2016). Since its visibility is relatively lower than streets and buildings, plots are occasionally neglected by agents and stakeholders in urban form activities. On a larger scale, plots systems are assessed for a new structure of public or private ownership in a particular territory – rural, urban, or suburban – while on a smaller scale, plots can be rezoned, or their use changed for different urban form features (Oliveira, 2016).

In general, the element of street blocks and plots increases as we move from the city centers – or central business districts (CBD) – to the peripheral areas of a city. The number of plots per street block expresses the greater or lesser diversity of agents and stakeholders that exist in the street block. Contrary to street blocks, the number of plots per street block decreases when moving away from CBDs to the city periphery (Oliveira, 2016). Ultimately, buildings, streets, and plots systems are nested into each other, and any transformation or development in one element has implications for the other elements in the urban form (Figure 1).

**Streets**

From an urban morphology standpoint, streets are the most stable element of urban form, and more amenable to transformation than the other elements. Streets can be in various shapes, widths, lengths, and design features, with different combinations of building positioning, height, and width, and plot system configurations of near or far frontage street alignment.

Streets are the public and democratic spaces of the city, the place where people of diverse socioeconomic status (SES) meet and interact not only with each other but as well with the physical aspects of the streets. The literature on streets reveals many points of views, which are at times in opposition with one another. For instance, Space Syntax founder, Bill Hillier, finds that streets are not conducive to bringing together individuals of different social backgrounds; he does not find that streets are reflective of society (Hillier, 2009). On the other hand, Appleyard’s (1978) examination of various street configurations – light traffic, moderate traffic, and heavy traffic – revealed that streets do indeed have a significant implication on human interactions (Appleyard, 1978); he found that people were engaging more, both socially and physically, with the light-traffic streets. This circumstance ties into another important consideration of streets: pedestrians. After examining street structures and pedestrian activity, Jacobs (1993) argues that streets are vital systems that create a balance between pedestrians and their mobility context, in motorized and unmotorized configurations (Jacobs, 1993).

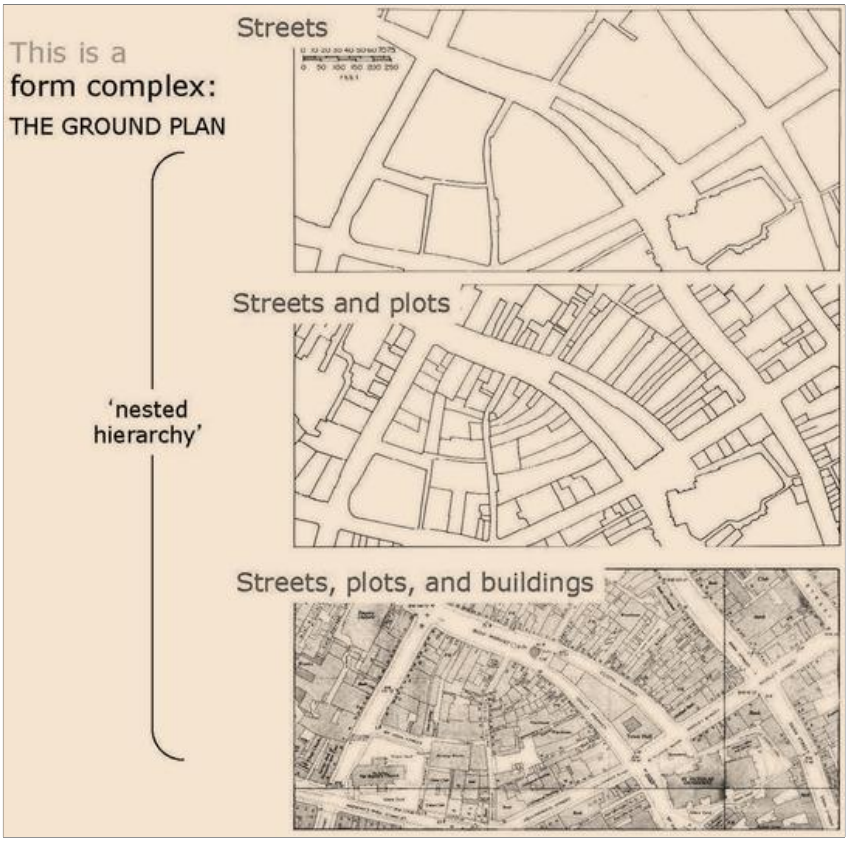



**Figure 1:** Hierarchy illustration for the urban elements (Conzen, 1981)

The role of urban elements in understanding the configuration and transformation of a built environment is unmistakable. The manner in which these elements are interpreted, however, has led to different perspectives of urban form studies.

The literature acknowledges that urban forms have many implications for the environment. Within the United States context, urban form includes traditional developments, New Urbanist developments (NU), and transit-oriented developments (TODs), all of which have been gaining attention in the last several decades. TODs are positioned at the "intersection" of transportation and built environment, with transportation having many implications on urban forms, implications which become more far-reaching in the face of social, ecological, and economic events (Camagni, Gibelli, and Rigamonti, 2002). Even though the literature includes mainly noise-related subjects, TODs still need further and robust investigations (Seto et al., 2011). This research aims to contribute to urban morphological studies by developing a better understanding of the impacts on transit-oriented developments for the quality of life (QoL) of the communities. The next sections review the concepts of TODs and QoL.

How might these factors be related to TODs in terms of soundscape? This is one of the interesting questions I am asked, and it certainly inspires visions of research ideas in my career. To start with, in terms of social and demographic implications on soundscape, I would expect to observe more people with differing backgrounds and socioeconomic characteristics. Since TODs aim to create a dense built environment with residential, commercial, and recreational areas, I hypothesize that TODs generate more anthropogenic (human-related) sound. In addition to investigating TODs with a variety of housing options and diverse age populations as well as densely populated neighborhoods, TODs would be interesting to analyze the nexus between built environment developments and soundscape approach. In addition to housing options, education level, gender, income, race, and ethnicity each play a role in soundscape perception. Many studies have looked at how socio-demographic features of the people in soundscape studies play a role in sound perception; findings present that all aforementioned socio-demographic and socio-economic characteristics (except gender) do, in fact, play essential roles in soundscape perception (Gozalo et al., 2018; Han et al., 2018; Kang, 2006; Zhao et al., 2016). Imagining TODs as a part of the built environment, I would undoubtedly state that TODs matter on soundscape implications and perception.

This shred of compelling evidence is enough for me to more deeply consider the question of soundscape and its implications on TODs. Economic factors, spatial mismatch of the specific population, such as minority and/or low-income are claimed to be exposed to higher noise levels (Dale et al., 2015; Hoffmann et al., 2003; Lam & Chan, 2008; Loganigro et al., 2018). According to these shreds of evidence, I can both consider that soundscape and TODs have a transective relationship and various conditions such as population, natural elements, neighborhood amenities may affect exposure to noise as a positive or negative externality in a TOD context. Therefore, TODs that are near transportation systems also affect QoL in terms of sound and noise aspects. Most importantly here, soundscape – the physical characteristics and psychological perception of the sound environment also affect QoL in TODs; it can become particularly problematic when transit services generate them, which in turn directly affect the TOD residents. However, there is a need for further study of TODs and such investigations. So, the next section focuses on definitions and implications of the soundscape to contribute the literature.

**What is Soundscape?**

The soundscape concept (physical characteristics and psychological perception of the sound environment) has offered an innovative and strategic method for planning and designing sound-related features from an acoustic point of view, by combining many factors with objective acoustic measures and the subjective perception of the acoustic environment (Schafer, 1993). In order to have a better understanding on soundscape, it is required to provide sound and noise terminologies.

**Sound**

The concept of sound has existed since the beginning of human history. Over time, many contexts have examined the context through both tangible and abstract approaches. Regarding the physical aspect, scholars have tried to understand the features of sound as a part of physics, particularly from the energy perspective. From the abstract point of view, philosophers and social scientists have attempted to provide an explanation on sound and the aural environment from the perspective of human perception (Carmona et al., 2010; Malpas, 1998; Vanclay et al., 2008).

Over the last several decades, the sound has been recognized to affect QoL and individuals' well-being, in addition to which, it has increasingly been identified as a valuable public health issue (European Environment Agency, 2014). Before continuing with an analysis of soundscape, a definition of sound is warranted.

Kennedy and Timerson (1996) defined sound "as a type of energy which mediates throughout solid, liquid or gas medium in the form of vibrations" (p. xi). In any medium that transmits sound all vibrating particles move minimal distances their regular position. In other words, a sound is conveyed in the platform of a perpendicular wave. The time it takes for a moving particle to complete one wave is “period” *T,* and the adjustment of the wave from a reference point is called a phase (Kennedy & Timerson, 1996). The resonances, or reverberation, are reproduced and the rate per second is described as "frequency," *f*, the unit of which is hertz (Hz). The distance between repetitive movement happening is called “wavelength” $\lambda$ (Kennedy & Timerson, 1996). Therefore, the distance of a conveyed sound wave is one cycle of vibration.

*Sound Level*

The unit of sound measurement level is *decibel*, and it presents a proportion or a relative value. Since the human ear does not react appropriately to sound strength or pressure, decibel can be defined as a proportion of two measurements in the logarithm version. So, decibel emerged as a unit to proportionate ten times bigger or smaller than the others (Avsar, 1998). For example, 20 decibels is ten times bigger than 10 decibels, and 30 decibels is 100 times bigger than 10 decibels (Avsar, 1998).

In order to quantify sound samples, studies in the literature have collected sound samples either directly from the site (in-situ sound sampling), or indirectly, using sound prediction methods (artificial network). To expand the information on the sound level measurement on site, since the sound is a type of energy, it is measured by a specific method that uses the logarithmic comparison method. The logarithmic method provides a constant comparison to each sound level itself. Specific sound level meters (dosimeter) measure the various levels of sound parameters that are important indicators. For instance, Ln is the level of sound level exceeded for n percent of the specified measurement period. In order to be practical, the literature suggests various levels of sound values. To demonstrate it, $L_1$, $L_{10}$, $L_{50}$, $L_{90}$ values represent maximum, intrusive, median, and background sound levels, respectively (Kang, 2006).

Studies that perform in-situ sound level measurements generally utilize a dosimeter that includes such adjustable values and configurations itself. In order to collect the sound level, now there is another issue; how to perform the sound level measurement. In this study, quantitative technique will be conducted by performing a grid method for the site-related measurements. Grid method technique has been performed at the various scale of study areas between 300 feet to 5000 feet. The method relies on virtual nodes on a site that is divided into grids, and each grid node is defined as a sound level measurement point (Brown, 1987; King et al., 2012; Morillas et al., 2011). For this purpose of the study, objective on-site measurements will be collected with sound pressure level meters, after which the measurements will be recorded by sophisticated audio recorders for further analysis processes. In order to adjust for variation in sound pressure level measurements, measurements will be taken at different times throughout each weekday and weekend day.

In addition to measuring the sound levels in different days in order to standardize the quantitative approach, sound pressure levels will be collected as equivalent continuous sound level (Leq) that is a parameter, and it allows entire sound energy during the time of concerned (Noise Control, 1991). As a general info, typical sound weight network consists of four major types; dBA, dBB, dBC, and dBD. In this research, as many other soundscape studies perform, dBA type of sound weighing is performed since it includes the closest frequency and sound rate to the human ear (Proplan, 2006). Apart from this value, dBC weight is used for high frequency such as wind turbine while dBD is applied for higher frequency (1-10 kHz) like airport and airplane noise. As a result, this dissertation performed dB(A) sound weight.

**Noise**

Noise can be defined as an undesirable sound type that has adverse effects on human hearing systems and perception and work performance, due to its role in changing the beauty and comfort of any acoustic environment. Since technological and social developments have been increasing for decades, the sources of noise have also escalated. According to noise control standards (ISO 1991), in modern society, noise pollution has emerged as a threat not only human health, but also fauna and flora, and the natural environment. Additionally, anecdotal evidence suggests that people's psychological and physical problems may be exacerbated by noise; to date, however, this has been largely ignored by the research (Schafer, 1994; Kang, 2004).

With a plethora of research in the adverse effects of noise, the focus of noise has now shifted from looking at the adverse effects of sound to a review of the entire acoustic environment, and the *neutral* effects of sound. Sound and noise studies have been conducted in various places of urban life, such as urban neighborhoods and national parks, urban acoustic, which examined urban land uses, quantifying the noise implications, and so on (Kang, 2004).

**Through the Soundscape**

The concept of soundscape emerged as an interdisciplinary field that linked the concept of sound with the noise. It is originated from the music and acoustic fields in the 1970s, the concept of 'soundscape' was quickly adopted by other disciplines, such as architecture, environmental health, psychology, sociology and recently, urban studies, gaining momentum in its importance for human perception (Truax, 1978; Rychtarikova & Vermeir, 2013). The role of soundscape has only in the last decade come to be seen as important in urban planning and landscape architecture. Urban planning and landscape architecture are characteristically related to sound. No matter what the context is, the shaping of the environment includes extensive outcomes for the sound environment. At the same time, the sound environment affects individuals' understanding, perception, health, and quality of life (QoL).

Nonetheless, since the 1970s, the fields of urban planning and landscape architecture have contributed to the development of the soundscape concept within a built environment, particularly with the contributions of Schaffer and Southworth (Schafer, 1973; Southworth, 1969). The built environment refers to any human-made places where people work, live, recreate, and engage in other activities. So, a built environment may include a variety of urban elements, such as parks, buildings, walkways, roads, street lights, community gardens, transportation networks, and so forth. By creating these places, urban planners and landscape architects are engaging with the outdoor activities; the very sound environment is therefore shaped by the fields of urban planning and landscape architecture. Even though landscape architects were expected to contribute to noise controlling in past decades, they have not done much in studying it. Later on, the awareness of urban planning and landscape architecture involved various phases and possibilities of the sound. The way of these two fields approaches to the sound that both urban planners and landscape architects may engage with sound studies in their planning and designs through consideration of features as such soundproof solids, covering, screening, the establishment of habitats for fauna, and locating water structures. Therefore, these fields are looking differently at the sound and seeing it as a subject for planning, design, research, and practice aspects to create a nexus between QoL and the built environment.

As defined above, the sound environment contains desirable and undesirable sounds that emerge from different sources. The primary sources of an acoustic environment are human, mechanical, or naturally originated sounds (Raimbault & Dubois, 2005), and while these sound sources may be directed or utilized to improve QoL, they have distinctive functions and meanings for individuals that may be perceived subjectively.

Studies do show, however, that human reactions to environmental sounds can be mediated by the surrounding soundscapes (Job and Hatifield, 2001). As Brown and Muhar (2004) explain, considering the positive and negative effects of urban sounds creates opportunities for the planning and design disciplines to a better environment (Brown and Muhar, 2004).

In this context, sound sources have been widely recognized for having the potential not only for masking or mitigating noise as unwanted sound but also for being considered something that is "wanted" (Schafer, 1993), and therefore improving soundscape perception due to their (the sound sources') positive attributes (Kang, 2007). This is the significance of the term soundscape.

**Soundscape**

Schafer established the relevance and needed for this, studies in the discipline of *soundscapes* have focused on assessing the relationship between people and their acoustic environment; and scrutinizing the sounds that human health and person's response to sounds through particular circumstances of the area.

Current definitions and characterizations of a soundscape vary among disciplines, such as acoustics, architecture, history, anthropology, music, and ecology. The term *soundscape* was initially described as a sonic environment, and the initial studies pioneered by Canadian composer R. Murray Schafer in the 1960s (Schafer, 1993). "Sound" in soundscape has already been defined; "scape," from "landscape" represents a view or vista of an area. "Soundscape," then, refers to an auditory or sonic vista of a setting that Schafer (1977) defines as "a sonic environment that includes any sound in the environment" (p. xi). Porteous and Mastin (1985) expand on Schafer's definition and explain that soundscape is all sounds in any place from a room to a region. They also mention that an acoustic environment consists of a series of components that place the listener at the center point of these components. This interactive nature of sound is highlighted by many: Truax (1999) proposed a sound environment as consisting of sounds that are perceived and understood by human beings; Turner et al. (2003) describe soundscape as an auditory environment with interacting receivers; and, Downing and Hobbs (2005) defined soundscape as an inclusive ambient sound environment.

**Soundscape and Perception**

Many scholars highlighted the perceptual context of the soundscape. Truax explained the soundscape as a way that a human or group of people perceive acoustic atmosphere while Yang and Kang stated that sound and soundscape occurs within human perception (Raimbault & Dubois, 2005; Truax, 1999; Yang & Kang, 2005).

Listening is an essential “space” for human perception and a human’s environment to interface with each other. However, since a person perceives sound differently depending on his location (Treasure, 2011), and since each sound source contains a different meaning for each person, the perception of sound becomes a challenging, but significant feature in soundscape research. Considering to give explicit information for listening to and hearing actions to assess the soundscape and perception relationship, listening is one of the most active senses of receiving the information.

To begin tackling this challenge, Truax (1999) breaks listening down into three types: listening-in-search, listening-in-readiness, and background listening. Even though there are many listening types, the most well-known is the listening-in-search, which is the most critical stage because humans seek sounds in a sound environment (Treasure, 2011). Listening-in-readiness represents the sound that is everywhere, and which humans can focus on, in any direction. Background listening concerns those sounds that remain in the background of humans' attention. When a human does not seek out a sound, it is unlikely that the sound has meaning.

In addition to Truax's classification, Raimbault et al. (2003) propose two categories of listening; holistic and descriptive. Holistic listening occurs when someone practices the soundscape with subjective meaning to human's activity while descriptive listening concentrates on the meaning of the soundscape concerning the surrounding objects. So, soundscape represents more physical attributes of the environment. The perception of particular sounds varies based on the permutation of sounds since the acoustic assets are changed, and the perceptual processing of the drives differs.

Considering the context of the dissertation, TODs could provide various unique and favorable sound sources in addition to the sole noise from the personal and transit vehicles. Thus, the research sets out to examine these unique features and their impacts.

This dissertation seeks to address the various gaps in the TOD literature and develop a methodology for evaluating soundscapes in the Dallas-Fort Worth area. The proposed method has several advantages over other methods including the TOD stakeholders as well as digitizing the sound levels.

## CHAPTER 3: MANUSCRIPT 1

## SOUNDSCAPES OF TRANSIT-ORIENTED DEVELOPMENTS (TODS): A MIXED-METHODS ASSESSMENT FROM A U.S. CITY

### Introduction

TODs are capturing much attention in playing pivotal roles in the interface between the environment, transportation, urban planning, and particularly around light-rail train stations (LRTs). Since LRT use in the United States has almost tripled from 1990 to 2010 with a greater increase than any other form of transit, TODs expectedly assume even bigger roles (Neff & Dickens, 2012). Defined as a complicated social phenomenon that measures individuals' state of being, and with their unique physical and environmental characteristics (Kerce, 1992), TODs contribute to the QoL as one of their key objectives. QoL includes both subjective and objective factors, including personal (Diener, 2000), community (Sirgy & Cornwell, 2002), socio-economic (Sirgy et al., 2006), socio-demography (Bowling et al., 2003), and health (Bize, Johnson, & Plotnikoff, 2007). The World Health Organization (WHO) Noise Guidelines also suggest the terms and conditions of health-related quality of life (HRQOL) as part of measuring the influence of a person's health status (Shepherd, Welch, Dirks, & Mathews, 2010).

Considering the scope of this paper from an environmental, urban design, and urban planning perspective, all these extensive lists of QoL characteristics and definitions refer to livability, connection, mobility, personal development, and community development in a broader context (van Kamp et. al., 2003; Smith, Nelischer, & Perkins, 1997). Addressing some of the QoL concerns, the increasing attention surrounding the positive and negative aspects of living in TODs—particularly as they relate to the noise QoL concerns, has prompted this research.

TODs encourage public transit usage and promote transit-friendly and compact, pedestrian-oriented, mixed-use communities, bringing residents closer to transit facilities and increasing transit ridership, decrease personal vehicle use and, promote a sense of community, thereby improving the QoL. Reducing private automobile use, in turn, reduces transportation costs, lowers automobile emissions, enhances local amenities, and promotes walking and biking activities. Furthermore, the mixed-use and compact urban form aspect of the TODs has cultural, recreational, educational, and health-related benefits including access to different types of public space, e.g., plazas, parks, and gardens, or playgrounds for different age groups (Curtis et al., 2009).

While offering these public goods, soundscape which consists of the entire "aural elements" or sounds people can hear in the built environment, remain as one of TODs' under-explored features (Schafer, 1993). These features cover both the positive (desirable) and negative (less or not desirable) sound range (Atkinson, 2007). Notwithstanding, to our best knowledge none of the studies have explored the QoL aspects of the association between TODs and sounds in terms of planning aspects. So, this research seeks to address the desirable and undesirable aspects of this association.

TODs cover unique sound sources ranging from the noise generated solely from transit vehicles to pleasant sounds allows distinguishing between the two. This study seeks to address this gap in the literature by evaluating and classifying various sounds in five TODs and five non-TODs in the Dallas-Fort Worth Metroplex area. The research method has several advantages over other techniques including interaction with multiple TOD stakeholders and sound receptors (i.e., designers, users, environment and planning experts and policymakers). The study first provides a brief overview of the TODs followed by their impacts on soundscapes. The next section proposes a mixed (qualitative and quantitative) methods approach, discusses the study limitations, findings, potential future research, and finally their policy implications.

***Important TOD Characteristics***

TODs are not new in the United States but have significantly evolved over the last few decades. The continuous growth of the transit facilities along with their cutting-edge technology not only facilitates mobility but also promotes better communities with higher QoL (Curtis et al., 2009).

Since not all TOD developments are located in close proximity to train stations (Kamruzzaman et al., 2014), describing their common characteristics seems imperative. TODs typically characterize compact, dense and walkable neighborhoods with permeable street networks (Brown & Werner, 2011; Renne & Ewing, 2013; Werner, Brown, & Gallimore, 2010) and mixed-use (Kamruzzaman et al., 2014; Vale, 2015), located along transit stations that encourage residents and users to ride public transportation rather than drive personal vehicles.

Nonetheless, TODs have evolved in time from many design and planning aspects. Calthorpe (1993) associates them with different conceptual schemes and diagrams while the American Planning Association (APA), the Transit Cooperative Research Program (TCRP), and the Urban Land Institute (ULI), have devised design guidelines and documents for them in the 2000s (Calthorpe, 1993; Dittmar & Poticha, 2004; Ewing, 1996; Jacobson & Forsyth, 2008; Dunpy et al., 2003; TCRP, 2002). However, the perceived TOD benefits expected to promote individual health may not be necessarily congruent with their social and QoL benefits propagated by policymakers and urban planners. For instance, according to Circella et al. (2017), surveys of transit users show that increasing TOD demand is growing mainly among young people while TODs seek to avail to all age cohorts regardless of their socio-demographic status.

***TODs, Soundscapes, and QoL***

Having said all this, how do TODs impact the QoL? Creating livable places for people near the transportation facilities undergirds the TODs' key purpose. While well-designed streetscapes could improve mobility, connection to neighborhood facilities, and natural amenities (Curtis et al., 2009), other factors such as air quality and sound affect the QoL in TODs as well (Kimball et al., 2013; Gu, He, Chen, Zegras, & Jiang, 2019). The sound may be perceived as noise when transit services magnify it and this occurrence directly impacts the TOD residents.

The interface between the soundscape and the QoL typically represents how sound impacts the city. Adopting Murray Schafer's soundscape typology, Fong (2014) examined soundscapes by comparing Bangkok, Thailand and Los Angeles. The author found that cultural and environmental accommodations affect the perception of urban noise. Soundscapes also affect the sense of place (Turner et al., 2003) ranging from improving the visual and sound image of urban areas (Rehan, 2015) or reducing the urban noise by encouraging physical activities i.e., walking and jogging (Kang, 2004), to generating attractive locations for improving the local economy (De Coensel et al., 2010), value of quietness (Baranzini & Ramirez, 2005) or promoting public participation in sound planning (Xiao, Lavia, & Kang, 2017). They can also improve our understanding of the cultural heritage of sound (Kang & Schulte-Fortkamp, 2016) through airport noise relationship (Ogneva-Himmelberger & Cooperman, 2010), airport noise reduction and willingness-to-pay for abatement (Wolfe, Malina, Barrett, & Waitz, 2016), environmental justice (Lagonigro, Martori, & Apparicio, 2018), and segregation and sound level management techniques (Casey et al., 2017).

While urban planners and transportation experts cannot obviously control the entire gamut of sound sources, they can manage soundscapes by exercising more explicit methods, such as zoning requirements for new developments (i.e., The City of New York's Zoning Resolution). Thus, urban and transportation planners should proactively value the acoustic environment to contribute to the urban environment (Schafer, 1993). In their seminal work, "*Toward an Urban Design Manifesto*," Appleyard and Jacobs (1982), have also warned urban and transportation planners against the negative impacts of noise that hinder creating a livable, higher quality of life comfortable environments, and access to opportunity and imagination.

Sound influences QoL in different ways: physiologically or mentally (Kang & Schulte-Fortkamp, 2016). Psychological and physiological concerns from exposure to noise may ensure stress responses, create negative social consequences, and sleep disturbances (Evans et al., 1998). The growing interest in how sounds affect the QoL lies partly in the human perception of the built environment, and "sounds of preference" that support human enjoyment or well-being (Brown, 2012). Envisioning sound as a resource rather than a liability, therefore, encourages treating the soundscape as a QoL factor, and not only when extreme sound levels might become a nuisance, but also when they have high qualities (Kang & Schulte-Fortkamp, 2016). Few studies have reported the sound quality associated with the physical and spatial features of an area different from people's perceptions of the ambient sound (Kempen et al., 2014).

Some studies primarily assess soundscapes in terms of vehicle-related noises. Those concerned with noise and vibrations, for instance, express reluctance in moving into TODs.  Houses within the first couple of lots adjacent to or within the TOD station perimeters do not sell as quickly as would other lots either (Renne, 2005). Loukaitou-Sideris and Schaffer (2014) examined noise levels in light-rail station platforms in Los Angeles County, where they measured noise levels at the freeway, and non-freeway stations, and compared and contrasted them by including several variables including traffic speed, canopy, and wall. Finding noise levels at freeway stations high enough, authors recommended using technology, design interventions, and regulations.

Other studies have also examined vehicular noise even though people near TODs typically drive less (Noland et al., 2014). Yet others calculate the negative/positive externalities or social costs/benefits associated with TOD noise with the total daily benefits of approximately $20,000, and only $14 as its diseconomy (Noland et al., 2014). On the other hand, decreased vehicle numbers correlate with lower sound levels. Thus, TOD sites equipped with bike roads or pedestrian paths enhance streetscapes resulting in reduced traffic speed and traffic-related sounds (Quis, 2001). Applying expanded traffic noise investigation in San Francisco with different kinds of vehicles in urban communities, one study shows that enhancing walking, biking, car sharing, public transit, and home-office working contributes to reducing urban noise, thereby, improving the QoL (Seto et al., 2007).

Noise disturbance and perceived noisiness (Lam, 2009) typically cause annoyance while pleasantness stems from natural sounds (Kang 2006; Murphy & Douglas, 2018). When traffic noise dominates, it creates disturbance and becomes a nuisance, especially in TODs. People living near transit-related uses, events, and developments state that vegetation can help reduce perceived environmental noise by visually blocking its source (Kang, 2006; Renterghem, 2018). Exploring people's opinion in another study, Renne (2009) measured the potential attributes of noise in both natural and the built environment as well as sound as a QoL indicator. More than 40% of the participants made notes of TODs' noisy locations while 38% believed they were quiet (Renne, 2009). Thus, people living near TODs have mixed opinions about the impacts of sound on them.

***Conceptualizing Soundscapes in TODs***

The proposed framework conceptualizes the QoL-TOD nexus by designating how TOD soundscapes may affect the QoL (Figure 2). The literature identifies TODs' five distinct characteristics (density, transit, land use, connectivity, and amenities) that potentially affect soundscapes (Dittmar & Poticha, 2004; Curtis et al., 2009; Pojani & Stead, 2015). TOD residents typically prefer higher density areas near transit stations and other close-by services. So, increasing density may also increase the sound levels in TOD areas. In a similar way, mixed-use developments with high sound levels and variations constitute in TODs. On the other hand, increasing multimodal transportation is expected to decrease or neutralize the sound because of lesser personal vehicles usage. Also, street layout and connectivity affects soundscapes. It is expected that more connected streets may decrease sound levels. As such, well-connected TODs with various street structures and elements provide better transportation and pedestrian activities. Connectivity may also make a neutral sound environment because of offering convenient street features.

Regarding the amenities, while nature-related amenities such as parks and recreational areas tend to provide a quieter acoustic environment, retails and other man-made structures and buildings are likely to increase sound levels. Figure 2 conceptualizes the synergistic relationship between neighborhood amenities and users on one hand, and soundscapes on the other.

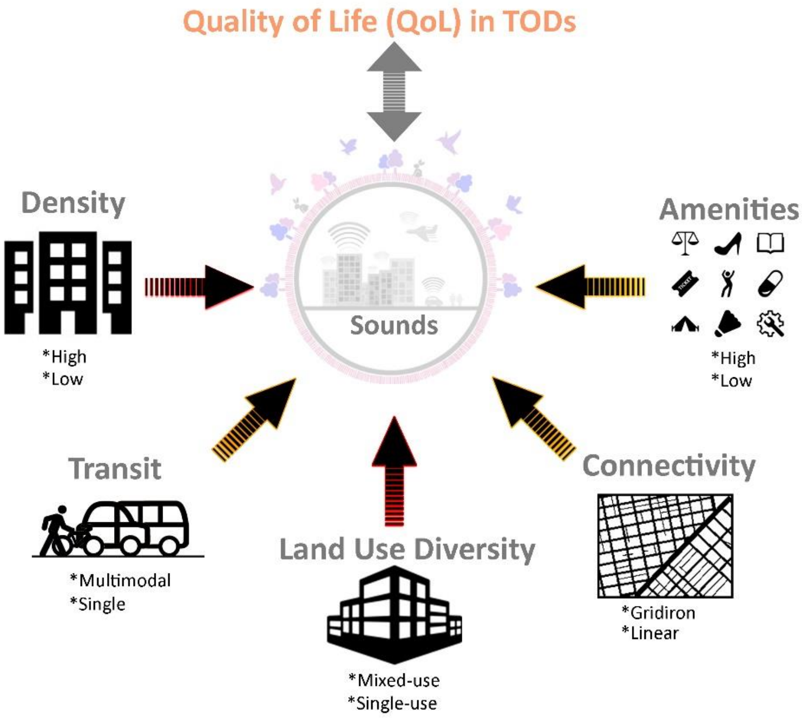



**Figure 2:** Conceptual Framework

**Research Method & Data**

***Research Process and Site Selection***

To assess the relationship between TOD buildings and sound, we first need to control for other TOD characteristics. To do this, after defining the study locations, we employed cluster analysis and classified TOD areas based on transit, density, land use diversity, neighborhood amenities, and connectivity as consistently stressed in the literature (Renne & Ewing, 2013; Scheer et al., 2017). The adopted research method covered various neighborhood characteristics based on QoL and health variables, including jobs and neighborhood amenities, i.e., entertainment, education, social services, recreation areas, library, shopping centers, schools, employment, and modes of transportation for each station. Even though phase one identified the selected stations, the second phase included a complementary qualitative process in the final study locations.

***TOD station area definition***

Ascertaining the spatial TOD boundaries proving somewhat challenging, identifying the station area required further investigation. Thus, we deferred to the literature for identifying the TOD station area. Since TODs are pedestrian-friendly environments and encompass property, and employment uses, walkability in and around them is crucial. To obtain more accurate sound samples, this study concentrates on a quarter-mile TOD area even though scholars recommend distances between a quarter- to one-and-a-half mile radius (Guerra & Cervero, 2013). Drawing on similar methodologies performed in other studies (Atkinson-Palombo & Kuby, 2011; Scheer et al., 2017), to perform comparative analyses, we identified 5 TOD and 5 non-TOD stations based on a two-phase suitability analysis.

***Sample***

Using a mixed-methods approach, this research conducted 57 interviews with individuals with intimate ties to TODs and measured sound pressure levels. Lasting between 10 and 30 minutes and covering the views of both those in favor and against TODs, 27 interviews were conducted with TOD residents, 22 with city officials, planners, and policy experts, and 8 with designers. While TOD residents were selected randomly, engagement in TOD projects and policies determined the selection criteria for interviewing the city officials, planners, policy experts, and designers. Using "snowball sampling" (Patton, 1987) to expand the number of expert interviews (i.e., the city officials, planners, and designers), the research then collected and transcribed the semi-structured, open-ended interviews on TOD soundscapes. To conceptualize the sound and noise patterns in TODs, conducting interviews with a relatively small number of participants alone did not seem reasonable, as the small sample size lowers the likelihood of generalizability. Using quantitative measurements offset this potential deficiency.

Despite the main themes remaining the same for all interview questions, the context and the number of items vary. While the interview questions for designers/planners and city officials/experts mainly concentrated on sound/noise and TODs, they focused on somewhat broader themes of living environments, QoL, and preferred soundscapes with slightly different data collection techniques for TOD residents.

Measuring sound pressure levels through a grid sampling method (Kang, 2004; Morillas et al., 2011; King et al., 2012), and conducting interviews with TOD residents, city officials, planners, policy experts, and designers included the two quantitative and qualitative data types used in this research.

Even though stations were identified in two phases, they do not constitute the only selection criteria. A qualitative process also determined the final study locations. For instance, although the Akard, Pearl, St. Paul, Union, and West End Stations potentially scored as TOD areas, they were eliminated from the study since they are located in the central business districts (CBDs), which may extremely affect sound levels. Also, a quarter-mile buffer overlapped among these stations.

Figure 3 illustrates station rankings based on the selection criteria (red dot in the figure) and LRT station scores. By identifying the basic TOD characteristics, we then clustered the land use, population, job, and neighborhood amenities and thereby ranked the stations. Cityplace, Park Lane, Mockingbird, Deep Ellum, and Baylor stations ranked in the top of the list and, selected for further investigation. Furthermore, even though non-TOD stations typically have lower sound levels because of TOD characteristics, for instance, mixed-land use, the research investigated the lowest-ranked five stations to use as non-TOD stations. Eventually, UNT Dallas, Lawnview, Camp Wisdom, White Rock, and Lake June stations were included, and this analysis resulted in selecting ten stations (Figure 3).

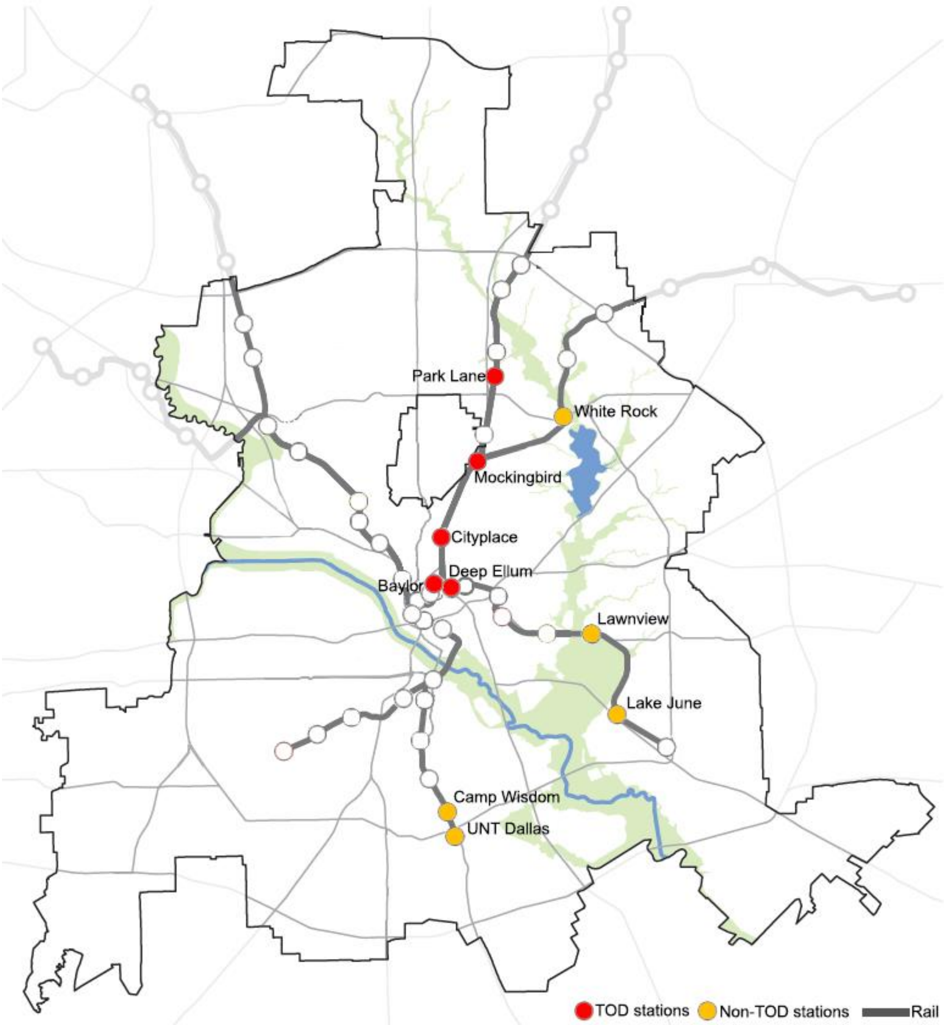



**Figure 3:** Study areas for TOD and Non-TOD stations. Source: Esri ArcMap 10.5

Sound pressure level measurements for the defined TOD stations along with the interviews were performed from September to December 2017 and March to July 2019.

To obtain different time slots sound levels were collected during weekdays and weekends at 10 a.m., 1 p.m., and 4 p.m. Gaining access to a grid point and conducting interviews with the TOD users occurred concomitantly. Sound level measurements took place in 650x650 (200x200 meter) grids within a quarter-mile of each station for getting the maximum sound levels (Figure 4). The TOD stations along with these grids were evenly, mostly, divided into nodes on a virtual grid overlaid on their plan (Figure 4). Acceptable grid sound measurements range from 250 feet to 2000 feet (Escobar et al., 2012; King et al., 2012) for each grid node, translated into SPL analyses for the TODs with roughly 0.125 (1/8) mile or 650 feet distance increments.  Applying 0.125-mile distance generated 11 to 14 sound level grids for each TOD location (Figure 4). To measure sound levels for the ten study locations at 10 am, 1 pm, and 4 pm time intervals and weekdays, we obtained 762 sound samples.

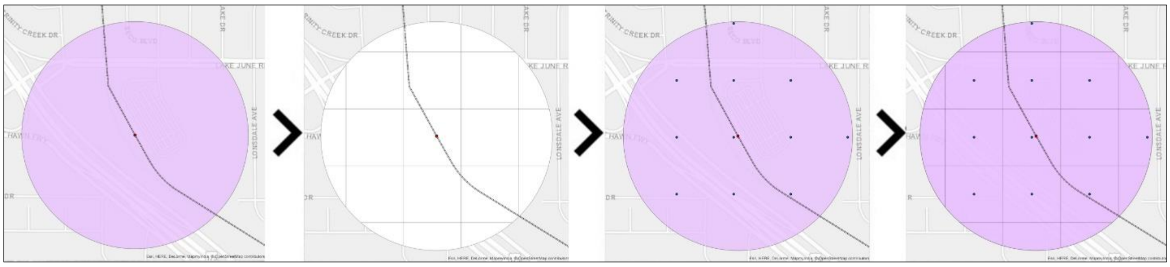


**Figure 4:** Sample study location and sound sampling grids and points of a TOD. Source: Google Earth Pro

Taken at a standard 1.5m distance from the ground, Landtek Instruments Professional Digital Sound Level meter 30-130 dB with Bluetooth equipment measured the sound pressure levels. Additional distance for measurements helped prevent echoes from entering the designated zones (i.e., Mockingbird Station). All sound pressure level measurements were collected with the A-weighted (dBA). To be practical, average quiet residential areas measure at 50 dB, freeways at 70 dB, heavy traffic at 85 dB, truck and shouted chat at 85 dB, honking at 110 dB, and a rock concert at 120 dB sound pressure levels (CHC, 2018). The model of sound pressure level meter of IEC651 Type 2, ANSI S 1.4. Leq fifteen-minute with implications on individuals noted in standard (King et al., 2012) adopted for this research proved a significant reference sign for measuring sound. Measurements occurred in periods that did not coincide with extreme weather conditions such as strong wind or heavy rain.

**Analysis and Findings**

Based on a mixed-methods approach, the study includes two types of analysis. The qualitative method summarized the survey questions focusing on the TOD actors – residents, designers, policymakers. Figure 5 (above) highlights the data clustering along with the overall mean values for each participant category. TOD residents consider cars, buses, trains, and sirens as the most frequently heard sounds while designers believe that talking, birds, water, and construction sound are the most relevant sounds in TODs. Experts also ranked trains, buses, and talking as most frequently mentioned sounds (Figure 5 above). This perceived versus the actual difference in sound has multiple attributes. Even though experts consider traffic-related sounds, designers take more natural and human-made sounds into account, while the TOD residents still perceive cars, buses, trains, and footsteps the most frequently-heard sounds. TOD soundscapes are not, therefore, transpiring for residents in designers' and experts' plans.

Further analysis on users' perceptions of sound sources in each station, confirms TOD stations generate more man-made sounds (Figure 5 below) with cars, buses, construction sites, sirens, and footsteps sounds ranked on top of the sound list.

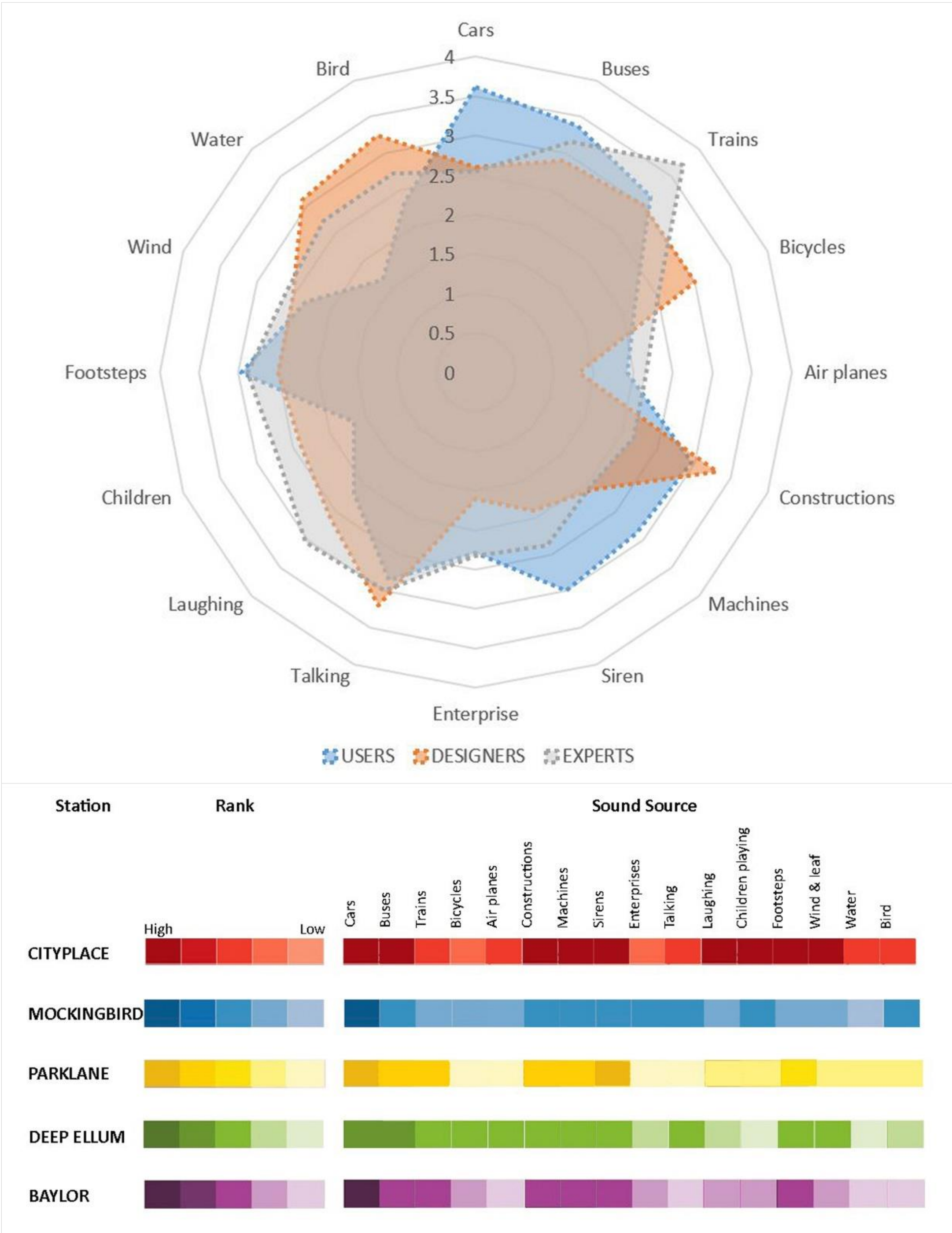



**Figure 5:** Summary Responses of Ranking of All Types Participants and Breakout for the Users' perception on each TOD

Table 3 illustrates sound level performance at each station, TODs, and non-TODs with the mean, STD, minimum and maximum sound measurements of the Leq fifteen-minute values. As control measurements, non-TOD stations turned out quieter than the TOD-stations. Based on the t-test analysis, a significant difference exists between TOD and non-TOD stations, and ANOVA test shows that there is a significant difference among the stations. The UNT station overall scored the quietest, with a mean Leq of 47.9 dBA. With the mean Leq of 65.7 dBA, Baylor station scored the quietest TOD. Cityplace and Park Lane stations include the noisiest TOD stations with the mean Leq values of 72.6 and 70.4 dBA, respectively.

**Table 3:** Measured sound levels of TOD and Non-TOD stations. Source: SPSS 25

| | | Non-TOD stations | | | | | TOD stations | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | UNT | Lawnview | Camp W. | White R. | Lake J. | Cityplace | Mockingbird | Park Lane | Deep E. | Baylor |
| $L_{eq}$ (dBA) | Mean | 47.9 | 55.9 | 54.9 | 61.0 | 65.0 | 72.6 | 65.9 | 70.4 | 67.4 | 65.7 |
| | STD | 2.82 | 1.20 | 3.32 | 2.38 | 2.24 | 4.01 | 1.98 | 4.02 | 3.38 | 2.03 |
| | Min | 44.3 | 54.5 | 48.0 | 56.4 | 61.0 | 70.1 | 64.8 | 68.3 | 65.3 | 62.6 |
| | Max | 53.3 | 58.0 | 61.0 | 65.9 | 67.6 | 75.0 | 67.0 | 72.5 | 69.4 | 70.4 |

In addition to descriptive analyses of the sound samples, the study examines TOD characteristics both at the sound sampling grid level and the neighborhood level. As such, the sound pressure level (SPL) serves as the study's dependent variable. Table 4 highlights the "nested" structure of the data collected in this study. Since all studied neighborhoods surround or are close to the sampling grid and share common features, they could not be treated independently from one another.

As Table 4 shows, Level I independent variables were mainly taken from Dallas Area Rapid Transit (DART), the North Central Texas Council of Governments (NCTCOG) and Google Earth, and level II variables from the ESRI Business Analyst, DART, and U.S. Census. While speed limit and street width represent the average values in each grid in TODs, street length, intersection density, building coverage, vegetation coverage, number of amenities, parks represent the sum of each grid.

**Table 4:** Variables and Data Sources

| Variables | Data Sources |
|---|---|
| Level 1 Dependent variable | |

| | | | |
|---|---|---|---|
| | SPL | Sound pressure level/s (at the center of each grid) | The authors |
| TOD feature | Level 1 Independent variables (Divided 650x650 square ft. -200 meter- level) | | |
| Transit | **Wscore** | Walkscore (linear) | Walkscore.com |
| | **MpH** | Speed limit (linear) | NCTCOG |
| | **Droad** | Distance to closest road (linear) | NCTCOG |
| | **Dstat** | Distance to train station (linear) | NCTCOG |
| | **Tstop** | Number of transit stops | DART |
| | **Troute** | Transit Route (feet) | DART |
| Density | **Veg** | Vegetation coverage (sq ft.) | DART, NCTCOG |
| | **Build** | Building coverage (sq ft.) | DART, NCTCOG |
| Diversity | **Luse** | Land Use diversity | NCTCOG |
| Amenity | **Amen** | Number of neighborhood amenities | NCTCOG, ESRI Business Analyst |
| | **Park** | Number of park and recreational area | NCTCOG, Park Score |
| Connectivity | **Grid** | Grid density (binary) | NCTCOG, Google Earth |
| | **IntDen** | Intersection density (linear) | NCTCOG |
| | **StWid** | Street width (feet) | NCTCOG, Google Earth |
| | **StLen** | Street length (feet) | NCTCOG, Google Earth |
| | Level 2 Independent variables (Neighborhood Level, a quarter-mile) | | |
| Neighborhood | **Tbus** | Number of Total business (linear) | ESRI Business Analyst |
| | **Temp** | Number of total employee (linear) | ESRI Business Analyst |
| | **Tpop** | Total population (linear) | ESRI Business Analyst, ACS |
| | **Trid** | Total ridership (linear) | DART |

This nesting logic results in the dependency through cases, thus, violating the independence assumption of ordinary least squares (OLS) regression. Therefore, standard errors of regression coefficients linked to neighborhood features based on OLS would be miscalculated, and regression deemed inefficient (Raudenbush & Bryk, 2002).

The best analytical approach to address this nesting hierarchy is multilevel linear modeling (MLM), which also refers to two-level hierarchical linear modeling because the dependent variable (SPLs) is a continuous value range between 44.3-80.3 dBA among all measurement points. Hierarchical modeling surpasses the limitations of OLS because it computes dependence among cases and generates more precise coefficient and standard error estimates.

In order to interpret the relationship between sound levels and the models, sets of statistical analyses were performed. The statistical analyses software SPSS v25.0 and HLM 7.03 (Hierarchical Linear and Nonlinear Modeling software) helped analyze the normality, multicollinearity tests, and multi-level linear modeling, respectively. Before performing multi-level linear modeling, the research performed all variance inflationary factor (VIF) values of the multicollinearity test that is within 1 and 10, with a maximum value of 5.31, and the mean value of 2.69, indicating acceptable levels of collinearity (Field, 2005).

The coefficients of all variables show the expected signs, many of which found significant at the 0.05 level (Tables 5). The significant variables are in bold font. The variables that control for the TOD and non-TOD characteristics show significant at various probability levels.

Considering the transit-related factors of TODs, the number of transit routes significantly increases the likelihood of the location having louder sound levels, while the distance to train station, walk score, and the number of transit stops do not show any level of significance. Looking at the non-TOD stations, none of the transit-related variables show significance. Surprisingly, none of the density-related variables of TODs, vegetation and building coverage, show significance either while vegetation coverage shows a negative significant relationship with the sound for non-TOD stations, though the coefficient level is only 0.001. Diversity feature of TODs shows a negative significant correlation as mixed-land use is one of the key attributes of TODs. In other words, the more diverse land use of TODs increases the likelihood of having higher sound levels in the developments. On the contrary, non-TOD stations do not show any level of significance on land use and sound association. Providing many amenities also turns out as one of TOD's key contributions. Neighborhood amenities in TODs show a strong positive relationship with sound levels while the number of parks shows a strong negative correlation with sound. Regarding the connectivity characteristics of TODs, including intersection density, street width, and street length, all variables show positive correlations with sound; however, street width is the only variable with a significant relationship with sound. Regarding the neighborhood-level variables, the total number of businesses and employees show a strong positive correlation with the sound level. So, the increasing number of businesses and employees significantly increases the likelihood of observing louder sound samples.

**Table 5:** Multi-level Linear Model with Robust Standard Errors

| | **TOD** | | | | **Non-TOD** | | | |
|---|---|---|---|---|---|---|---|---|
| | Coefficient | Standard Error | t-ratio | p-value | Coefficient | Standard Error | t-ratio | p-value |
| Constant | 67.519 | 5.053 | 13.362 | <0.001 | 51.296 | 2.574 | 19.927 | <0.001 |
| | | *Level 1* | | | | *Level 1* | | |
| Wscore | 0.082 | 0.052 | 1.558 | 0.125 | 0.080 | 0.072 | 1.106 | 0.274 |
| Dstat | −0.000 | 0.001 | −0.714 | 0.478 | 0.000 | 0.001 | 0.478 | 0.635 |
| Tstop | -0.274 | 0.272 | 1.006 | 0.319 | -0.461 | 0.390 | -1.182 | 0.243 |
| **Troute** | **0.001** | **0.000** | **2.237** | **0.029** | 0.001 | 0.000 | 1.794 | 0.079 |
| Veg | −0.010 | 0.000 | −1.391 | 0.170 | **-0.001** | **0.000** | **-2.430** | **0.019** |
| Build | -0.001 | 0.000 | -0.564 | 0.575 | 0.000 | 0.000 | 1.763 | 0.084 |
| **Luse** | **-0.048** | **0.022** | **−2.147** | **0.036** | -0.005 | 0.025 | -0.220 | 0.827 |
| **Amen** | **0.401** | **0.081** | **4.900** | **<0.001** | **-1.362** | **0.538** | **-2.528** | **0.015** |
| **Park** | **-0.771** | **0.377** | **-2.043** | **0.046** | -0.646 | 1.202 | -0.537 | 0.594 |
| IntDen | 0.325 | 0.307 | 1.058 | 0.295 | -0.220 | 0.677 | -0.302 | 0.746 |
| **StWid** | **0.112** | **0.053** | **2.123** | **0.038** | 0.046 | 0.033 | 1.376 | 0.175 |
| StLen | 0.000 | 0.000 | 0.722 | 0.473 | **-0.002** | **0.005** | **-2.287** | **0.027** |
| | | *Level 2* | | | | *Level 2* | | |
| **Tbus** | **0.052** | **0.010** | **5.150** | **<0.001** | 1.760 | 1.436 | 1.226 | 0.225 |
| **Temp** | **0.001** | **0.002** | **2.559** | **0.013** | **-0.070** | **0.028** | **-2.468** | **0.017** |
| Tpop | 0.002 | 0.001 | 1.655 | 0.103 | 0.012 | 0.007 | 1.670 | 0.101 |

## Discussion

This research set out to examine TOD characteristics with sound and delve deeper into characteristics such as environment, planning, and transportation. To do that, the research conducted a mix-methods approach. The study findings contribute to ongoing debates on the juncture of QoL and sounds by including TODs with their proximity to transit, density, diversity, neighborhood amenities, and connectivity as the five attributes of their planning and design.

### *Transit and Soundscapes*

Research has examined claims about transit noise and TODs. However, both participants and sound measurements in this study show divergent views on how TODs and their surrounding areas generate sounds from different sources. Even though train sounds dominate other sound sources in TOD stations, according to the TOD agents –residents, designers, and policy makers-they do not seem to create major QoL problems. Instead, participants consider personal cars and sirens as noisy. Familiar with the TOD setup, the residents expect train noise at TODs. Except for Mockingbird, on the ground location of all other stations with tracks and platforms, provides consistency in interpreting the sounds. Even though driving personal vehicles constitute the dominant transportation mode, TOD stations are multi-modal and generate different sounds. As part of the multi-modal transportation, the TOD users ranked people’s footsteps or bicycle sounds as less annoying compared to personal vehicles. The quantitative aspect of the research also reinforces this finding as only the amount of transit routes affect the sound level.

***Density and Soundscape***

TOD users prefer the highest density areas located in centralizing TOD stations resulting in inconsistent housing patterns for both multi-story and high-rises. However, compared to single-family houses on the outskirts of TODs, these housing types fare as less desirable (Lawton 2003). Studies show that potential noise could affect TOD residents. However, this research shows that while due to high density, a few TOD stations like Cityplace, generate unwanted noise according to the participants, other stations, i.e., Mockingbird and Deep Ellum provide sounds that study participants favor even with high frequency. Designers and policy experts also support this finding.  One expert confirmed that many TODs provide different sound sources. However, statistical analyses did not confirm these findings as neither building nor vegetation coverage shows significant correlations with sound levels. This conflict also verifies how people’s QoL in terms of sound ought not to be represented only by their quantitative aspects.

***Diversity and Soundscape***

Land use diversity varies from place to place. TODs offer different types of housing and land use. For instance, designing commercial, retail, and multi-unit housing patterns near TODs are quite common. While this precedent creates visual homogeneity, it also creates heterogeneous soundscapes. Both experts and TOD users point this out and are cognizant of the fact that different land uses generate different sounds. The multi-level analysis also confirms these statements from a purely quantitative aspect.

Many cities are dealing with increased noise from mixed-use developments located next to train stations. Apart from contextual diversity, TOD designers emphasize both architectural, visual as well as soundscape diversity. Furthermore, policy experts suggest increasing visual and audio diversity is highly related to design around TODs. An interviewee expert in this study also expresses similar concerns in the TODs:

*"Building footprints, parking areas, and other structures were designed to hinder without losing visibility and special sounds of TOD feeling."*

***Neighborhood Amenities and Soundscapes***

The number of neighborhood amenities including libraries, coffee shops, as well as parks - public space and recreational areas- play significant roles as neighborhood amenities that not only enhance the relationship between pedestrian access and bike routes but also provide various natural and anthropogenic sound sources. Public space provides vegetation, water features, and various animal species. All these features enhance the local natural sounds (Hedblom et al., 2017). Since providing more public space is a key feature in TODs, more natural and anthropogenic sounds are expected around them. Based on the sound levels measurements and analysis in this study, neighborhood amenities –such as restaurants, schools, hospitals- may increase the sound levels while the number of parks and recreational areas decreases the sound level. Due to sporadic locations of neighborhood amenities, and that they may not affect the TOD locations as expected, obtaining these distinct sound additions in station zones were conceivable since the research design examined each TOD grid by grid. Therefore, whether or not neighborhood amenities contribute to pleasant soundscapes by providing more "gentle" natural environments into the TODs or man-made enough to keep the "rigid" sounds away from them remain unanswered.

***Connectivity & Soundscapes***

Scholars typically stress connectivity between TODs, street networks, roads, bus, and train stops, bicycle ways, and pedestrian paths. A well-connected street network with sound reinforced traffic signage, street width, street length, and frequent intersection density may invite more people and leads to various natural, anthropogenic, and mechanical sound sources.

Based on these features, gridiron layouts provide more sound diversity as observed at Deep Ellum and Mockingbird stations. However, since inappropriate for visual access compared to radial or linear street patterns, whether the gridiron layout provides higher sound levels, this research could not confirm that. Nonetheless, TOD stations, such as Park Lane and Cityplace stations, linear street layouts located near highways, with vehicle noise dominating include the highest sound levels. Also, street width and lengths considerably affect sound levels. Our study confirms that increasing street width also increases the likelihood of higher sound levels and Hupeng, Kang, and Hong (2017) also confirmed these findings while we could not confirm Zhou, Kang, Zou, and Wang's (2016) strong positive correlation between street length and sound levels.

Each TOD station creates its unique sound sources, while sound/noise is a relatively forgotten aspect of the QoL. Scholars, experts, and policymakers have emphasized various aspects to incorporate TOD and QoL considerations into the transportation and urban planning decisions, but sound and noise. As an expert interviewee stated: *"Honestly, this is a conversation that is new to me. I've attended many ULI and "Rail-Volution" events, but have yet to see any information about noise/sound and its effect on TOD."* This study does not seek to offer a best practice approach to selecting soundscape, which indeed requires further research for future practice at TOD stations. The goal, however, was to present a snapshot of current soundscape attributes across various stations given the sound characters of TODs.

***Emergent Patterns***

Three patterns emerged from sound measurements and interviewing TOD users and experts. These patterns capture the variations of sound sources in TODs. As in many other urban areas, TODs represent positive, negative, and neutral sound features that ultimately affect the residents' QoL.

*Positive soundscapes*

The association between sound, QoL, and human response cannot be separately assessed. That is, experiencing the sound is a rational reaction to the QoL. Even though some might question a direct correlation between sound and QoL, the research sought to explore such connections by measuring sound measurements and variations. To do this, TODs exemplify positive sound contexts. The prevalent positive sound profiles in Mockingbird and Baylor stations fit into this category. Sound measurements and recordings occur at a level that TOD users perceive as more attractive. Research participants living near TODs did not evaluate train and vehicle noise, and considered them as trade-offs, and preferred other sounds, i.e., birds, social chats, and commercial/retail music.

*Negative soundscapes*

Since TODs generally serve as a “centrifugal force” from trains and vehicle-related sounds, their radial pattern coupled with other elements may not produce pleasant sounds. Cityplace and Park Lane stations showed similar patterns. Even though the “centrifugal force” patter applies to many TODs, intervening factors from other structures or surrounding buildings, and construction-related noise with long-range reverberation sources might exacerbate the situation. Located above ground, traffic noise from all directions reaches the Park Lane Station. TOD residents in these locations also stressed fatigue from road noise as well as sirens round-the-clock, particularly in Cityplace and Park Lane stations. According to a participant:

> *“Some nights, my kids wake up in the middle of nights because of sirens! I both live and work in this location for a long time; however, traffic and construction are annoying even when I am in a meeting in my office."*

*Neutral soundscapes*

Some urban areas correspondingly provide both positive and negative sound sources with different impacts on residents. The Deep Ellum station represents a neutral urban area with regard to sound. While some complaint about vehicular noise, shouting and nightclubs in this location, others prefer natural sounds like birds chirping and falling water. Although the TOD station is located near a two-lane street, participants generally evaluated the sound as neutral. Thus, sound levels and participants in these locations reveal several natural sources, compensating for adverse effects of unwanted sounds in the core TOD station. In addition to TOD users, experts also refer to this equilibrium:

*"We do what we can to mitigate undesirable sound sources (such as train horns railroad crossings) and provide desirable sound sources (water, parks, etc.)."*

Based on these patterns, sound sources create different perceptions. Despite being a fact of urban life, while to some sirens fare negatively, other TOD residents prefer natural and anthropogenic sounds and typically evaluate them as positive. TOD amenities may provide versatile sounds as opposed to only traffic or transit-related noise.

**Conclusion**

This research evaluated the relationship between sounds –as a part of QoL aspects- and TODs. It first provided an overview of the literature, followed by proposing a conceptual framework for evaluating the qualitative and quantitative aspect of sounds. It then compared them with non-TOD stations in and around them**.** Expressing concerns over vehicular noise emerged as the dominant pattern leaving QoL somewhat vague and imprecise. This study aimed to investigate the TODs' impacts on the QoL by examining their emerging sound patterns.

The intersections of the soundscape, QoL, and TODs have multiple implications for urban planners and urban designers. First, soundscapes can discern the similarities and differences in perceiving sound effects in the QoL of different places. Exploring the TOD soundscapes consisting of sound sources, ambiance, activities, street schemes, and socio-demographic features reveal more information about their QoL to urban planners, transportation experts, and urban designers. According to an expert:

*"Encourage developers to add sound-creating features in their developments and consider adding sound in place-making considerations. For example, adding fountains to green space areas."*

As an offshoot of the first lesson, the second lesson addresses the positive connotation of TOD sounds. Even though many studies have solely concentrated on the adverse implications of TOD sounds, they are also associated with positive sounds as well. Hence, soundscapes can enhance TODs too. As a practical application, planners can create “ideal TODs” by considering soundscapes from the pre-development throughout the completion phase. Since TODs provide specified characteristics, planners can balance the sound and noise implications accordingly. As one of the experts in this research highlighted:

> *“With the right kinds of sound and noise combinations, the users' experience can be significantly enhanced. With the more disturbing sounds, it can drive away pedestrians (no pun intended).”*

Third, living in TODs involves trade-offs relative to living in other developments. Since the research places much emphasis on the QoL aspects, several agencies have developed acceptable sound levels. For instance, the U.S. Department of Housing and Urban Development (HUD) defined the same acceptable noise level of 65 dBA (HUD, 2013). Based on this recommended noise level, TOD stations exceed both these suggested guidelines implying that they are significantly noisier than mono-functional residential developments. Therefore, TOD locations affect residents’ QoL both physiologically and psychologically. The physiological impacts include health-related concerns in which researchers have already highlighted the nexus between hearing loss and exposure to noise levels (Passchier-Vermeer & Passchier, 2000). In terms of the psychological effects, TOD noise levels could increase stress and concentration problems (Garcia, 2001).

From a broader environmental and planning level, TOD stations have their unique featured sound sources, which require more analysis including their multi-modal transit accessibilities. Research participants typically advocate the role of design in TOD plans, incorporating the impacts of sounds more effectively compared to other development types with various facilities (Minet et al., 2018). This is an opportunity to respond to

Offenhuber, et. al.’s (2018) call on sound implications of TODs’ architectural attributes as they may contribute to individuals’ subjective sense of hearing in addition to visual qualities. But architectural projects could be assessed by a set of criteria other than their visual/spatial qualities.

TODs purportedly provide diverse sound sources, and by doing so, give rise to balanced sounds. While TODs consist of sound sources that might negatively affect the built environment, they might also positively transform sounds. TOD residents have particular expectations from amenities, facilities, and design guidelines. While some land uses including commercial in mixed-use developments or nightclubs near houses produce noisy activities, facilities like nature conservation areas may generate pleasant or quiet tranquility ambiance. Landscaping, vegetation and water features, may help balance sounds in TODs. Besides aesthetic features, these elements increase the natural tone in TODs and serve to mask negative sounds. Some expert interviewees commented that:

> *"To have a true mix of uses, there are going to be a mix of sounds. There is also the challenge of the longevity or repetitiveness of certain sounds. Train horns every 15 minutes may cause hysteria, but they also provide the highest level of safety. Finding the right balance is the challenge, but that is what makes urban planning so fun…"*
> *"Finding the right balance of uses and creating some separation of uses where it is an issue (i.e., do not place a nightclub on the ground floor of residential unit…)"*

Noise abatement and zoning policies exemplify another practical solution according to experts. As Adams et al. (2006) highlighted, while individuals may not be so keen on noise levels, context sources, distance, and control over noise may be more critical to them. Since sounds from trains, personal vehicles, commercial uses, and plazas characterize TODs, they still highlight the importance of community ambiance within an acceptable range of mechanical, natural, and anthropogenic soundscapes. Several experts and TOD users acknowledged that:

*“The biggest challenge is working with rail providers to establish quiet zones in TODs. In Downtown Carrollton, it took years to establish quiet zones. While it was a priority for the City, it was challenging to get the rail providers to work quickly.”*

*“Cities should continue to find solutions to hours of operations noise issues with a mixed-use development (residential and retail in a vertical mixed-use) and late-night uses. The concern is bar/ restaurant locations open late at night disturbing residents. This is typically handled through city permitting and operating rules and licenses, however, reports of citizen complaints continue in our region, and it appears there is difficulty enforcing these."*

The proposed approach provides a comprehensive assessment of soundscapes based on an inclusive compromise of TOD-oriented sounds.

## CHAPTER 4: MANUSCRIPT 2

## "LISTENING" TO URBAN MORPHOLOGY CHARACTERISTICS IN TRANSIT-ORIENTED DEVELOPMENTS (TODs)

### Introduction

With its potential to address quality of life (QoL) concerns globally, urban morphological characteristics have been investigated across numerous fields. The characteristics of building density and pattern, street layout, and land use have been widely studied using various methods of urban morphological parameters (Xie, Huang, & Wang, 2006). As the majority of urban morphological research has been published in these contexts, sound remains as one of urban morphology's under-explored features. Considering the wide scope of the topic, this research revisits the fundamentals of urban morphological elements applied to the sound environment. Urban morphology has been introduced in the site investigations of soundscape, which can be considered the entire set of aural elements in an environment, in terms of urban form (Schafer, 1993; Kang, 20007; Salomons & Pont, 2012). However, none of these studies examined the essential characteristics of urban morphology in terms of sound aspects, particularly in a coherent and explicable urban form such as transit-oriented developments (TODs).

According to Conzen (1978), the urban morphology concept emerged after the 1930s to demonstrate a functional spatial structure, as the urban form discussion had been limited to societal and economic perspectives for decades. Several European scholars contributed to the urban morphology debate in a broader context (Gottman, 1961; Wissink, 1962), as did a number of American geographies (Conzen, 2001; Vance 1977). The development of urban morphology studies has continued in various areas including land use (Relph, 1987), architectural history (Kostof, 1991), culture (Conzen, 1996), and urban forms (Mumford, 1938). The implications of urban morphology on sounds have remained fairly unexplored in the United States but have been evaluated in European contexts.

Given the extensive scholarly discussion regarding definitions of urban morphology and urban form and their interdisciplinary complexity, along with scales of application ranging from the streetscape to regional overview, no precise definitions have received consensus. Even though the relationship between urban form and urban morphology is generally correlated, demarcation of urban form has essentially become a separate field or context, particularly in recent decades in the U.S. Nonetheless, urban morphology characteristics include several essential variables: buildings, plot systems, and streets.

The literature proposes materials such as buildings, facades, green areas, roads, and highways as a way of understanding urban forms; however, this does not lead to a conceptual recognition of the full morphological content, and far less to any systematic investigations of morphology as a spatial configuration of the buildings and streets. To contribute to urban morphology studies, this research aims to investigate the building, street, and plots within a well-defined setting – transit-oriented developments (TODs). The primary reason for examining TODs in addition to quality of life attributes is that these developments tend to have clearly delineated street, building, and plot configurations spatially. As FBCI (2007) highlights, “morphogenetic” or form-based urban design tools and strategies in TODs emerge as essential urban components.

Among other objectives, TODs’ urban morphologic characteristics contribute to quality of life, which is a complicated social phenomenon that may refer to a person’s state of life, reflected in their levels of needs and satisfaction of the circumstances including environment (Kerce, 1992). Therefore, quality of life represents and individual’s satisfaction with their environment. Since satisfaction includes both subjective and objective contexts, quality of life can be related to various factors, including personal (Diener, 2000), community (Sirgy & Cornwell, 2002), socio-economic (Sirgy et al., 2006), socio-demographic (Bowling et al., 2003), and health (Bize, Johnson, & Plotnikoff, 2007). From health and sound perspectives, health-related quality of life (HRQoL), as also suggested by the World Health Organization (WHO) Noise Guidelines, is an important part of measuring the influence of a person's health status (Shepherd, Welch, Dirks, & Mathews, 2010; WHO, 2009). Considering the scope of this paper within urban morphology, urban design, and urban planning, all these extensive list of characteristics and definitions thus refer to livability, connection, mobility, personal development and community development in a broader context (van Kamp, Leidelmeijer, Marsman, & de Hollander, 2003; Smith, Nelischer, & Perkins, 1997). Quality of life has been also examined as it relates to neighborhood noise through various survey-based measurements (Neitzel et al., 2012; Nitschke et al., 2014; Botteldooren, Dekoninck, & Gillis, 2011) as well as in the intersection of urban design, transportation and urban planning fields as seen in, for example, transit-oriented developments (Curtis, Renne, & Bertolini, 2009).

In this sense, TODs aim to bring residents closer to transit facilities, thereby improving quality of life by reducing personal vehicle use, increasing transit ridership, and promoting a sense of community. Reducing private automobile use reduces transportation costs, lowers vehicle emissions, and enhances local amenities, in addition to promoting walking and cycling. Further, the mixed-use and compact urban form aspects of TODs have other cultural, recreational, educational, and health-related benefits including public spaces such as plazas, parks, gardens, and playgrounds for diverse age groups (Curtis, Renne, & Bertolini, 2009). While TODs offer an array of public goods, such as offering multi-modal transportation and neighborhood amenities, sound remains one of the most underexplored features of TODs and urban morphology. Therefore, very few studies have explored the association between urban morphology, TODs, and sounds as they pertain to QoL. Therefore, this research explores the urban morphology features of TODs by distinguishing their associated sounds.

The research aims to identify sources of sounds based on the distinctive characteristics of TODs. With regards to QoL, the research seeks to examine the unique features of TODs and their effects on sound. Thus, the study addresses gaps in the urban morphology literature and develops a methodology for identifying the sounds of various TODs, applied in the Dallas-Fort Worth region. The proposed methodology has several advantages over other methods of examining sounds in TODs.

This paper first provides a brief overview of urban morphology and urban form, followed by the ways in which these affect sound. The research then proposes a quantitative method of analysis and discusses study limitations, results, and recommendations.

## Literature review

### *Urban Morphology*

The history of architecture and urban structure in the U.S. includes slightly different patterns from those of Europe, reflecting the technological and social transformations that typically develop concurrently over time. Encompassing this theme, American patterns generally originated from a "soft" European architectural style, attempting to enhance these prototypes through the approach of unique American circumstances (Pierson, 1970). Following the colonial period, early city planning in the U.S. was remarkably influenced by European urban layouts in characterizations and principles (Conzen, 2006). One reason for different patterns between the U.S. and Europe may lie in numerous terms and concepts, such as aesthetic and building activity, that gained great attention in the European literature of urban morphology, which were not applied in the U.S. to the same extent. Only a limited number of concepts are relevant to American geography in terms of morphological frameworks and characteristics (Conzen, 2006).

Town planning is related to building forms in any understanding of the physical settlement of American neighborhoods. As Conzen highlighted, Moudon's study of buildings types in the milieu of building typology was a key analysis for the traditional American form (Conzen, 2001; Moudon, 1982; 1986). Marshall and Caliskan (2011) address urban morphology in terms of explanatory and diagnostic means, and adopt several methods for identifying elements, types, and patterns of urban form applied as design units for further design interventions. Even though urban plans and forms are justified for building layouts in their study, they are not based upon a systematic assessment.

In the extent of urban morphology studies in the U.S., literature remains insufficient to guide diverse research objectives. Very few studies have been conducted in the U.S. at various scales of practice (Conzen, 2001). In one of those few studies, Moudon studied residential building types in a neighborhood in San Francisco by applying building typologies relating to local architecture and architectural history (Moudon, 1986). Moudon found significant variations between the spatial structure of residences built in the 1920s and those built in the 1960s. In another study, Ryan examined the city of Detroit between 1951 and 2000 to observe the morphological transformations over this time (Ryan, 2006). Six housing redevelopments from the 1990s were compared with former developments on the same sites in 1951. The author discovered that urban developments in the later time period were significantly different in design, having abandoned several pedestrian access ways and public spaces. (Ryan, 2006).

In another study, Schmiedeler assessed several town forms, such as public squares and railroad plans primarily in Minnesota and Iowa and discussed whether such plans demonstrate a spatial meaning for Midwestern urbanization (Schmiedeler, 2007). The findings of the research pinpointed central squares and linear structures as requiring further study, while railroads still refer to strong validity in terms of urban morphology. As several studies have contributed to the nexus between urban morphology and TOD, an examination of relevant common characteristics of TODs is warranted.

*Characteristics of TODs*

Transit-oriented development is not a new phenomenon in the United States; however, TODs have experienced major advancements in recent decades as transit services continue to grow not only in facilitating mobility, but also in promoting better communities and in enhanced technology (Curtis, Renne, & Bertolini, 2009). TOD projects utilize urban planning and design strategies including multi-modal transportation, mixed-use activities, and public space hierarchies. These projects are often intended to promote economic development as well through aesthetics and the integration of different modes with mixed-use development and parks, plazas, and gathering spaces for civic engagement. Even though some research has explored the relationship between urban design and TODs, this scholarship is limited (Calthorpe, 1993; Dittmar & Ohland, 2004; Dunphy, Deborah, & Michael, 2003; Ewing, 1996; Ewing & Bartholomew, 2013; Jacobson & Forsyth, 2008; TCRP, 2002).

Although TODs are physically designed by professionals and controlled, lobbied for, and regulated by experts, their projected social factors often fall short on urban morphological outcomes. Advocates of TOD projects, however, emphasize that TODs have positive effects through urban design related aspects and the promotion of active living, although inclusivity and equity issues remain. One of the fundamental purposes of TODs is to create functional and healthy places for people in conjunction with transportation facilities. QoL is closely connected to direct and indirect elements of the TOD environment (Belzer & Autler, 2002). Another study showed that well-designed streetscapes can increase mobility and the connectivity to neighborhood facilities and natural amenities (Belzer & Autler, 2002; Curtis, Renne, & Bertolini, 2009). Ratner and Goetz (2013), furthermore, examined the effects of TODs on urban form and land use in Denver, Colorado. They analyzed TOD-related data for current and proposed rail transit stations and demonstrated that regional land use and urban form have been significantly transformed over the decade 2000-2010. The research, in keeping with the findings of numerous other studies (Cervero & Murakami, 2009; Knowles, 2012; Mejia-Dorantes, Paez, & Vassallo, 2012), suggests that TODs contribute to an increase in the average density of dwelling units, retail, and medical offices, which results in changes to urban morphologies. Other factors, such as air quality and sound, also affect QoL in TODs (Kimball et al., 2013). Sound can become particularly problematic when generated by transit services, and these concerns can directly affect TOD residents.

TODs provide sets of facilities that are potentially "game changing" interventions to urban morphologies. Do the characteristics of urban morphology – buildings, plots, and streets – affect sounds and/or create patterns for sounds? Further literature examines the urban morphology of TODs.

*TODs as Urban Morphology*

Despite the challenge of applying urban morphology, few studies have investigated case-specific features of TODs in terms of the urban morphology context. The node-place model is the most popular urban morphological description of TODs in the literature (Bertolini, 1999). Based on this framework, the node refers to the transit station and transportation while place represents the surrounding area in terms of land use. The model simply provides an urban morphological interpretation for the dynamics of TODs from two aspects: enhanced transport facilities and the supply of increased heterogeneity and densification of land use. As a result of this transformation, land use can ideally offer further urban morphological changes. Therefore, TODs include a binary urban morphological connotation – they are transit stations with transportation facilities and places for individuals to live, work, socialize, recreate, and shop (Bertolini, 1999; Li et al., 2019). The node-place model includes five quintessential TOD formations (Figure 6). The first formation is the dependence category, which shows that both transportation facilities as well as land use are less developed even though they may both have potential for growth. On the contrary, the second category is stress where transport and land use are both overdeveloped and there is a strong competition for place. Another category that is more desired from a TOD is balance, in which transportation facilities and land use are coordinated and integrated appropriately, resulting in benefits for both. The last two categories are unbalanced node and unbalanced place. While unbalanced node represents that transportation facilities overwhelm land use developments, unbalanced place is distinguished by land use developments exceeding transportation facilities.

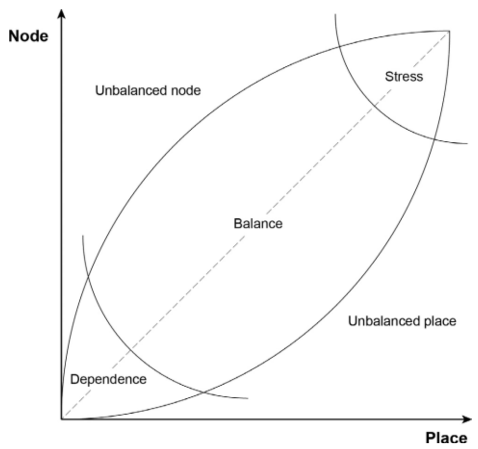



**Figure 6:** Node-Place Model of TODs (Source: Bertolini, 1999)

Several studies have proposed various index and typology-related measurements based on Bertolini's model (Atkinson-Palombo & Kuby, 2011; Kamruzzaman et al., 2014; Lyu et al., 2016; Wey et al., 2016). As several scholars suggest incorporating the "oriented" element of transit-oriented developments (Vale, 2015; Wegener, 2004), the literature explores the node-place model in terms of transportation and urban planning in numerous countries; however, it has not revealed the urban morphological interrelation between transportation, land use, and sound.

*Extending TOD node-place model through sound*

While many other studies attempted to extend or modify in morphology accordingly (Lyu et al., 2016; Wegener, 2004), this research develops a model with the sound features of urban morphological characteristics as "oriented" pieces of TODs. This study, therefore, extends the node-place model through incorporating the "sound" dimension in addition to other node and place dimensions (Figure 7).

Based on our representation, the "stress" category is the least preferred as it represents a chaotic noise level. Sound propagation in urban built environments is significantly influenced by urban morphology. In some studies, various morphological parameters for buildings, roads, and green areas have been applied to sound-related studies to characterize urban form (Margaritis & Kang, 2017; Wang & Kang, 2011). Margaritis and Kang (2017) investigated the effects of green space factors on land use by considering traffic noise implications. The authors examined 25 settlements and further advance level analyzed of six of them, finding that there is no difference between the high traffic volume and high green space. Wang and Kang (2011) compared two representative cities from China and the United Kingdom by considering the noise aspects of building form, land use, traffic pattern, and road density in a number of pre-defined urban areas. The authors found correlations between road density, building density, and noise. They showed that the UK case study city exhibited excessive noise implications because of the increase in transportation facilities, while the Chinese example includes higher building densities with greater land uses in terms of urban morphological indices (Wang & Kang, 2011).

On the other hand, a “balanced” TOD form may offer a more harmonious or preferable acoustic environment, as land use and transport are expected to be integrated, although higher sound levels may still be produced. As a balanced form is expected to provide various built and natural environment for the residents, the actual and perceived noise level in these urban settings will differ. In other words, acoustic parameters of these settings and what the individuals perceive as sound are dependent upon various environmental factors within the “balanced” TOD conditions affect those perceptions (Berglund, Lindcall, & Schwela, 1999; Uppenkamp & Röhl, 2014). Similarly, Shephard, Welch, Dirks, and Mathews (2010) studied the the relationship between noise annoyance and sound levels as a part of health-related quality of life in Auckland, New Zealand by conducting a survey for measuring noise sensitivity. These authors suggested that sound pressure level is not always consistent with noise annoyance, and that sound levels may not provide information relevant to acoustic comfort or noise annoyance.

Considering "dependent" circumstance that represents a quieter zone because of less development of land use and transport, King, Roland-Mieszkowski, Jason, and Rainham (2012) compared solely residential with mixed-use areas regarding sound implications. The authors claimed that there was less variations in transportation factors, such as infrastructure and traffic, and human activity, because of the absence of diverse building typologies resulting in lower sound levels in residential land use areas. In a similar context, Baloye and Palamuleni (2015) investigated four main land use categories – residential, commercial, transportation, and educational- in Nigeria. Their findings supported the argument that residential and educational facilities are the quietest land uses.

Based on our representation, "unbalanced node" is expected to include more transportation-related noise because of highly developed transport facilities. Some studies have investigated the effect of morphology in urban areas on the spatial distribution of traffic sound levels (Guedes, Bertolini, & Zannin, 2011; Salomons & Berghauser, 2012). Considering TODs particularly, the small number of studies on sounds have primarily assessed vehicle-related noise. When traffic noise dominates, it creates disturbances and becomes a nuisance, especially in TODs (Lam, 2009). Another study calculated the costs associated with noise as negative externalities in the city of Jersey City, where the total daily cost of TOD benefits was approximately $20,000 and the diseconomy for noise was $14 (Noland et al., 2014). Furthermore, decreased vehicle numbers correlate with lower sound levels. Therefore, TOD sites equipped with bike routes or pedestrian paths result in reduced traffic speeds and traffic-related sounds, in addition to an enhanced the streetscape (Quis, 2001). Applying traffic noise investigation in San Francisco with different types of vehicles in urban communities, Seto et al. (2007) showed that enhancing walking, biking, car sharing, public transit, and home-office working contributes to reduced urban noise and improves QoL. However, these studies have primarily been limited to specific contexts of sound levels, which may not represent all types of urban morphology features.

As the final category, the "unbalanced place" is expected to have more building and construction-related noise because of the highly developed land use. Yuan et al. examined the built environment characteristics on various land use and noise relationship in Wuhan, China (Yuan et al., 2019). Their findings show that high-rise and high-density areas are the major noise contributions to noise pollution. In the same study, the authors also identified that the combination of businesses, open spaces with hard surfaces, industrial uses, and residential mix of land are associated with the high sound levels (Yuan et al., 2019). This helps to clarify the concern over noise in mixed-land use areas typical of TODs. In Australia, for instance, residential properties adjacent to or within the TOD areas are typically not sold as quickly as other properties within the TOD (Renne, 2005). In another study, Renne (2009) included natural and built environmental noise as potential measurement attributes and explored the opinions of TOD residents on sound as a quality of life indicator. More than 40% of participants considered TODs to be noisy locations, while 38% believed they were quiet (Renne, 2009). This indicates that people living near TODs have mixed opinions about the impacts of sound on these environments.


**Figure 7:**Extended Node-Place Model with sound (Inspired source: Bertolini, 1999)

Adding elements of an urban morphology framework to the study of the TOD concept grants a wealth of prospective comparative data, analyses, and methodologies, with the potential to generate a deeper understanding of present and future developments.

Given that the literature, however, is primarily focused on roads, highways, building density, and façade-related performance noise assessments, very little attention has been given to urban morphology elements -buildings, plot systems and streets- and their cumulative impacts on sound. Therefore, it is necessary to provide comprehensive views on the interrelationships between urban morphology elements and sound aspects. This research aims to fill this gap in the urban morphology and sound literature through the incorporation of TODs. By addressing the shortcomings of existing studies and the need for more sound-related studies, the nexus between sound and urban morphology characteristics within TODs is investigated.

**Methodology**

For the scope of this research, after gathering information from cities in Texas (Dallas, Richardson, and Plano), TOD design companies, Dallas Area Rapid Transit (DART), and TOD-related technical reports, five TOD stations were selected for the study: Cedars, Downtown Plano, Galatyn Park, Mockingbird, and Park Lane (Figure 8). These were selected after evaluating all designated TODs by DART authorities as well as the formerly identified design companies in the Dallas-Fort Worth (DFW) metroplex, which typifies the growth and prosperity of the U.S. Sunbelt since the 1970s. Indeed, after successfully branding Dallas and Fort Worth as one unified area, the region has been experiencing a high growth rate and transforming its urban form accordingly (Hanlon et al., 2010).

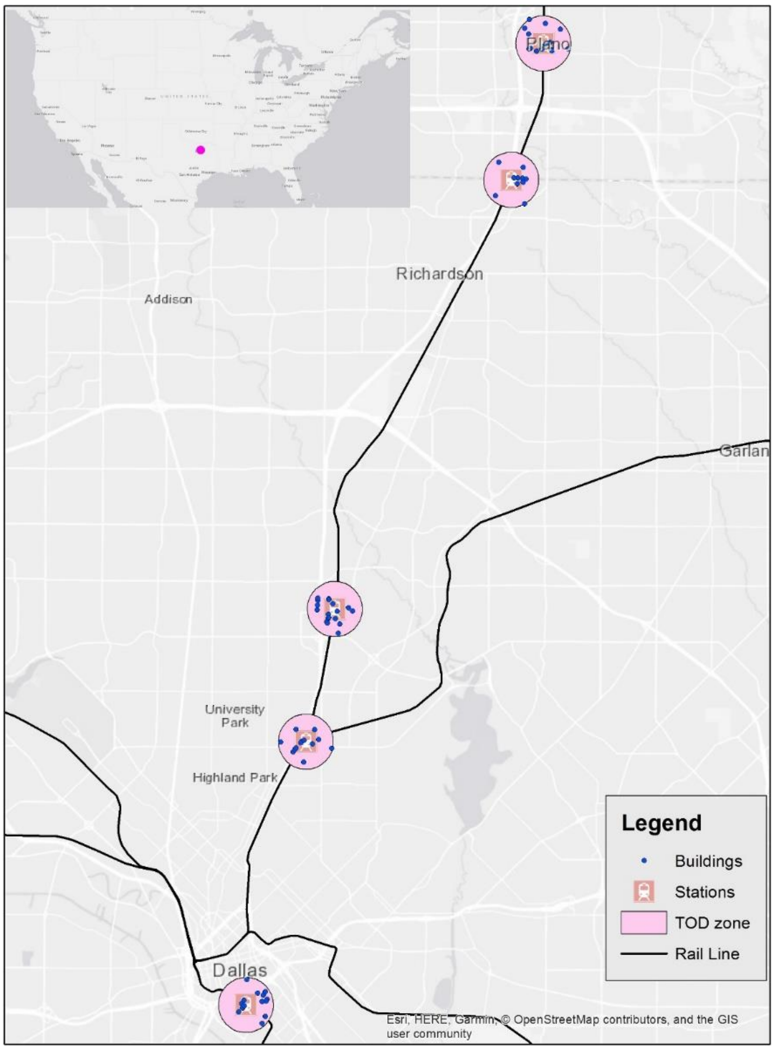
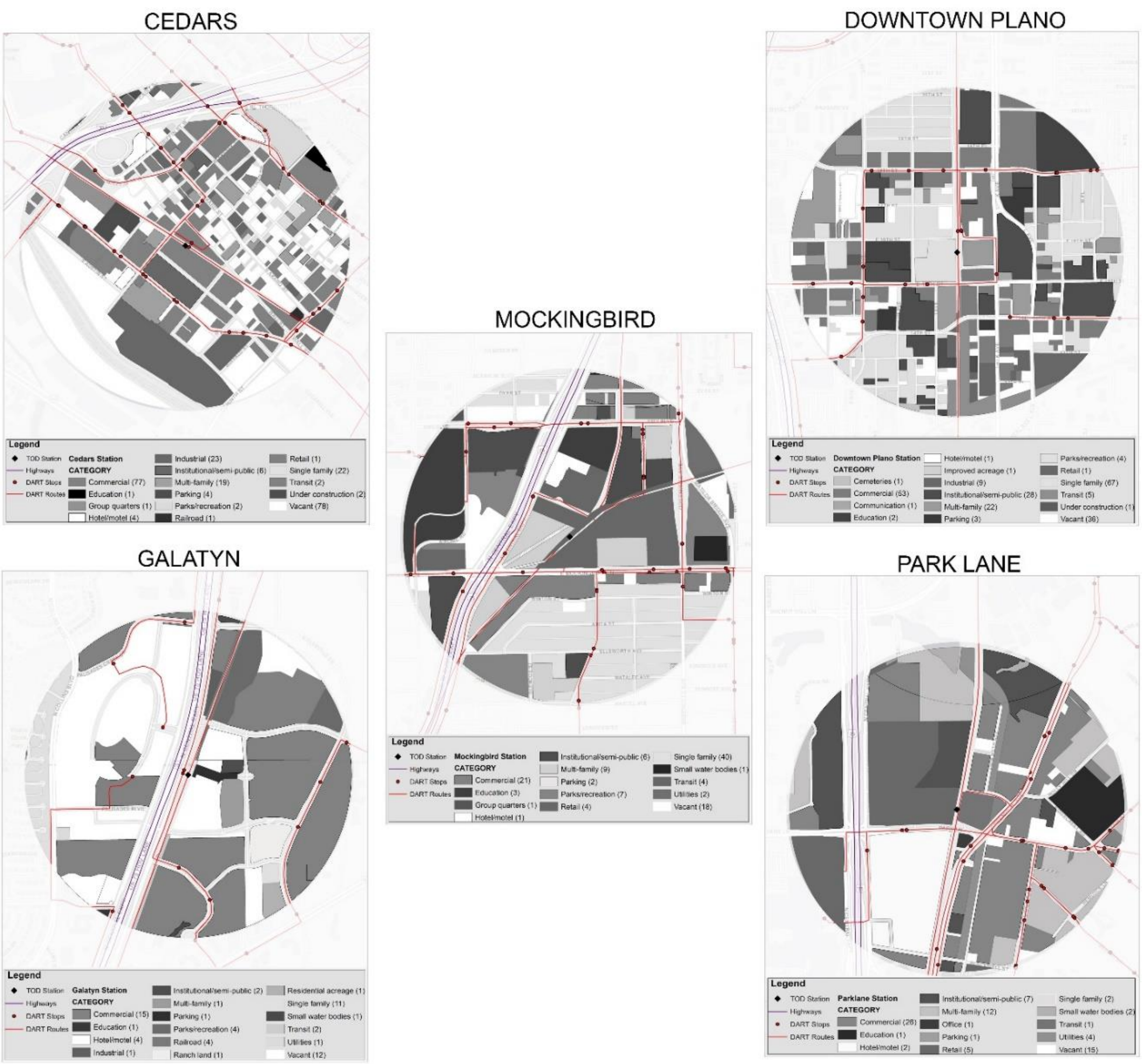



**Figure 8:** Study Locations

**Data Collection and Sampling**

To apply our node-place sound model into the selected TODs, the research followed two main procedures: examining the degree of transportation and land use integration in order to characterize each TOD in terms of sound, and further investigating on urban morphology characteristics –building, plot, and street- both analytically and spatially. The literature suggests that the radius of a TOD from its station ranges from a half-mile to one and a half miles. This study used the suggested TOD area of a half-mile to obtain more detailed sound samples (Atkinson-Palombo & Kuby, 2011; Guerra, Cervero, & Tischler, 2012).

Considering the transportation and land use integration, the researchers obtained the transit routes and stops along with the number and variety of land uses in the half-mile TOD areas (Figure 9). These data were gathered from government (North Central Texas Council of Governments, or NCTCOG) and transit authorities (DART).




| Category | Cedars | Downtown Plano | Galatyn | Mockingbird | Park Lane |
|---|---|---|---|---|---|
| Land Use Type | 15 | 16 | 16 | 14 | 13 |
| Number of Land Use | 243 | 235 | 62 | 119 | 79 |
| Transit Route | 95 | 49 | 36 | 112 | 70 |
| Transit Stops | 41 | 24 | 12 | 32 | 27 |

**Figure 9:** Morphological review of the TODs in terms of transport and land use

After collecting TOD integration information, there researchers adapted established techniques for data collection on sound sampling to examine the relationship between sound and urban morphology characteristics. The quantitative data consists of both sound pressure levels and sound sources measured through a method that was adapted from "grid sampling" (Morillas et al., 2011; King et al, 2012). While the grid sampling method evenly divides areas into nodes on a virtual grid overlaid on a plan, this research model applied this method over a virtual linear route to investigate buildings, plots, and streets. Previous studies suggest distances for line or grid measurements between 300 feet (approximately 100 meter) and 5,000 feet (1,500 meter) (Escobar et al., 2012; King et al., 2012; Yildirim & Ozdil, 2016). Measurements were taken ranging from 1/8-mile (approximately 200 meter) to 1/4-mile (approximately 400 meter) distance based on availability and avoiding obstacles such as walls, highways, and topography.

Since buildings are the smallest urban morphology features in the study, the researchers started by identifying buildings. To do this, the buildings within a half-mile radius of these five TODs were identified using an NCTCOG buildings database. To collect the sound samples using a standardized method, the key buildings with twenty-five thousand square feet or more in each TOD were geocoded as building measurement points. This phase included 71 building sampling points: 14 for Cedars, 15 for Downtown Plano, 10 for Galatyn Park, 14 for Mockingbird, and 18 for Park Lane TODs (Figure 8).

The next phase examined plots and involved the selection of sound sampling points, where buildings are located, and the main selections criteria, as plots that surround and include the buildings were examined for the sound implications. The sound levels in plots were sampled from their corner points (Figure 10). Based on this selection criteria, 275 sampling points for the plot systems were included: 55 for Cedars, 58 for Downtown Plano, 38 for Galatyn Park, 52 for Mockingbird, and 72 for Park Lane.

Following buildings and plots, streets were selected following the same procedure. As a sound sampling methodology, streets are slightly different due to their linear nature. Therefore, in order to apply a standardized approach, streets on which the buildings and plots are located were selected from their midpoints (nodes) on a virtual line overlaid on their plan (Figure 10). Nodes on these lines in the street segments were used for measuring sound levels. By applying this analysis, 220 street segment sampling points were calculated: 80 for Cedars, 31 for Downtown Plano, 36 for Galatyn Park, 37 for Mockingbird, and 36 for Park Lane.

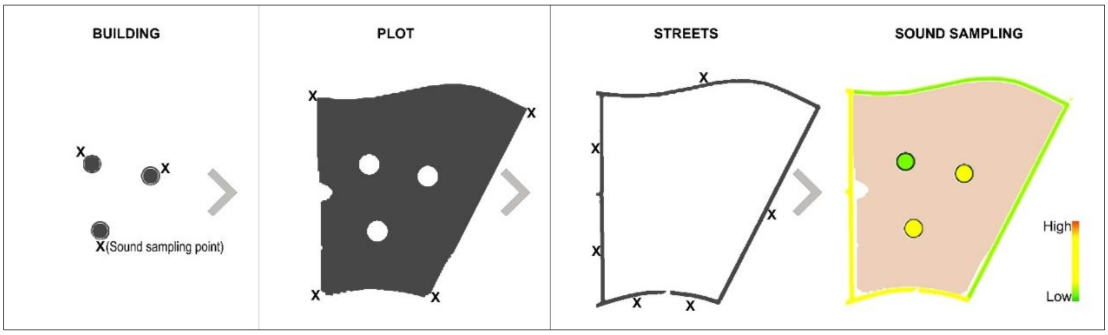



**Figure 10:** Sample sound measurement approach for urban morphology characteristics

For the sound pressure level measurement, taken at a standard 1.5 meter distance from the ground, a Landtek Instruments Professional Digital Sound Level meter 30-130 dB with Bluetooth equipment was utilized. Additional distance for measurements helped prevent echoes from entering the designated zone for a number of buildings around Mockingbird Station. All values were recorded in decibels with the A-weighting (dBA) model of sound pressure level meter of IEC651 Type 2, ANSI S 1.4. $L_{eq}$ one-minute with implications on individuals noted in standard (ISO 1996-1) adopted for this research proved significant as a reference sign for measuring sound. Sound pressure level (SPL) measurements were performed twice in each sampling location and on both weekdays and weekends at 10 a.m., 1 p.m., and 4 p.m. from September 2018 to March 2019 to obtain sound samples at different times. For reference, average quiet residential areas measure at 50 dB, freeways at 70 dB, heavy traffic at 85 dB, and honking at 110 dB sound pressure levels (CHC, 2018). The measurements were taken in time periods that did not coincide with extreme weather conditions such as strong winds or heavy rain.

### Analysis and Findings

Table 6 below illustrates sound level measurements for each building, plot system, and street segment of the TODs, including minimum, maximum, mean and standard deviation (STD) of the one-minute $L_{eq}$ values. Regarding buildings, the findings show that the buildings of Cedars station were the quietest, with a mean of $L_{eq}$ of 65.33 dBA. Park Lane station has the buildings with the highest sound levels, with mean $L_{eq}$ values of 72.33. With reference to plots of the TODs, the sound measurements demonstrate the same pattern. In addition, the sound pressure levels measurements of buildings revealed in a similar pattern regarding street segments. While Cedars station includes the mean of 65.44 dBA, Park Lane station measurements show 71.64 dBA of sound levels.

**Table 6:** Measured sound levels in buildings, street segments, and plot systems of TODs

| | | Cedars | Downtown Plano | Galatyn | Mockingbird | Park Lane |
|---|---|---|---|---|---|---|
| **$L_{eq}$ (dBA) Buildings** | Min | 56.80 | 57.60 | 62.10 | 59.30 | 62.50 |
| | Max | 72.60 | 76.90 | 75.90 | 76.20 | 77.60 |
| | Mean | 65.33 | 70.51 | 68.46 | 71.09 | 72.33 |
| | STD | 3.91 | 4.08 | 3.04 | 3.58 | 3.55 |
| **$L_{eq}$ (dBA) Plots** | Min | 55.10 | 55.10 | 58.30 | 58.30 | 56.80 |
| | Max | 76.90 | 77.30 | 76.90 | 77.00 | 77.10 |
| | Mean | 66.06 | 69.87 | 67.80 | 71.11 | 71.68 |
| | STD | 4.31 | 4.37 | 3.52 | 3.51 | 4.05 |
| **$L_{eq}$ (dBA) Streets** | Min | 55.10 | 55.10 | 59.30 | 58.90 | 58.30 |
| | Max | 76.90 | 76.90 | 77.00 | 77.30 | 77.60 |
| | Mean | 65.44 | 70.00 | 67.94 | 71.51 | 71.64 |
| | STD | 4.08 | 4.24 | 3.31 | 3.53 | 4.31 |

After providing a general scope of the sound measurements among urban morphology elements, the study also scrutinized the sounds at each TOD location to discern sound variety at each TOD. Figure 11 highlights the variety of sound levels in each TOD according to each urban morphology element. In terms of sound range for the building level, Galatyn station shows a lower range (13.8 dBA) while Downtown Plano shows the highest sound range (19.3 dBA). Regarding the sound range of plots, the same pattern emerged, albeit with a smaller gap compared to the building sounds; Galatyn shows a lower sound range (18.6 dBA) and Downtown Plano displays the highest range (22.2 dBA). Additionally, the sound range of the street segments shows a similar pattern, in that Galatyn has a lower range with 17.7 dBA while Downtown Plano and Cedars each procudes 21.8 dBA. When the overall mean of urban morphological characteristics are considered, Downtown Plano and Cedars TODs lead with the higher sound range with 21.1 dBA and 19.8 dBA, respectively.

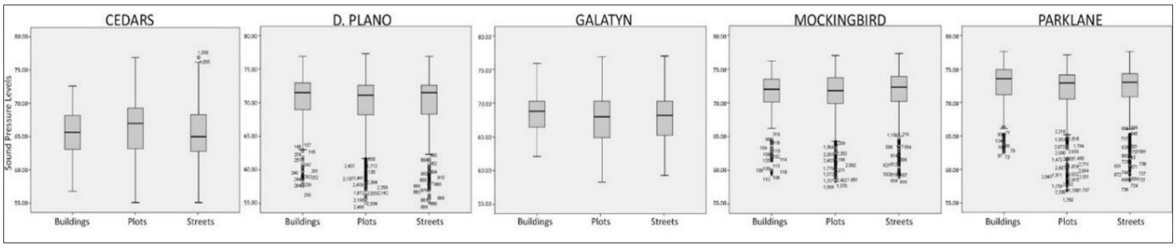



**Figure 11:** Sound variety of buildings, street segments, and plot systems of TODs

Before performing further analyses, several tests were conducted regarding the sound measurements. Since the research aims to analyze sound measurements among all urban morphology characteristics in the selected TODs, sound measurement samples and normality of distribution were tested. To this end, the test of homogeneity of variances was performed for all sound samples. All study locations showed significant difference for the Levene's test, except for the means of Galatyn station (Table 7). Therefore, the study followed the ANOVA method for Galatyn sound measurements and followed the Kruska-Wallis Test for the other measurements of TODs. Before performing this test, Kolmogorov-Smirnov normality tests were performed based on the sample size. From these analyses, the TODs show a significant difference within various degrees and some urban morphology characteristics. For instance, there is a significant difference at Cedars station between streets and plots, as well as buildings and plots. However, there is no significant difference between the sound levels of buildings and streets. In addition, the Downtown Plano station also shows significant difference for the relationship between buildings and plots. Since the test of normality of sound samples in Galatyn station shows significant level of homogeneity of variances, the data followed the ANOVA, post-hoc test (the Levene's test statistic of p value is 0.059>0.05). Based on the results of this test, there is significant difference between the sounds of streets and plots, as well as buildings and plots. Mockingbird station shows a different pattern compared to other TODs, and a significant difference between streets and lots. The sound sample comparisons of Park Lane TOD also show different patterns from the other TODs, with significant differences between streets and buildings as well as buildings and lots.

**Table 7:** Test results of mean comparisons in buildings, plots systems, and street segments of TODs

| | | | Kruskal-Wallis Test/ANOVA Test | | | | Test of Normality/Homogeneity of Variances | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Test Statistic/Mean Difference** | **Std. Error** | **Sig.** | **Adj. Sig.** | | **Statistic** | **df** | **Sig.** |
| **Comparisons (Cedars)** | Street | Building | 12.744 | 61.051 | 0.835 | 1.000 | Street | .110 | 336 | **0.000** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Street | Plot | -194.766 | 36.913 | **0.000** | **0.000** | Building | .062 | 1920 | **0.000** |
| | Building | Plot | -182.022 | 63.083 | **0.004** | **0.012** | Plot | .110 | 1320 | **0.000** |
| **Comparisons (Downtown Plano)** | Street | Building | 85.535 | 46.262 | 0.064 | 0.193 | Street | .161 | 360 | **0.000** |
| | Street | Plot | 27.569 | 32.725 | 0.400 | 1.000 | Building | .166 | 744 | **0.000** |
| | Building | Plot | 113.105 | 42.607 | **0.008** | **0.024** | Plot | .169 | 1392 | **0.000** |
| **Comparisons (Galatyn)** | Street | Building | -.52382 | .24654 | .085 | - | Levene's Statistic | Df1 | Df2 | Sig. |
| | | Plot | .14399 | .16041 | .642 | | | | | |
| | Street | Plot | -.66781* | .24512 | **.018** | - | 2.829 | 2 | 2013 | 0.059 |
| | | Building | -.14399 | .16041 | .642 | | | | | |
| | Building | Plot | .66781* | .24512 | **.018** | - | | | | |
| | | Building | .52382 | .24654 | .085 | | | | | |
| **Comparisons (Mockingbird)** | Street | Building | -92.269 | 45.710 | 0.044 | 0.131 | Street | .160 | 336 | **0.000** |
| | Street | Plot | 109.525 | 31.332 | **0.000** | **0.001** | Building | .118 | 888 | **0.000** |
| | Building | Plot | 17.256 | 43.863 | 0.694 | 1.000 | Plot | .116 | 1248 | **0.000** |
| **Comparisons (Park Lane)** | Street | Building | 127.933 | 51.441 | **0.013** | **0.039** | Street | .165 | 432 | **0.000** |
| | Street | Plot | 46.665 | 36.374 | 0.200 | 0.599 | Building | .200 | 864 | **0.000** |
| | Building | Plot | 174.598 | 46.959 | **0.000** | **0.001** | Plot | .171 | 1728 | **0.000** |

* The mean difference is significant at the 0.05 level.

## Results and Discussion

As demonstrated by the findings of the sound measurements for urban morphology characteristics, the results reveal that sound levels include various patterns regarding buildings, plots, and street segments. Since the research examined these elements in TOD areas regarding sound, this section incorporates these urban morphological characteristics in a discussion of sound implications by posing the hypotheses that the distribution of sound levels remains the same among the urban morphological characteristics.

*Node-Place Model of TODs*

Regarding TOD characteristics of transportation and land use integration, this study shows that balanced TODs in terms of transport and land use include overall higher sound levels compared to TODs in the unbalanced place category. To demonstrate this, the average overall sound levels among all urban morphology characteristics of Park Lane and Mockingbird are 72.1 dBA and 71.2 dBA, respectively, while Cedars and Downtown Plano, representing TODs with unbalanced place, include 65.6 dBA and 70.2 respectively. This may be caused by integration between transportation and land use producing a synergy of numerous other activities, increasing the environment sounds.

Considering the urban morphology characteristics individually, at the sound levels of buildings, balanced TODs –Park Lane and Mockingbird- include the higher sounds, with 72.3 and 71.0 dBA, respectively. As Galatyn is in between dependence and integrated level of TOD morphology, it includes lower sound levels of 68.5 dBA. Looking at the unbalanced place TODs, Downtown Plano and Cedars have relatively lower sound levels with 70.5 and 65.3 dBA, respectively. Considering the plots, the pattern between integrated, dependence, and unbalanced place remains the same, while the sound range between integrated TODs and unbalanced place reduces. The sound levels of integrated TODs are 71.7 and 71.1 dBA, respectively while the unbalanced TODs are 69.9 and 66.0 dBA. At the street level comparisons, the same pattern continues with the lower mean of sound levels for each study area. Integrated TODs include 71.7 and 71.1 dBA sound levels and unbalanced TODs have 70.0 and 65.4 dBA.

*Buildings and sound level*

Since the sound sampling of the buildings are not normally distributed, the researchers performed non-parametric tests for the buildings (the Shapiro-Wilk test is $0.00<0.05$). Considering buildings and their characteristics, the research obtained various patterns. As a null hypothesis, it was assumed that the distribution of sound levels would be the same among building features. After running a series of Kruskal-Wallis H tests, the model showed that there is a statistically significant difference in sound level and the building height, $\chi^2(5) = 13.628$, $p=0.018$. In other words, building height affects the sound levels – the higher the building, the greater the sound level- (Figure 12 first chart). In a similar way, there is also statistically significant difference between sound level and the building width, $\chi^2(5) = 23.855$, $p=0.000$, which means building width influences the sound levels –the wider the building, the greater the sound level-(second chart in Figure 12). The research also compared the sound levels among TODs by grouping the buildings. Considering building use, all buildings were classified into four categories; apartment, business, school, and other (such as police headquarters and hospital). The test also shows that there is a statistically significant difference among building uses, $\chi^2(3) = 9.433$, $p=0.024$. It shows that the other category, mainly including special categories of buildings, had the highest mean value followed by the business-related buildings. Based on same analytical test, there is also a statistically significant difference among TODs, $\chi^2(4) = 26.661$, $p=0.000$. Surprisingly, TOD stations, with the integration of transportation and land use, Park Lane and Mockingbird, included the highest mean ranking (Figure 12 last chart). Perhaps, this integration also creates various activity in a favor of noisy acoustic environment and that’s why integrated TODs include higher sound levels.

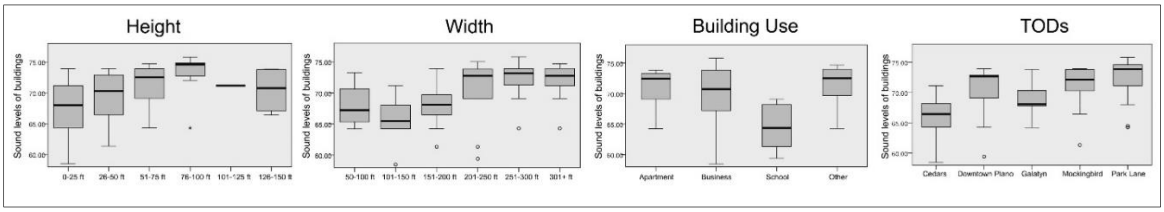



**Figure 12:** Building characteristics and sound level comparisons

*Plots and sound level*

In addition to building features, this research also considered whether plot characteristics have associations with sound. To do this, as a hypothesis, it was assumed that the distribution of sound remains same among plot characteristics. After running a series of Kruskal-Wallis H tests, the results show that plot size does not include any significant difference among sound levels, $\chi^2(3) = 1.701$, $p=0.637$. So, even though moderate size (1.1-5.0 acres) of plots and the largest size of plots (10.0 or more acres) have the highest mean values, this does not show any significance level (First chart in Figure 13). Considering the plot use and sound relationship, there is also no significant difference, $\chi^2(4) = 2.899$, $p=0.575$, although commercial and institutional categories have the highest mean ranking while education includes the lowest mean and it is followed by vacant plots (second chart in Figure 13). The research also tested the relationship between sound and TOD stations. The test shows significant difference among TODs, $\chi^2(4) = 16.365$, $p=0.003$. In other words, the plots of Park Lane and Mockingbird stations are the loudest while those of Cedars station are the quietest.

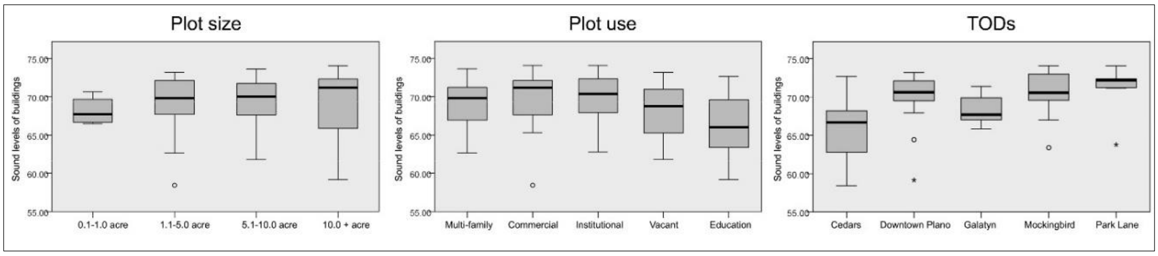



**Figure 13:** Plot characteristics and sound level comparisons

*Streets and sound level*

Finally, the research examined the street segment related features and sound level relationships. It was hypothesized that the distribution of sound level would not be affected by the street segment characteristics. Various street segment characteristics showed, however, that there is a significant difference among sound levels. For instance, the longer street is, the higher the sound level with Kruskal-Wallis H test indication, $\chi^2(4)$ = 21.065, p=0.000 (First chart in Figure 14). Street width also illustrates similar patterns, as the sound increases with increased street width, and there is a significant difference among street widths, $\chi^2(2)$ = 101.688, p=0.000. The research also considered the speed limits of the street segments, and there is a significant difference between speed limit and sound levels, $\chi^2(3)$ = 57.583, p=0.000. The pattern is very similar to street length and street width in terms of increasing speed limits corresponding to louder sound levels (Third chart in Figure 14). Finally, the sound levels of street segments were assessed through clustering at the TOD level. The analysis shows significant difference among TODs, $\chi^2(4)$ = 72.509, p=0.000. The sound levels of street segments show a similar pattern with the plots and buildings, with higher sound levels in Park Lane and Mockingbird stations and lower sound levels in the Cedars station.

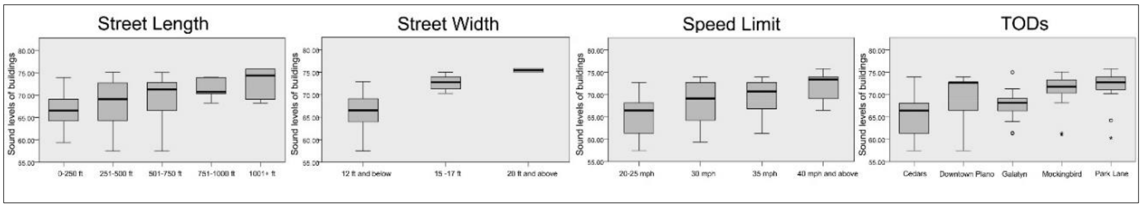



**Figure 14:** Street characteristics and sound level comparisons

After observing differences in sound among urban morphological characteristics, the research sought to identify spatial patterns regarding sounds. Considering the overall high level of sound, the highest three sound level locations were interpreted within a high-higher-highest categorization. This method served to facilitate the identification and explanation of the relationship between sound levels and urban morphological elements. To verify this nexus, the sound level measurements were analyzed based on buildings, street segments, and plots by performing ArcMap functions. The mapping process portrays the buildings as points, the streets as axial linear lines, and the plots as polygons.

Considering the urban morphology discourse of the study, knowledge of urban morphological conditions that guide change in urban development over time requires an understanding of various elements including sounds. Looking at the study area, varied sets of urban tissue can be observed, some of which are suburbanized subdivisions with car-oriented urban layouts, and some of which are more affected by the central business district (CBD), with high-rise buildings and heavy traffic. Since the philosophy of TOD both attempts to offer mass transit for residents and also to create pleasant communities with urban design features, this transformation becomes more challenging for the sound implications  as well within the existing car culture. Since the urban tissue had been developed considering the vehicle convenience in the past, drive along any arterial roads with the big box stores and retails, drive-through restaurants and pharmacies, strip shopping plazas, and small or large office or special use buildings contribute to vehicle-related sounds. Additionally, the types of buildings developed for uses like hotels are linked to various vehicle related systems including customers, employees, food, cleaning, construction, and garbage facilities. Another example is medical-related big box single or multi-purpose stores. These building uses also include specific configurations, such as large parking lots, multiple entrance and exit points, and special internal and external routes for emergency vehicles. The sheer scale of these and building morphologies and the traffic they generate should be considered as potential noise factors.

The analysis supports these claims of urban morphological disorders on noise. Table 8 shows the existing use of buildings, plots include the buildings, and streets of various lengths that surround the buildings and plots with various lengths. Based on this algorithm, the building uses and plots show a notable effect on noise level. In particular, commercial (primarily hotels) and special use (medical, hospital, and police headquarters) buildings represent higher sound levels. Regarding TOD implications with relation to urban morphology, buildings and land use forms with dense business concentrations increase the magnitude of sound levels. This upholds findings of a number of other studies (Yu et al., 2010; Lu et al., 2014).

**Table 8:** Characteristics of urban morphology elements on high sound levels

| **Site** | **Element** | **High** | **Higher** | **Highest** |
|---|---|---|---|---|
| Cedars | Building | Elementary | Apartment | Secondary School |
| | Street | 1,136 ft | 1,331 ft | 1,567 ft |
| | Plot | Education | Residential | Education |
| Downtown | Building | Police HQ | Town home | Recovery Systems |
| | Street | 1,821 ft | 1,976 ft | 2,512 ft |
| Plano | Plot | Special Use | Residential | Commercial |
| Galatyn | Building | Fine Arts | Hotel | Hotel |
| | Street | 1,792 ft | 2,215 ft | 2,633 ft |
| | Plot | Special Use | Commercial | Commercial |
| Mockingbird | Building | Commercial | Commercial | Special Use |
| | Street | 1,140 ft | 1,242 ft | 1,481 ft |
| | Plot | Multi-tenant | Multi-tenant | Center |
| | Building | Special Use | Special Use | Commercial |

| | | | | |
|---|---|---|---|---|
| Park Lane | Street | 2,743 ft | 3,029 ft | 3,377 ft |
| | Plot | Medical | Hospital | Multi-tenant |

Looking at the street segments, the arterial roads that serves for these buildings are generally wide and winding roads as opposed to a settled grid street layout. Since this monopoly of the road structure also carries huge amounts of traffic including public transportation services such as buses and street cars, it is expected to include high sound levels. Furthermore, the number of street segments and the length of the streets demonstrate a correlation between sound and street features. Thus, increased street connections correspond to higher sound levels. As can be seen in Figure 15, almost all TODs include this street pattern, which is the backbone of the road hierarchy. Therefore, heavy traffic circulation on these streets during most of the day also results in a lack of pedestrian and biker activity. At this point, it is useful to observe the challenges, including sound aspects, of between automobile dependent versus TOD-related morphology.

Regarding the spatial distribution of sound levels in our analyses, the presence of major arterials was the most significant factor affecting sound levels. This also confirms the findings of numerous other studies (Basti, an-Monarca et al., 2016; Guedes et al., 2011, Han et al., 2018). Higher sound level measurements occurred adjacent to primary highways due to vehicle flow. Correspondingly, as it was also analyzed in this section, road speed limit affects sound levels; proximity to primary highways with over a 40 mph speed limit resulted in noisier urban morphology elements compared to minor arterials with 20 and 25 mph speed limits.

Spatial arrangements of the sound level measurements for each urban morphology element also illustrate a hierarchical pattern, indicating that when sound level measurements are at peak level in the streets, there is a greater likelihood of increased the sound levels of buildings and plots. In some cases, however, the buildings may exhibit altered sound levels dependent upon their morphological attributes, such as heights, widths, and building use, while the characteristics of plots have lesser implications on sound levels compared to building and street segments.

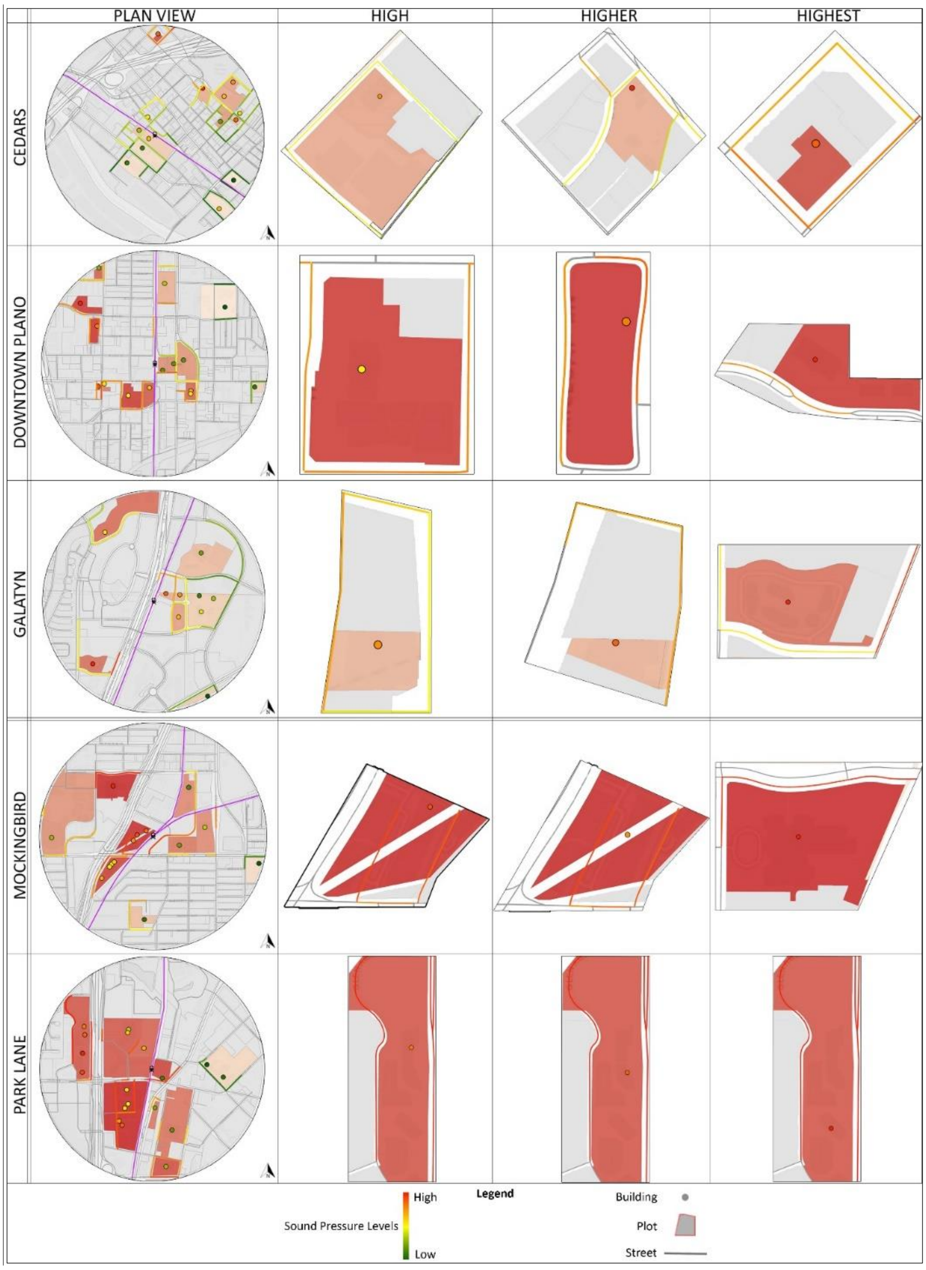



**Figure 15:** Urban morphology elements and sound ranking with TOD plan views

**Conclusions**

The main aim of this research was to investigate the nexus between urban morphological elements and sound level in TODs. Urban morphological characteristics including buildings, plots, and street segments were analyzed in terms of spatial and statistical arrangements. The findings of this research statistically indicate that there are significant relationships between urban morphology elements and sound levels. Regarding spatial patterns of urban morphological elements, building uses, plot patterns, and the characteristics of roads, such as street length and widths have implications for higher sound levels.

The arterial with numerous big box store buildings typically continues for a long distance, passing through various patterns. From an urban morphology perspective, the idea of TODs with transit stops and sets of characteristics such as density, mixed land uses, and recreation areas could divide major arterials with several intersections to discontinue the dominancy of one linear road. This transformation could also contribute to changes in sound sources and levels. When annoyance from sound is caused by roads, railroad, or trains, several alternatives might be adapted to control sound levels by taking into account the sound features of buildings, plots, and streets. This could involve noise barriers or excluding train horns- before (preferably) or after implementing the TOD projects, as Bunn & Zannin (2016) suggested.

Considering the morphological diversity of TODs with regard to building, plot forms, and street segments, various sound sources are included. Regarding urban design and policy lessons from this urban morphology study, design guidelines and zoning policies on noise may be applicable approaches. However, as Scheer (2010) emphasized, with a lack of understanding of the significance of urban morphology characteristics, design guidelines and zoning policies are insufficient and inferior retreats. Thus, the continuing education of urban morphologists, planners, urban designers, and decision-makers is imperative.

The study of urban morphology spans several fields and disciplines; however, as Conzen and Whitehand highlighted, the use of the urban morphology term has been ambiguous (Conzen, 2001; Whitehand, 2012). This circumstance thus urges a variety of pertinent efforts to enhance the rigor of the urban morphology debate (Whitehand, 2014). This study aims to contribute to this call for further research from sound and urban morphology perspectives. With widespread resistance to change on urban form, interpreting the sound levels of buildings, plots, and streets provides a more systematic and dynamic procedure to the spatial framework of the physical urban fabric (Gu, 2018). Therefore, investigating sound levels in particular among transit-related developments provides an application based on consolidating assessments of urban morphological patterns. This study can also prompt an initial evaluation the TODs, policymaking that can impact the quality of life of for those residing in urban environments, and perhaps even the designation of new districts by understanding the importance of urban morphology and sound.

## CHAPTER 5: MANUSCRIPT 3

## THE RELATIONSHIP BETWEEN SOUND AND AMENITIES OF TRANSIT-ORIENTED DEVELOPMENTS[1]

### Introduction

Noise is defined in different ways; some define it as unwanted sound, while others describe it as the combination of sounds that adversely affect hearing (Stephen & Mark, 2003; WHO, 1999). Noise, particularly environmental noise including transportation, industry, construction, and neighborhood, is often a foremost environmental issue (Kang, 2017). Transportation-related noise influences more than 90% of the U.S. population, although the level of noise is not usually high enough to be considered a threat to public health (US DOT, 2014). There is no doubt that exposure to excessive sound levels is a part of daily urban life; however, all types of human settlements worldwide—including urban, suburban, and rural—risk exposure to potentially harmful levels of vehicle and traffic (Firdaus & Ahmad, 2010). Exposure to transportation-related noise has been examined in various contexts with regard to public health concerns such as chronic diseases, hearing loss, stress, and sleeping disorders within a general context of quality of life (QoL). Before addressing the scope of the paper with regard to QoL and sound aspects, an operational definition of QoL is warranted (Lee & Sener, 2016). While objective measurements of QoL consider income and crime rate variables, they do not typically reflect personal experience (Sirgy et al., 2006) or subjective evaluations including perceived life satisfaction based on positive or adverse feelings (Diener, 2000). Regarding this category, SF-36 is a measurement of psychosocial and psychological distress and well-being (Lins & Carvalho, 2016). Some contend, however, that subjective indicators cannot solely interpret QoL as

[1] Used with permisson of publisher, 2019

personal welfare if it does not reflect the totality of personal circumstances (Felce & Perry, 1995). Researchers have also suggested its aggregate form (Bowling et al., 2003; Sarch, 2012). The last classification of QoL dimensions falls within discipline-specific dimensions. Public health and social science scholars have investigated the relationship between housing, neighborhood facilities, and QoL (Sirgy & Cornwell, 2002; Bize, Johnson, & Plotnikoff, 2007). From health and sound perspectives, health-related quality of life (HRQOL) can be a part of this classification by measurement of the influence of a person's health status (Shephard et al., 2010). Furthermore, the World Health Organization (WHO) Noise Guidelines are in favor of HRQOL measurements (WHO, 2009). Considering the scope of this paper—from environmental research and urban design to urban planning—these extensive lists of QoL characteristics and definitions refer to livability, connection, mobility, personal development, community, and economic development in a broader context [17–19]. QoL has also been examined for neighborhood noise through various survey-based measurements (Shepherd et al., 2010; Neitzel et al., 2012; Nitschke et al., 2014; Botteldooren, Dekoninck, & Gillis 2011), as well as in the intersection of environment, transportation and urban planning fields, such as transit-oriented developments (Boorse, 2001).

Transit-oriented developments (TODs) are capturing attention globally and becoming a pivotal context in the conjunction of transportation and urban planning, particularly around light rail train stations (LRTs). LRT use in the United States has almost tripled from 1990 to 2010, with a greater increase than any other form of transit (Neff & Dickens, 2012). Light rail transit is a type of mass transit featured by electric powered trains performing fixed routes on the track corridors with traffic signal priority (Boorse, 2001). Commuters entrain at dedicated stations that are designated with various features.

Those features can be related to either locating the station platform (i.e., ground level, underground, or elevated) or the facilities within the stations (i.e., restroom, seating bench etc.).

Regarding the location of this study, the Dallas-Fort Worth (DFW) region has been a portrait of the growth and prosperity of the U.S. Sunbelt since the 1970s (Hanlon, Short, & Vicino, 2010). After being successfully officiated as a part of regional marketing and establishing a collaborative identity, Dallas and Fort Worth as one unified region, the area has experienced an increasing population growth rate (Hanlon, Short, & Vicino, 2010; NTC, 2019). This phenomenal challenge of addressing QoL in a rapidly growing region resulted in considering TODs on a wider “metroplex”-level scale. This study revisits the amenities of train station from TOD and non-TOD attributes through the lens of sound aspects.

Ideal TODs provide critical livability attributes to the built environment by facilitating the use of multi-modal transit rather than driving and by increasing walking and biking (Curtis et al., 2009; Calthorpe, 1993; Ewing, 1999; Dittmar & Poticha, 2004; Jacobson & Forsyth, 2008; Ewing & Bartholomew, 2013). For instance, TODs tend to generate higher-density communities with diverse land uses such as commercial, residential, and retail, and can also offer improved street connections for walking and biking circulation. Effective TODs address all age groups, creating multiple cultural, recreational, and educational facilities and opportunities (Curtis et al., 2009). These characteristics also produce distinctive sounds.

TOD-related sound mainly originates from train stations, neighborhood features such as roads, buildings, and density, and personal and transit vehicles within TODs. However, literature rarely identifies the implications of specific amenities on sound in train stations. Primary questions remain unaddressed—for instance, what other factors contribute to the emergence of noise in a TOD neighborhood? How might a TOD as a type of urban form influence these factors? Do such amenities have different effects in non-TOD and TOD neighborhoods? Little empirical evidence is presented in the literature on the mechanisms of TOD-related sound and how the built environment might affect these.

This research seeks to address this gap and investigate the relationship between TOD attributes and sound pressure levels (SPLs). Neighborhood-level data (within a radial or Euclidian quarter-mile distance, as suggested by (Guerra, Cervero, & Tischler, 2012; Atkinson-Palombo & Michael, 2011), were used from the U.S. Census and North Central Texas Council of Governments (NCTCOG). ArcMap (10.6) tools for street and intersection-related data were utilized to examine neighborhood-level non-TOD and TOD features and SPLs at the stations (Guerra, Cervero, & Tischler, 2012; Atkinson-Palombo & Michael, 2011).

## Literature Review

### *Urban Form and Noise*

Urban form refers to the physical characteristics that constitute the built environment, including the shape, size, density, and configuration of settlements (Dempsey et al., 2010). Furthermore, urban form directly and indirectly affects travel behavior and air quality in addition to noise, which is the primary focus of this research (Tang & Wang, 2007).

Several studies have modeled noise within various urban forms. Tang and Wang (2007) assessed urban form in historic cities with various road types and different densities of intersections to investigate possible traffic noise patterns and noise levels (Tang & Wang, 2007). Furthermore, Guedes, Bertolini, and Zannin (2011) conducted research that is similar in some ways to that of Tang and Wang by examining heavy and light traffic to determine whether noise levels decrease at intersections with low speed. Guedes, Bertolini, and Zannin's research findings differ, however, because they considered other factors such as pavement material, the proximity between sound and source receivers, and street configurations. They also examined the physical features of urban morphology, such as compactness of place, the number of public spaces, and the physical position of buildings on the streets, and concluded that all these factors have significant impacts on noise.

Lee, Chang, and Park (2008) evaluated environmental noise through noise mapping to quantify the urban sound environment. The objective of their study was to identify how the interaction between sound and urban form influences noise in an urban environment. In other research, Salomons and Pont (2012) examined the relationship between traffic noise in the built environment and urban density and form in the Netherlands. Their findings indicate that building form has significant impacts on sound levels.

From another perspective, Souza and Giunta (2011) developed a model, Artificial Neural Networks, to assess sound in street environments. The results of the study show that street configurations alter the sound levels in urban environments. In a broader comparative study, Wang and Kang (2011) investigated how urban morphological features affect noise in the United Kingdom and China. Their study posits that urban morphology and its characteristics commonly have substantial implications for noise levels, even though the two countries studied demonstrate different urban patterns.

Considering more transportation-related studies, Can et al. (2008) conducted experimental research by defining noise descriptors and real urban traffic circumstances at five locations along a major road in Lyon, France. They examined a one-way three-lane road with five-story buildings on both sides. The road segment investigated was crossed by six intersections and carried more than one thousand vehicles per hour. The authors aimed to understand the effects of red and green phases of traffic lights on noise propagation; however, they were not able to obtain their target findings. Wu, Kang, and Zheng (2018) examined the acoustic environment of railway stations in China regarding sound field characteristics by conducting a mixed-method study in a waiting hall. The authors also aimed to propose acoustical design solutions for high-speed railway stations.

***Reviewing TOD Characteristics***

As TODs are multi-disciplinary constructs, researchers from numerous disciplines, including transportation engineering, real estate, planning, and urban design, have been investigating TODs since the 1990s. TODs have experienced significant transformations as transit services continue to evolve not only in mobility options but also regarding improved technology (Curtis et al., 2009). The current concept of TODs was pioneered in the U.S. in the 1990s, but the applications and characteristics of TODs can be observed worldwide. Pojani and Stead (2015) sought to understand how urban design features could be implemented for TODs in the Netherlands. In other studies, Pojani and Stead also examined TOD practices in Sweden and Austria in terms of planning policies affecting TODs. This research concentrated on policy implications by performing secondary data analyses. In another study, Kong and Pojani (2017) examined the applicability of TOD principles in Beijing, China by focusing on commercial streets surrounding TOD stations. Another study investigated TODs in terms of physical activity benefits relating to the walkability of TODs in Hong Kong. Another study conducted an analysis in the rail stations of New York City and Hong Kong by comparing land use, socio-demographic and economic characteristics of TOD stations, concluding that the two cities have several factors in common, such as heavily used rail transportation.

Recent TOD facilities tend to comprise an essential set of transportation and urban design qualities and emphasize aesthetics to promote economic development. TODs typically offer multiple transportation modes including walking, biking, public transportation, and private vehicles, public facilities, such as parks, plazas, and gathering spaces, and mixed-use developments and civic engagement. A consistent body of research has explored the relationship between urban planning, transportation, and TODs (Calthorpe, 1993; Ewing, 1999; Dittmar & Poticha, 2004; Jacobson & Forsyth, 2008; Ewing & Bartholomew, 2013).

The literature demonstrates that TODs influence QoL in several aspects. The fundamental purpose of TODs is to create functional places for people by integrating public transportation facilities with places where people live, work, and play (Calthorpe, 1993). Belzer and Autler concluded that well-designed streetscapes could increase mobility, the connection of neighborhood facilities, and natural amenities (Belzer & Autler, 2002). According to the literature, the benefits of TODs range from more street connectivity and multi-modal transportation to greater inclusivity for all ages and increased (Curtis et al., 2009). Some of these outcomes, however, can generate negative externalities, such as air pollution and noise (Kam et al. 2011). Transportation-related noise is one of the foremost types of urban noise. According to the literature, characteristics of TODs, such as mixed land uses and multi-modal transportation, are directly associated with sound levels. In other words, TODs affect a neighborhood's sound level, which is one of the essential indicators of QoL.

*TOD, Stations, and Noise*

Although TODs are intended to enhance QoL through enhanced mobility, neighborhood characteristics, and multi-modal transportation, the noise levels of TODs affect QoL adversely. The literature confirms that noise has psychological impacts (the annoyingness or pleasantness of sound), mental effects (sleeping disorders, anxiety) or both (Kang & Schulte-Fortkamp, 2017). The mechanisms of noise exposure may cause critical problems such as noise-induced hearing loss, cardiovascular disease, and sleep (WHO, 1999). TODs are considered to be essential factors in ideal urban environments; however, traffic-related noise poses an explicit threat to QoL (Han, Joo, & Oh, 2010).

A number of studies have investigated the relationship between TODs and noise. One study examined components of TODs such as the indoor and outdoor acoustic environment of metro stations (Kim et al., 2015). Another study shows that people are reluctant to move into TODs because they are concerned about noise and vibrations [55]. For example, houses within the first lots adjacent to TOD stations are typically not sold as quickly as other lots (Renne 2005) located within TODs. In another study, Renne (2009) considered noise as a QoL indicator and performed interviews to record TOD residents' perception of noise. More than 40% of the participants considered TODs noisy locations, while 38% believed they were quiet. Thus, people living near TODs have mixed opinions about the effects of sound on their daily lives.

Other studies examined the negative externalities of sound in TODs, which generate noise related to driving, even though people near TODs generally drive less (Noland et al., 2014). Studies have calculated the costs associated with these negative externalities. Based on one such computation, the total daily cost of TOD benefits in the city of Jersey City is approximately $20,000, with only $14 in negative externalities for noise (Noland et al., 2014). Since decreased motor vehicle numbers correlate with lower sound levels, TOD sites with facilities such as bike paths or pedestrian ways enhance the streetscape and lead to reduced traffic speed and traffic-related sounds (Ouis, 2001). Applying expanded traffic noise investigation in San Francisco with different types of vehicles in urban communities, one study demonstrates that enhancing walking, biking, car sharing, public transit, and home office working contributes to reduced urban noise and improves QoL (Seto et al., 2007).

Regarding the relationship between noise, train stations and tunnels in terms of public health, Xie, Peng, Wang, and Zhang (2019) conducted experiments in tunnels to examine the effects of high-speed rails on hearing. The authors found that acoustic discomfort occurred when a train passed in the middle of the tunnel. In a similar study, Maclachlan, Ögren, van Kempen, Hussain-Alkhateeb, and Persson Waye (2018) examined the relationship between annoyance and rail vibrations while considering neighborhood distance to analyze public health implications by using a self-reported questionnaire of 6894 persons in Sweden. The findings of the study highlight that there is an association between the distance from a rail transit station and annoyance from noise. In another study, Mao et al. (2019) examined more broadly the relationship between underground transportation and environmental quality, including thermal environment, air quality, lighting environment, and acoustic comfort. Their findings regarding acoustic environment show that subway platforms are noisier when a train leaves compared to when it arrives at platforms.

Despite the correlation between TODs, stations, and sounds, little empirical evidence exists at the station and neighborhood scales regarding how sound might be affected by station facilities and TOD characteristics. This is primarily due to the lack of data available and the difficulty of sound pressure level data collection at both scales. Therefore, by addressing the shortcomings of existing studies and the need for more sound-related studies, this study examines the nexus between SPLs and TOD and non-TOD station amenities.

## Research Methods

### *Research Process and Variables*

To assess the relationship between the amenities of TOD stations and sound, it is necessary to first control other factors of amenities and neighborhoods. To do this, the research team aimed to define study locations as the first phase of the research method. As an initial process, cluster analysis was used to classify rail station areas based on density, diversity, land use, and walkability, built environment features extensively suggested by the literature (Scheer et al., 2017; Renne & Ewing, 2013). The research team included various neighborhood characteristics based on QoL and health variables, which included jobs within a quarter-mile radius and neighborhood amenities including entertainment, education, recreation areas, libraries, shopping centers, healthcare, population density, employment, and modes of transportation for each station. In the second phase of the study selection, a qualitative process determined the final study locations.

### *TOD Station Area Definition*

TODs are expected to include pedestrian-friendly urban design and employment density. In light of this, the literature suggests that the proximity of TODs to the station range from a quarter mile to one and a half miles. To obtain more accurate sound samples, this study used the suggested TOD area of a quarter mile (Guerra et al., 2013). Drawing on similar methodologies performed in previous studies (Atkinson-Palombo & Michael, 2011; Scheer etl al., 2017), based on the two-phase suitability analysis, the researchers identified the TOD and non-TOD stations to perform further advanced comparative analyses (Table 9). Since the literature primarily highlights three built environment factors that indicate whether a station performs as a TOD, the research aimed to group existing stations based on built environment performance. Thus, data for the three characteristics were collected and analyzed at each station beforehand, and a normalization procedure was performed to standardize each built environment factor between 0 and 1. The sum of population and employment refers to the total population added to the number of jobs based on the U.S. American Community Survey, while land use density distinguishes various land use categories such as retail, education, and residential, and ranges from 0, indicating and entirely single-use area, to 1, where the land is evenly divided among various land uses. Finally, intersection density is the sum of all types of intersections within each station area (Scheer et al., 2013).

**Table 9:** Variables for station criteria

| Station Type | Activity Density | Land Use Density | Intersection Density | Total |
|---|---|---|---|---|
| | **Sum of Population and Employment** | **Land Use Coverage Categories** | **Sum of All Type of Intersection** | **Total Normalization Score** |
| **Non-TOD** | 0.19 | 0.07 | 0.15 | 0.40 |
| **TOD** | 0.44 | 0.29 | 0.56 | 1.29 |

Based on the study selection process, Figure 16 illustrates TOD stations and study locations based on the selection criteria (yellow dots refer to TOD study locations and blue dots represent non-TOD stations). Most of the regions' TOD stations were constructed in 1996 and 1997, and TOD features were implemented through various economic and development incentives, such as tax increment financing (TIF), to date. In addition, TOD construction emerged from different motivations. For instance, proximity to the central business district made stations such as West End, Akard, St. Paul, and Pearl inherently logical for development as TODs, while developers' attention and initiations occurred at Mockingbird, Downtown Plano, Park Lane, and Cedars stations. Additionally, various factors such as medical district and hospital effects (Baylor Medical station), and business hub locations (City Place, Victory and Market Center stations), which are associated with population, employment, land use diversity, and intersection quantities, were instrumental to TOD development for these stations (DART, 2008; DART 2019). Considering the non-TOD stations, the normalized cluster analyses show that the sum of population, employment, land use diversity, and intersection density remains low. Non-TOD stations also differ from other stations in the figure as they are operated by Dallas Area Rapid Transit (DART), whereas other stations serve heritage and commuter rail services (TEX Rail and Trinity Railway Express) (TRE, 2019). As an explanatory note, although the region includes 84 train stations, 17 stations with different rail infrastructure, including heritage railroads and commuter rail, were excluded in order to standardize study locations. This resulted in the selection of 67 light rail train stations (Figure 16). After identifying these stations, the research team identified 22 stations as TODs and 45 stations as non-TODs in order to obtain a standardized comparison framework to observe the implications of sounds on TODs and non-TODs.

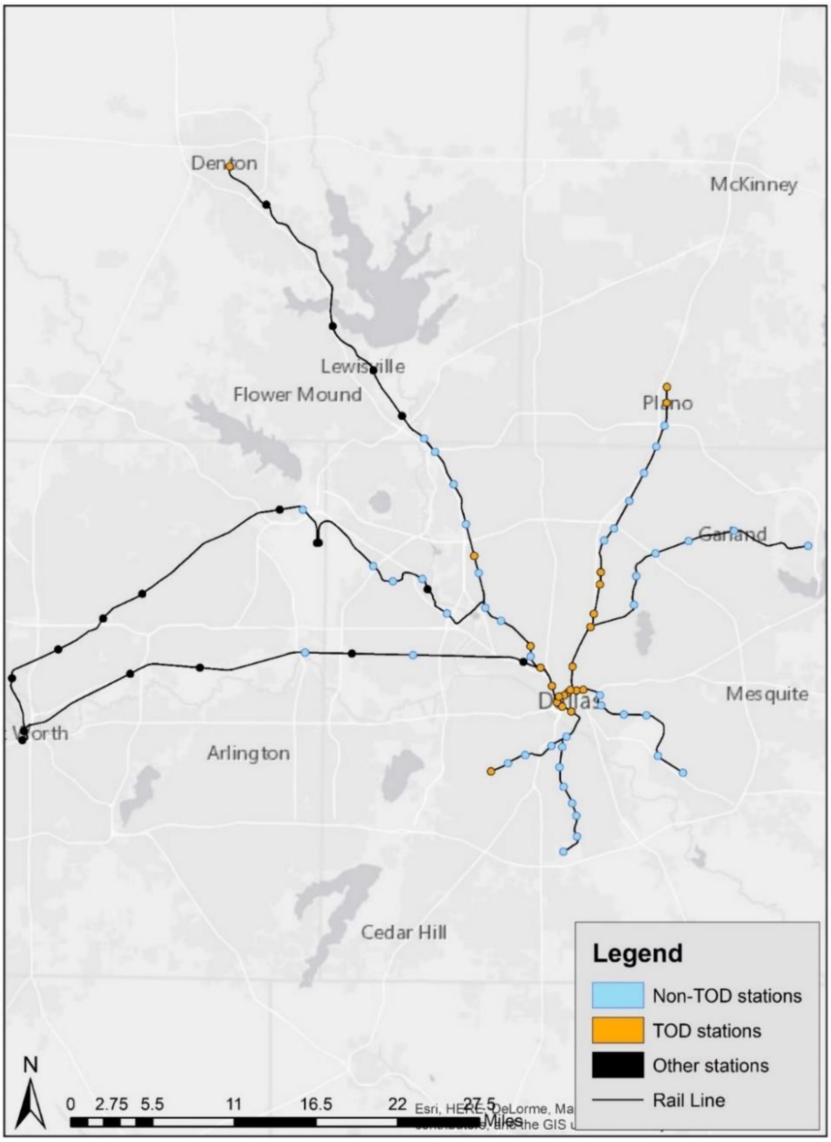



**Figure 16:** Study locations (Source: NCTCOG, 2019).

The researchers performed sound pressure level (SPL) measurements with the A-weighted (dBA), considered a Level 1 dependent variable, at each study station at different time intervals and days of the week. SPL measurements were performed on selected days from October 2018 to March 2019 at 10:00, 13:00, and 16:00. Furthermore, measurements were recorded for both weekdays and weekends to control for differences in other variables, including ridership effects across these time frames.

For the sound pressure level measurement, Landtek Instruments Professional Digital Sound Level meter 30–130 dB with the capacity to weight frequencies to either the

A, C, or F (flat) scale with windshield (to reduce the effects of wind and air movements in the microphone) and Bluetooth equipment was used. Sound levels were measured at a standard 5 ft (1.5 m) distance from the ground, rails, and curbs and 10 ft (3 m) distance to station entry plazas if available (i.e., Mockingbird Station) and front, middle, and rear sections of the platforms. As Figure 17 illustrates, sound level measurements took place at six randomly selected locations on each train station platform to obtain maximum sound samples based on the standardized approach. Since train stations are located at side platforms or center platforms for all study locations, the sampling approach was arranged according to these factors. For stations with side platforms, the sampling was performed on both sides (three on each side), while stations with center platforms followed the six sampling points at the stations. Eventually, the researchers obtained a total of 402 sound samples in 67 study locations. Measurements were aimed to prevent any echo from the entrance region, and all values were recorded in decibels (dBA). Average quiet residential areas tend to register at approximately 40 dB, freeway traffic at 70 dB, and a car horn at 110 dB (CHC, 2018).

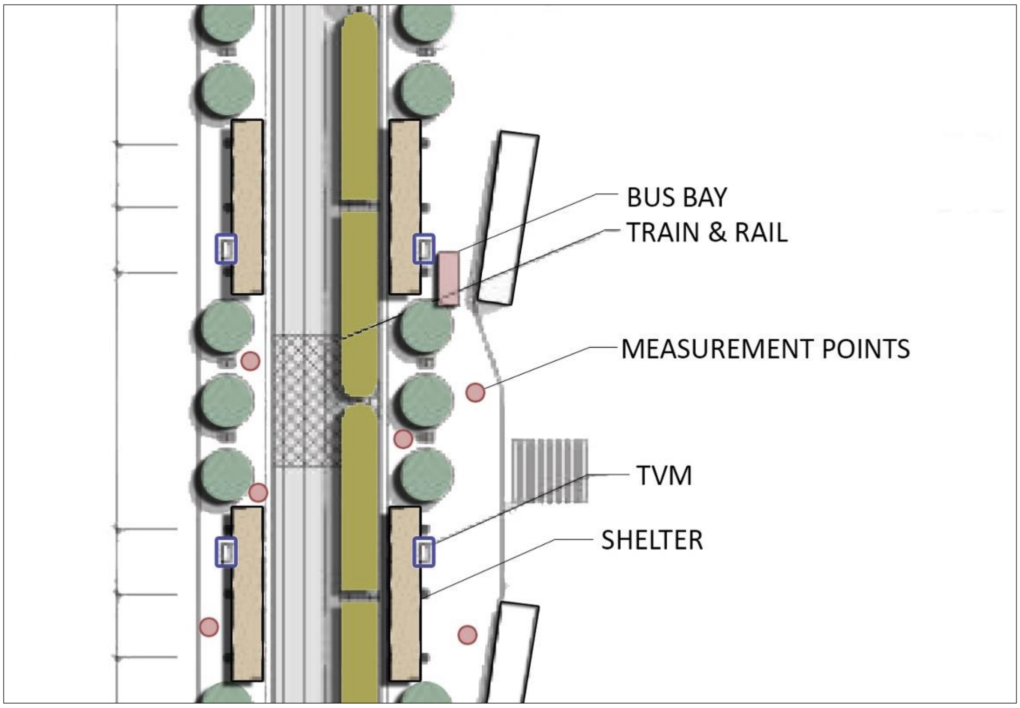



**Figure 17:** Sample sound measurement approach (Source: DART, 2008)

The model of sound pressure level meter was IEC651 Type 2, sound level meter standards by International Electrotechnical Commission, ANSI S 1.4. The $L_{eq}$ fifteen-minute method was performed for this research to identify variations in sound over time because of its significance as a reference sign of sound investigation in addition to its implications on people (Gavin Howard et al., 2012; Piccolo et al., 2005; Gaja et al., 2003). The measurements were gathered by the researchers in periods that did not experience extreme weather conditions, such as strong wind or heavy rain. Further, the measurements were conducted when there were no trains in or heavy construction machines around the stations to avoid excessive SPL and homogenize the measurements across the TOD stations as the research team encountered several outlying circumstances: seven instances of rainy or windy weather conditions, two emergency situations (ambulance and police sirens), and two instances of excessive construction noise around the stations (Deep Ellum and West End).

In addition to sound measurements, various attribute data were collected for both station and neighborhood levels to investigate the implications of such features on sound pressure levels. To control for built environment at both levels, the research first identified station amenity-related variables (Table 2). Since train stations exist as public or semi-public environments, the research aimed to include as many station-related amenities as possible and examine the relationship between sound and each amenity individually. As a note on variables, the research team removed the presence of public art at the stations, as all stations except for one displayed public art. Variables that were considered, as suggested by literature, included structural features like walls within the stations, restrooms, information centers, ticket offices, crew rooms, and map boxes to observe whether they emitted sound throughout the stations or not (Yao et al., 2017; Loukaitou-Sideris & Schaffer; 2014; Houston et al.,2016; Shimokura & Soeta, 2011). Also, crew rooms, restrooms, shelters, benches, windscreens, bus bays, and trash receptacles are regularly cleaned by custodial staff in the study locations (DART, 2016). Therefore, light or heavy cleaning may result in changes to sound levels. Trash receptacles can also produce additional sound from the disposal of rubbish.  Furthermore, an average typical front-end garbage truck produces sound levels between 65 dBA and 94 dBA (DSA, 2003). Ticket vending machines (TVMs) or ticket offices are also examined in several studies regarding sound and station facility relationships (Su & Caliskan, 2007). The number of parking spaces is considered to assess the relationship between sound levels and personal vehicle and ride-sharing services (Uber or Lyft) adjacent to the stations (California HST, 2018; US DOT, 2014). Bike facilities are important features of TOD stations as a part of multi-modal transportation (Yao et al., 2017 & US DOT, 2014). Stations designed with bike lockers encourage frequent and high usage of bicycles as a mode of transportation (US

DOT, 2014). In other words, biking and more bike-related amenities tend to correlate to less personal automobile usage around the stations. Transit ridership is one of the main goals of transit agencies on commuting services for individuals (Yao et al., 2017; Dinno, Powell, & King, 2011). Facility type is another significant variable in the literature, particularly for sound implications. Several studies attempted to examine stations located at ground level, elevated, or underground to examine the acoustic features of train stations in terms of reverberation, finishing materials, tunnels or elevated materials aspects (Yao et al., 2017; Shimokura & Soeta, 2011). The analyses also controlled for numerous built environments, socio-demographic, and geospatial variables at the neighborhood scale (Table 10). The most frequently highlighted variables in the literature on urban noise at neighborhood level are street connectivity, traffic speed, population, employment, neighborhood amenities and presence of grid street layouts (Gershon et al., 2006; Jacobs, 2018; Gozalo, 2016; Wu, Kang, & Jin, 2017; Han et al., 2018). These data were collected by various local, regional, and national data sources. As Table 11 shows, Level 1 independent variables were obtained from Dallas Area Rapid Transit (DART), the North Central Texas Council of Governments (NCTCOG), and site visits. Level 2 variables were extracted from the NCTCOG and the U.S. Census. Speed limit represents the average speed limit of the road segments in each study location and street density is the sum of the streets within each study area at a quarter-mile radius. The number of jobs was extracted from the NCTCOG and the U.S. Census American Community Survey 5-year estimates during the period 2010–2014. Since these data are available at a half-mile radius, they were first summed to find the activity density and divided into two in order to examine the activity density at a quarter-mile buffer.

**Table 10:** Variable review summary on both train station and neighborhood levels.

| Author/s | Train Station-Related Variable | Method | Location |
|---|---|---|---|
| Dinno et al. | Partial or full enclosure of a station and rail | SPL measurement | San Francisco, Bay Area Rapid Transit (BART) |
| Yao et al. | Platform design, station size, train platform v. train inside v. combined effects | SPL measurement | Toronto, Canada |
| Yao et al./U.S. DOT Federal Railroad Administration | Bikes, bicycle racks, bicycle parking lots, bikers | SPL measurement | Toronto, Canada |
| Yao et al./Loukaitou-Sideris and Schaffer/Houston et al./Shimokura and Soeta | Structural platform includes wall, lateral wall, or similar material in the stations | SPL measurement | Toronto, Los Angeles, Japan |
| Shimokura and Soeta | Architectural elements of the stations—shelter and roof | SPL measurement | Japan |
| Shimokura and Soeta | Reflection from the structural elements in the station such as message board | SPL measurement | Japan |
| Yao et al./Shimokura and Soeta | Platform facility type (whether the station is elevated, above or underground) | SPL measurement | Toronto, Japan |
| Wu, Kang, and Zheng/Su and Caliskan | Ticket office, ticket machine, kiosk, customer information | SPL measurement and Survey for Acoustic Comfort | China, Turkey |
| Wu, Kang, and Zheng | Waiting hall including seating bench | SPL measurement and Survey for Acoustic Comfort | China |
| California High Speed Rail Authority/U.S. DOT Federal Railroad Administration | Parking structure, kiss-n-ride passenger drop-off adjacent to a train station | SPL measurement | California |

| | | | |
|---|---|---|---|
| Yao et al. | Ridership | SPL measurement | Toronto, Canada |
| Dinno et al./Wu, Kang, and Zheng/Loo, Chen, and Chan | Population, sociodemographic features, and ridership | SPL measurement | San Francisco, Bay Area Rapid Transit (BART) |
| Dinnoo et al./Gherson et al./Shimokura and Soeta/Loukaitou-Sideris and Schaffer | Speed limit | SPL measurement | San Francisco, New York City, Japan, Los Angeles |
| Jacobs/Gozallo and Morillas | Grid | SPL measurement | Various cities around the world, Chile |
| Wu, Kang, and Jian/Han et al. | Street and intersection density | Prediction modelling, Digital projecting | China, China |

***Statistical Analysis***

Sound pressure level (SPL) is the dependent variable in this study. As this is a continuous variable, regression modeling can be used. As shown in Figure 18, the data used in this analysis demonstrate a “nested” structure and need to be analyzed accordingly. Since all neighborhoods studied surround transit stations, they share characteristics of the stations, such as street connectivity. Therefore, such characteristics could not be considered independent. The nesting structure is inclined to generate dependence among cases, violating the independence conjecture of ordinary least squares (OLS) regression. Standard errors of regression coefficients connected to neighborhood characteristics relying on OLS will subsequently be miscalculated, and therefore regression coefficients will not be efficient (Raudenbush & Bryk, 2002).

**Table 11:** Variables used to explain the odds of sound pressure level (SPL) in the transit-oriented developments (TODs).

| Variables | Data Sources |
|---|---|

| | | |
|---|---|---|
| **Level 1 Dependent variable** | | |
| SPL | Sound pressure level/s (at each station) | The authors |
| **Level 1 Independent variables (Station Level)** | | |
| Seat | Number of seats | DART, site visit |
| Board | Number of message boards | DART, site visit |
| Trash | Number of trash receptacles | DART, site visit |
| Shelt | Number of shelters | DART, site visit |
| Crew | Number of crew rooms | DART, site visit |
| Busb | Number of bus bays | DART, site visit |
| Winds | Number of windscreens | DART, site visit |
| BL | Number of bike lockers | DART, site visit |
| TVM | Number of TVMs | DART, site visit |
| Ride | Number of riders | DART, NCTCOG |
| PLot | Number of parking lots of stations | DART, Google Earth |
| Facility type | Whether the rail is on the grade rail or aerial platforms (dummy) | DART, Google Earth |
| **Level 2 Independent variables (Neighborhood Level, a quarter-mile)** | | |
| Sden | Street density (linear) | ArcGIS, NCTCOG |
| Gden | Grid density (binary) | ArcGIS, NCTCOG |
| SpLim | Speed limit (linear) | ArcGIS, NCTCOG |
| Amen | Number of amenities (linear) | ArcGIS, Google Earth |

| | | |
|---|---|---|
| ActDen | Sum of jobs and population (linear) | ACS 20162010-2014, NCTCOG |
| Wscore | Walkscore (linear) | Walkscore.com |

Hierarchical modeling surpasses the limitations of OLS, computing the dependence among cases and generating more precise coefficient and standard error estimates. In the context of a hierarchical model, each level in the data profile is represented by its configuration, and these configurations are statistically related. Hierarchical linear modeling (HLM) computes for dependence among samples; in our model, this is the dependence of neighborhood levels on the characteristics of the TODs. Hierarchical linear modeling demonstrates a parallel pattern to regression modeling while it operates, as with a multi-level data configuration. Thus, hierarchical linear models were estimated for the various outcomes of sound pressure levels.


**Figure 18:** Conceptual hierarchical linear modeling (HLM) Nesting Structure for the Variables.

In this research, the sound pressure levels (SPLs) of the stations were processed on neighborhood characteristics in the Level 1 configuration. The intercepts and coefficients of Level 1 models were operated on neighborhood characteristics in Level 2 models. Essentially, since different models were projected, only the intercepts randomly varied, whereas all the regression coefficients were performed as fixed. These are denoted as "random intercept" models. Later, regression coefficients were agreed to vary across higher level units randomly, and interactions within levels were computed. These are entitled random coefficient models. In order to interpret the relationship between sound levels and the models, sets of statistical analyses were performed. The statistical analysis software IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, NY, USA) and Scientific Software International HLM for Windows, version 7.03 (Scientific Software International, Inc. Skokie, IL, USA) was utilized to analyze the correlation tests and multi-level linear modeling, respectively. Before performing these tests, the research performed all variance inflationary factor (VIF) values of the multicollinearity test that is within 1 and 10, with a maximum value of 7.73 and mean value of 2.87, indicating acceptable levels of collinearity (Field, 2005).

**Findings and Results**

Pearson correlation coefficient was used for the measurement of linear dependence between sound and other variables (Table 12). The correlations between sound levels and the indicators are shown in Table 3. Overall, Level 1 variables of non-TOD stations are significantly associated with sound levels that are significantly correlated with the seating benches, message boards, ticket vending machines (TVMs), and shelters ($p < 0.05$). When we look at the same scale indicators of TODs, message boards and facility types are significantly associated with the sound levels. Level 2 indicators also include a relatively significant correlation with amenities for non-TOD stations.

**Table 12:** Pearson correlation coefficients between sound measurements and indicators

| **Non-TOD Level 1** | **S** | **TR** | **TV** | **MB** | **CR** | **BL** | **RR** | **BB** | **WS** | **Sb** | **F** | **PL** | **R** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPL | 0.296 * | 0.002 | 0.316 * | 0.343 * | −0.187 | −0.078 | −0.126 | 0.145 | 0.178 | −0.383 ** | 0.221 | −0.006 | 0.066 |
| Non-TOD Level 2 | AM | Sden | G | Aden | Sp | WS | | | | | | | |
| SPL | 0.296 * | 0.127 | −0.206 | -0.210 | 0.248 | −0.056 | | | | | | | |
| TOD Level 1 | S | TR | TV | MB | CR | BL | RR | BB | WS | Sb | F | P L | R |
| SPL | −0.269 | 0.160 | 0.289 | 0.475 * | −0.022 | 0.059 | −0.055 | 0.247 | −0.278 | −0.047 | 0.524 * | 0.157 | 0.106 |
| TOD Level 2 | AM | Sden | G | Aden | Sp | WS | | | | | | | |
| SPL | 0.366 | −0.060 | 0.078 | −0.126 | 0.356 | −0.040 | | | | | | | |

* Correlation is significant at the 0.05 level (two-tailed); ** Correlation is significant at the 0.01 level (two-tailed). S: Shelter, TR: Trash receptacles, TV: Ticket vending machine, MB: Message board, CR: Crew room, BL: Bike Lockers, RR: Restrooms, BB: Bus bays, WS: Windscreen, Sb: Seating bench, F: Facility, PL: Parking lot, R: Ridership, AM: Amenities, Sden: Street density, G: Grid, Aden: Activity density, Sp: Speed limit, WS: Walkscore.

The coefficients of all variables show the expected signs and many of them are significant at the 0.05 level (Tables 13 and 14). The significant variables are in bold font. The variables that control for the non-TOD station amenities are significant at the various probability levels; however, they do not show significance for the model. The odds of sound levels at non-TOD stations represent a positive and robust relationship with station amenities. This illustrates a causal correlation between the station amenities and sound levels.

The number of TVMs and bus bays in non-TOD stations significantly increases the likelihood of the location having louder sound levels, while the number of seating benches decreases the odds of a non-TOD station having louder sound levels. The sound level of the non-TODs at a quarter-mile distance is also highly significant at the neighborhood level. Controlling the covariates, a neighborhood with a higher speed limit is more likely to have higher sound levels in the neighborhoods.

**Table 13:** Hierarchical linear modeling of log odds of sound levels in non-TOD stations

| | **Coefficient** | **Standard Error** | **t-ratio** | **p-value** |
|---|---|---|---|---|
| Constant | 42.816 | 6.518 | 6.568 | <0.001 |
| Level 1 | | | | |
| Shelters | −0.439 | 0.303 | −1.450 | 0.157 |
| Trash receptacle | −0.004 | 0.142 | −0.035 | 0.973 |
| TVM | 2.389 | 0.897 | 2.662 | 0.012 |
| Message board | 2.108 | 1.384 | 1.523 | 0.138 |
| Crew room | −2.686 | 1.596 | −1.682 | 0.102 |
| Bike lockers | −0.495 | 0.427 | −1.161 | 0.254 |
| Restrooms | −1.017 | 0.845 | −1.203 | 0.238 |
| Busbays | 0.807 | 0.346 | 2.329 | 0.026 |
| Windscreens | −0.024 | 0.165 | −0.146 | 0.885 |
| Seating bench | −0.098 | 0.044 | −2.192 | 0.036 |
| Facility | 2.305 | 2.027 | 1.137 | 0.264 |
| PLot | −0.001 | 0.002 | −0.545 | 0.590 |
| Rider | −0.000 | 0.000 | −0.667 | 0.509 |
| Level 2 | | | | |
| Amenity | 0.263 | 0.285 | 0.924 | 0.361 |

| | | | | |
|---|---|---|---|---|
| Street den. | 0.012 | 0.202 | 0.059 | 0.953 |
| Grid | −0.823 | 1.226 | −0.671 | 0.506 |
| Activity den. | 0.000 | 0.000 | 0.422 | 0.676 |
| Speed | 0.495 | 0.092 | 5.377 | <0.001 |
| Wscore | −0.017 | 0.027 | −0.642 | 0.525 |

Considering the TOD stations, there is a remarkable variance from non-TOD stations. Almost all Level 1 variables, except crew room and bus bays, show varying degrees of significant relationships with sound levels. The number of shelters in a TOD station significantly decreases the likelihood of the location having louder sound levels. Bike lockers, restrooms, and seating benches also significantly reduce the likelihood of louder sounds. Furthermore, message boards, trash receptacles, and TVMs significantly increase the likelihood of the location having louder sounds. This suggests that amenities which emit sound themselves, such as TVMs and message boards, increase sound levels in TOD stations, whereas amenities that represent passive interaction, such as seating, or structure-related amenities, including restrooms, bike lockers, and shelters, are more likely to have neutral or negative tendencies for sound levels. Moreover, stations located on aerial platforms include higher sound levels compared to stations with at-grade rail platforms.

Regarding neighborhood-level variables, the number of neighborhood amenities significantly increases the likelihood of observing louder sound samples. Similarly, street density, and particularly grid street schemes, of TOD stations also increase sound levels. Conversely, a higher walkscore decreases the probability of a TOD neighborhood having a louder sound level. This is due to higher walkscores representing more walkable neighborhoods and potentially lower vehicle noise. Surprisingly, activity density, including population and employment, around the TOD stations shows a significant relationship with sound; however, its coefficient is almost zero. Thus, the TOD neighborhood areas influence sound levels, corresponding to the built environment components of the neighborhood but not significantly to the socio-demographic characteristics.

**Table 14:** Hierarchical linear modeling of log odds of sound levels in TOD stations

| | **Coefficient** | **Standard Error** | **t-ratio** | **p-value** |
|---|---|---|---|---|
| Constant | 72.547 | 6.635 | 10.934 | <0.001 |
| Level 1 | | | | |
| Shelters | −2.168 | 0.246 | −8.809 | <0.001 |
| Trash receptacle | 0.508 | 0.124 | 4.071 | 0.003 |
| TVM | 2.061 | 0.530 | 3.889 | 0.004 |
| Message board | 3.406 | 0.213 | 15.953 | <0.001 |
| Crew room | −1.556 | 1.503 | −1.036 | 0.327 |
| Bike lockers | −1.710 | 0.297 | −5.753 | <0.001 |
| Restrooms | −1.787 | 0.348 | −5.125 | <0.001 |
| Busbays | −0.559 | 0.294 | −1.903 | 0.089 |
| Windscreens | 1.295 | 0.100 | 12.914 | <0.001 |
| Seating bench | −0.076 | 0.025 | −3.048 | 0.014 |
| Facility | 14.202 | 1.025 | 13.843 | <0.001 |
| PLot | 0.021 | 0.002 | 10.622 | <0.001 |
| Rider | 0.000 | 0.000 | −4.821 | <0.001 |
| Level 2 | | | | |
| Amenity | 0.877 | 0.129 | 6.784 | <0.001 |
| Street den. | 0.206 | 0.024 | 8.412 | <0.001 |
| Grid | 13.457 | 1.007 | 13.353 | <0.001 |
| Activity den. | 0.000 | 0.000 | 3.226 | 0.006 |
| Speed | 0.511 | 0.059 | 8.596 | <0.001 |
| Wscore | −0.624 | 0.120 | −5.198 | <0.001 |

**Discussion**

The aim of this research was to examine the amenities of train stations and surrounding neighborhood areas associated with sound and to assess such characteristics in regard to transportation and urban planning policies. To achieve this, the research team investigated station amenities and the built environmental and socio-demographic characteristics of neighborhoods surrounding non-TOD and TOD stations to explain likely patterns of sound levels. Other scholars have concentrated on the effects of socioeconomic characteristics, particularly age, gender, and education level (van Kempen et al., 2014; Korpela et al., 2009; Evans, 2003; Booi & van den Berg, 2012). on sound levels. However, the scope of this research accounts for variables at two levels of geography, namely, at the station and neighborhood levels, and controls for neighborhood differences using hierarchical modeling.

While socio-demographic characteristics, such as population density and employment density, do not attribute implications on sounds, amenities of stations and built-environment-related factors have effects on the likelihood of a quiet or noisy TOD or non-TOD station environment. Neighborhoods with more built environment characteristics, including neighborhood amenities such as parks and libraries, as well as dense street and road connections, are more likely to generate higher sound level acoustic environments. A dispersed built environment form, higher street density, higher speed limits, and more grid street configurations are the primary drivers of higher sound levels, particularly in TODs, which confirms other scholars' findings (Han et al., 2018; Yu & Kang, 2017).

Additionally, both station and neighborhood amenities of non-TOD stations have fewer implications on the sound level compared to TOD stations in this research. This evidence suggests the complexity of various components of TODs that have implications on sound propagation compared to non-TODs. As these findings demonstrate distinct features of TODs and their amenities, the researchers urge the adoption of policies that consider the effects of noise on buildings as cities consider building more TODs. Even though monitoring sound levels at each station may be difficult, a general consideration of noise level allowances at the neighborhood or station level may help to improve residents' QoL. Hence, applying a noise ordinance for TODs and non-TODs using guidelines such as Caltrans' "Traffic Noise Analysis Protocol for New Highway Construction, Reconstruction and Retrofit Barrier Projects" may reduce certain noise levels to improve QoL (Caltrans, 2011).

As sound is highly associated with public health, quality of life (QoL), perceptions, the built environment, and amenities, it is a crucial factor for consideration by engineers, planners, transit authorities, and local city officials. Increasing the amenities, land use varieties, street densities, and speed limits of neighborhoods is likely to increase the sound levels. Before enacting policies related to these aspects, decision-makers might investigate the perception of increasing or decreasing sound levels for residents.

The differences observed between TOD and non-TOD stations may, however, be caused by the context or limitations of the research. Moreover, since sound is affected by many station and built-environment characteristics, the research inherently includes generalizability issues, as other station amenities and neighborhood features in different cities or countries could affect sound implications. Also, since several variables were calculated through the ArcMap tools and secondary data sources, some of the assumptions and sampling are not avoidable for this research, as well as the SPL meter calibration procedure. Nonetheless, the study aimed to investigate the relationship between TOD and non-TOD station characteristics with particular focus on built environment characteristics. Further studies may examine this by including more socio-economic variables, urban design features, as well as studying areas surrounding stations to evaluate the effects of distance on sound levels by conducting a survey-based quality of life measurement of sound implications to clarify the effects of high sound levels at TODs.

**Conclusions**

Cities are increasingly considering implementing TODs to improve the QoL of residents. While TODs promote healthy living environments around transit centers that serve many people with rail stations and facilities, they threaten public health in terms of the acoustic implications of station amenities. This research found that amenities of TOD and non-TOD stations, among various indicators from the station and neighborhood levels, have implications on acoustic realms. In addition to station amenities, neighborhood characteristics also affect sounds.

The research team identified that both station- and neighborhood-level indicators play a significant role in contributing to lower or higher sound levels, and this pattern most notably occurs in TOD stations. This may be caused by the characteristics of TODs, which encourage dense population, activity, land uses, and more connective street layouts for multi-modal transportation. Another critical implication for the planning and transportation fields is that each TOD station includes unique sound sources and characteristics. This “locality” compels more consideration for the planning and design of each TOD. Therefore, specific design and planning efforts should keep sound in mind when addressing the context of a TOD area. This research suggests that local authorities considering the implementation of TODs perform surveys to acquire a better understanding of local preferences. However, it is imperative to keep in mind that, as Shephard, Welch, Dirks, and Mathews (2010) discussed, sound pressure level is not always consistent with noise annoyance, and SPLs do not provide information relevant for acoustic comfort or noise annoyance (Shepherd et al., 2010). So, considering QoL perspectives, various further research directions could be followed to draw a more robust conclusion (Seidman & Standring, 2010). However, the goal of this study is similar to the

DYNAMAP Project, aiming to generate an acoustic impact map to assess and manage noise and to provide an urban case study from a different point of view (Zambon et al., 2017).

Understanding the characteristics of sound and sound environments is critical for urban planners, landscape architects, transportation planners, and policymakers to develop policies that manage sound level environments in TODs. One of the goals of current policies, such as noise abatement, has been to incorporate sound level management into stations and TODs. This research could be applied by approaching TOD station management and surrounding neighborhoods to present the study's findings in order to promote participatory planning, so that the complexity of the TOD concept may help to manage Not in My Backyard (NIMBY) concerns of neighborhood residents.

To further support acoustic experts, urban planners, urban designers, public health experts, and policymakers focusing on this issue, many of the largest U.S. metropolitan areas, including Denver, Portland, Minneapolis, and Dallas, have been adapting TOD concepts to create transit-friendly urban hubs, in recent decades (Cervero et al., 2004) managing noise concerns at the station and neighborhood level, health outputs may improve and TODs may better serve their residents and visitors. Moreover, strategies that integrate urban design, public health, technology, and regulation within a collaborative arena of planning, policy making, and acoustics hold promise for increasing health outputs of TODs, including the potential to address noise concerns.

# CHAPTER 6

## CONCLUSION AND POLICY IMPLICATIONS

This chapter discusses the overall results of the previous three chapters comprehensively. The first part focuses on the main goal of this doctoral research and delves into the impacts of the various characteristics of TODs on sound and its perception by TOD actors. The second part evaluates the variability of TODs with regard to sound implications. The third section develops policy considerations by taking into account the local, regional, and national sound-related policies in terms of maintaining a promising level of sounds in TODs. Furthermore, the social and environmental aspects of the study are followed by policy implications.

While soundscape studies have been increasing towards various directions nationally and globally, there has yet to be an attempt to define TODs and their relationships with the sounds at the site-specific level of understanding. This study is one of the pioneer efforts that analyzed the TODs at the various micro scales to identify the urban environment characteristics regarding the implications of sound by performing a strategic approach.

Defining the TODs and non-TODs in the Dallas-Fort Worth region was the key phase of the study. Since not-all train stations and surrounding environment can be considered as TOD, the study first defined the features of TODs. During the TOD selection phase, the study also adopted TOD areas as several scholars proposed the TOD area between a quarter-mile to a mile and half proximity. Also, this study explored the relationship with sound and TODs by performing a quarter-mile and a half-mile distance in order to obtain maximum sound samples for better precision.

Following TOD operational definition and TOD area identification phases, the study has found a close relationship between soundscapes and TODs at various scales. The nexus between sound and TODs was aimed to unfold by examining the TOD characteristics.

TODs include common features such as compact urban environment, pedestrian and bicycle-friendly transportation facilities, public and civic spaces near train stations (TCRP, 2002). While these characteristics promote various social, economic, and environmental benefits such as $CO_2$ emission reduction, housing premium increase (Cervero & Kockelman, 1997; Renne & Wells, 2002), the relationship between sound and such characteristics remain unpacked. There is no doubt that local and regional authorities are considering more TOD implementations both nationally and globally. This pattern should also remind that the sound environment of previous and existing TODs are subject to change with the concern of the positive, neutral, or negative. Also, what policies can be adopted or at least considered regarding those positive, neutral, and negative sound circumstances of TODs?

My study on the TODs and sound relationship could offer a gamut of contributions to the policy and design implications particularly with the sound–in which they are a shortfall in TOD context. On one hand, the key features –connectivity, diversity, neighborhood amenity, multi-modal transportation, density- of mainly land use and transportation of TODs contribute to the acoustic environment. On the other hand, local, regional, or national policies should be integrated into pre-planning, during the implementation, and post-implementation phases of TODs.

**The Role of "TOD Actors" on Sound**

Sounds with the physical characteristics and psychological perception of the sound environment affect QoL in TODs; it can become particularly problematic when transit services generate them, which in turn directly affect the community. At this point, it is noteworthy to identify various stakeholders who are involved in the planning, design, and construction of TODs as various stakeholders may have different considerations of the sounds for the process of TODs.

The process of planning, design, and construction of TODs involves pre-, during, and post-phases, each of which engages a set of stakeholders. Here, I identify two main categories of stakeholders: directly-engaged and indirectly-engaged stakeholders. Directly-engaged stakeholders include developers, architects, urban designers, and residents; (this final category, residents, may itself be divided further into the sub-categories of residents, business owners, employees, community groups, and NGOs). Indirectly-engaged stakeholders are essentially local transportation authorities and those involved in politics.

*Directly-Engaged Stakeholders*

In the planning phase of TOD construction, a developer decides to make a change on an existing physical form, such as a neighborhood or shopping mall to create a TOD; the developer can be a property owner, an authority in transportation or belong to a group of individuals who own land. For the developer, the decision to create a TOD is affected by many factors, the most important of which is economics in nature. Timing, as well, is critical for the success or failure of TOD planning, design and construction, particularly as construction trends in terms of politics, technology, and finance are always changing – the developer must be in tune with the larger-scale trends (Whitehand, 1992). The developer's primary role throughout all TOD phases is to select buildings types while considering population and neighborhood amenity density a process that involves discussions and debates about technical concerns with other TOD stakeholders.

Architects and urban designers comprise the next set of essential stakeholders of TODs. After the idea of the TOD process is accepted, the developer passes partial authority to architects and urban designers – which may include engineers, consultants, and real estate experts – to deal with the local authority and residents. The role of the architects is not only to designate specific uses and features of TODs but also to work with local governments collaboratively in order to address the needs of residents. Considering the collaboration of design professionals, builders – who can be local government or any other third-party organization – become involved with the construction phases of TODs. At this point, debates or needs are supposed to be finalized, and constructional (physical) work is the measurement of developers' success on TODs.

Finally, residents are the key directly-engaged stakeholders of TODs. The decision of needs might be at the various range due to the diversity of residents of the TOD environment. People living in the prospective TOD environment, visitors of the environment, and employees or business owners of the local environment within the TOD zone are all considered to be in this category. During the design or hearing phases of TODs, many of these stakeholders express their preferences for new developments in TOD zones because after all, the process affects all stakeholders. They may be asked to participate in surveys, design meetings, or brainstorming sessions about the TODs. So, residents generally play an active role throughout the entire process of planning, designing, and constructing TODs.

*Indirectly-Engaged Stakeholders*

Local transportation authorities can be considered indirect engaging stakeholders even though they may also be directly involved in the physical built environment aspect. The local transportation authority, due respect within different states or cities with the regulations, generally maintains two essential roles: development control and planning. A transportation authority may give authority to planning officers or engineering teams, and act as a mediator between the various parties involved in TODs – the developer, designers, and residents – to balance potential conflicts between stakeholders. As Duffhues et al. (2014), Belzer et al. (2004), and Greenberg (2004) indicate, various stakeholders often have competing and contradictory interests that will need to be balanced and negotiated.

The next set of stakeholders who engage with the TOD phases indirectly are politicians. Local politicians may have the power to act as a direct developer. However, their roles mainly include more general schemes. Key local government decision-makers have to account for the needs and vision of the larger community as a whole; this means that they are continually being challenged to make tough decisions in the face of resource constraints. A forum that brings stakeholder groups together, therefore, can help alleviate or even overcome the short-term pressures faced by many politicians. Such a forum may allow for a greater understanding of what decisions are possible in the short term, which in turn advances the TOD agenda in the long term. A transparent decision-making framework, therefore, becomes essential in building trust between all stakeholders, mainly for political leaders, as they negotiate trade-offs, benefits, and consequences. Acknowledging the multiple-actor dimension, and allowing for honest and constructive engagement between the stakeholders comprise the key for the success of these relationships as many planning theory offers some guidance on a more communicative rationale for decision-making (Cornwell, 2008; Healy, 1993; Willson, 2001).

As a general conclusion of TOD stakeholders, various stakeholders try to understand how each one of these groups pursues its particular goals, what are the motives underlying attitudes and how many, occasionally conflictive, interactions between different stakeholders take form in the TODs. As expected, each of these groups is not heterogeneous, and it is bounded by particular responsibilities. Some common characteristics can be found in each type of stakeholder. Considering the TOD scale and complexity, the stakeholders and the idea that it varies in different parts of a built environment makes it challenging to allocate TOD solutions at the site from local or regional aspects.

**Unpacking the Heterodox Sound Pattern among the TOD Actors: What does a designer/planner/transit authority envision and what does a resident hear in a TOD?**

Considering the sound aspects of the aforementioned TOD actors, it is expected to have various points of view due to the nature of the engagements. When we look at the role of architects, urban designers, and landscape architects in TODs, they attempt to bear in mind the sound and noise attributes of some built environment features.

Based on the first essay findings, urban designers and architects took into account the traffic-related sounds –rail and automobile- and some natural sounds –waterfall features- in the designing and planning phases of TODs. However, residents and visitors of TODs, are still experiencing cars, buses, and trains noise. According to the survey I conducted, residents prefer to hear more natural sounds since they expressed that they hear more traffic and construction sounds in TODs. Furthermore, transit authorities and policymakers have less authority or involvement in sound and noise features. However, they highlighted that their concerns are more related to transportation-related noise. So, they aim to reduce vehicle noises with regulations and zoning ordinance with some policies. Based on these examples, my research highlights that directly and indirectly-engaged stakeholders of TODs do not have consensus on sound context. While designers, planners, architects, and policymakers are concentrating on different sound and noise roots and implications, residents are exposed to some other sound and noise sources. Therefore, as a solution to this disagreement, all actors should come together in some sound-related workshop/charrette types of community meetings to express their preference for sounds from TODs. By doing this, as my study findings emphasize, major concerns would be solved regarding the soundscape approach.

**How should a TOD sound like?**

***Pre-development policy approaches***

In cases, almost all existing ones, the sound is not considered in the phases of TODs. So, in order to eliminate this problem to improve the QoL of residents, the sound should be included in the phases of TODs. So, the sound should be added in various phases of TODs. To start with the pre-design phase of TODs, designers, planners, transit authorities, and neighborhood organizations should initiate sound-related ideas. For instance, on the basis of a scenario case, a workshop for a pre-development phase of TOD on soundscape may include the presentation of task (i.e., DART D2-Central Business District- Subway Project), soundscape addition phase for the residents, employees, employers, architects, urban designers, landscape architects, urban planners, city officials, transit authorities, and non-profit neighborhood organization with an informative agenda including the potential transactive relationship of sound and urban environment with the proposed TODs.

***During the development policy approaches***

In a similar concept of pre-development approaches, a workshop can be fulfilled during the TOD implementation phase. While several environmental and community engagement meetings are organized, soundscape implications would be a beneficial task for participants with oral, written, and interactive engagement activities. TOD design and planning can also be enhanced by various activities, such as sketching or listening practices of the potential TOD noise sources. Even though transit authorities coordinate series of meetings regarding community information, those neighborhood meetings generally include only noise and rail-related vibration prediction activities (i.e., DART Cotton Belt Corridor Noise and Vibration Impact Assessment). Therefore, there is a need for sound-related additions such as workshops or charrettes so that all stakeholders of TODs can participate in the process during the TOD implementation phase inclusively and this exercise may offer on the emergence of sound-related policies.

***Post-development policy approaches***

Post-development policy approaches can occur in various ways. While the majority of the existing policies are mainly about traditional zoning codes, there are also form-based codes and other relevant design-build standards at the local city and transportation authority-related, regional, or national scales.

Beginning with traditional zoning codes, the United States Housing and Urban Development Department (HUD) has produced one of the most comprehensive traditional zoning codes on sound (Table 15). Based on HUD's sound criteria on traditional zoning code, there are three categories; acceptable (sound level is below 65 dB(A), normally unacceptable (between 65 to 75 dB(A), and unacceptable (sound level is over 75 dB(A). HUD also proposes that the interior sound level not be more than 45 dB(A) (HUD 24 CFR B, 2013).

**Table 15:** HUD Site Acceptability Standards (HUD 24 CFR B, 2013)

| Noise Zone | Day-night average sound level (in decibels) | Special approvals and requirements |
|---|---|---|
| **Acceptable** | Not exceeding 65 dB | None |
| **Normally Unacceptable** | Above 65 dB but not exceeding 75 dB | • Environmental assessment and attenuation required for new construction<br>• Attenuation strongly encouraged for major rehabilitation<br><br>Note: An environmental impact statement is required if the project site is largely undeveloped or will encourage incompatible development. |
| **Unacceptable** | Above 75 dB | • Environmental impact statement required<br>• Attenuation required for new construction with approval by the Assistant Secretary of CPD or Certifying Officer |

The City of Los Angeles includes one of the most comprehensive regulations at the local city-scale (Figure 19). The city of Los Angeles has numerous ordinances, and enforcement practices that apply to intrusive sound and that guide existing developments or new constructions. The City's "all-inclusive" noise ordinance (LAMC Section 111 et seq.) inaugurates sound measurement and criteria, minimum sound levels for different land-use zoning classifications, as well as specific uses (radios, television sets, vehicle repairs and amplified equipment, etc.), hours of task for more specific cases (construction activity, rubbish collection, etc.), and standards for defining noise (City of Los Angeles, 2010).

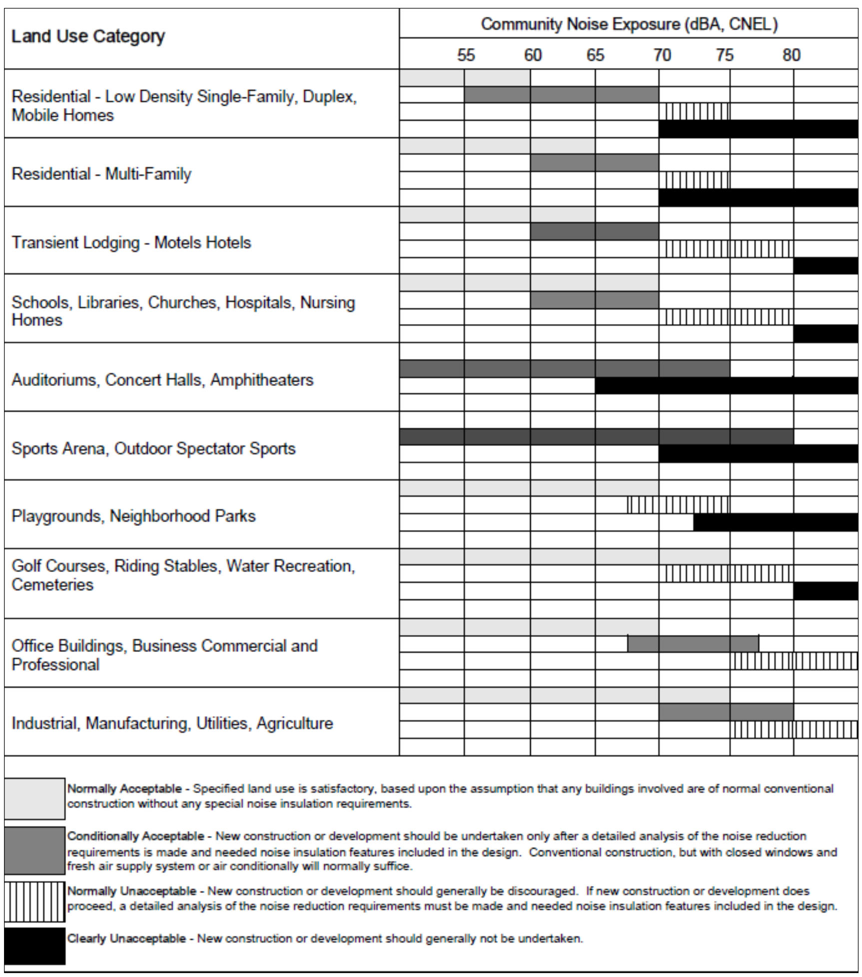



**Figure 19:** Sound Level Criteria on Traditional Zoning Codes and Special Events of the City of Los Angeles (Source: California Office of Noise Control, Department of Health Services, 2010)

When we look at the form-based codes, it is generally considered as a part of the zoning or design guidelines of local cities. To illustrate, the city of Lansing has included noise in several form-based codes, such as under general provision, and minimizing the noise level for accessory use of residential areas. For the general provision, the guideline includes specific standardization as such:

> *Audible noise or the sound pressure level of a WESC or TMT shall not exceed 55 decibels at any property line. No WESC or TMT shall create, regardless of decibel levels, any ticking, humming, or another sound which annoys, and finally noise and sound pressure levels may be temporarily exceeded short-term events such as utility outages and/or severe wind storms.* (City of Lansing Zoning Ordinance User Guide, 2017).

Also, since the main concentration of a form-based code is how buildings are in a relationship with the street, as opposed to traditional zoning that is more focused on what types of uses or events are happening, several cities, including Cincinnati and Virginia Beach, have now included sound criteria in the streetscape guideline (Madden & Russell, 2014).

While each state or city adopts various noise-related policies, here I focus on the standards set by the state of Texas. The Texas Department of Transportation (TxDOT) has released a traffic noise toolkit that highlights traffic noise; the toolkit is governed by the National Environmental Policy Act (NEPA) and addressed by roadway projects and the Federal-Aid Highway Act. This act ensures that the Federal Highway Administration (FWHA) establishes and publicizes guidelines and standards for highway-related noise levels so that interested parties, such as organizations, urban planners, traffic planners, and environmental practitioners, may know and benefit from the established standards and regulations. Figure 20 shows how FHWA has categorized sound, based on certain sound levels and land use activities.

Based on this tool, suggested sound levels for residential developments is 67 dB(A), as it is for many other outdoor activities taking place in and around hospitals, libraries, parks, trails, and so forth, while the sound level for hotels, offices, restaurants, and other categories that are not listed in Activity category 4 and 5 is 72 dB(A).

| Activity Category | FHWA (dB(A) Leq) | Description of Land Use Activity Areas |
|---|---|---|
| A | 57 (exterior) | Lands on which serenity and quiet are of extra-ordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. |
| B | 67 (exterior) | Residential |
| C | 67 (exterior) | Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, day care centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section 4(f) sites, schools , television studios, trails, and trail crossings |
| D | 52 (interior) | Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios |
| E | 72 (exterior) | Hotels, motels, offices, restaurants/bars, and other developed lands, properties, or activities not included in A-D or F. |
| F | -- | Agricultural, airports, bus yards, emergency services, industrial, logging, maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing. |
| G | -- | Undeveloped lands that are not permitted. |

**Figure 20:** Suggested sound levels of TxDOT for the various land use activities (Source: TxDOT Environmental Affairs Division, 2019).

Apart from the transportation-related guideline for the state of Texas, there are more specific sound-related guidelines at the city scale. For instance, the city of Houston has categorized its maximum permissible sound levels into two main strands: residential property (65 dBA for daytime and 58 dBA for nighttime hours) and nonresidential property (68 dBA for all times) (City of Houston, 2017). In another and closer example, the city of Fort Worth has issued a sound regulation on building codes that include residential, commercial and mixed-use areas. Based on this regulation, the allowance sound level for residential properties is 70 dbA for daytime and 60 dBA for nighttime, while commercial and mixed-use developments are 80 dBA for daytime and 70 dBA for nighttime (City of Fort Worth, 2012).

Considering the Texas state for sound and noise-related policies and regulations, dealing with noise and controlling it to under some levels goes back to the 1960s when the National Environmental Policy Act (NEPA) and a year later Federal-Aid Highway Act involved abatement of roadway traffic noise (Texas Department of Transportation, 2011 p. 2). Since then, it is hard to say that noise regulations have been changed. Considering to have a noise regulation on TODs is also a miracle in Texas. Therefore, based on my findings, noise regulations and policies are incredibly “outdated” and “forgotten”. Furthermore, enforcement and city codes in the state of Texas generally refer to the "subjectivity" of noise regulations as Texas Department of Transportation highlighted: "The determination of "unwanted" (refers to noise) sound is very subjective and can vary substantially from one person to another (Texas Department of Transportation, 2011 p.19).” This uncertain approach of including subjective manners results in unreasonable noise both indoor and outdoor places in the state. In a very similar statement, the city of Austin defines noise as such: "a) is louder than that permitted in this chapter, or b) disturbs a reasonable person of normal sensibilities" (The City of Austin, Texas 1992). Therefore, since the determining what "a reasonable person of normal sensibilities" is an extremely challenging term, it is difficult to figure out the noise, and its features as the interpretation of this statement are too vague.

Based on these uncertain and vague regulations, however, my research highly recommends local officials, transportation-authorities, and form-based organizations to create a comprehensive guideline on sound for urban planning and landscape architecture practices by considering the World Health Organization's suggested sound levels and TxDOT guidelines. I am assured that a prospective list could offer a great potential to be extended with various activities as cities need to figure out noble strategies on TODs for dealing with noise within the urban environment.

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