“Are We Connecting?” Planning Barriers to Transportation Network Connectivity in the Phoenix Metropolitan Region

by

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ABSTRACT

Transportation network connectivity has been linked to positive urban outcomes, including increased rates of active transportation, reduced reliance on automobiles and other social and economic benefits. While many stakeholders in greenfield development processes have emphasized the positive benefits of connectivity and connectivity has increased in many U.S. metros in the past two decades, many street networks remain fragmented and local connectivity remains far below that of historic patterns. This paper explores barriers to and influences on connectivity outcomes in new community construction in the Phoenix metropolitan area, employing mixed qualitative and quantitative methods. Interviews were conducted with members from various stakeholder groups in the subdivision development process. Case studies were developed with space syntax and network analysis measurements to illustrate the influence of variables and stakeholders on the planning process. Participants illustrated a complex political and economic reality surrounding the concept of connectivity, with site conditions and development market dynamics playing the clearest roles in shaping connectivity. The result is subdivisions are achieving moderate levels of connectivity and improving from historic patterns of dendricity but remain entrenched in planning paradigms built around self-contained sites and the policy and market limitations for robust connectivity beyond individual developments.

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1 INTRODUCTION

Overview: Context for Streets in the Modern City

Streets continue to become a greater topic of interest amongst American planning scholars and practitioners as vehicles for solving environmental, economic, and social challenges presented to the urban world in the 21st century. Given the environmental consequences of the current arrangement of the American transportation system (35% of all emissions as of 2020), which has risen with America's continued reliance on the automobile (Environmental Protection Agency, 2021). Street design and composition has been observed as a key determinant of transportation futures, and poor decisions about streets may lead to less resilient futures which lock in energy and carbon-intensive pathways throughout society which are difficult to uproot (Barrington-Leigh and Millard-Ball, 2019). Streets are also increasingly interpreted as the laboratories for the implementation of new technologies (National Association of City Transportation Officials, 2013). Recent protest movements, particularly surrounding racial injustice and unrest in Western countries, have reignited conversations about the street as essential public and democratic space, since streets become the spaces of visibility for the marginalized and those in protest (Kohn, 2004; Tiwari, 2017; Fagg, 2021). Interest in new street design trends is rising as sprawl continues outward, particularly as jobs decentralize and suburban space must take on more diverse land use patterns and different demands on the urban street (Ingram, 2011; Lopez, 2014).

Creating a sound network of streets is critical to the longevity of a sustainable city, and a poorly designed network can almost permanently embed shortcomings and ills of the urban environment. In a modern narrative of streets, *The History of Street Networks,* Laurence Aurbach demonstrates a key fact about urban space which is especially true in the United States: that while the organization and composition of street space is fluid and has been reimagined in countless ways, the location and orientation of streets is largely permanent in urban space (Aurbach, 2020). The location of streets rarely changes, even after major shocks and system overhauls to cities, and the organization of streets and subsequent effects are rarely erased from the built environment.

Such a sentiment is echoed by many planning scholars who call attention to the permanent consequences that the location of streets and the design of broader street networks has on the development of urban space. Streets have been described as the “virtually permanent backbone of the city,” serving as the primary routes of movement through cities and determining the durable means by which urban services are delivered (Barrington-Leigh and Millard Ball, 2019). By serving as spaces of both mobility and accessibility and arrival, streets become vital entities in determining the vitality and success of cities (Zavestoski and Agyeman, 2014). Streets serve as the primary venue for social activity, a sentiment understood as early as Jane Jacobs’ seminal work which describes streets as a fundamental variable in the quality of social and economic life in the city, fundamentally altering how cities experience local economic activity, build social resilience and manage crime (Jacobs, 1961; Southworth and Ben-Joseph, 1997). Streets have been called a “prerequisite for resilient cities,” and understood to be essential to building cities that can weather the dynamics of changing climate, weather, and Earth systems (Feliciotti, Romice and Porta, 2016; Lydon, 2017). Scholars thus point to a strong conclusion that the street is a fundamental building block of the city which must be treated with care by planners and planning actors, given the effects that street and street network design have on the basic functions of the city. It is essential to understand not only the outcomes, but also the processes, which shape a feature of the urban environment that is nearly permanent and expensive to retrofit to better ends.

Planning practice manuals and professional literature echo the same sentiment. The 2013 Urban Design Manual written by the National Association of City Transportation Officials takes these practiced beliefs a step further to suggest that streets are the “interstitial space,” serving as the “catalyst by which cities are enabled to exist” (National Association of City Transportation Officials, 2013). The New York City Street Design Manual employed by America’s largest local transportation authority describes streets as essential to any “quality of life” and “functionality” of urban space, places where all urban actors make demands on space which must be accounted for in the planning practice (New York City Department of Transportation, 2018). The Manual for Streets published by the James Taylor Chair in Landscape and Livable Environments states that streets provide five basic functions for cities, three of which are essential to the basic life of the city: movement, access, and the foundational idea of place (James Taylor Chair, 2011). This selection of professional literature demonstrates the reach of the conceptualization of streets as essential to the function of urban places, and fortifies the importance of street design and street placement in the planning profession.

Introducing Streets as Networks

One functional conception of streets comes through the application of network theory to street networks in urban space. Discussions about urban systems, such as transportation, are best served by being introduced through the lens of network design. A network at its heart is a distribution of various distinct features, normally vertices and edges (with other complex elements added to this simple framework), with relationships built up through the distribution of these features and their relationships to one another in the network. Networks are found in a diverse array of settings. Developing from graph theory, network understandings of systems have been taken up by new disciplines, including urban planning, as a method of reliable quantitative analysis and discovering interdependent relationships.

Considering practical application to the planning discipline, street networks are a foundational type of spatial network found in cities. Streets represent spatial networks insofar as they function as “connected linear elements” producing “enduring networks” between origins and destinations distributed through space, most often with intersections and junctions representing nodes and street segments representing linear edges throughout the network (Marshall et. al., 2018). While alternative conceptions of street networks exist, the majority of planning practitioners rely on this model for understanding street systems in cities as networks to be analyzed quantitatively (Porta et. al., 2006; Marshall et. al., 2018).

Spatial network design has become a primary means of understanding street networks, and has become a framework frequently employed by transportation planners in a diverse array of problem settings (Farahani et. al., 2013). The application of networks in planning is moving beyond disaster and utility planning to measure many other properties of the form and function of urban space. Networks provide an analytical tool for understanding urban territory and how people may interact with it (Dupuy, van Schaick and Klaasen, 2008). The number of problems in planning to which network systems and theories have been applied is growing (Sevtsuk, 2014), as poor street network design begins to apply costs to cities in the United States and abroad and cause major impediments for installing urban sustainability and resiliency into the modern city.

Network theory applied to streets uses a foundation of three interconnected components which can be used to understand the nature of street networks - density (or centrality), configuration and connectedness (Marshall, 2005; Marshall, Piatkowski, and Garrick, 2014). Scholars frequently point to street networks that have many areas of high centrality (Schuerer and Porta, 2006; Hillier, Yang and Turner, 2012), are configured to promote legibility, visibility and direct movement (Lynch, 1961; van Nes and Yamu, 2017) and, most importantly for this paper, provide a high degree of connectedness to create numerous choices of direct routes through cities (Marshall, Piatkowski and Garrick, 2014; Boeing, 2020).

Planning literature continues to emphasize the connectedness of urban systems as a critical determinant of urban outcomes (Boeing, 2020). Connectedness, or connectivity, affects the number of routes that can be chosen between origins and destinations (that is, increased complexity), the distances between origins and destinations, the "relatedness" of different urban features, and the overall efficiency of movement through an urban system (Barnes, 1969; Peponis et. al., 2008). In urban studies, connectedness is most often applied to street networks, especially given the role of streets in most urban places to serve as the primary channels of movement and access in urban space. Connectivity is a variable applied to the understandings of many urban phenomena, including public health outcomes (Oakes and Forsyth, 2007; Marshall, Piatkowski and Garrick, 2014; Iravani and Rao, 2020) , environmental sustainability and resiliency (Lee, 2019; Sharifi, 2019), land use (Ozbil et. al., 2015; Koohsari et. al., 2015), and transportation performance and mode choice (Pasha et. al., 2016; Zlatkovic et. al., 2019). Debates surrounding connectivity and the importance of its implementation through urban policy are built on the evaluation of the benefits connectivity can provide in such topic areas. While connectivity remains relatively favorable and sought after in numerous corners of planning academia, implementation remains varied and contentious amongst planning practitioners, and less is known about the political economy surrounding connectivity in the planning practice. This paper finds its home within this topic of connectivity and its uptake in planning practice.

Research Problem

As introduced in the preface of this paper, streets are a near-permanent component of the built environment. Once constructed, streets rarely move and are unlikely to change without costly retrofit or urban restructuring (Marshall, 2005). Street network designs fundamentally alter how mobility and accessibility will be experienced in cities over long time horizons.

However, these permanent street networks, as they are currently being built in the United States, may be failing to build the foundation for a sustainable and resilient urban future. Street connectivity has fallen dramatically in the United States since the 1930s, and has only begun to increase once again in the past two decades (Barrington-Leigh and Millard-Ball, 2019; Boeing, 2020). Disconnected street patterns have played a fundamental role in producing what is often characterized as “urban sprawl” from a transportation perspective - disconnected, disorderly and low-density street networks spreading outward with accompanying low-density urban development (Gundmondssen and Mohajeri, 2013; Barrington-Leigh, 2015).

Thus, a sprawling street pattern is set into the landscape of the United States, with repair sure to be costly for public and private actors alike and the effects of sprawl becoming more difficult to remove from the urban environment over time (Ewing and Hamidi, 2015; Spirkova et. al., 2020). As cities continue to expand outward, street network design in greenfield development will continue to serve as a determinant of the sustainability of the American city, given the lack of change exhibited in street networks over time (Romem, 2016). Continuing similar patterns of disconnected streets may play a major barrier in the improvement of transport and land use sustainability in American cities for the foreseeable future (Talen, 2011). Additionally, a lack of academic knowledge and potential practiced solutions for producing more sustainable transportation networks continues to inhibit action toward greater transportation sustainability.

Research Rationale

Hundreds of studies have been published in the past two decades suggested a measurable relationship between connected street patterns and positive urban outcomes (meta-analyses, such as Ewing and Cervero, 2010; Wang and Wen, 2017; and Naess, 2019, provide a glimpse at the scale of studies completed on the subject). However, less is known about how stakeholders in the planning practice interact with the concept of connectivity. While a handful of communities, such as Eugene, Oregon and Salt Lake City, Utah, have introduced public connectivity policies widely hailed as innovative in the past 20 years, there is little known about how connectivity is being implemented.

It is understood that connectivity is increasing in American cities, albeit slowly, and these gains have been linked to increases in sustainable urban behavior and function. But less is known about how connectivity is being reclaimed in the current American planning environment, and why connectivity is implemented in certain urban settings and not in others. It is critical to gain understanding of these questions about where connectivity is being increased and why, in order to inform planning professionals and produce more articulate policy to increase urban street network sustainability.

It is especially important to improve understanding of how connectivity is approached in the planning practice in America's fastest growing cities, where population continues to grow and outward expansion is continuing at a rapid pace. Many of these fast-growing metros, such as Phoenix, Las Vegas, Houston, and Dallas, are concentrated in the “Sun Belt” region of the United States. Many metropolitan areas in the Sun Belt have demonstrated population growth rates of 10 to 20% and year-to-year growth rates hovering around 1.5 to 2% (U.S. Census Bureau, 2020). This explosive growth is creating high demand for greenfield development; an illustrative example can be found in Phoenix, Arizona, where over 270 square miles of new greenfield development was constructed between 2010 and 2020. The manner in which this greenfield development demand takes form will likely determine how Phoenix is able to improve upon urban sustainability and resiliency in future decades. Developing an understanding of connectivity in Phoenix and other Sun Belt metropolitan areas is crucial for building capacity for sustainable urban growth in the current planning environment in the United States.

Research Questions

The purpose of this research is to answer the following question, in light of the context and rationale for research put forth in this section:

“What variables currently shape the implementation of transportation network connectivity in the Phoenix metropolitan area?”

The following secondary research questions are assessed in this study:

- What attitudes toward connected development shape the decisions of stakeholders in the greenfield development process in Phoenix?
- How do various stakeholders in the greenfield development process in Phoenix shape connectivity outcomes in new developments?

- What are common barriers to the implementation of connectivity in the Phoenix metropolitan area?
- Which inputs in planning processes have promoted connectivity or improved connectivity outcomes?

Research Objectives

The following are the main qualitative objectives of this research paper:

- Define relationships between stakeholders in the process of greenfield neighborhood design and how connectivity is shaped by actors in these processes in Phoenix.
- Assess attitudes toward street connectivity amongst public and private stakeholder groups involved in greenfield development in the Phoenix metropolitan area.
- Determine common barriers to implementing transportation network connectivity in the planning environment of Phoenix, Arizona.

The following are the primary quantitative objectives of this research paper:

- Provide preliminary quantitative evidence of connectivity outcomes in modern greenfield residential developments in the Phoenix.
- Develop case studies illustrating how transportation network connectivity is affected by various stakeholders and processes in the Phoenix metropolitan area.

2 Literature Review

Defining Connectivity

Practical Definitions for Study

As street connectivity and network design becomes a more important property of urban design affecting planning policy, it is critical to produce a precise definition for what connectivity is and how connectivity relates to similar concepts in the discipline of urban transportation planning. In its narrowest and most quantitative sense, connectivity can be defined as the “number of connections and paths a street network can produce” (Ewing, 1997). However, connectivity applied to urban space demands broader definition which better capturs the overall function of connectivity in the built environment. An alternative effective definition of connectivity is the measurement of “how well streets connect to one another, and the density of locations where changes in direction can occur” (Mecredy et. al., 2011). Echoing these definitions are those used by many American transportation planning agencies, stating that connectivity reflects “how well street networks enable multiple routes between the same origins and destinations.” (Chester County Planning Commission, 2019; Kentucky Transportation Cabinet, 2020). Many local ordinances, such as Eugene, Oregon; etc., define connectivity by specific street network properties which offer functional benefits for a community (Handy, Paterson and Butler, 2003).

Many planning practitioners use a broader definition of connectivity, understanding it as “how well streets connect to one another” (Utah Department of Transportation, 2020) or, similarly, “the number and quality of street connections” (Lehigh Valley Planning Commission, 2011). In the American Planning Association’s guide to street connectivity policy, connectivity is assessed as the “quality of connections in a street network" (Handy, Paterson and Butler, 2003; Handy and Boarnet, 2010). The term quality in these definitions provides implicit insight, demonstrating that not only is the proliferation of street connections important for urban function, but also the function of those streets and connections and how they allow for quality movement for different modes of transportation. Some scholars also add the "directness of available routes" to this broader definition of connectivity, reflecting that connectivity leads to broader patterns in the urban landscape.

This paper will take on aspects of the broader definition of connectivity posited by planning professionals, defining the term as how often a street network intersects with itself and the quality of those connections insofar as it allows for changes in direction and new routes to be formed across urban space.

Connectivity as Proxy for System Complexity and Resilience

At a simple level, connectivity provides complexity through greater combinations of choice within a network, providing redundancy and greater route choice in urban street networks. Such redundancy spreads drivers, pedestrians, and other street users throughout urban space as new routes become available. This dispersion of urban activity results in greater opportunities for urban activity to form, including retail and other urban services, and provides detour routes and relieves congestion on centralized areas and routes which can cause system failure (Sharifi, 2019; Fusco and Venerandi, 2020). Such defense against system failure is one hallmark of a resilient and complex system (Tomaszewski et. al., 2009). Street connectivity has been defined as a proxy for a resilient system with appropriate complexity to handle the non-linearity of modern urban challenges (Feliciotti, Romice and Porta, 2016).

More theoretically, connectivity is described as a key component for complex systems; that is, non-linear relationships between constantly changing components which together form a single cohesive pattern of behavior across multiple layers (Turnbell et. al., 2018; Mata, 2020). Applying this to real space with street networks, connectivity can alter transportation behavior in non-linear ways, and is an essential part of building resiliency and complex decision pathways in cities at multiple layers, both at local and broader urban scales (Fusco and Verenandi, 2020). Connectivity provides opportunities for many new decisions to be made in urban space; in transportation, new routes which can provide opportunities for different efficiency calculations (i.e. which mode of transport to take based on costs), transportation influences on urban structures (i.e. land use) become far more complex and resilient, and the greater flexibility in decision pathways can result in systems more suited for urban change over time.

Necessity of Defining Accessibility and Connectivity in Relationship

Connectivity differs in definition from the concepts of accessibility and urban access. While producing a precise definition for these concepts is a slippery ordeal, this must be done to produce a correct understanding of the concept of connectivity and its potential roles in the urban fabric (Gutman and Patel, 2017). David Levinson and David King provide a definition of access in urban space rooted in political economy, defining it as “the ability for people and firms to interact, whether through employment, production, consumption or sales” (Levinson and King, 2008). Other academics define access as the ease in reaching urban destinations (Farber, 2016). Sustainability literature has framed this conceptual “ease” of access in terms of energy use and time required to reach destinations, taking real resources from and causing externalities upon all urban residents (Song et. al., 2017).

While the definition of accessibility remains difficult to pin down, a clear distinction which is central to developing broader conversations about the implications of street connectivity and network design emerges in the discourse on accessibility. Connectivity captures the ability for transportation network users to maximize movement through space, whether through additional routes or additional efficiency and variety between different modes of transportation, In this sense, connectivity becomes a “destination-less” measurement which integrates knowledge about how network form will ultimately shape urban behavior. In contrast, accessibility has been traditionally defined by the availability of destinations in an urban network for various users and is applied by considering a network’s ability to produce interactions and connections within urban space in political, economic, and social dimensions.

Accessibility has historically remained a largely theoretical definition and scholars have increasingly called for a more practice-oriented approach to accessibility capable of handling the complex and often political realities of urban systems (Koenig, 1980; Levinson and King, 2008; Guida and Caglioni, 2020). A recent scholarly push for a more comprehensive understanding of urban access by policy experts in urban planning, engineering and finance has led to the development of a three-pronged approach to accessibility which serves as a telling indicator of the current direction of practice-oriented literature surrounding accessibility (Gutman and Patel, 2017). In this three-pronged approach developed by Ventner, Mahendra and Hidalgo, access can be defined as the “quality of mobility,” “access to suitable transport” and “access to opportunity” (Ventner, Mahendra and Hidalgo, 2019). While the third prong of this approach addresses accessibility as more traditionally understood in the transportation planning discipline, the other two prongs develop a broader understanding of access which ties together the concepts of both accessibility and connectivity, insofar as they determine outcomes of socioeconomic activity in the city. Connectivity and network design can fundamentally shape urban access and the ability of a city to provide pathways to full participation in urban functions.

Measuring the Effects of Connectivity

Tools and Methods Used for Studying Connectivity

While accessibility literature begins to take a more comprehensive approach to integrating mobility and accessibility as systemically linked properties of the urban environment, much of the transportation planning practice has failed to develop policy mechanisms which achieve this integration. This is particularly apparent in the property of connectivity and assessing its effects, benefits and drawbacks on the function of the modern city. Connectivity is often measured as a distinct property of the urban landscape which is indicative of greater benefits for urban efficiency, quality of life, and sustainability (Handy, Paterson and Butler, 2003).

Street connectivity and the effectiveness of various neighborhood design strategies has been most critically examined through quantitative connectivity literature. This class of literature distills the built environment into quantitative phenomena which can be measured in a variety of urban settings to examine statistical relationships between these quantitative characteristics and other variables or urban outcomes, such as active transportation trips, traffic safety measurements or public health outcomes.

A myriad of variables have been used to attempt to measure the connectedness of a transportation network. The most commonly used variables are intersection density and block length, which respectively measure the number of intersections (three or more links) in a given area and the length of one or both dimensions of an urban block. The prevalence of these metrics is likely due to the less involved computational processes needed to calculate these measures and the relative lack of difficulty in translating these straightforward metrics into policy in the planning discipline (Handy, Paterson and Butler, 2003; Boeing, 2020). Other common metrics include link-node ratio (LNR), which measures the ratio of network links (segments between intersections) and network nodes (intersections), and intersection type ratio, generally measured by calculating the percentage of intersections in a given area which are four-way intersections (Boeing, 2018).

As computing power has increased, the complexity and dynamism of connectivity measurements has increased accordingly. Most notable has been the rise of network-based scores which require significant computing power to create large numbers of routes to assess the function of street networks, using street connectivity and other variables to assess the function of urban street networks. One commonly used network-based score has been the route directness index (RDI/GRDI), which assesses the ratio between a direct route between points and the network distance between those same points (Hess, 1997; Randall and Baetz, 2001; Ciscal-Terry et. al., 2016). These points can be parcels or various types of destinations in the urban environment (Stangl, 2019). Network GIS tools, such as ESRI's Network Analyst extension, or other specialized tools such as ViaCity by TranspoGroup are used to run such analyses in academic and professional planning environments.

Another set of metrics made increasingly common in connectivity literature are metric and directional reach, set forth by Peponis, Bafna and Zhang (2008) and expounded upon and applied in other quantitative network studies (Ozbil, Peponis and Stone, 2011; Feng and Zhang, 2019). Metric reach measures how many street network segments can be reached within a certain set network distance from a point or set of points, while directional reach assesses the same metric reach while seeking to maximize the number of segments which may be reached in a particular cardinal direction (Ozbil, Peponis and Stone, 2011). These metrics have demonstrated one pathway for beginning to tie connectivity and urban network design to accessibility and the use of urban space, particularly in transit accessibility and performance studies (Lee, 2005; Ozbil and Peponis, 2012; Farber and Marino, 2017; Manout, Bonnel and Bouzouina, 2018) and increasingly used in assessments of urban accessibility for many services and the quality of access for various modes of transportation (Tal and Handy, 2012; Guida and Caglioni, 2020).

Greater computing power in the 21st century has also transformed the scale at which connectivity and network design measurements can be completed, creating new possibilities for understanding macro-scale trends in how the built environment shapes urban behavior. Open source network data (i.e. OpenStreetMap) and accompanying available tools for completing large-scale coding and geospatial assessments (i.e. OSMnx) have fundamentally changed the scale at which analyses and measurements of urban networks can be completed (Boeing, 2019). These tools have used straightforward connectivity metrics across national and global scales to understand longitudinal trends over time and to present broader trends in network design (Boeing, 2020; Barrington-Leigh, 2020). Space syntax methods, which test the spatial configuration and functional properties of street networks and individual streets with measures such as integration and betweenness, have begun to provide network-wide measurements which can offer opportunities to understand social organizations and interactions within a network, creating new understandings in the value of connectivity in affecting the sociospatial nature of cities (Hillier and Hanson, 1984; Yamu et. al., 2021).

As complexity in measurements of connectivity and network design have increased the quantity and scale of connectivity studies, so too has it increased the ability of scholars to combine connectivity and network design metrics to produce neighborhood typologies and more complex variables that are more closely related to experienced conditions in the urban environment. Scholars have increasingly relied on scenario modeling of sample network areas exhibiting different levels of connectivity and network redundancy (Berrigan, Pickle and Dill, 2010), the production of neighborhood typology (Stangl and Guinn, 2011), or the creation of connectivity indices which use GIS to combine the presence of multiple indicators of street connectivity and network redundancy into a single metric (Ozbil et. al., 2011; Knuiman et. al., 2014). The associations between walking behavior and connectivity, as discussed later in this review, have heavily factored connectivity into walkability assessments which are created from a host of different characteristics of the built environment (Carr, Dunsinger and Marcus, 2010; Shashank and Schuurman, 2019). Some scholars indicate the need to innovate in complex metrics to capture a truer reflection of the function of urban networks (Haynie, 2016).

Alternative measures have been applied to address statistical biases and the inability to capture some neighborhood dynamics in connectivity studies, such as the efficiency of external connections to surrounding urban destinations. Song and Knapp (2004) and Stangl (2019) have developed frameworks for understanding external connectivity through route directness indices and relationships between internal connectivity gains and the surrounding community, promoting the development of connectivity studies which tie internal connectivity gains to overcoming barriers to destination access in surrounding areas.

Measuring Connectivity to Meet Specific Purposes

Scholars continue to raise arguments pertaining to the purpose of measuring connectivity, asking a question of whom connectivity is supposed to serve. Arguments have been made to suggest that the primary purpose of connectivity is to support a wider array of modes of transportation, particularly pedestrians and bicyclists who are most affected by reductions in street connectivity and direct route creation in cities (Rodriguez and Joo, 2004). Efforts have been taken to measure connectivity with pedestrian and non-vehicular networks included to set research within the planning paradigm of supporting active transportation through interventions to improve connectivity (Tal and Handy, 2012; Ellis et. al., 2016). These efforts and accompanying studies run on such networks demonstrate that providing connectivity measurements on non-vehicular systems can fundamentally change how connectivity in a neighborhood is understood (Berrigan, Pickle and Dill, 2010). Studies have demonstrated that such alterations often demonstrate hidden additional connectivity benefits embedded in the form of traditional gridded neighborhoods (Chin et. al., 2008; Tal and Handy, 2012). Studies have also shown that measuring for non-vehicular connectivity can open opportunities for policy and lower-cost infrastructure interventions which can promote connectivity in urban forms with lower existing connectivity (Randall and Baetz, 2001; Berrigan, Pickle and Dill, 2010; Tal and Handy, 2012; Lundberg and Weber, 2014). Case studies in this paper build models in accordance with the findings of this literature.

Debates Surrounding Connectivity

Introduction to Academic Debate on Connectivity

Transportation connectivity has become a popular topic of study in the past two decades, as interest in compact city development has continued to rise and methodologies have been innovated to allow for widespread and consistent implementation of connectivity measurements, as discussed in this review. Connectivity metrics have been examined for correlation with a wide range of urban outcomes associated with resiliency and sustainability, including increased active transportation, physical activity, and economic productivity. Connectivity has been determined to play a crucial role in three variables relevant to this paper: a) reductions in car dependency and diversification of mode share; b) improvements to the function and resilience of transportation networks; and c) development of socioeconomic health in cities. This review categorizes relevant literature by these three primary variables identified through a broad range of emerging studies.

Reductions in Vehicle Dependency and Diversity in Urban Mode Share

Recent scholarship demonstrates that there are two means by which street connectivity reduces vehicle dependency and diversifies mode share in an urban transportation network. The first method involves increasing demand for alternative modes of transportation by making active transportation trips more attractive while inducing new trips due to increased network accessibility and the establishment of new economic and social patterns (Frank et. al., 2006; Berrigan, Pickle and Dill, 2010). The second method affects the existing supply of vehicle trips by reducing overall trip distance and vehicle miles travelled (VMT) on vehicle trips in a network. While these two effects are concentrated on shorter trips, these effects are interrelated and evidence supports that these effects play an important role in shaping the urban transportation economy of many American communities, especially given the fact that over 50% of all trips taken in the United States are less than three miles and are completed at a neighborhood scale compatible with active modes of transportation (Moudon et. al., 2005; Ercan et. al., 2017; INRIX, 2019).

Increases in Rates of Active Transportation

The relationship between compact neighborhood design (particularly neighborhoods exhibiting high levels of statistical connectivity) and increased numbers of active transportation trips is particularly well-developed. While these effects are generally weak (Berrigan, Pickle and Dill, 2010; Ding et. al., 2014; Hajrasouliha and Yin, 2015; Zlatkovic et. al., 2019; Handy, 2020) to moderate (Ewing and Handy, 2009; Ewing and Cervero, 2010; Fan, Wen and Koweleski-Jones, 2014), they are consistently observed as significant between regions and between neighborhood typologies controlled for other variables (Ewing and Cervero, 2010; Wang and Wen, 2017). Such consistency suggests a critical connection between street connectivity and the capacity of cities to support trips on foot or by bicycle, given the far more severe effect that increased trip distance and decreased trip efficiency from reduced connectivity will likely have on users of these modes of transportation (Buehler, 2010; Berrigan et. al., 2010).

The ability for street connectivity to increase trip efficiency in service of benefiting active transportation is well documented in academic planning literature. Efficiency is accomplished through connectivity through the reduction of distances between origins and destinations and the greater ability to provide easy connection and wayfinding between points, which is particularly supportive for transportation systems relying on active connections to transit stations (Kim et. al., 2016; Woldemanuel and

Kent, 2016). Connectivity also provides a diversity of routemaking that is critical for encouraging long-term shifts toward active transportation, with a mix of long and short routes with multiple, overlapping pathways for pedestrians encouraging various volumes of active transport traffic indicative of a complex system (Ozbil et al., 2011). Connecting active transportation users (particularly bicyclists and pedestrians) to longer possible trips through transit usage, connectivity improves local accessibility to transit stations for local users, often increasing transit system usage and providing transit efficiency through the placement of a greater number of potential users within reach of transit (Tasic et. al., 2016).

The capability of street connectivity to promote active transportation trips is frequently scrutinized but has enjoyed general consensus from quantitative study for the past two decades (Handy, Boarnet and Paterson, 2003; Ewing and Cervero, 2010; Wang and Wen, 2017; Hall and Ram, 2018), even as scholars have offered possible complexities in the findings revealed through space syntax and network analysis sciences tying these benefits to more complex variables such as network intelligibility and centrality (Scheurer and Porta, 2006, Sharmin et. al., 2018) or have relegated connectivity as a tertiary variable in decision-making surrounding active transportation trips (Pirro and Fisher, 2011). Deducing the relationship between active transport trips and connectivity is particularly difficult due to the susceptibility of the variable to self-selection biases, as individuals choose to live in neighborhoods based on transportation preference and thus select connected neighborhoods which may provide an environment more amenable to active transport trips (Ewing and Cervero, 2010). Studies on urban form and active transport have shown that there is a significant relationship between active transport trip generation and connectivity after controlling for this potential bias (Christiansen et. al., 2014; Kamruzzaman et. al., 2015).

Reductions in Overall Vehicle Miles Travelled (VMT)

While an increase in active transportation will produce the effect of lower vehicle miles traveled (VMT) amongst urban residents, a reduction in VMT also captures a broader ability for street networks to affect most vehicle trips as well. Connected street networks will often result in reduced travel distances, particularly noticeable on local trips in communities where connectivity is paired with greater local access to amenities, commercial activity and other urban opportunities (Fan and Khattak, 2008; Salon et, al., 2012).

Quantitative studies have demonstrated that higher street connectivity maintains an inverse relationship with VMT per capita (Frank et. al., 2007; Kakumani, 2010; Nordin, Majid, and Johar, 2012). Additionally, a myriad of recent models and studies have shown significant reductions in overall system VMT and overall trip costs (including commute, non-commute and trips related to service distribution) in networks with high street connectivity (Fan and Khattak, 2008; Ding et. al., 2017; Wygonick and Goodchild, 2018; Zlatkovic et. al., 2019). Street connectivity associated with lower energy use per capita (Randall and Baetz, 2001; Litman, 2016) and lower emission loads in most metropolitan areas (Ewing and Hamidi, 2005; Lee, 2020).

The effect of connectivity on VMT reduction has been found to be more individually significant than that of other urban design features, including land use diversity or regional employment accessibility (Ewing and Cervero, 2010; Salon et. al., 2012). These effects are particularly important in modern service economies where deliveries are common and service delivery is dispersed across urban areas; urban street connectivity and accompanying density of road links can significantly improve service performance and reduce environmental impacts of such deliveries through reduced VMT and improved route diversity (Wygonick and Goodchild, 2018; Amaral and Cunha, 2020). The relationships between connectivity and VMT are better understood because of the inelasticity of the variable of VMT, measuring reductions to existing trips without mode shifts which otherwise still take place.

Improved Transportation System Performance

Studies have associated street connectivity with improved transportation network performance and reduced congestion. Numerous studies and traffic analyses of intersections, corridors and broader network performance indicate that improvements to street connectivity (and producing its subsequent traffic distribution) and increases in network "betweenness" (or connectivity in relationship to accompanying links between nodes) can be an effective alternative strategy to road-widening and volume increases along major collector and arterial roadways, since traffic loads are distributed throughout networks and away from arterial segments and intersections (Tasic, Zlatkovic, and Martin, 2015; Zlatkovic et. al., 2019; Akbarzadeh et. al., 2019). This is generally supported by scholars studying street connectivity and street network design (Handy, Paterson and Butler, 2003; Marshall and Gerrick, 2011; Ewing, 2020). This finding was corroborated by other studies which demonstrated improved regional "level of service" on different types of network links in highly connected street networks (Zlatkovic et. al., 2019) and reduced overall congestion at intersections (Ewing, 2020), particularly in places where there is a minimal speed differential between high movement and low movement streets (Alba and Beimborn, 2005). A study by Barrington-Leigh and Millard-Ball (2017) found that higher connectivity neighborhoods also reduce long-term automobile ownership and vehicle demand for individuals, suggesting the ability for connected street networks to promote broader outcomes of reduced automobile reliance and strains on vehicle transportation systems.

Some studies suggest that there are limits to using street connectivity to promote system sustainability, and that a moderate level of connectivity may reap these benefits of improved system performance and network mobility in a way that high connectivity street grids cannot (Ryan and McNally, 1995; Handy, Paterson and Butler, 2003), even as high connectivity networks promote other positive outcomes such as decreased fatality risk and improved emergency service efficiency and access (Marshall and Gerrick, 2011). Some scholars have also suggested that networks with high levels of connectivity can be victims of their own success by promoting direct and efficient routes to large-scale destinations, causing a new form of congestion, particularly when local conditions and network layouts promote a large number of turns and route changes associated with connectivity (Wen, Chin and Lei, 2017).

Literature largely supports the theory that connectivity is capable of developing street network sustainability - that is, the ability for a transportation network to handle growth pressures and changes to the network environment. This is important as planners consider methods for transitioning away from sprawling patterns of development where congestion is managed by lowering densities and promoting new outward growth to handle increasing demand. At a practical level, studies suggest that connectivity can provide a planning alternative to capacity expansion with long-term savings produced through the reduction of demand for local capacity-increasing road projects as required in less resilient, low-connectivity systems (Tasic, Zlatkovic and Martin, 2019).

Improvements in Traffic and Pedestrian Safety

Connectivity has been determined to have effects on safety for vehicle drivers and active transport users. The effect of street connectivity on traffic safety is controversial and remains relatively undetermined by scholars. Connectivity has been associated with increased crashes with lower mortality, stemming from a greater number of available vehicle miles and conflict points associated with accidents (Marshall and Garrick, 2011; Tasic and Porter, 2016; Ewing et. al., 2016), though some studies tie a higher number of overall fatalities to connected street networks (Moeinaddini et. al., 2017). Street connectivity has also been linked to small to moderate decreases in vehicle crashes and overall crash mortality (Mohan, Bangdiwala, and Villaveces, 2017; Litman, 2017; Najaf et. al., 2018). Other studies show ambiguity toward a finding with no clear relationship between connectivity and vehicle safety (Gladhill and Monsere, 2012). It is difficult to determine the causes of increased traffic risk - studies show competing effects from street connectivity, where reduced VMT and vehicle trip demand can reduce overall probabilities of crash risk, but increased numbers of conflict points can produce more crashes (Marshall and Garrick, 2011). A review of literature loosely suggests that connectivity increases the number of potential crashes in a network but may reduce overall crash severity.

Pedestrian safety has been largely found to improve pedestrian safety (Zhang et. al., 2012a; Litman, 2017), though this is not a uniform finding (Graham and Glaister, 2003; Osama and Sayed, 2017). Some measures, such as street density or calculations which measure with pedestrian facilities included, may provide more stable predictions of pedestrian safety returns from connectivity (Zhang et. al., 2012a; Osama and Sayed, 2017). A great number of studies suggest improvements in traffic safety for all users due to connectivity, particularly in the reduction of severity in accidents, though this may be heavily influenced by other factors in urban form (Ewing et. al., 2016) and additional safety techniques may be needed (Mohan, Bangdiwala, and Villaveces, 2017).

Socioeconomic Benefits and Relationship with Crime

Network connectivity has been linked to numerous social and economic benefits, which continue to be subject to further study in emerging literature. Most notable of these effects (and subject to the most comprehensive study in the disciplines of public health and planning) is the perceived benefit of increased physical activity in neighborhoods exhibiting high connectivity due to greater active transportation, access to recreational amenities embedded in daily urban life, and other influences on regular behavior (Kaczynski et. al., 2014; Jia et. al., 2019). Rates of physical activity have been found to be reportedly higher in neighborhoods with higher levels of quantitative connectivity (Saelens et. al., 2003; Boarnet et. al., 2008; Koohsari et. al., 2014). Physical activity has been found to be encouraged by street connectivity regardless of age group, significantly increasing activity for young people (Schlossberg, 2008; Berrigan, Pickle and Dill, 2010; Oliver et. al., 2015) and the elderly (Nyunt et. al., 2015; Cerin et. al., 2017, Barnett et. al., 2017). Cul-de-sac development has also been connected to depressed rates of physical activity (Rajamani et. al., 2003).

However, physical activity and improved public health outcomes remain in doubt in the predominant literature on street connectivity. Some studies assessing connections between physical activity and street network design have found no relationship between street connectivity and its ability to improve physical activity rates (Saelens and Handy, 2008, Moudon and Stewart, 2013). Other studies have discerned negative relationships between connectivity and physical activity, suggesting other characteristics of sociodemographic composition and urban form affect physical activity to a greater degree (Mecredy, Pickett and Janssen, 2011). Comprehensive space syntax studies assessing connectivity and physical activity have found that the relationship between the two is likely strong but complex; high control on permeability (i.e. which modes can enter), high global accessibility, and lower local accessibility are together most likely to predict the greater levels of physical activity.

Treatments required to encourage non-commute walking and bicycling have been suggested to be far different in applied planning than those for encouraging commute walking. Statistical research suggests that neighborhood design is less important than other factors in promoting walking and bicycling outside of commuting because destinations are not required for recreation activity, and thus the effect of connectivity is substantially smaller (Ding et. al., 2017). Self-selection bias, socioeconomic background and neighborhood choice continues to heavily affect public health and physical activity connections with urban form characteristics such as connectivity (Boone-Heinonen et. al., 2011; Garfinkel-Castro et. al., 2017).

Connectivity has been frequently invoked by New Urbanists and tenants of other modern design movements as a method of improving neighborhood social development and sense of community, which has been hailed as an important factor in safety and well-being for urban residents (Francis et. al. 2012) and reportedly declining in American urban places (Scopelliti and Guiliani, 2004; Farahani, 2016; Klinenberg, 2019). The ties between sense of community and urban form have rich history in the academic planning tradition, even being clearly articulated as a central theme in Jane Jacobs' seminal work on cities (Jacobs, 1961) and in other important planning works

(Jacobs, 1993; Duany and Speck, 2000). However, in practice, there is little consensus on the connection of connectivity and a sense of community and social cohesion.

Increased social activity and reported social cohesion have been measured at the neighborhood level when streets are more connected (and routes are overlapping and integrated) within limited proximities (Talen, 2011; Cooper et. al., 2014; Boniface et. al., 2015, Can and Heath, 2016). Conversely, research demonstrates that as connectivity declines, particularly in suburban settings, so does social connection and reported relationship building (Oluseyi, 2006). Some studies loosely suggest a connection between social activity and connectivity by demonstrating that conditions suitable for walking (such as connected street patterns) increase social development by creating more social opportunities in public space and increasing the number of possible social contacts who can be reached as a “destination” in a given neighborhood (Wood, Frank and Giles-Corti, 2010; Farahani, 2016). This trend is not found to be universal, with denser environments with the highest level of connection and integration resulting in lower cohesion (Mouratidis and Poortinga, 2020).

Such findings have been heavily contested by scholars. Studies of “New Urbanist” neighborhoods have found that while gridded, connected streets are slightly more likely to promote “neighboring behaviors” and social development, it is unlikely to shift the reported sense of community amongst residents (Cao, Handy and Mohktarian, 2006; Lovasi, Grady and Rundle, 2011). Residents of traditionally connected urban areas have also continued to report lowering levels of social interaction over time (Farahani, 2016). Some New Urbanist scholars and other researchers have pressured academics to reconsider the ability for the built form to affect behavior, arguing against a form of physical determinism in the built environment (Talen, 2015). These social studies are also particularly susceptible to self-selection bias as residents choose neighborhoods based on social or residential preferences and identity expression and may provide deficient controls for identifying relationships between urban form and social trends (Talen and Koschinsky, 2013).

Additionally, the benefit of social cohesion and interaction cannot be discussed without a critique via a potential tradeoff: the rise of crime from increased opportunities for interaction under the connected conditions which have been suggested to increase social cohesion. While seminal works of the planning field have argued that such social cohesion via neighborhood accessibility and opportunities for activity ("eyes on the street") will decrease crime (Jacobs, 1961), the academic tradition of planning has long supported the opposite.

Oscar Newman's Defensible Space provided a foundational argument that increased neighborhood permeability and a loss of neighborhood definition via greater connectivity would result in greater crime (Newman, 1972). This finding has been supported by a wave of studies, particularly those studying property crime (White, 1990; Johnson and Bowers, 2010; Foster et. al., 2014). Such a concept was also articulated in the earliest days of neighborhood-level master planning, and foundational modern planning concepts such as Perry's neighborhood unit were predicated at reducing connectivity and permeability in the interest of reducing crime (Perry, 1929; Lawhon, 2009).

Societal changes and increasing capabilities to measure the complexities of both crime and connectivity through more advanced methods have given rise to increasing critiques of the idea of defensible space, and modern planning theory is beginning to be reshaped in support of greater connectivity and social permeability in neighborhoods

(Summers and Johnson, 2016; Armitage, 2016). Planning studies showing increases in crime in connected neighborhoods may still recommend that planners value the more concrete benefits of connectivity over the socially fluid phenomenon of crime (Foster et. al., 2014).

Finally, a review of potential socioeconomic benefits promoted by street connectivity requires a brief analysis of claims pertaining to the effects of street connectivity on economic productivity and development in urban places. Connectivity has been tied to the production of local agglomeration economies and socially dynamic growth in urban centers due to increased opportunities for social mixing and potential knowledge exchange as more individuals choose active transportation and benefit from potential social activity in shared spaces due to increases in connected street environments (Rohani and Lawrence, 2017). Street network complexity and connectivity have also been shown to be able to predict economic activity center development at a regional scale over longer time horizons, suggesting the role of connectivity in shaping broader economic clustering and agglomeration effects (Ozuduru and Guldmann, 2013). Active transportation trips spurred by a more amenable urban form to such trips provides increased purchasing and economic activity in connected neighborhoods (Transport for London, 2018).

Connectivity in street network forms has correlated with greater household income, though this trend only holds at fine-scale analysis which excludes macroregional analysis across an array of community types (Carpenter and Peponis, 2010). Regeneration of traditionally well-connected infill neighborhoods and interest in amenity-rich suburban living may be driving this shift (King and Clarke, 2015).

Socioeconomic effects are particularly difficult to discern because of the greater role of self-selection biases in such studies (Boone-Heinonen et. al., 2011; Talen and Koschinsky, 2013) and the indirect effects of connectivity on the urban environment via its other more well-documented effects on urban life such as active transportation increases or reductions in vehicle use. However, studies continue to indicate that street connectivity may be provide numerous social and economic benefits in cities which may significantly increase quality of life, public health, and positive economic outcomes for urban residents, albeit set in the proper conditions. Greater study is needed of the interrelated urban forms which maximize purported benefits of street connectivity to better understand relationships between connectivity and its measured potential benefits.

Shortcomings of Quantitative Analysis

Lack of Consistency and Reliability in Findings

A central problem in evaluating the effectiveness of connectivity is the conflicting findings found by individual studies and meta-analyses assessing the role that street connectivity and other measurements of urban form can play in predicting positive outcomes in the built environment. Ewing and Cervero (2010) is one such meta-analysis used authoritatively in planning literature showing the positive impacts of compact urban design (including increased transportation network connectivity) on achieving sustainable urban outcomes. Other meta-analyses (Handy and Boarnet, 2005; Wang and Wen, 2017) find more uniform support for the effects on compact urban form characteristics on the built environment and their ability to transform the function of modern cities.

However, a series of later meta-analyses complicate these findings significantly. Stevens (2017) and Naess (2019) demonstrate that the effect which compact design has on the built environment may be significantly lower than generally accepted by previous meta-analyses. Naess joins other scholars in calling into question the degree to which quantitative tests (and collections of these tests in meta-analysis) can provide predictive tools for demonstrating how measures such as connectivity will affect urban behavior, particularly as it comes to transportation (Knight and Marshall, 2014; Naess; 2019).

The problem of inconsistent findings is further revealed at the level of individual studies, which reveal variable relationships due to study area, contextual factors of network relationships and geometry, or confounding variables. (Frank et. al., 2008, Knight and Marshall, 2014). The lack of clear consensus points to the difficulty in making planning policy decisions based on these results, particularly costly ones which will make significant impacts on the built environment.

Most studies are clear that no single variable can dramatically change urban function on its own. Even optimistic accounts of how urban form improves success in sustainable urban planning goals determine that the gains made by increasing individual variables in the city (i.e. improving street connectivity) are likely small, and large-scale transformation of the built environment may require combinations of multiple variables of the built environment, particularly changing cities through a combination of Ewing's "5D's" of urban form (Ewing and Cervero, 2001). Transportation variables such as route choice and mode preference are heavily influenced by qualitative measures and variables that are often not captured in quantitative measurement (Papinski and Scott, 2011; Thomas and Tutert, 2015). Measures such as integration and other space syntax forms may be capturing how complex variables can better reflect how connectivity can affect urban sustainability and development goals (Napatov et. al., 2015).

The alteration of urban form can produce unintended consequences without other interventions or changes to the built environment. Utilizing an example from the debate over Portland, Oregon's street connectivity metrics, it was found that improved street connectivity could harm both local and arterial street function by causing additional congestion and additional vehicle trips, without embracing other interventions such as meeting a certain threshold of connectivity and controlling the design of local streets (Handy, Paterson and Butler, 2003). The effects of the built environment on urban behavior is non-linear, and other interventions are generally necessary to realize the effects of an urban design variable such as connectivity. It is difficult to assess the effect on urban behavior that changing a single feature of the urban environment will cause, creating inconsistent results.

Other ills plague the ability to measure connectivity and associate it with urban outcomes. Poor methodology, particularly when studies do not properly account for self-selection and urban preference, continues to cast doubt on findings (Boone-Heinonen et. al., 2011, Naess, 2019). Pre-existing income, gender, ethnicity and other social characteristics of communities frequently confound and complicate predicted benefits of urban form characteristics on urban behavior and outcomes (Frank et. al., 2008; Carlson et. al., 2012; Garfinkel-Castro et. al., 2017).

Even in studies with well-controlled methods, differing definitions of connectivity also create challenges in several dimensions. While variables such as link-node ratio, total pathway miles and intersection density may seem to be measuring very similar phenomena in the built environment (greater routes and increased connectivity), they can produce dramatically different results (Stangl, 2019). For example, a gridded rural area may produce very low intersection density counts with low total pathway miles by virtue of the low number of streets, the area may maintain a high link-node ratio, especially if most intersections in the rural area are four-way intersections (Dunn et. al., 2018). Connectivity definitions also change based on the definition of the network used for such an analysis. Assessing connectivity based on vehicle networks versus networks which include routes for both vehicles and pedestrians will produce significantly different results, and will require significantly different interpretations in how connectivity affects urban behavior (Tal and Handy, 2012; Ellis et. al., 2015).

The Modifiable Areal Unit Problem, a common bias found in the GIS sciences upon which many quantitative urban form studies rely, causes problems for many connectivity studies. Quantitative measurements of urban form are statistically sensitive, and changing the boundaries of a study area in an analysis of urban form can dramatically alter the perceived level of connectivity in that area, complicating the ability to compare studies and find clear relationships between the built environment and urban outcomes (Zhang and Kukadia, 2005). For example, a connectivity study done in Phoenix, Arizona by Stangl (2015) revealed that neighborhood-level connectivity scores applied by local transportation officials in the development process often produced fairly high connectivity scores, given the measurement focused on local street networks within the neighborhood. However, if the boundaries of these studies were altered slightly to include surrounding areas, such as arterial roadways surrounding neighborhoods, connectivity scores dropped dramatically. This same effect often occurs in macro-scale connectivity analyses, where taking connectivity measurements across an entire urban area may still produce biases based on where the “boundary” of the urban area is drawn and the context of the built environment where said boundary is drawn (Dunn et. al., 2018). Studies, including the one described in this paper, must be set within the context of broader longitudinal and global-scale connectivity analyses (Jia et. al., 2019; Boeing, 2020).

The purpose of addressing shortcomings in how academics currently measure connectivity is not to completely cast doubt on the effort to measure the effects of compact urban form and advocate for more sustainable patterns of development: such effects are well-documented. Rather, it is to present conversations regarding built form, connectivity and street network design, and the need to broaden study of these metrics to capture the political and economic dimensions of connectivity. Therefore, there needs to be careful consideration about what is being achieved in the local planning context with connectivity. This is the gap in literature which this thesis paper is designed to begin to address, addressing the difficulty in policymaking in planning.

Political Economics of Connectivity

Assessing Non-Qualitative Approaches to Urban Transportation Connectivity

There is a broader problem that should be addressed as urban connectivity is considered by policymakers and planners. Improving connectivity is a costly investment in newer areas and even more so in existing built-up areas, and these costly changes are at risk of resulting in minimal benefits in promoting urban sustainability and desired changes to urban behavior (Stevens, 2017; Manville, 2017). This reality makes improving connectivity a risky investment for planners to advocate for without complete clarity in predicted outcomes.

A mixture of practical and empirical analysis alludes to a difficult environment of values which further complicates the implementation of street connectivity without full certainty of its tangible benefits for urban stakeholders. Developers, who are most commonly in charge of local street layout, maintain interests frequently in conflict with calls for greater connectivity (Handy, Boarnet and Paterson, 2003). Developers may reject connections to other communities on the basis of potential effects to property value and assessment, particularly when the neighboring developments belong to other land uses or housing marketed to other income groups (Alawadi, 2017). Because of the boundaries of the developers' interest (creating the most suitable product on a given project site), developers may view projects, especially residential developments, as individual products or "islands" in an urban area. Such a view may create significant resistance to connectivity without a clear description of the method and location of connectivity required between developments (Lehigh Valley Planning Commission, 2015). Developers have expressed financial pressure from increased area dedicated to streets and infrastructure in well-connected neighborhoods, due to larger amounts of pavement and infrastructure investment required and lower amounts of saleable land for developers (Lehigh Valley Planning Commission, 2015; Auerbach, Fitzzhugh and Zanisca, 2021). Practical guidance from the planning discipline suggests that developers may reduce opposition to connectivity standards with the creation of buildable area or opportunities where developers are granted additional flexibility to make neighborhood design proposals function (American Planning Association, 2009; Utah Department of Transportation, 2020).

Numerous scholars invested in the plight of the neighborhood street have tied developer attitudes to the production of modern urban space, and state how the developer as a stakeholder in planning processes may be naturally inclined to discourage planning in modern planning processes. Knox (2008) has illustrated that the modern local street (the object of interest in most connectivity studies) is a "market device for selling homes," both in its design and orientation. The layout of streets is designed to “maximize the profit and impact on the local housing market from a particular development,” and street design has been simplified (and developers have advocated for the simplest, low-intervention street designs) for the sake of “transferability” and “mass production of similar products” between cities and between regions. Street networks, even gridded streets, are dictated by consumer preference without local public control of street space, and consumer demand is unlikely to be mobile in short-term efforts to alter broader neighborhood design strategies.

Graham and Marvin (2001) and Alawadi (2017) go further to suggest that the modern production of street networks in isolated, developer-designed communities reflect a “spatial expression of economic strategy” in the neoliberal era, favoring the private sector distribution of goods in places where public and private needs intersect (such as in the development of streets). Practically applied, widespread developer-friendly planning strategies such as Planned Area Development (PAD) zoning and promoted flexibility of street design through private street ownership may reflect the challenges of creating meaningful connectivity in the modern city. The widespread ceding of the development of the American street network to private interests has made the separated neighborhood unit the most important feature to understand in the modern urban morphology, given that it a tangible example of many currents of modern social and economic theory, from increasing secession of the wealthy from societal responsibility to the continued global reliance on neoliberal economic strategy (Mehaffy, 2015).

Local residents, particularly in communities neighboring new construction or communities being retrofitted which exhibit greater connectivity, have been documented to express concerns about the rise of connectivity within and between developments. The primary resident objection arises from the rise in traffic from neighboring developments or the loss of existing conditions which residents perceive to reduce traffic impacts, such as in cases of “stub streets” or cul-de-sac expansion (Handy, Boarnet and Paterson, 2003). The public sentiment tying street connectivity to increased congestion can concern residents who are affected by internal or external connectivity additions in communities, even if many residents seek amenities and conditions which are commonly associated with walkable neighborhoods (OKI Regional Planning Forum, 2007; Montemurro et. al. 2011; Brookfield, 2017). The perception of crime and popular understandings of how crime occurs in cities continue to be a motivating force against street connectivity (Beavon, Brantingham and Brantingham, 1994), and concepts such as having easily “defensible” space in urban places holds sway with residents impacted by debates and projects affecting connectivity (Newman, 1972; Johnson and Bowers, 2010). Residents may see connectivity increases as a decision actively made by planners against neighborhood preferences, such as pedestrian safety from traffic, desired insulation of crime through defensible space and neighborhood separateness (Montemurro et. al. 2011; Lee, Conway and Frank, 2017).

Other actors have been illustrated to be involved in the debate over connectivity within the planning practice. Local political resistance can frequently stymie efforts to improve connectivity in developments, especially in areas where street networks have historically lacked connectivity (Lehigh Valley Planning Commission, 2015). However, greater process and policy-based studies are needed to better illustrate the phenomena of political resistance to improved connectivity. Homeowners associations and private neighborhood governments may have increased fees and financial pressure over time due to the increase in infrastructure which must be maintained and subject to neighborhood fee structures, though broad research shows that developers seeking to provide more urban characteristics in neighborhoods have turned to HOA-controlled private streets as a method of producing dense and connected street patterns (Grant and Curran, 2007). Communities vary dramatically in their political economies, and will produce vastly different arrays of stakeholders.

Examples from past case studies suggest potential policy avenues for improving connectivity and mitigating resistance to such measures. Developers may provide less objections to demands or recommendations for additional network connectivity if backed by state and regional policy supporting overall network connectivity goals, supported and codified in local street plans dictating collector and local streets, and potentially the creation of predictable policy environments (Handy, Boarnet and Paterson, 2003). Tax incentives and public-private partnerships have also played a crucial role in easing the ability to create mixed-use developments, new neighborhood destinations, or other features which are generally supported by more connected development, which may support a push for more connected neighborhoods to maximize the use of such non-residential investments (Talen, 2011). Broad evidence from developer interactions with connectivity requirements demonstrate the challenges in ameliorating the private good sought after by the developer with the public goods sought out by local governing agencies when neighborhood design remains in private control for the vast majority of American communities.

Investments in urban form characteristics linked to positive urban outcomes should instead be set within broader systems of economics and policymaking, and flexibility is necessary to promote connectivity in places where connected and nodal urban form has been neglected for many decades (Talen, 2011; Winters, Buehler and Gotschi, 2017). Connectivity is an essential component of developing a less vehicle-dependent future, but it may not be desirable to view connectivity as a consistent or single-handed force for promoting a more sustainable transportation future. While connectivity is an essential component of the built environment in a more sustainable future (one which reduces VMT, lowers vehicle dependency and improves transportation safety, amongst other goals), the full realization of the benefits of these changes to the urban form will require supportive land use policy (zoning, subdivision standards), transportation planning and creative policymaking to make urban form investments worthwhile, especially in existing built-up areas demanding retrofit (Talen et. al., 2011; Ozbil and Peponis, 2012; Lehigh Valley Planning Commission, 2015).

Literature remains scant, and case studies illustrating how connectivity is handled in the planning process between relevant stakeholders are largely limited to a handful of high profile examples of connectivity policy which have received a great deal of attention from planning practitioners, particularly in a few states such as Oregon (West and Lowe, 1997; Handy, Boarnet and Paterson, 2003; Stangl, 2015) and Utah (Utah Department of Transportation, 2020; Ewing et. al., 2020; American Planning Association, 2021a). Generating a broad range of case studies and local examples is essential for designing meaningful policies to promote connectivity. Given the fact that the benefits sought afteutahr by connectivity in an existing network or a new development area are highly contextual, connectivity must be designed in a way which realizes the values and urban outcomes desired and serve sets of stakeholders which are diverse and vary severely in influence over planning decisions between contexts (Zhang et. al., 2006). Further research is necessary to understand the applied debates surrounding connectivity in the planning practice, especially in the gathering of new case studies in other places where small details in policy and development processes may be producing different outcomes in connectivity.

Additional study is also necessary to build practical decision-making knowledge in the planning practice, which can answer the question: “when is connectivity desirable?” Even with the possible benefits of connectivity articulated in literature, there are potential drawbacks in system function (increased traffic crashes, potential congestion) and in overall effects on the urban landscape (loss of open space opportunities, loss of emphasis and maintenance of topographic features) (Southworth and Ben-Joseph, 2004). Connectivity may produce unintended consequences in routemaking and fail to realize the benefits sought after by planners implementing connectivity policies due to surrounding land use, existing network construction, cultural values or a lack of overall participation in policies (Zlatkovic et. al, 2019). Case studies of how connectivity is integrated into street design processes and neighborhood designs in different contexts is essential for considering how connectivity can be implemented to produce benefits for a large range of urban stakeholders.

Assessing Trends in Connectivity

While connectivity in urban transportation networks, particularly streets, has been observed to be potentially beneficial to the efficiency, resiliency and quality of life in urban places, trends in connectivity in the American built environment reflect a widespread movement away from connectivity in the 20th century as the United States departed from traditional gridded growth patterns and embraced new transportation technologies, with only recent trends showing a recommitment to connectivity (Aurbach, 2020; Boeing, 2020).

Before 1900, American street networks were heavily gridded and had high levels of connectivity (Southworth and Ben-Joseph, 1994; Hanlon, Short, and Vincino, 2009). Contrary to the modern era, rapid urbanization in America in the 19th and early 20th centuries was accompanied by a rapid construction of urban grids spreading out from central cities. Early communities considered “suburbs” in the 1800s, such as Chicago’s early suburbs Riverside and Cicero, featured connected street systems surrounding transit (Hanlon, Short, and Vincino, 2009).

The connectivity and complexity of street networks in the United States dove after the middle of the 20th century, exacerbating a trend which began in the 1920s and 1930s as the paradigm of urban transportation shifted from one focused on transit and active transportation by necessity to one focused on the private automobile (Southworth and Ben-Joseph, 2004). This necessitated traffic control which favored functional separation of vehicles from pedestrians, bicyclists, and transit users, and fewer conflict points to speed up and ensure safety for drivers (Aurbach, 2020).

Cities were increasingly designed for a future that fully favored the automobile, from the local level in Perry’s neighborhood unit model and the Radburn model (Perry, 1929; Lawdon, 2009) to the macro-level in the modernist designs of Le Corbusier and other architects of the 1930s and 1940s. The United States government codified this reduction in connectivity through FHA Subdivision Standards and federal guidance and design books for new neighborhood construction, favoring large blocks, reduced connectivity to encourage lower-density living, and to reduce construction costs for housing developers (Federal Housing Administration, 1936; Southworth and Ben-Joseph, 1994; Aurbach, 2020). In this period, street connectivity began to decline and land uses began to be disassociated with one another in kind.

The post-war period most commonly associated with suburbanization and auto-oriented design saw the creation of durable policy to disconnect streets and neighborhoods from one another. Federal engineering standards and guidance from groups such as the Institute for Traffic Engineers would all but codify a functional classification system of arterial, collector and local streets and dendritic street patterns. These actions culminated in the full dendricity that was found in American subdivisions between 1970 and 1995, enabling the modernist vision for dendritic street model and creating large-scale superblocks of disconnected, insular streets, particularly within arterial road grids that were built to support such large-scale blocks of development with automobile-only access.. (Aurbach, 2020)

Connectivity, both in American cities and abroad, reached its lowest point, both in aggregate and within most American cities, between 1990 and 1999 (Barrington-Leigh and Millard-Ball, 2019). However, trends toward more connected streets in the United States emerged after 2000, as significant decreases in fully disconnected and dendritic street patterns and increases in more gridded patterns of development were observed (Barrington-Leigh and Millard-Ball, 2019; Boeing, 2020). While as a whole, "sprawl" and disconnected urban networks have continue to increase in aggregate since 1970, the rate of growth has slowed in the past few decades, and variation is great across the country as to whether cities are densifying and new development is becoming more compact, or if sprawl is continuing at a rapid pace (Lopez, 2014).

Particularly relevant to this paper, rates of "sprawl" as defined by irregular and undefined street network development have decreased substantially in the Western United States since the late 1990s (Lopez, 2014). This may be due to increased water pressures and strictness surrounding infrastructure expansion slowing less compact outward growth (Lang, 2002), the lack of resilience and changing approaches to development risk following housing market busts, or changing market preferences (Kane and York, 2017). Development patterns have grown to become more compact and gridded while infill development in more connected areas has increased (Kane and York, 2017; Boeing, 2018).

However, connectivity in street networks across the areas of greatest growth in the U.S., particularly in metropolitan areas of Sun Belt cities such as Phoenix, Tucson, Dallas and Houston, remains low relative to other cities in the United States (Boeing, 2020). Two findings can be applied to begin to understand this aggregate resistance to improved connectivity. The first indicates that past connectivity levels are predictive of future levels of connectivity in street networks, alluding to the challenges of producing a more connected street network in one historically built for vehicles, as Sun Belt metros have been (Barrington-Leigh and Millard-Ball, 2019). The connectivity of existing street networks is likely to influence neighboring development due to the availability, or expectation of future availability, of services and transit options accessible to pedestrians (Marshall, 2005; Barrington-Leigh and Millard-Ball, 2019). The second finding is that the rise in connectivity in places where the segregated neighborhood unit dominates development, such as Phoenix, limits the ability to produce connectivity. While connectivity is increasing in individual neighborhoods in Sun Belt metros, employing more gridded streets with orthogonal orientations, these communities remain separated by arterials and lack outlets into the surrounding community (Mehaffy, 2015; Stangl, 2019). The benefits of connectivity, as illustrated in this literature review, are unlikely to appear in communities which are gridded and connected within neighborhood boundaries but fail to efficiently extend connectivity to other destinations beyond residential neighborhood units (Porta, Latora and Crucitti, 2012; Mehaffy, 2015). These studies reveal a complex ecosystem of new street development in Western cities such as Phoenix, with overall patterns of sprawl and disconnection reducing but variation in street patterns and overall density of streets declining.

Global-scale connectivity studies, made possible by advancing GIS technologies and the increasing accessibility of large computing systems, are providing comprehensive and real-time understandings of connectivity changes over time. The trend of improving connectivity found in the United States is not reflected globally, as trends of urban sprawl increase with the rapid urbanization of the world (Liu and Meng, 2020; Lincoln Institute of Land Policy, 2021). Considering connectivity in new developments since 1975, connectivity has dropped in over 90% of the world's 134 most populous countries (Barrigton-Leigh, 2020), and that decline has continued in 71% of the world's countries, rebuking narratives of improving street network sustainability globally (Barrington-Leigh and Millard-Ball, 2019). Many of the nations providing contrast to the global trend and exhibiting overall improvements to urban transportation connectivity since 2000 have generated policy and produced large-scale investments in network-wide connectivity, particularly for the benefit of non-motorized means of travel such as walking and bicycling (Barrington-Leigh and Millard-Ball, 2019). Such a reality reflects the importance of consolidated policy responses and a comprehensive conception of the purpose of connectivity to further improve connectivity in the future. Collections of international examples, such as resumed gridded development in Latin America, irregular but connected street networks in Japan, and complex fused grids designed for pedestrians and bicyclists in Northern Europe demonstrate the ability for countries to overcome trends of lessening urban connectivity (Barrington-Leigh and Millard Ball, 2019; Boeing, 2021).

New developments in the United States are often increasing connectivity without such a coordinated policy response, with little guidance from state and federal agencies and limited commonalities between local governments in their responses to promoting connectivity, let alone their definitions of beneficial connectivity (Barrington-Leigh and

Millard-Ball, 2015; Lehigh Valley Planning Commission, 2015). A wide variety of connectivity policies have been put in place, ranging from development incentives and statistical requirements for large greenfield development proposals and design guidance manuals and changing engineering and public works standards (Handy, Boarnet and Peterson, 2003; Weiner, 2016). Ultimately, urban places which enacted development requirements, plans or design guidance documents which encouraged or required connectivity had the greatest gains in connectivity in the past two decades, reflecting the necessity of coordinated policy and dedicated investments to realize improved connectivity (Boeing, 2020). Literature remains lacking in the evaluation of various measures to improve connectivity and the political economy surrounding street connectivity and urban transportation networks, leading to inconsistencies in how effective policy and variabilities in connectivity policy outcomes are understood.

Gaps in Literature

Literature demonstrates that scholarship provides consensus that connectivity provides benefits for the sustainability, safety, and resilience of urban space, particularly when set within a broader array of variables supporting sustainable urban development, such as density, accessible urban services, and diverse land use patterns (though the magnitude of these benefits is contested). However, this extensive literature survey has sought to illustrate the limitations of such studies, and the other dimensions of study necessary to understand connectivity.

In particular, policy-oriented approaches to connectivity in the practice of planning remain limited, though street network design is an intensely political process produced through a variety of actions from public and private actors. Though connectivity has been widely hailed as a benefit by planning scholars and practitioners alike, less research has been done to understand the political economics of connectivity, and why connectivity remains a frequently sought goal in the planning practice but is implemented only at a slow pace, as trend analysis in connectivity demonstrates (Barrington-Leigh and Millard-Ball, 2019; Boeing, 2020). Few models have been developed to understand how connectivity is shaped by various stakeholders in the planning process. Developing a preliminary version of such a model, along with providing a policy-oriented approach to connectivity, describe how this study contributes to the broader academic debate on the merits and application of connectivity in the American urban landscape.

This, along with many other connectivity studies, should be done in regional analyses to capture local complexities in the study of processes and effects of promoted connectivity. This thesis paper provides a policy-oriented connectivity study for one particular region, the Phoenix metropolitan area in the southwestern United States, which cannot describe the decision-making processes of connectivity at a global scale but can provide useful case study insights and serves as a bellwether for understanding connectivity and factors impacting street network design in the American Sun Belt. This research fills in a gap in both academic and practical knowledge for understanding connectivity and street network development factors in the American Sun Belt and the Phoenix metropolitan area.

Connectivity studies should also be updated frequently to reflect the rapidly changing demands on urban street networks around the globe, and new insights must be continually generated from new developments to continue to tell a useful story about connectivity in urban America. In particular, there is a need for understanding how the political economy of different regions shapes the production of street networks in new communities, and it is imperative that planners learn lessons from these examples to leverage more sustainable street network design. Such updates ensure that academics and planning practitioners alike continue to maintain access to information describing changes in street networks over time.

3 METHODS

Methods Overview

This thesis utilizes mixed methods, employing both qualitative and quantitative strategies to complete research. Qualitative methods were completed first, utilizing a literature review, semi-structured interviews and a primary source review of local policies and codes related to subdivision design and development. Case study areas were analyzed with quantitative measurements to critically engage with the results of qualitative methods used in this thesis research. Quantitative methods, particularly geospatial analysis methods, were used to illustrate findings from qualitative methods. Case studies were expanded upon using responses from interviews and knowledge and findings from existing studies and literature on the topic.

The gap in research which this study addresses requires a descriptive method of research. This research is designed to explore relationships between groups of stakeholders and actors in processes surrounding street connectivity and network design in greenfield developments in the Phoenix metropolitan area. This thesis research takes a known set of processes (political, economic, and administrative decisions surrounding new development design) and actors (a wide variety of stakeholders influence the development design process), and assesses the relationships between them to describe how different known actors respond and influence connectivity in neighborhood design. Causal relationships are not determined, but correlations and connections are explored within the context of the planning economy in Phoenix, preparing information for guiding future deductive research.

This research is inductive in design. This research answers the question of how network connectivity is being shaped in one regional planning context - the Phoenix metropolitan area - and describes patterns and potentials theories of change surrounding connectivity in greenfield development. Tentative hypotheses and the foundations of new theories as developed in this study may provide insight and guidance for planning academics and practitioners beyond the Phoenix region.

Mixed Methods Strategy

Semi-Structured Interviews (Primary)

This study employed interviews to complete the following objectives:

- Understand the role of different stakeholder groups in the process of building new developments in the Valley, and their relationships in the current development processes of Phoenix
- Learn about the policies surrounding connectivity and network design in various communities within the Phoenix region
- Discover attitudes and approaches toward connectivity found in different stakeholder groups
- Learn about specific project outcomes in the Phoenix region and how various street network designs came to proliferate the Phoenix region
- Gather information to assist in quantitative case study development

Seventeen interviews were completed with a variety of planning and land development professionals from public agencies and private firms. These interview subjects were selected from an initial contact list, including professionals who frequently interact with greenfield development projects in the Phoenix metropolitan area. These interview subjects were strategically chosen because of their widespread involvement in a range of new developments representing one or more stakeholder groups.

A minimum of one professional was to be chosen from each of the following sectors based on theory and professional planning knowledge of street network development:

- Local government planning departments
- Regional transportation planning body/MPO planning agency
- Land use planning firms
- Transportation planning firms
- Homebuilders/residential developers/construction clients

Additionally, private sector professionals involved with developments exhibiting noteworthy increases in connectivity were sought after in the initial search for interview subjects. Public sector planning professionals from corresponding communities were also sought out in the initial search for interview participants. The roles of the seventeen participating interviewees are listed in **Appendix B** (all names made anonymous for integrity of data collection).

Interviews were conducted using a semi-structured method. Consistent questions were asked to each interviewee, with sets of questions prepared for each stakeholder group **(Appendix B)** and opportunities were presented for additional questions to be asked in order to follow up on particularly relevant experiences or individual case studies or projects mentioned by interviewees. Additional questions in each interview were designed to focus on the processes and specific decisions made in these case studies and projects in which the interviewee mentioned personal experience.

Each interview was scheduled as 45 minutes long, including 15 minutes built into scheduled times to accommodate the semi-structured format where follow-up questions may have been asked. The length of the interviews in this study ranged from 50 to 90 minutes, with one interview as an outlier at 110 minutes of interview time. Over 23 hours of recorded interview data were collected from interview participants. Five interviews were held in-person, and twelve interviews were held in a remote setting in secure Zoom meetings hosted by Arizona State University due to COVID-19 restrictions in place during the completion of this study.

Interviews were guided with interview instruments ranging from eight to ten questions, depending on which questions were relevant for each stakeholder group. Questions were held consistent between interviews with members from each stakeholder group. Sample interview instruments utilized to complete interviews with participants from public and private sector stakeholder groups are included in **Appendix D.**

Data collected from interviews was kept anonymous, with only the stakeholder group or discipline to which each interviewee belonged tied to the data included in this study. Data was transcribed using Zoom's built-in audio transcription software and manual editing and clarification of the transcripts. Transcripts were supplemented with notes taken during each interview to highlight key points, arguments, and ideas included by the interviewee. These notes were attached to interview transcripts and used when completing content analysis for this study.

Interview Content Analysis and Modeling (Primary)

After transcription, interview data was processed using a simple content analysis to create a reliable method of comparison between interviews. This manual method utilized conceptual and relational strategies of content analysis. Conceptual analysis was used to determine the frequency and presence of different themes and concepts, and relational analysis was used to find connections, similarities and potential differences and conflicts between actors and processes in greenfield neighborhood development in the Phoenix region.

Each transcript and note sheet was searched through for key ideas and themes common to one another using coding categories. Each additional variable, document or process which was reported by interview subjects to potentially shape connectivity in greenfield development was identified and listed separately, with the actors involved in each included. Coding categories were developed for overall topic categories (documents, processes, factors/variables, outcomes), and additional coding categories were developed at a finer grain of analysis to capture common themes and ideas between interviews. Frequency of each theme emerging from interview data was recorded, and coding notes were gathered into a single large outline where they were organized into the thematic and relational analyses of this study.

Relationally, common themes were drawn from each interview, and details, quotes and examples related to each theme were grouped together to demonstrate the strength of possible variables and connections in the process of planning for connectivity in new subdivisions in Phoenix. Comparisons were also drawn between members of similar stakeholder groups (i.e. local planning officials between cities in the Phoenix metropolitan area). The result of the conceptual analysis was a set of themes which could be used to interpret case studies of connectivity outcomes in the Phoenix metropolitan area.

Case Study Selection

Five case studies were selected to demonstrate the effects caused on network connectivity by various themes and concepts discovered through interviews and subsequent content analysis. These case studies were to be subject to geospatial network analysis as detailed later in this section, and included **(Figure 1)**:

- Verrado – Buckeye, Arizona
- Blue Horizons – Buckeye, Arizona
- Norterra/Union Park – Phoenix, Arizona
- Sonoran Foothills – Phoenix, Arizona
- Tramanto – Phoenix, Arizona

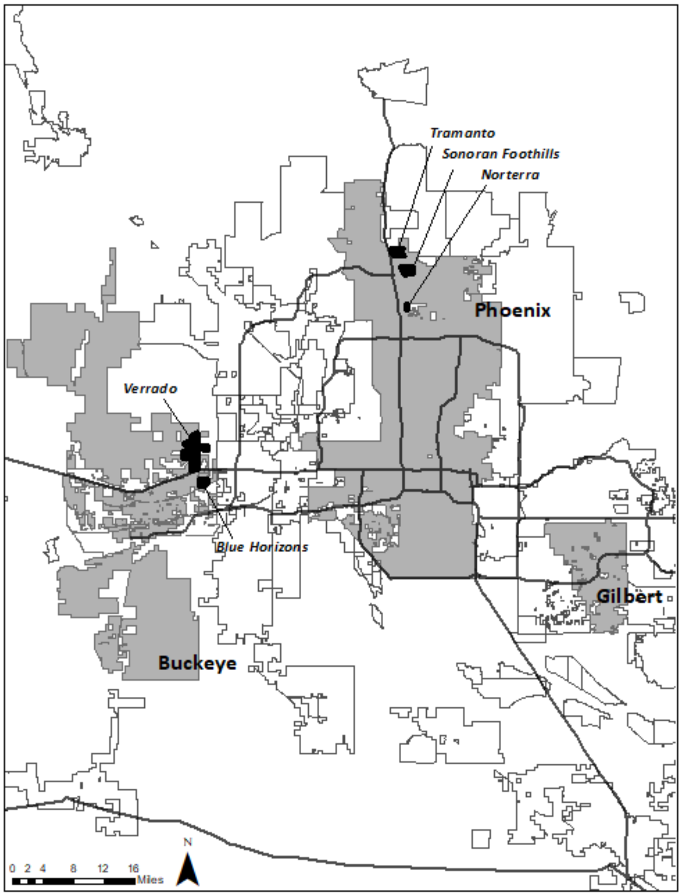


Figure 1. Analysis Case Studies (Schumerth, 2021)

Additionally, two reference street networks which represent polarized street network outcomes in Phoenix were created in the GIS network analysis environment and used for comparison between case studies: one dense grid indicative of traditional development in Phoenix (Coronado, Phoenix) and one large tributary network indicative of the height of disconnected suburban development in the Phoenix region (Cave Creek).

Primary Source Content Analysis

Current planning policy documents were collected for each municipality within which a case study was completed. For each community, land use and transportation planning and engineering documents were collected:

- Subdivision ordinance
- PAD (or comparable) zoning ordinance
- Residential or subdivision design standards
- Access management standards or similar transportation access guidelines
- Street section requirements and street design requirements and guidelines
- Public works codes related to streets and network design

Based on interviews with representatives from each local governing body in a municipality containing a case study, where questions were asked to gather information about the policies and documents which most shape the work of greenfield network design, additional documents were collected which these representatives stated played a role in determining the outcome of transportation networks in new communities.

These guidelines were analyzed through conceptual content analysis policies and ordinances shaping street network design, with a particular focus on policies and ordinances connectivity, including but not limited to:

- Local street layout requirements
- Open space and open space connectivity policies
- Intersection spacing requirements
- Ingress/egress requirements
- Connectivity policies
- Multimodal connectivity policies
- Street sections and design policies

Additional notes were taken to record each of the policies or regulations shaping connectivity in that particular community. Findings were used to further interpret the results of geospatial analyses in case studies. Policies and ordinances designed to affect connectivity and street network layout which were assessed through this content analysis method and complemented the other steps of analysis in this study, including the results narrative from interview methods.

Primary source analysis was only completed in the communities with case studies determined in order to manage the scope of this Master's thesis. As discussed in the Future Directions for Research section of this thesis, an assessment of the frequency and potential effectiveness of various strategies to improve or manage connectivity in communities should be considered by future scholars; however, this lies outside of the scope of this current study.

Geospatial Analysis and Case Study Development (Primary Data)

The central quantitative method in this paper was a geospatial analysis of the five existing case studies from recent planning in Phoenix, designed to illustrate various policies and processes which shape street connectivity in recently constructed greenfield developments. This analysis measured the existence and effectiveness of connectivity through various quantitative metrics and basic morphological analysis, promoting an assessment of how planning processes are shaping outcomes in built communities. Completing analyses on five distinct case studies in different Valley municipalities and with different groups of stakeholders involved in the planning process provided a means for comparison to discover how connectivity has been successfully developed in some communities and may be subject to barriers in coming to fruition in other communities.

Geospatial analyses were completed in network data environments constructed for each of the four case study communities assessed in this study. Network data environments were built from datasets and layers summarized in **Table 1**. Additional datasets used in various GIS analyses in this study are summarized in **Table 2**.

Table 1
Network Data Environment for Case Studies - Data Summary

Data Layer	Data Type	Data Source	Data Access	Notes
Street centerlines (internal)	Polyline (shapefile)	City of Buckeye; City of Phoenix; City of Casa Grande; Town of Gilbert	ASU Map and Geospatial Hub (accessed February 6, 2021)	Clipped for each case study community by merged and dissolved subdivision boundary.
Subdivision boundaries with phasing boundaries	Polygon (shapefile)	Maricopa County Recorder's Office	ASU Map and Geospatial Hub (accessed February 9, 2021)	Manually merged and dissolved to create additional layer with only external primary boundary of subdivision
Non-street pathways	Polyline (shapefile)	Manually created in ArcGIS Desktop 10.8. Sourced from aerial imagery from USGS.	N/A	Manually drawn using 2021 aerial imagery of case study communities (ESRI)
Intersections	Point (shapefile)	Manually created in ArcGIS Desktop 10.8. Generated using Intersect with street centerline data, see source above.	N/A	Manually created in ArcGIS Desktop 10.8. Generated using Intersect with street centerlines; Delete Identical.

Table 2

Additional Datasets for Case Studies - Data Summary

Data Layer	Data Type	Data Source	Data Access	Notes
Origin polygons (parcels)	Polygon (shapefile)	Maricopa County Assessor's Office, ASU Geospatial Hub	ASU Map and Geospatial Hub (accessed February 11, 2021)	Parcel polygons created with ArcGIS geocoding established across Maricopa County.
Destination points (parks)	Point (shapefile)	City of Buckeye; City of Phoenix; City of Casa Grande; Town of Gilbert	ASU Map and Geospatial Hub, accessed October 1, 2021	Centroid points created from polygons of parks layers provided by local governments by creating X/Y centroid points in layer and creating features from X/Y events.
Destination points (commercial locations)	Point (shapefile)	City of Buckeye; City of Phoenix; City of Casa Grande; Town of Gilbert	N/A - manually created by author	Centroid points created from polygons of parks layers provided by local governments by creating X/Y centroid points in layer and creating features from X/Y events.

Preliminary subdivision analysis was completed for each subdivision by producing maps of neighborhood land use by parcel and transportation networks through the neighborhood.

- Street hierarchy by classification (including non-vehicular pathways identified
- Land use
- Street network by development boundary (subdivision boundary, phase boundaries, subdivision parcel boundaries)

With this information, morphological analysis is completed using concepts and methods from the network analysis and space syntax subdisciplines to draw conclusions about connectivity outcomes in several subdivisions from the Phoenix metropolitan area. These quantitative measurements are designed to illustrate how the processes, relationships, and potential impediments to connectivity interact and have affected the construction of subdivisions in the Phoenix region, while providing precise new knowledge about the levels of statistical and functional connectivity in various types of subdivisions being built in the Phoenix region. The quantitative analysis of this study is also designed to provide an experimental roadmap into new methods of measuring the function of connectivity in subdivisions, which may equip future researchers and planning professionals with additional tools for promoting effective connectivity in the development of new greenfield communities. Three types of measurements were collected in the quantitative portion of this study: basic, space syntax and complex network measurements.

Basic Network Measurements

Basic network measurements assessing network connectivity were taken in each of the three case study communities selected for this study. Several basic measurements were collected and are detailed in the text of this methodology section in **Table 3**.

Intersection density and connectivity overlays were used to understand the distribution and raw degree of connectivity in each case study. Intersection density was calculated with two metrics: one density measurement including cul-de-sacs and one not including cul-de-sacs in the measurements. These calculations also provided a Total Junctions metric which was used to create other metrics for this study. Intersection density was compared to the total area of the development as measured using dissolved residential subdivision parcel boundaries provided by the Maricopa County Recorder's Office. Intersection density was calculated as:

Int Dens. = (total intersections inc. cul-de-sacs)/square area.

The ingress/egress rate metric was employed to provide a simple measurement of external connectivity of each case study community, assessing the degree of connection with the surrounding built environment. The ingress/egress rate was measured against the total perimeter of the subdivision as determined using dissolved residential subdivision parcel boundaries provided by the Maricopa County Recorder's Office. The ingress/egress rate was calculated as:

Ing./Eg. Rate = (total street segments intersecting perimeter)/total perimeter

Intersection typology was developed to measure the number of each type of intersection in the study (three segment, four segment, cul-de-sac (terminus)). To be used as an effective measurement for network analysis, two types of intersection typology measurements were created to compare case study communities: ratio measurements (ratio of three-segment and four-segment intersections based on the total number of junctions without intersections) and percentage measurements (percentage of all intersections including cul-de-sacs which were classified as three-segment, four-segment and cul-de-sac (terminus)). The ratio values were paired with another measurement of the total number of "cells" in the street network of each case study subdivision (the total number of discrete areas bounded fully by streets; a city block is an example of a "cell" in a street network) and plotted on a multivariate scatter plot developed by Marshall (2005, 2018). The three percentage values for each case study were plotted on a ternary scatter plot and developed by Marshall (2005). The use of these plots allowed for comparison between case study communities and the use of previous space syntax datasets allowing for comparison with many other existing model and "real-world" street networks globally. The ratio, percentage, and cell values were also used for direct numerical comparison between case study communities. Measurements using intersection typology allowed for finer-grain analysis and a greater ability for comparison between case studies and existing street network typologies detailed in other works (Southworth and Ben-Joseph, 2004; Marshall, 2005; Aurbach, 2020).

These measurements provided simple metrics of connectivity which convert characteristics of neighborhood design into quantitative measures that can be compared to other communities, both regionally and globally. Additional comparison was provided by utilizing neighborhood network typologies developed by Ewing (1996), which allowed for a comparison of the Phoenix area case studies to hypothetical networks which illustrate different levels of overall connectivity and urban legibility (Marshall, 2005). All measurements were completed in ArcGIS Desktop 10.8 equipped with the Network

Analyst extension. The source, definitions, data required for measurements and unit of comparison for each method is included in **Table 3.**

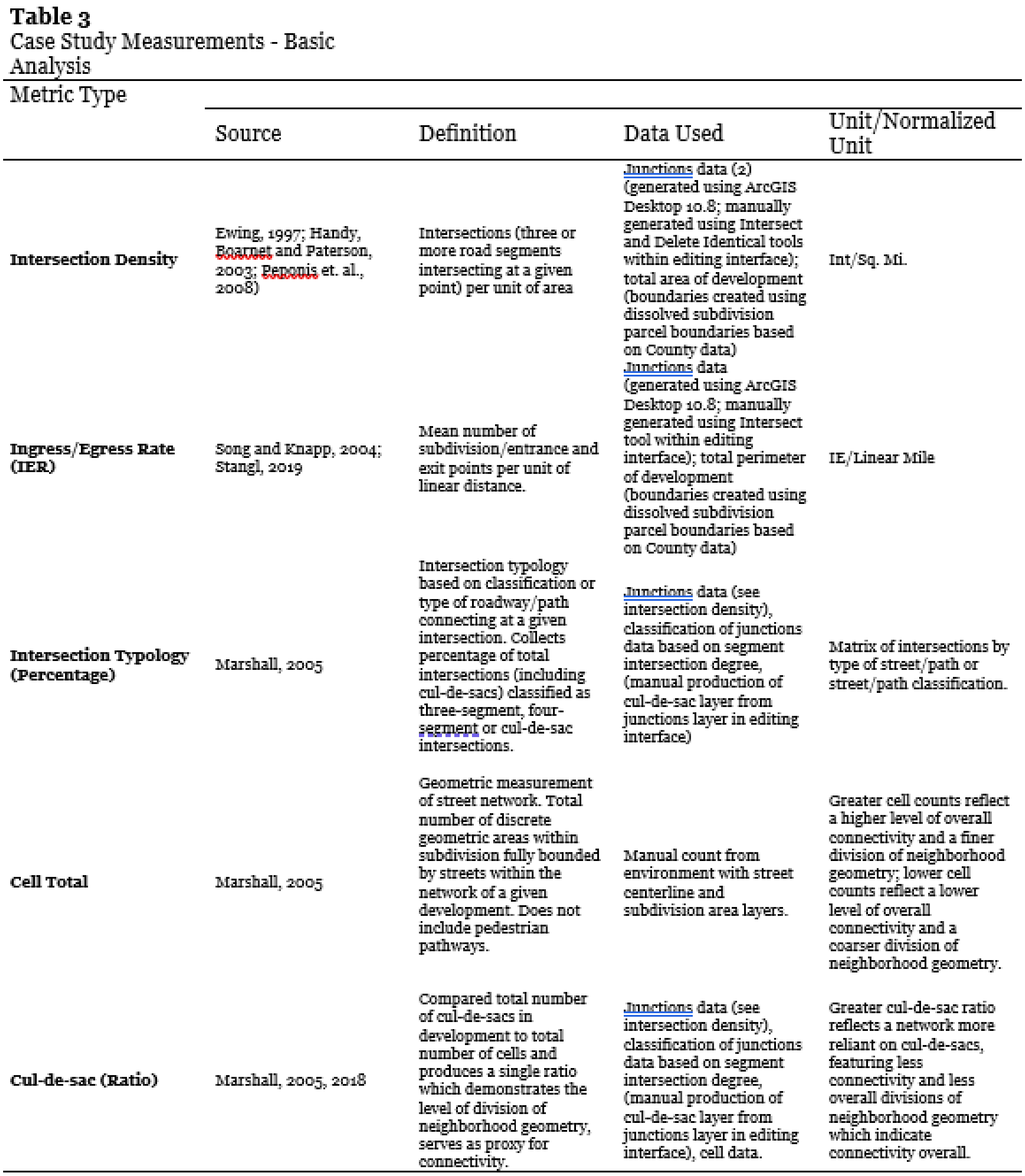


Table 3
Case Study Measurements - Basic Analysis

Metric Type	Source	Definition	Data Used	Unit/Normalized Unit
Intersection Density	Ewing, 1997; Handy, Boarnet and Paterson, 2003; Peponis et. al., 2008)	Intersections (three or more road segments intersecting at a given point) per unit of area	Junctions data (2) (generated using ArcGIS Desktop 10.8; manually generated using Intersect and Delete Identical tools within editing interface); total area of development (boundaries created using dissolved subdivision parcel boundaries based on County data)	Int/Sq. Mi.
Ingress/Egress Rate (IER)	Song and Knapp, 2004; Stangl, 2019	Mean number of subdivision/entrance and exit points per unit of linear distance.	Junctions data (generated using ArcGIS Desktop 10.8; manually generated using Intersect tool within editing interface); total perimeter of development (boundaries created using dissolved subdivision parcel boundaries based on County data)	IE/Linear Mile
Intersection Typology (Percentage)	Marshall, 2005	Intersection typology based on classification or type of roadway/path connecting at a given intersection. Collects percentage of total intersections (including cul-de-sacs) classified as three-segment, four-segment or cul-de-sac intersections.	Junctions data (see intersection density), classification of junctions data based on segment intersection degree, (manual production of cul-de-sac layer from junctions layer in editing interface)	Matrix of intersections by type of street/path or street/path classification.
Cell Total	Marshall, 2005	Geometric measurement of street network. Total number of discrete geometric areas within subdivision fully bounded by streets within the network of a given development. Does not include pedestrian pathways.	Manual count from environment with street centerline and subdivision area layers.	Greater cell counts reflect a higher level of overall connectivity and a finer division of neighborhood geometry; lower cell counts reflect a lower level of overall connectivity and a coarser division of neighborhood geometry.
Cul-de-sac (Ratio)	Marshall, 2005, 2018	Compared total number of cul-de-sacs in development to total number of cells and produces a single ratio which demonstrates the level of division of neighborhood geometry, serves as proxy for connectivity.	Junctions data (see intersection density), classification of junctions data based on segment intersection degree, (manual production of cul-de-sac layer from junctions layer in editing interface), cell data.	Greater cul-de-sac ratio reflects a network more reliant on cul-de-sacs, featuring less connectivity and less overall divisions of neighborhood geometry which indicate connectivity overall.

Space Syntax Measurements

Space syntax methods were used to achieve a number of objectives to improve the quality and usefulness of the study:

- Provide a method for comparing various dimensions of connectivity between case study communities
- Provide more precise analysis of the function of connectivity in subdivisions
- Corroborate findings through the use of multiple methods of quantitative analysis
- Illustrate qualitative findings of the study

The space syntax measurements of connectivity were pioneered by Hillier and Hanson (1985) and refined by scholars applying space syntax principles to transportation system behavior (Southworth and Ben-Joseph, 1994; Marshall, 2005; Marshall, 2018). This study measures three properties of network structure which were developed by Marshall (2005) and utilized in other subsequent research in transportation planning: continuity, connectivity and depth. Continuity examines relative length of routes within a given network; applied to real street networks, a

Table 4
Route-Specific Measurements - Space Syntax Methods

Metric Type	Metric Description
Continuity (l)	Number of segments (n) in a given route (measured from intersection to intersection identified in network analysis environment).
Connectivity (c)	Number of other distinct routes (n') connected to a given route
Depth (d)	Network distance of a route from a datum route (major arterial), based on the minimum number of unique routes which must be used to reach that particular segment. Can also be described as the minimum number of turns required to reach route.

network with high continuity will feature many routes which travel longer distances within a given network analysis area, connecting with many other routes and creating more direct routes within a network. Connectivity analyses how often connections are being made by routes; networks which do not exhibit a connected pattern of development (such as a tributary network full of cul-de-sacs) will have most of its routes create very few unique connections to other routes, resulting in a poor experience of connectivity. Depth measures the number of unique routes (and generally the number of turns, in most network typologies) required to reach a particular route; deep networks are associated with disorienting and indirect patterns of development which negate the overall experience of connectivity. The space syntax measurements utilized in this study via ArcMap 10.8 Network Analysis are detailed in **Table 4.**

Routes were defined as continuous stretches of streets or pathways which do not terminate. To determine this for each case study network, alignments (street names in network) and street hierarchy (arterial-collector-local) systems were assessed to determine these functionally continuous routes. The three values from **Table 4** were calculated for each route in the network using the ArcGIS 10.8 Network Analyst extension and calibrated and checked for qualitative accuracy using printed maps including street and path centerlines, street hierarchy and intersection types.

To assess the overall performance of the network structure of each subdivision, and to compare the performance of connectivity and related route structure variables between subdivisions, relative scores for each variable were developed. To create these scores, all values for each route-specific variable in **Table 4** were added together to create sum values found in **Table 5.**

Table 5
Sum Measurements - Space Syntax Methods

Metric Type	Metric Description
Total Continuity (L)	Sum of all continuity values assigned to routes throughout neighborhood network
Total Connectivity (C)	Sum of all connectivity values assigned to routes throughout neighborhood network
Total Depth (D)	Sum of all depth values assigned to routes throughout neighborhood network

The sum values for all three variables were then added together to create a single network structure score (N = L + C + D). Relative scores were created by dividing the route-specific values **(Table 4)** by the network structure score. This calculation created three relative score variables are detailed in **Table 6**. Relative scores from each case study subdivision were plotted on a ternary chart called a "netgram" by Marshall (2005), allowing for relative continuity, connectivity and depth to be assessed in each subdivision within a single graph space. The theoretical graphed street networks ("perfect grid" and "tertiary" representing two extremes of transportation network connectivity) were used as comparison benchmarks, along with several sample street network types from earlier research (Ewing, 1996) for reference.

Table 6

Relative Score Variables - Space Syntax Methods

Metric Type	Metric Description
Relative Continuity (L')	Total continuity (L) value divided by total network structure score (N).
Relative Connectivity (C')	Total connectivity (C) divided by total network structure score (N).
Relative Depth (D')	Total depth (D) divided by total network structure score (N).

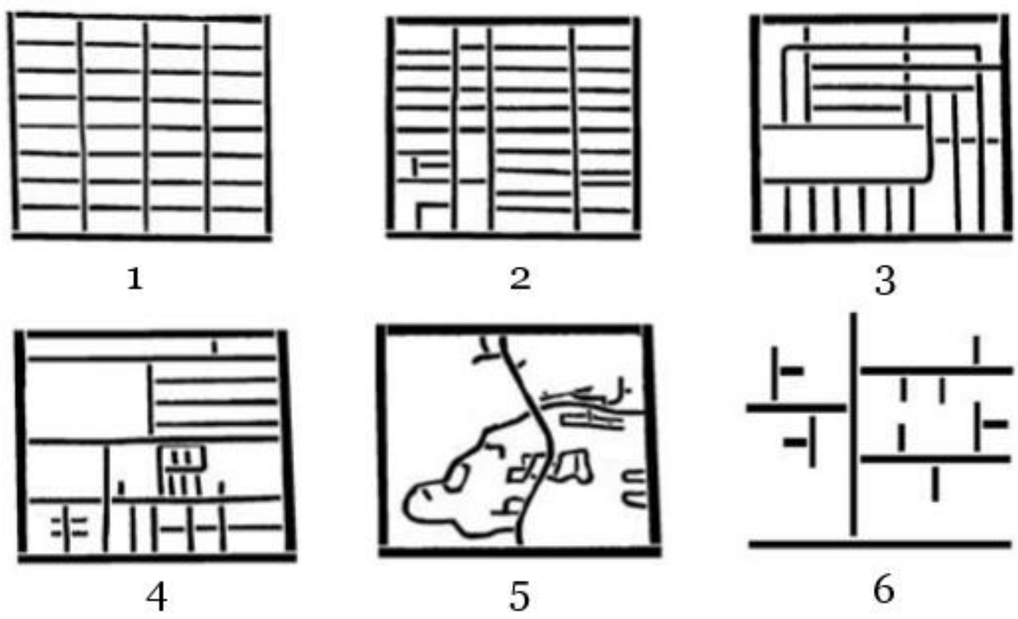


Figure 2. Comparison benchmark networks for quantitative analysis (Originally published in Ewing, 1996; graphic reproduced and utilized from Marshall, 2005).

Ultimately, numerous benefits are achieved through the implementation of space syntax methods when measuring suburban connectivity. Space syntax study, even within the confines of relatively rudimentary analyses such as the one designed here, allows for the analysis of variables which deeply impact the experience of street networks, particularly by users sensitive to changes in the built environment such as bicyclists and pedestrians. These variables are independent but influence one another in manners which are illuminating to understanding the function of a given street network.

For example, a network with high connectivity scores but high depth may have a high degree of internal connectivity (i.e. within subdivision walls), but require several turns or route changes to exit a development and reach a major pathway (i.e. an arterial). A network with high connectivity and low depth likely demonstrates a network designed for through movement and a high degree of accessibility. A network with low continuity but high connectivity may feature many short, truncated routes and require a large number of turns, resulting in high network depth.

Patterns in the built environment can be discerned with greater precision through these space syntax measurements. Such pattern identification is critical when assessing how qualitative variables and political, economic and social processes surrounding urban development, providing a greater precision for assessing network outcomes and which forces may most contribute to the production of the built environment being measured.

ViaCity Network Measurements

More complex network measurements were developed to measure the effectiveness of connectivity outcomes in each of the greenfield communities selected as case studies for analysis. These measurements, including Route Directness Index and ViaCity Index score, are two measures which assess the overall functionality of connectivity by investigating the directness of routes in local (i.e. specific nearby destinations) and global (i.e. all parcels in a particular subdivision) environments. Such measurements also take into account the mesoscale functionality of the community and connectivity outcomes shape a subdivision's relationship with the surrounding urban environment. Ultimately, this method of advanced geospatial analysis provides a platform for identifying how particular inputs in the processing of developing each case study community affected the production of effective connectivity in a given community.

These additional measurements were completed using the ViaCity for ArcGIS Desktop application (ArcMap 10.2.2). This software was developed by TranspoGroup Inc., a transportation planning and design firm based in Portland, Oregon. Distribution of the program was done with permission from Brent Turley, senior project manager at TranspoGroup overseeing the use of the program by the firm. The program has been used by planner practitioners, as well as in consultations done by TransoGroup with other planning agencies.

The route directness and overall connectivity (ViaCity Index) scores were completed by inserting the two network data environments produced for each case study into the ViaCity for ArcGIS program. These network data environments were added with parcel datasets and the centroid point shapefiles for the destination types included in this study (information about these layers can be found in Table). The layers in the network data environments for this study were calibrated with the ViaCity program before the completion of any analyses in the program. Two analyses were run for each case study: a "parcel-to-destination" analysis which measured route directness and ViaCity scores from parcels to nearby commercial destinations, and a "parcel-to-parcel" score which created a single aggregate accessibility score based on the ability to connect freely through the neighborhood area.

While Route Directness Index and ViaCity Index scores were both calculated for each analysis type, ViaCity scores were used for the final results of the study because of its greater sensitivity to distance decay and the effects of increased network distance on those moving through urban space without a vehicle. Descriptions of the methodology for calculating each score value are included in **Table 7.**

Table 7
Case Study Measurements - ViaCity Analysis

Metric Type	Formula	Origin/Destination Pairs	Analyses Run
ViaCity Commercial Destinations Score	VCS = (RDI + RDS) / 2 **where** RDI = Euclidian Distance/Network Distance **and** RDS = (-100/z)*y*100 (y = route distance and z = distance ratio in user defined parameter)	Origin: parcels (as measured to a midpoint on side of parcel adjacent to street/path centerline); Destinations: schools, commercial facility, parks (point centroids within parcels)	All route types (all parcels, pedestrian/bicycle network included)
ViaCity Index (Overall Connectivity Score)	VCS = (RDI + RDS) / 2 **where** RDI = Euclidian Distance/Network Distance **and** RDS = (-100/z)*y*100 (y = route distance and z = distance ratio in user defined parameter)	Origin: parcels (as measured to al midpoint on side of parcel adjacent to street/path centerline); Destinations: all corresponding parcels within case study area (midpoint on side of parcel adjacent to street/path centerline)	All route types (all parcels, pedestrian/bicycle network included)

Methods Summary and Justification

Table 8

Methods Summary by Proposed Research Question

Research Question	Methods
"What variables currently shape the implementation of transportation network connectivity in the Phoenix metropolitan area?"	**Literature Review** **Semi-Structured Interviews (SSI)** **Basic Content Analysis**
What attitudes toward connected development shape the decisions of stakeholders in the greenfield development process in Phoenix?	**Literature Review** **Semi-Structured Interviews (SSI)** **Basic Content Analysis**
How do various stakeholders in the greenfield development process in Phoenix shape connectivity outcomes in new developments?	**Semi-Structured Interviews (SSI)** **Basic Content Analysis**
What are common barriers to the implementation of connectivity in the Phoenix metropolitan area?	**Basic Content Analysis** **Case Study Selection** **Case Study Development** **Geospatial Analysis**
Which inputs in planning processes have promoted connectivity or improved connectivity outcomes?	**Basic Content Analysis** **Case Study Selection** **Primary Source Content Analysis (Case Study)** **Geospatial Analysis**

4 RESULTS

Numerical citations in the Results section indicate a finding from an interview panelist. An anonymous key for interview panelists is provided in ***Appendix B*** *of this paper.*

Qualitative Results

Interviews conducted with planning professionals from various public agencies revealed two primary levers which planners in the public sector utilize to affect the level of connectivity exhibited in the transportation networks of local communities. Transportation planners and traffic management professionals were revealed to be a decentralized yet powerful set of stakeholders shaping the prevalence of connectivity in the street networks of American communities. Less universally, land use planning and controls were found to vary between communities but play a significant role in steering the outcome of community connectivity. These findings were corroborated by planning professionals and designers from the private sector.

Traffic Management

Public power over the design of the transportation network in the Phoenix metropolitan area is "highly decentralized." (1). Phoenix's arterial system, a large grid of 4-8 lane regional roads which are planned as an accessible system for the entire Valley, is dictated primary by the regional Metropolitan Planning Organization (MPO), the Maricopa Association of Governments (17). *The Major Streets and Routes Plan* produced by the MPO as a regional transportation planning body manages the placement and design of major arterial roadways (Maricopa Association of Governments, 2011). There are "few opportunities" for altering the ultimate planned locations for this regional network of roadways (1, 2).

In contrast, the local road network, which comprises over 85% of the transportation network mileage in most Valley communities (City of Phoenix, 2021), is largely within the control of the private sector, particularly subdivision and master-planned communities developers (1, 6). According to one public planner in the study, the power of municipalities and local planning departments to shape the transportation network directly lies "within the collector network, which are mostly engineered to manage the connection between local streets laid out by the developer and arterial roads laid out by the regional planners." (1).

Though the system of planning the transportation network of the Phoenix metropolitan area is highly decentralized, it remains a powerful and primary force in shaping how the transportation network is developed. The private sector ultimately determines the final location and specifications of local streets, this does not mean that the public sector lacks all influence in the creation of street networks. Interview participants, particularly from the public sector, pointed to the regulatory role that local governments have successfully ascertained.

Most of these regulations are rooted in the requirement for public commitment to "safety and human welfare." Some private sector participants believed that the public sector's ability to transform local street networks remains powerful. As a homebuilder stated,

> *"...the public commitment to "safety" in "safety and human welfare" has resulted in a lack of local challenges in how transportation design is conducted in neighborhoods; since free-flowing, conflict-free traffic is seen as safer, cities exercised broad power to enforce this..." (15).*

Interpreting safety and human welfare primarily through the lens of safe vehicle movement between sites has resulted in a powerful public mandate to shape local road networks proposed by the private sector. Traffic calming measures were referenced by seven participants when followed up with to discuss how the public shapes the local road networks laid out by private actors (1, 4, 5, 6, 9, 13, 15). Some traffic calming and internal safety interventions in Valley communities include banning four-way intersections (6, 13), promoting the use of curvilinear streets and avoiding long, straight stretches of roadway (5, 15), and creating shorter blocks and breaks in street alignments to discourage cut-through and faster-moving traffic (1, 4, 9).

The mandate for safety in managing the road network is most clearly visible through the handling of higher speed traffic on collectors and arterials. According to one transportation engineer, "many municipalities resist the creation of more connections between collectors and local networks." (9). However, as echoed by another planner, the connectivity between local and collector streets is the primary variable being managed, and "there isn't much concern in the public planning process for local street level connectivity." When followed up with, this planner stated that "a lack of clarity of its benefit and avoiding risk" were reasons for this lack of concern. Involved in the development of the Official Street Map and General Plan for a suburban Phoenix community, they stated that,

> *"...we plan collectors and connections through reverse engineering, ensuring that collectors are not overwhelmed at particular points from local routes, while reducing overall conflicts." (1)*

Public planners stressed the role in which access management standards, which are present in most communities in the Phoenix region, play in the reduction of connectivity in the Phoenix region. Intersection spacing requirements extending up to a quarter-mile along arterial roadways and several hundred feet along collectors (for both public roadway intersections and intersections for private driveways and access roads) create far fewer opportunities for connections in the local transportation network (2, 4-6). Such reductions in access are done primary to avoid causing many conflicts at high speeds (2, 5).

Such standards were cited as befuddling plans put forward by private developers and transportation planners (9, 13). Such planners find that traffic safety offsets, access management standards and intersection spacing requirements "severely limit" opportunities for pedestrian improvements, connectivity, and improved mobility for people living in new subdivision developments (13). As such, "only larger developments are capable of providing access in multiple directions and providing [a] greater degree of routemaking" (12). Additionally, intersection spacing requirements and designated intersections for collectors on the Official Street Maps and circulation plans held by most local planning agencies "can result in intersections designated too far north or south, forcing smaller developers to struggle to build reasonable access to their property" (13). Access management was cited as a measure for "improving safety" by "many public works departments" (2).

Ultimately, shaping the street network around safety of the road network results in transportation design shaped by "risk management," according to one planner. As he quoted,

> *“risk management leads to reducing the number of intersections and creating environments where people [pedestrians] avoid intersections entirely to alleviate risk.” (1).*

Understanding intersections, particularly ones with high levels of activity, as a liability is a significant barrier to increased connectivity, which by nature of the property increases the number of possible directions of movements and conflicts within a transportation system. Particularly given the “safety mandate” and the liability of local government for the safety of its residents, the current combination of reliance on vehicle motion and liability management results in reduced connectivity.

Politics, Planners and Advocacy

The public role in enforcing traffic and access management standards is the most frequently cited public barrier to connectivity, as has been demonstrated in numerous pieces of academic and popular-level planning literature (Brindle, 2001; Williams and Levinson, 2011; Stangl, 2015). However, there are additional dimensions to the public role in shaping connectivity which are most often found in formal planning decision-making processes, from project applications and reviews to formal public hearings. An analysis of the political dimensions which emerged in the qualitative data collection of this study revealed the challenges in promoting and implementing connectivity in new American street networks.

This study revealed that different public departments and agencies, particularly within local government, bring interests to the process of planning review, which spread far beyond what has been articulated in past research. Processes which bring members of public agencies together in planning, such as pre-application meetings and design reviews, are moments where the level of connectivity proposed in a relevant development is subjected to debate and the competing interests of departments. The demands and public responsibilities of each of these departments shapes the way in which *connectivity* is built out once a project is approved.

The agency most commonly referenced by both private and public sector interview panel members was the fire department, who serves as a part of most public planning reviews in American local communities (Talen, 2012). In subdivision reviews, fire departments are mostly focused on promoting greater accessibility for fire service in the event of an emergency (4, 6, 7, 10). However, according to one representative from an engineering firm, fire departments are less concerned about overall connectivity and its routemaking effects and more about ensuring access points from multiple directions (10). Applied to subdivision planning, this results in a resistance to cul-de-sacs (which limit access to a single direction) and promoting multiple ingress and egress points to a particular development. However, given that poor connectivity is largely overcome by fast automobile traffic, there is less of a concern about internal connectivity. Other effects, such as fire departments' advocacy for wider streets to ensure free movement for large fire vehicles and trucks, frequently alter connectivity because of the higher amount of infrastructure required for each segment of roadway and the effect of such costs on the ability to feasibly create gridded street networks (10, 14).

Sanitation was found to play an indirect set of roles in swaying connectivity. According to one East Valley planner, sanitation departments seek to break communities into "pods," producing relatively direct routes while avoiding leaving and re-entering subdivisions or crossing major roadways to complete trash service (2). Sanitation also remains "the greatest advocate toward wider streets in most local agencies," pushing against greater connectivity through the imposition of greater costs per segment of infrastructure (9, 10). Other features which promote greater connectivity, such as residential alleys, are frequently opposed by sanitation due to difficulties of access for trash collection vehicles, a fact reiterated by public and private interview panel members (6, 15).

Police departments were referenced as affecting connectivity through demands for greater access for emergency services, similar to fire departments, and connections between crime and neighborhood permeability which is increased via increased connectivity (2, 7). Unique to Arizona's varied local water distribution networks, water service providers were referenced to increase roadway width through provisions requiring water lines to be run under public roadways via public utility easements (P.U.E.s), restricting developer willingness to implement connectivity (4, 6). Sewerage agencies were references as increasing connectivity because of the need for straight service lines and the benefit of gridded streets in capital improvements (15). Parks and recreation departments were also referenced as increasing connectivity through their role often advocating for increased quality and connectivity for trails and open spaces (1). Planners frequently referenced the far greater role planners traditionally play in Phoenix land use patterns as opposed to transportation network development (2, 6, 7, 8).

Table 9. Relationship with Connectivity by Public Agencies

Agencies Commonly Involved in Planning Review, Referenced in Study	**Relationship**
Fire	+/-
Sanitation	-
Police	+/-
Sewerage	+
Water Management	-
Parks/Community Services	+
Source: Noah Schumerth, 2021	

As both contributors and mediators in various planning processes, planners themselves were referenced as being liable for public policies and attitudes which reduce overall network connectivity. "City planners are fighting against 'squares' with provisions for curvilinear streets," said one planner in the study (4). Subdivision guidance in the form of "residential design standards or similar documents" apply measures which can harm overall connectivity and griddedness (2). Planners frequently appeal to the benefits of curvilinear, less connected streets in order to "reduce sightlines in an attractive manner" (4), "avoid continuous through streets creating traffic," (5, 15), "promote neighborhood interest and positive neighborhood perception" (4). Additionally, planners referenced requiring large lot sizes and minimum lot widths in many residential zoning districts (and a balance of larger lots to offset the presence of smaller lots) as a barrier to connectivity imposed by planners (4). Unique to growing communities with large amounts of greenfield land in the Phoenix area, there are challenges to shifting from former rural or county development standards (particularly for subdivisions and larger developments) to a more urban pattern of developments; planners are frequently appealing to rural character and "failing to consider the demands of urban service provision" (3).

Cost management amongst planners was a significant barrier to connectivity imposed by public planners during the subdivision planning process, as stated by multiple members of the interview panel. According to a public planner whose municipality maintains virtually all local and collector streets built in new developments, planners are:

> *"often thinking about the maintenance liability which will be shared by city residents in several decades. With increased connectivity creating more infrastructure to maintain, the public sector may not be necessarily in favor of the greatest level of connectivity" (4).*

Planners recognized the cost of implementing features which promote connectivity in Phoenix's urban landscape, such as new stoplights and high-visibility ("HAWKS") crossings, additional entrances and exits to new developments, and specialized infrastructure which can realize the benefits of connectivity. As one planner stated, "these are expensive for the private side to build, and the public side to maintain" (1). As such, planners in many communities, "are making minimizing infrastructure a goal, albeit a secondary one" (4). The result is a "traditionally middling response from local government" in promoting connectivity (12).

There were benefits to connectivity articulated by the professionals included in this study. Connectivity was seen as a benefit mostly because of its utility, "allowing for better routemaking and the ability to navigate around obstacles in the street environment, ultimately making streets a better public service" (6). Connected development was also referenced as providing opportunities for public planners to improve social interaction and community building because of the greater number of neighbors within reach and the potential for "greater walkability" (6, 14). Public planners were suggested to "feel less incentive" to make private services more efficient through connect[ivity]," (9), nor "connectivity as a means to improve safety" (10).

Homeowners as stakeholders in the development process can produce a major barrier to implementing connectivity which extends beyond the boundaries of individual subdivisions, and realizing planned future connections which are the result of the staggered construction of most American cities. One planner remarked, "homeowners are frequent forces of opposition to connectivity" (6). This most often occurs when new subdivisions and developments are brought forward for public hearings; residents are prepared to "argue against perceived increases in traffic that will come from planned connections" (9).

More than one participant in the study illustrated the political challenge to connectivity posed by homeowners by looking at scenarios surrounding stub streets, where streets reach the boundary of a new subdivision and await connection with a future development. A planner in the study reflected that it is "politically infeasible to believe, as planners, that stub streets will be expanded in most cities whenever homes are on [them]" (6). Planners referenced requirements in multiple Valley communities which require subdivisions to provide stub streets on streets without homes located on them, usually as small cul-de-sacs between homes at the edges of developments (6, 9, 15). Unfortunately, this practice is also increasingly opposed by developers seeking to maximize the number of homes located on each piece of infrastructure built (10). Homeowners in existing communities can serve as a frequent barrier in the process of shaping community connectivity, often making one of the "few tools of the public side to promote connectivity" difficult to implement (6, 10). Without an alignment with site conditions which makes extending stub streets the most economical or feasible option (such as a required ingress point on a given side of a subdivision), it is difficult to implement connectivity in this manner.

A factor which amplifies the power of existing homeowners to oppose increased connectivity in neighborhoods is the lack of clear stakeholder in the public who may approve of additional connectivity. Most activism and public participation by residents surrounding connectivity is from existing residents, who are "overwhelmingly opposed" to increased connectivity and movement between neighborhoods (1). Advocates for "better neighborhood development are few, motivated only by a vision for the community," and "rarely receive anything for participation in such activism, especially given such advocates are unlikely to be residents of the surrounding area of a proposed development." As such,

> *"…new development falls into a blindspot of ownership; only NIMBY neighbors may offer advocacy for alternative [neighborhoods] designs, they're going to be against connectivity, especially external connectivity, citing traffic and public safety" (1).*

Two participants of the study noted the lack of clear metrics for counteracting resident concerns in a meaningful way in public hearings. Missing metrics such as a “missing level of service concept for pedestrians” and “clear data presentable by planners in support of connectivity” makes overruling resident concerns difficult (1). Ultimately, “a lack of systematic analysis of quality in bicycle and pedestrian networks” leads to a lack of political will to support connectivity (1, 2). Missing tools in the public planning process further contributes to the prevalence of attitudes against connectivity.

At the heart of the political economy of connectivity is the theoretical tool of *vision*. Vision was revealed in this study as a broad, powerful tool used to respond to powerful constituencies and stakeholders in the inherently political process of planning and approving a subdivision project. As one planner on the panel stated, “vision is political” (3).

Vision was described as having varying levels of power in shaping connectivity outcomes in the city. Contradictory opinions about the role of public vision emerged from the interview panel. From one planner stating that planning agencies in local governments have “no social role” which can influence connectivity (1), to another stating that the public planner’s role is “not about crafting a centralized community vision,” (3) to a third planner stating that “community vision can transform what types of projects become feasible” (2) What originally appeared to be contradictory conceptions of the public role in shaping connectivity became a more robust vision of how public and private actors interact. A closer look at interview suggests that different *scales* of vision may be responsible for the connectivity which has been successfully implemented into the urban fabric of Phoenix.

The power of private sector vision as the primary variable shaping connectivity in the planning process was clearly apparent. Over half a dozen participants discussed, in some capacity, how connectivity was largely observed to be a product of private sector vision, and private sector vision shaped the political discourse surrounding a proposed subdivision project (2, 3, 7, 8, 10, 13, 14, 16).

Vision translates into more formal political agreements, taking the form of development agreements, design guides which are "inherently political documents," as they become the documents to convince councilpersons, commissioners, and planners to adjust or create ordinances and standards to accommodate the vision of development (8, 14). The sale of the vision to the community and stakeholders through public channels was referenced as making it possible to work to do something markedly different in neighborhood design, as mentioned by a planner in Buckeye, Arizona:

> *"The stronger connectivity found in many New Urbanist communities in the Valley such as Verrado [in Buckeye] was done through development agreements and the sale of a cohesive vision for an entire community – essentially building its own city through a vision...this is what created the break from the norm in Phoenix neighborhood design." (7).*

One example referenced by planners on the interview panel was a pair of Gilbert, Arizona subdivisions built in the early 2000s and renowned for a greater urban character and higher level of griddedness in design: Agritopia and Morrison Ranch. It was expressed by an interview panel member familiar with the two projects that the griddedness and high levels of connectivity exhibited by these projects were a product of choices made by the developers, to "take advantage of site conditions and appeal to a particular theme, in the case of Morrison and [Agritopia], farming heritage and neotraditional design" (3). The public role in both of these projects was twofold: "realize the developer's vision within public regulations," and "integrating a variety of residential land uses and creating 'complete communities' aligned with Gilbert's land use policies" (3). As a former Gilbert planner stated:

> *"Development processes are not 'what the [Town] wants'…the [Town] does not create a centralized community vision, the Town manages regulations' (3).*

Agreement came from other public planners (1, 4, 7); one stated that the public role "lies in service delivery for new communities proposed – utilities, ensuring minimum levels of ingress and egress, and other factors which impact those service[s] which are normally public." (1). Design decisions, particularly overall connectivity, are "largely driven by the public sector." (1). The public sector may also follow the private sector after a new vision for a community is successfully put forward; the two Gilbert projects and their successes ultimately led to the realignment of Gilbert's zoning ordinance and "character areas" to accommodate greater connectivity (3). The accommodation and success of private vision ultimately shaped public ordinances and codes surrounding connectivity.

Tools such as Planned Area Developments were referenced repeatedly by members of the interview panel (2, 6, 10, 13, 14). According to one private transportation planner, the "planned area development" or "master-planned community" model ensures greater developer control of open space, amenities, and community theme, "allowing for the kind of total control of a vision," and the needed arrangements for that vision, "which can make small homes and gridded development possible by a developer" (2). As one planner pointed out, this allows variables such as consumer demand for connectivity and mixed uses, and approaches to master planning which respond to market demand, to shape connectivity more clearly. For example, when housing demand is high, as it was in the early 2000s, master-planning becomes more common to create large numbers of housing units and product types, and there is less segmentation between communities:

> *"Large-scale, multi-phase projects lead to more diversity in products, more connectivity, and a greater likelihood of griddedness and connectedness emerging in the city as a whole." (10).*

It is through arrangements such as Planned Area Developments that connectivity is being realized through private vision. Both in community vision and in the approach of a particular community to respond to market forces, the public role in affecting connectivity is largely regulating and attempting to preserve private sector visions and market approaches to developments. Emblematic of this role was one quote from a private land use planner on the panel, who stated that, "municipalities are rarely a barrier in connectivity." This quote indicates less that cities play an outsize role in promoting or discouraging connectivity, but rather are more in a position of oversight and mostly realizing private sector vision (13).

The political conditions surrounding the implementation of connectivity ultimately illustrates that connectivity is successfully implemented as a product of private sector vision and decision-making. However, the conflicts surrounding the role of the public sector reveal that the public sector has limited tools for promoting connectivity in Phoenix's planning processes, but does possess certain vision-building tools which was flexible and salient when responding to powerful political actors (i.e.

councilmembers/commissioners and constituents) who provide a great deal of influence on the ultimate outcome of communities.

Private Sector Dynamics Affecting Connectivity

Public and private planners on the panel suggested numerous benefits for developers and private sector stakeholders integrating transportation network connectivity into proposed subdivision developments. Most commonly cited was the role that connectivity can play in selling a particular type of community, communicating themes such as family-orientation, walkability, and traditional design which can appeal to new market segments of homebuyers (6, 7, 8). Connectivity remains interpreted as a method for increasing the accessibility of neighborhood amenities that sell new buyers to homes in a particular subdivision (7, 8, 13). Trails and connectivity designed to increase recreation opportunities was claimed to be one of the most asked for amenities by potential buyers (12, 13), an appealing amenity to modern suburban buyers.

Connectivity was cited as also providing an opportunity to provide a greater number of housing products, particularly denser products which require greater proximity to other amenities (3, 12). One land use planner cited connectivity as decreasing market friction between housing types, and enabling developers to "increase the number of housing markets which can be reached" in a given development without harming housing values overall (12). Concurrently, connectivity was suggested by public and private planners alike to promote "social cohesion" for residents in new subdivisions, reducing "us vs. them" attitudes referenced by a planner in this study (6, 12). Connectivity was linked to market benefits in higher resale values in the long-term, allowing developers to market homes in developments as sound, long-term investments for buyers (13, 15). Connectivity also allows for a greater number of homes to be fitted onto a site, with the increased yield providing developers with greater flexibility and profit opportunities in development (1, 15). Connectivity was cited as increasing market efficiency and design expediency, allowing for streamlined construction methods which can move a project quickly from plan to completion, necessary given the current financial realities of subdivision construction (15).

Data from interviews reflected a key theme: market strategy is the primary factor in dictating connectivity outcomes. This phenomenon was directly observed by a myriad of interview participants (1, 3, 6, 7, 8, 12). Throughout the interviews of the study, it was discovered that the heavy impact of real estate market dynamics on street network design and neighborhood layout has dramatically altered patterns of connectivity in the Phoenix metropolitan area, creating opportunities for connectivity and producing new barriers to creating durable connectivity in Phoenix street networks.

At the most functional level, participants stated how connectivity proposed in new subdivisions is significantly affected by demand markets in residential development (1, 3, 10, 15). Market demand is leading to the construction of smaller lots to promote yield, aiding in the production of greater connectivity (13). Planners shared experience that as housing demand increases, as it has been in the decade preceding this study, master-planning large subdivisions becomes more common to create “a large number of homes which appeal to a range of product types” (10). This leads to “an overall lower level of segmentation” across a community, “connecting different amenities and housing types,” because of the ability for phased master-planned communities to control the types of connections between areas under a single developer, in addition to the “rise in griddedness from such developments because of the large amount of construction and needed efficiency required at any given time” (10).

Interview results demonstrated many further complexities in how market dynamics shape connectivity. In particular, street and network connectivity has been absorbed into the development process as an amenity and an indicator of the development of a particular type of community. Connectivity has been "implemented when paired with a particular product" (8). As one public planner stated,

> *"Street layout matters for community marketability, just like home design" (7).*

The well documented rise in demand for urban amenities in suburban environments (OKI Regional Planning Forum, 2007; Montemurro et. al. 2011; Brookfield, 2017) has been linked to improved connectivity in new-build neighborhoods and subdivisions. New demand for open space and "urban-lite" (7) communities has led to a shift toward a more communal pattern of activity for residents (7, 8). The effort to build a greater number of community facilities, more diverse land uses, and trail networks in subdivisions, and ensuring a high level of access to these new facilities by homeowners, has resulted in an increase of connectivity to create shorter routes and greater visibility of community amenities for residents (1, 3, 7, 12, 13). Connectivity itself has become an amenity as "trails have become the most asked for amenity in new communities," leading to trail connections (particularly "internally") becoming an industry standard in larger subdivision developments (12, 13).

More broadly, connectivity was cited by several participants as a method by which developers sell a vision of a particular type of community (2, 3, 7, 12). One planner referenced previous efforts in their own community, where farmland owners came forward over the past 20 years with large subdivision projects with a more urban feel, using neotraditional and agricultural themes. To clearly articulate these themes, a strong street grid was built throughout the communities (2, 3). The grid was also employed because of the master-planned nature of these communities; with greater control of amenities, central open space, and overall community theme, developers of these communities reduced overall lot size and employed a grid to increase the yield of homes while promoting a more communal neighborhood development pattern (3).

Beyond neotraditional communities, members of the interview panel cited the use of grids and network connectivity to promote sales and solidify the identity of communities to various demographic groups. One example provided by planners in the study was the use of connectivity to attract families to new developments by selling connectivity as a tool for connecting more readily to parks, neighbors, and community amenities (7, 8). The grid is used to both sell community identity in a crowded and increasingly fragmented real estate market by invoking emotion and feeling, and to promote and highlight community amenities constructed to differentiate and produce new value in subdivision communities (3, 12). As one land use planner stated,

> *"Creating an emotional connection to a neighborhood through our design…and seeing a neighborhood as a destination, is critical when we design a new neighborhood" (12).*

However, this emotional and personal appeal can both benefit connectivity or harm it, and some of the strongest community emotions identified in the study are those which were cited as harming connectivity by participants (2, 3, 4, 5, 9, 12, 15, 16). Just as connectivity and gridded transportation networks can provide powerful imagery of a more urban and connected lifestyle sought after in suburban communities, the ongoing demand for the articulation of the themes of security and privacy in neighborhood life was found by interview participants to be playing a major role in resistance to improvements to connectivity in new suburban communities. One public planner stated that marketing a subdivision with an “image of complete control” and that is “set apart from those around them” is a “salient concept,” “selling for many new buyers and residents seeking to live in these new places” (6). The production of an exclusive product – “built on the perceived value of security and exclusivity” – is “essential” and is a “primary method by which [private sector] stakeholders shape the process of making communities more connected” (6). One planner described the rising demand for privacy and exclusivity in residential communities as the most important barrier to the development of more widespread connectivity in new neighborhoods (6), and numerous other panel participants referenced the perception of community “security,” “privacy,” or “exclusivity” by new homebuyers as a restriction on connectivity (2, 3, 4, 5, 9, 12, 15, 16).

Ultimately, connectivity becomes “negatively associated with neighborhood openness” (3). A “built-in fear of outsiders” was referenced by two planners, which leads to greater pressure for gating, private street platting, and the elimination of public connectivity (3, 6). Connectivity becomes a tool which cuts against private goals of security, privacy, and exclusivity, themes which invoke deeply emotional responses (12). One barrier identified to overcoming the push for private security and exclusivity in subdivision design is the “power of emotional responses in selling a community to those who are most likely to live there” (12). Land use planners working for clients are seeking to create powerful emotions to draw buyers into the community (3, 12), and feelings of “exclusivity and being set apart from others” is a “particularly salient” theme (2, 12).

Gating is a tool being “increasingly used” in many municipalities in the Phoenix metropolitan area, with powerful effects “counteracting direct routemaking and connections” (15). While the level of openness toward gating varied amongst public planners representing different communities in the Valley (1-8), and some cited benefits to gating and reducing the publicness of streets (such as “saving on liability costs to the city” (5)), most public sector interview subjects were wary about gating, responding to questions about gating with apprehension about the severe disconnection of neighborhoods from the rest of the city. Public sector respondents were hesitant about the effects of gating on “ensuring circulation that comes from connectivity” (2), “emergency access and service distribution” (7, 8), and uncertainty about the quantitative benefit of gating (1). One planner directly questioned whether it was worth the loss of the benefits of connectivity to preserve a “marketing device used to set a community apart” (2). In opposition, the private sector “favors gating” to “preserve exclusivity” (2, 6), increase the “perception of privacy” (2, 6), and to “control amenities for overall gain (2). As more developers seek out gating as a method of setting neighborhoods apart as distinct and with greater private control over safety (one homebuilder cited that at one national homebuilding agency, over 95% of new projects are gated) (15), gating continues to be seen as a key barrier to connectivity that is rooted in deeply held emotional responses to neighborhoods.

Private streets were referenced frequently as an alternative to gating and connected to the potential for *greater* physical connectivity in new subdivisions (2, 5, 6, 12, 15). Developers facing pressure to increase connectivity (whether from the market or from public stakeholders) often seek narrower streets to offset the infrastructure costs of increased connectivity, particularly when the product type sought after by the developer encourages a more urban, gridded pattern of development (2, 12). This is most often done through the proposal of unique street sections via a Master Circulation Plan in a PAD guide or a similar document submitted for public review (5, 6). Developers in the Phoenix region frequently seek smaller setbacks and gridded streets, but concerns by public agencies (particularly “fire, sanitation, and public works”) create resistance to approving these measures (12, 15). Because private streets become untenable in the process of street development, private streets are sought after which “are far more likely to win appeal from local requirements, following custom cross sections with amended access and spacing requirements.” (6). While these private streets arrangement face “some Valley scrutiny” because they “cause a risk of liability in the public sector taking over ‘unsuitable’ streets in the future” (5), and these streets are more likely than not to be gated (6), private streets are one mechanism being used to circumnavigate the barrier that some private sector planners and engineers assert that the public imposes. Private streets may create arrangements which “create more internal connectivity while cutting against…goals to make things more broadly connected” (6).

In general, the cost of infrastructure remains a key barrier to the implementation of more cohesive and connected street networks in new subdivisions. Connectivity increases the total amount of infrastructure provided throughout a new community. Developers echoed the widespread desire to build narrower streets with smaller setbacks to streets in many communities, which was create more opportunities for street connectivity, but cities claim such conditions are “unsafe” (12). With “higher costs” and a “lesser capability for producing connected streets,” several developers stated that they may oppose the imposition of connectivity improvements even in instances where it is sought after in principle by builders and developers (12, 13).

> *“with four lanes of pavement, two traffic lanes and two parking lanes, required on even local streets, connectivity becomes much harder to create and costs go way up” (14).*

Private actors in the process of designing a subdivision "are tasked with minimizing costs and the requirements for infrastructure" (10), creating a natural barrier in current development processes toward producing connectivity. This is baked into the current paradigm of new subdivision development,

> *"Developers are rarely newcomers to subdivision development – they know what it takes to maximize lots with a certain price point to pay for infrastructure and maximize profit" (4).*

The demand to "build as little infrastructure as possible" (7) to "minimize costs" is deemed to be imperative to the outcome of connectivity (7, 10). Private control of local transportation design leads to cost driving the connectivity outcome, and the approach to cost in the current planning process results in cost shaping connectivity. Pedestrian connectivity, in the form of pathways and other infrastructure, becomes, "something developers are unwilling to pay for, and [the level of connectivity] is ultimately a product of what we can get developers to pay for" (2).

Views on the cost of improved connectivity were not consistent between public and private stakeholders. The construction of alleys were seen to be too costly in many developments, though it was stated by the homebuilder representative that cost prohibitions "depended on the local regulatory environment." (15). These alleys were often used to realize "small-lot construction." (15). Meanwhile, two public sector planners stated that they try to encourage alley-loaded or detached-garage residential products to add "residential variety and promote a better street environment," (6), but are rejected due to the addition of "additional costs" (3, 6). There was evidence that the public sector "does not receive clear demonstrations from the private side that there are prohibiting costs from these additions [alleys and paths]" (6).

According to several private sector representatives, the “disconnect between development finance and public requirements and processes exacerbates ‘the cost problem’ for connectivity” and creates an additional barrier to promoting connectivity (15). Design requirements mentioned included minimum street widths, large turning radii for cul-de-sacs and intersections, and infrastructure design were described as hampering the ability to follow public pressure for greater connectivity (6, 11, 12, 13, 15, 16). Public processes “adding ‘back-end’ comments” and extending the length of the review process ‘without predictability’” were noted to adding developer cost in a manner which reduced flexibility for developers in meeting public demands (12, 13, 15). Such flexibility was noted by one planner as a critical tool to “find ways to achieve good compromises between city and developer, such as creating connectivity” (5).

As the homebuilder representative in the study noted, predictability of process leads to lower costs and a “greater willingness” to provide public amenities as recommended by the public sector, including connectivity (15). A lack of predictability in the ownership structure surrounding the amenities which produce connectivity, including the larger street networks, parks, pathways, and other amenities is a continued cost concern, and is “an undefined point in most local neighborhood planning processes” (5) and hampers the “ability to build these around [cities]” (1). As such, both design and clarity of process “dramatically shape communities, often by reducing the efficiency or effectiveness of neighborhood network design” (15). A disconnect between private finance and public design regulation leads to a potentially serious barrier in connectivity implementation.

Multiple interview panelists suggested that hesitation to increased connectivity due to cost is far from exclusive to private stakeholders in the planning process.

According to one public planner, their cities (and “others in the Valley”) frequently considers the maintenance liability which will be shared by city residents in several decades after initial construction. Increased connectivity results in more infrastructure to maintain and may result in both “political” and “administrative” disfavor toward connectivity.

> *“While maybe secondary, minimizing infrastructure becomes a goal for us public planners here” (4).*

Another planner pointed to the difficulty in the costly investments in specialized infrastructure to maintain connectivity in the Phoenix metro, particularly “at smaller scales within Phoenix’s large blocks” (1). The cost of infrastructure such as “HAWKS signals, new roads and crossings, and specialized infrastructure” is “hampering connectivity,” and that cost exists for “both the private side in construction and the public side in maintenance.” Additionally, the current model was described as not creating enough “costs in service delivery” in deliveries, emergency services, or civic infrastructure to warrant greater costs created by connectivity (1, 13). Without a “clear argument for bearing these costs,” the public side is unlikely to advocate for the costs of connectivity (6).

Tangential to cost, financial risk was brought up continuously in the study as a variable in the development of connected street networks. As stated that developers have a clear understanding of how to maximize a necessarily predictable return on investment in development, master-planned community developers were described as having residential and commercial project managers who have “particular project types” which have deeply entrenched funding mechanisms and are deemed to be “safe investments”

(3). Developers are “risk-averse” financially, and changes to the method of design of master-planned communities, whether residential or other uses, “are unlikely to develop quickly, even in response to clear market demands” (12, 15). Increased connectivity throughout new neighborhoods between land uses, even as demand increases, is unlikely to be quickly realized due to financial risk and historically entrenched financial mechanisms for realizing overall profit and the required return to private stakeholders in the process of building a subdivision.

One potential barrier to connectivity was summarized by a land use planner who suggested that the way in which development stakeholders approach the question of connectivity (largely through a “competitive, production-based lens”) may lead to challenges in increasing connectivity beyond individual developments (12). They stated that the current private approach to connectivity, determined by the required financial outcomes of designing and building on a site, will not,

> *“…necessarily represent a shift in increased connectivity, but rather a focus on creating ‘better connectivity’ and rethinking connectivity…such as creating better trails and amenities. Developers thrive on differentiation…” (12).*

In the current development model, connectivity “assets” such as trails and improved street design are likely to be used more to improve appeal to particular segments of the market, which in turn results in a push for a greater security in sales through market differentiation (12). This connectivity improves internal connectivity and produces better outcomes within particular developments, but fails to develop the functional connectivity found in “connecting neighboring land uses and destinations” (2).

Connectivity between developments constitutes a financial risk to development; residential and commercial developers in the current landscape of master-planned community development are “rarely designing communities to connect or complement one another” (12). Ultimately, different portions of master-planned communities, and these communities adjacent to others nearby, are “separated by walls and require arterials and collectors to connect,” isolated and designed to minimize impacts from surrounding developments (4, 14). Planners in the study cited risks caused by connecting more closely with surrounding communities, including “maintaining distinct community identity,” “maintaining property values,” and “avoiding traffic” (4, 12, 14, 15); these risks carry over into development finance (12). One public sector stakeholder with a background in industrial and commercial development pointed to the fact that residential and commercial sites remain “incompatible” to most planners, both public and private.

> *“We [planners] see these two uses as a compatibility issue, but the commercial development is only in existence because of residential development. They are more than compatible; they’re even integral. The solution around incompatibility is through design. How can these uses be safely and meaningfully integrated and meshed together through connectivity and good design?” (4).*

The result was cited to be “greater challenges to implement mixed-use development,” (3), as found by interview panel members from Buckeye and Gilbert (3, 7, 8).

Numerous planners described a general apathy toward mixed-use development in Arizona, and in particular taking on financial risk to embrace greater land use connectivity in the development of new subdivisions (4, 5, 12, 13, 15). This apathy was explained in the study to emerge from the large quantities of available land in much of the Phoenix region (4) and the overall lack of responsibility to "generate demand" for people to utilize connectivity to reach other nearby land uses in a manner which does not rely on the vehicle and the current infrastructure system in the Phoenix region (12, 15). The existing lack of demand for pedestrian connectivity paired with the financial burdens and missing infrastructure within development stakeholder systems for providing connectivity leads to an overall lack of pressure to implement greater connectivity.

Managing Site Characteristics

Participants of the interview panel identified numerous variables which affect the ultimate connectivity of a street network before the members of the private sector enter into the complex processes of interaction with other stakeholders in the subdivision development process. These variables were most commonly associated as being managed by land use planners, urban designers and consultants who are involved in developing the design of the subdivision. The interview panel demonstrated that connectivity outcomes are heavily dictated by variables which are pre-existing conditions of the site of the proposed subdivision, and are largely the responsibility of the private sector to manage in the development processes of communities in the Phoenix region.

Topography

The most referenced barrier to connectivity in the street networks of subdivisions was elevation change and topography. Land use planners stated the "preserving views" (8) and "giving…the sense of elevation change" (12) were essential for maximizing the value of a site with more unique topography. Maintaining views from streets in the development becomes the primary focus of the orientation of streets in these subdivision (14). Geography was cited as being "often the most significant barrier" to development, with "planned lakes, streams, and arroyos" (12) being the primary topographic barriers to connectivity throughout the Valley. The presence of washes in Arizona particularly shapes the resulting design of new communities; these features "create fingers of development between washes," and serve as a "frequent barrier to connectivity" in the Valley (13). As a former planning manager stated,

> *"land is flat; topography is a major predictor of whether we will see a developer seek more gridded development. We won't see those grids in a topographically diverse area." (3).*

Lot Size

The planned size of lots in a subdivision is a "strong predictor of how much of a grid will form" in a given neighborhood (14). Smaller homes and "entry level products such as subdivisions planned for 'starter homes'" tend to be gridded (10); as one planner stated, developers constructing starter home communities, "build for more efficient design and construction, and the grid allows them to do that in the construction phase" (10). Larger lots were cited as making it more difficult to produce a yield of sales necessary to support the greater amount of infrastructure needed to build a gridded network of infrastructure, and does not provide "the same benefit for maximizing the number of homes as it does for smaller homes" (8). However, lot size is not a perfect predictor of griddedness and connectivity – "one developer may look for gridded streets to meet a certain design, one developer may look for less gridded streets in the same price point." The effort to create a grid to accommodate a particular lot structure in the community may be subject to the effort to capture "more particular market segments." (9).

Lot Maximization

Integral to orienting the street network to a particular lot size is the goal of maximizing the number of lots contained within a particular subdivision, which is the key measure to settle in order to ensure that a subdivision's development meets the goals development firms create for return on investment from the development. As two public planners stated, "private maximization of the number of lots on a site is the primary goal for most of the street design in Buckeye" (7, 8). This leads to,

> *"…creating a block structure, whether broken up into smaller pieces or featuring continuous blocks, which promotes yield, and that's what we expect to see in most developments" (1).*

One engineer with a background working on large subdivision projects summarized the role of lot maximization in the development of a street network:

> *"From an engineering perspective, there is a need to sell homes and every home makes money, and so road networks in subdivisions are designed to maximize the number of homes in each communities based on the product type desired" (10).*

Planning for homes leads and has a strong correlation with the production of infrastructure, as homes tied directly to infrastructure wherever possible, "in the interest of maximizing number of homes on each street" (9). This meets the need to "create X number of lost at Y amount of money per lot to pay for infrastructure and turn a profit" (4, 5). This was concurred to by the homebuilder representative in the study, who stated that homebuilders were not found to be opposed to the grid, and may support them in many instances. "Long, straight streets are the most efficient for installing and maximizing lot count, and we recommend this to our planning consultancies" (15). Lot maximization was the primary impetus for support of gridded community design from homebuilders. Griddedness reduces waste that may hinder maximizing the number of lots in a community, "wasting space on curves in odd lot shapes and sizes where we lose value overall" (15).

Utilities

The accommodation of underground utilities plays an invisible but salient role in the development of street networks in the Phoenix metropolitan area. The "physics of utility systems will not change," as a homebuilder stated, and "…developers will always seek to use regular, straight alignments and longer straight stretches where necessary to run sewer and water infrastructure" (15). Such utility arrangements were found to be one of the primary factors in maintaining street alignments throughout a development, even of the roadway located above the infrastructure is not continuous and a utility easement extends beyond a road (1, 9). Using regular street alignments designed by local municipal engineers and planning bodies "assists in both streamlining development and providing longer stretches appropriate for utilities." (1). Additionally, larger utility easements and rights of way, meanwhile, can both serve as opportunities for non-vehicular connectivity (trails, etc.) or serve as a hinderance for connectivity, limiting opportunities to connect neighborhoods located on either side of a larger utility-owned property or to run additional segments of a transportation network along such utility corridors because of the private property rights asserted by the utility companies (1, 5).

Project Scale

The proposed scale of a given development is a key predictor of potential connectivity, according to eight members of the interview panel. Scale was denoted as impacting development in three key ways: the greater perimeter and connection opportunities arising from the physical size of a development, the greater control over connectivity outcomes produced by the development agreements, amendments and political processes unique to larger subdivision developments, and product delivery dynamics required for making large developments feasible within pre-established financial parameters (2, 3, 9, 12, 13, 14, 15, 16)

According to participants, the area of developments encourages greater connectivity in the Phoenix metropolitan area because of the increased likelihood of making connections to existing and planned arterial and collector roads. The largest developments frequently require access points from multiple sides of the development, in order to comply with existing street plans and to ensure proper ingress and egress which meets local development ordinances (2). As such, the opportunities for connectivity naturally increase as the community requires a greater number of directions for access. Additionally, because of the private sector impetus to provide a “greater degree of direct routing” for residents sought after by homebuilders and developers consulting with land use planners (12).

> *"Larger subdivisions have far less barriers to pedestrian access given the larger number of access points on each side of the development, often putting together collector and arterial roadways on more than one side of the development" (13).*

This benefit from increased community extends to other features such as trails and regional amenities; "the infrastructure necessary for robust connectivity is often far more easily implemented within larger communities" (13). Making appropriate connections to trails and other nearby amenities is "far more difficult for smaller developments," which are less likely to be adjacent to trails and amenities and have "less options to make it work [financially]" (12). Large communities have a greater ability to connect to such amenities "and integrate them directly into and through these developments" (14). Relatedly, it was indicated by an engineer in the study that crossings of major barriers (such as arroyos in Phoenix's outer suburbs) require a certain scale of development to make sense; a bridge to preserve arroyo flow may not be feasible in smaller developments and may result in more fragmented neighborhoods. (9).

The scale of communities was stated to affect how much flexibility and leverage private developers have to amend and control the standards of development for a particular community. As the homebuilder representative in the study stated, large master-planned sites selling a premium product have greater flexibility to have connected and specialized infrastructure integrated into neighborhoods:

> *"Communities such as Verrado are completely different from what traditional homebuilders can do – developers there have the time and manpower to do [more urban design] – project scale matters" (15).*

Larger developments allow for the amendment of standards which can prohibit more urban and connected products from being realized in subdivision planning. Standards which restrict the feasibility of connectivity, such as traffic and access management standards, can be amended in larger community development agreements because of the negotiation and trade-offs taking place between public and private stakeholders in the planning process (14). In working on unique standards for communities with communities which, connectivity can be better advocated for by creating spaces for agreements between parties which can assure that costs and requirements do not change in the midst of a large project while the city can ascertain additional public goods, such as connectivity. (14).

In some of the Valley's largest master-planned communities (such as Verrado in Buckeye and DC Ranch in Scottsdale), the ability for these larger communities to amend standards can provide opportunities for advocacy for connectivity by local governments. Particularly in processes such as the review of development agreements, local governments have "greater ability" to "set the need for street connectivity up in a way which meets a particular positive goal for a large neighborhood," leading to potentially more feasible political arrangements for promoting connectivity (7, 8). One land use planner echoed this sentiment, stating that development agreements in larger communities,

> *"...make [it] easier for local governments to work with developers to integrate and continue pathways and other community amenities that people want" (12).*

The ability for large developments to manage connectivity at a finer scale was also discussed in interviews. As one land use planning professional stated, firms have the capability to maximize connectivity that is actually implemented through comprehensive design in large-scale communities. When "building an entire city in a huge master-planned community," the specifics of connectivity, from "wayfinding to the relationship with different land uses to the experience of connectivity, is capable of being defined and realized by a single set of planners" (14).

Finally, large-scale developments with several different types of products were considered by several professionals in the study to be more likely to produce gridded and connected streets by virtue of the efficiency of construction on a grid. The primary benefit of griddedness lies in the ability to do large-scale construction more easily – this is a greater demand for larger communities needing to deliver large numbers of homes to market quickly to recuperate investments in the development (9). As a land use planner stated, when housing demand is high, as in the current planning period of the early 2020s, master-planning becomes more common to create large numbers of housing units and product types, and there is less segmentation between communities:

> *"Large-scale, multi-phase projects lead to more diversity in products, more connectivity, and a greater likelihood of griddedness emerging in the urban fabric – there is a need to put multiple products quickly out to market (11).*

Other Variables

Several other variables were discussed by at least two participants of the interview panel, but played a small role in the overall picture of connectivity developed in the study. These site characteristic variables included site shape and climate factors. These variables may have become through more comprehensive analysis and may merit further study to understand their role in shaping connectivity.

Site shape was referenced by one private and one public planner in the study, stating that less “traditional” (non-Euclidian) parcel shapes can significantly alter connectivity. “Sites not bound by gridded arterials, when they’re hemmed in by a unique arrangement of streets,” can make creating a continuous and connected transportation network in a subdivision difficult. This is “further exacerbated by access management regulations” (4) which limit ingress and egress points and require spacing that can leave “few options” for connecting the development (12).

Climate was brought up by one land use planner and a homebuilder in the study. These planners shared a perception that the harsh climate for a large portion of the year in Phoenix discouraged planners and developers from willingness to connect streets and paths for the purpose of active transport and walkability (13, 15). However, both of these planners countered points about climate in interviews with the idea that climate may benefit connectivity in a less direct manner by using the grid to control sunlight exposure to homes. “No one wants a west-facing home,” stated one interview participant, citing how home prices are affected by overexposure to heat and light in the desert, “…the premium is in north-south lots…the grid system is pure economics in the desert.” (15).

Quantitative Results

Basic Analysis Results

Intersection density results were largely consistent between the case study communities (**Figure 2**). All communities except a single New Urbanist subdivision in north Phoenix were between 140 and 160 intersections per square mile, comparable to numerous other American metropolitan areas (Ewing, 1996, Environmental Protection Agency, 2020). A single community, Norterra, exceeded 300 intersections per square mile**.**

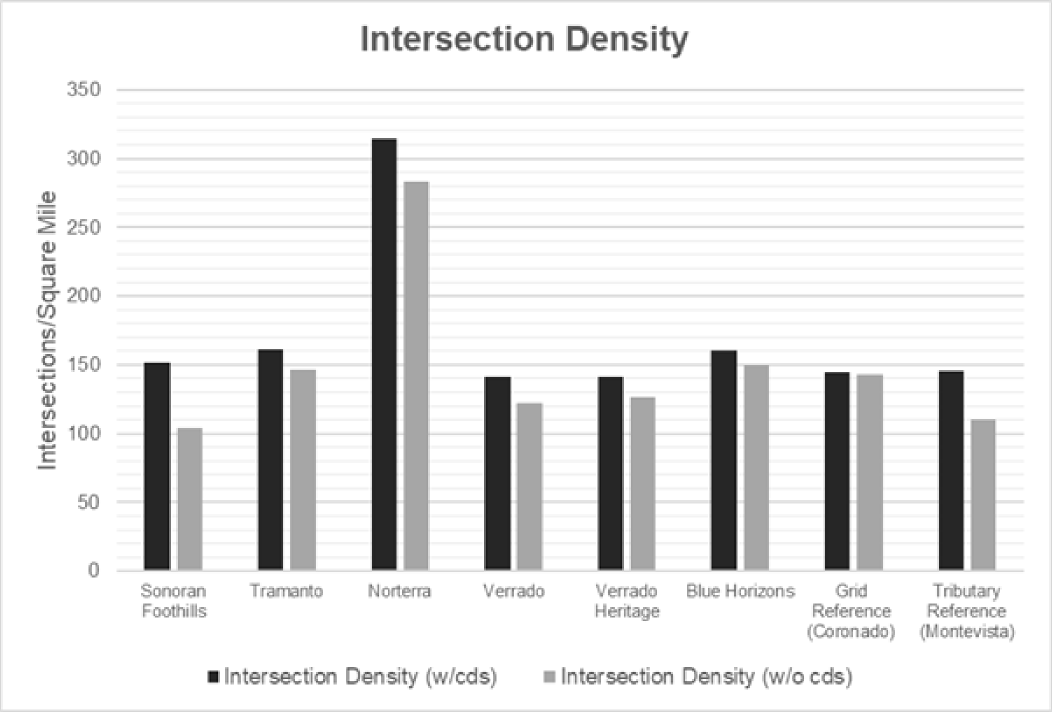


Figure 3. Intersection Density by Case Study

Ingress/egress rates, a measurement for neighborhood permeability, varied far more between communities **(Figure 3).** The grid reference model from central Phoenix had a high level of permeability, with many streets entering and exiting the original platted subdivision grid. Norterra, the New Urbanist subdivision in north Phoenix, featured a high degree of connectivity with surrounding developments. Tramanto and Verrado featured limited connectivity to surrounding communities, relying on arterials or collectors to connect communities and topography dramatically shaping the community's ability to connect to surrounding communities. Sonoran Foothills and Blue Horizons also featured limited connectivity reserved for major collectors or arterials.

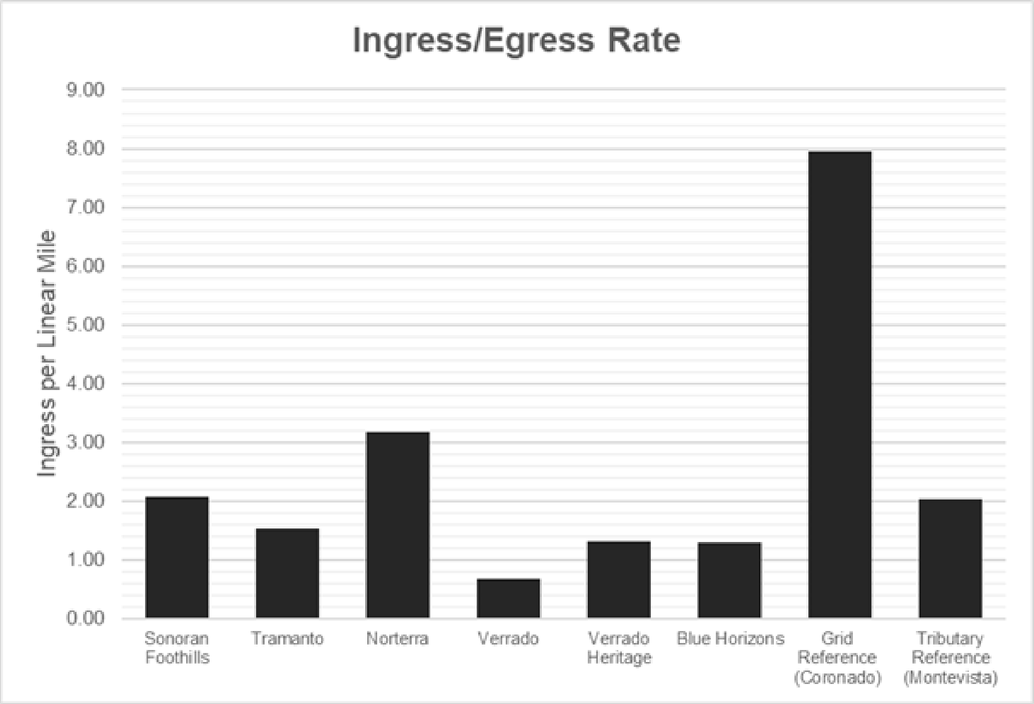


Figure 4. Ingress/Egress Rate by Case Study

An analysis of junction type reveals a divergence between griddedness and overall connectivity in the case study communities (Figure 4). All of the case study communities featured higher numbers of T-intersections (3-way intersections) over X-intersections (4-way intersections), reflected in the "T-ratio" being close to 1 in most of the case study communities. The Norterra and Verrado communities, both built with subareas designed to provide a more urban grid network, provided a higher ratio of X-type junctions. One community (Sonoran Foothills) matched the tributary reference "T-ratio" of 1, representing a more dendritic design for the community network.

Griddedness requires a high degree of 4-way intersections, with frequent opportunities to move in several directions at a given point. Gridded networks demonstrate higher levels of X-type intersections than T-type, where multiple intersections must be traversed to have the same potential for directional change in urban space. Only the grid reference community in urban Phoenix reflected a greater level of X-type intersections than T-type intersections.

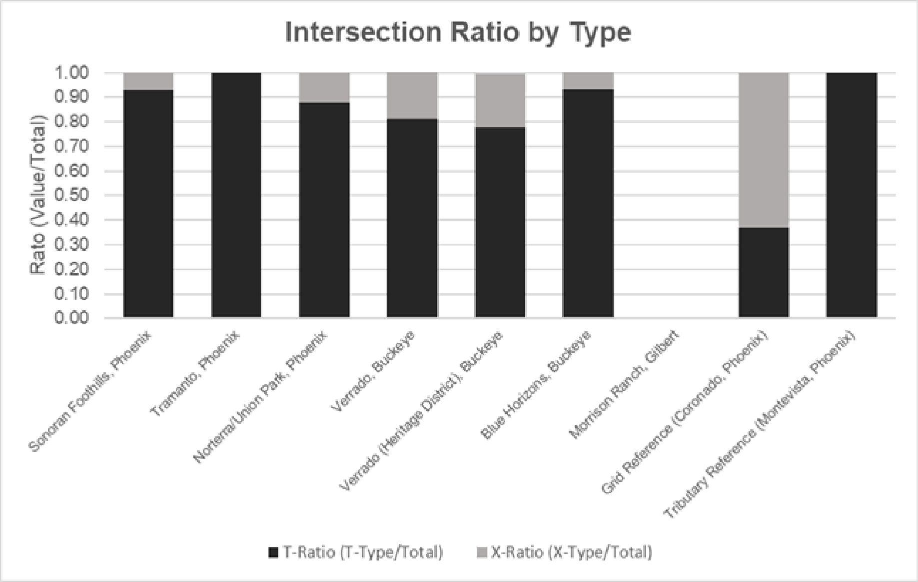


Figure 5. Intersection Type by Case Study

A further measure of griddedness are two inverse metrics known as "cell ratio" and "cul-de-sac ratio," which measure the number of cells and cul-de-sacs against one another. In a true gridded network, the cell ratio will be 1 and the cul-de-sac ratio will be 0. The opposite ratios will be exhibited in a true tributary network with cul-de-sacs and no "bounding segments," such as arterials, surrounding the network (Marshall, 2005). The grid reference was a nearly perfect grid, with a cell ratio of 0.98 and an accompanying cul-de-sac ratio of 0.02. The tributary reference was a moderate tributary network, with a nearly perfect split between cell ratio (0.48) and cul-de-sac ratio (0.52). (footnote: the Phoenix metropolitan area features few true tributary networks because of the macro-grid development pattern of the region. All of the case study communities featured semi-gridded cell ratios, mostly hovering around 0.75 to 0.85. One community (Sonoran Foothills) had a tributary structure, which was indicative of its network design of small grids and subnetworks with limited direct connections to other parts of the development.

The graph in **Figure 5** utilizes a chart type developed by Marshall (2005) and can discern the griddedness of the development patterns of case study communities. Communities with a high X-type ratio and a high cell ratio exhibit high levels of griddedness, while communities with a high T-type ratio and a high cul-de-sac ratio exhibit low levels of griddedness and a greater level of dendricity. **Figure 5** shows that most communities exhibit a "T-cell" pattern, featuring enclosed blocks enlarged or made more irregular through reliance on T-intersections in network design.

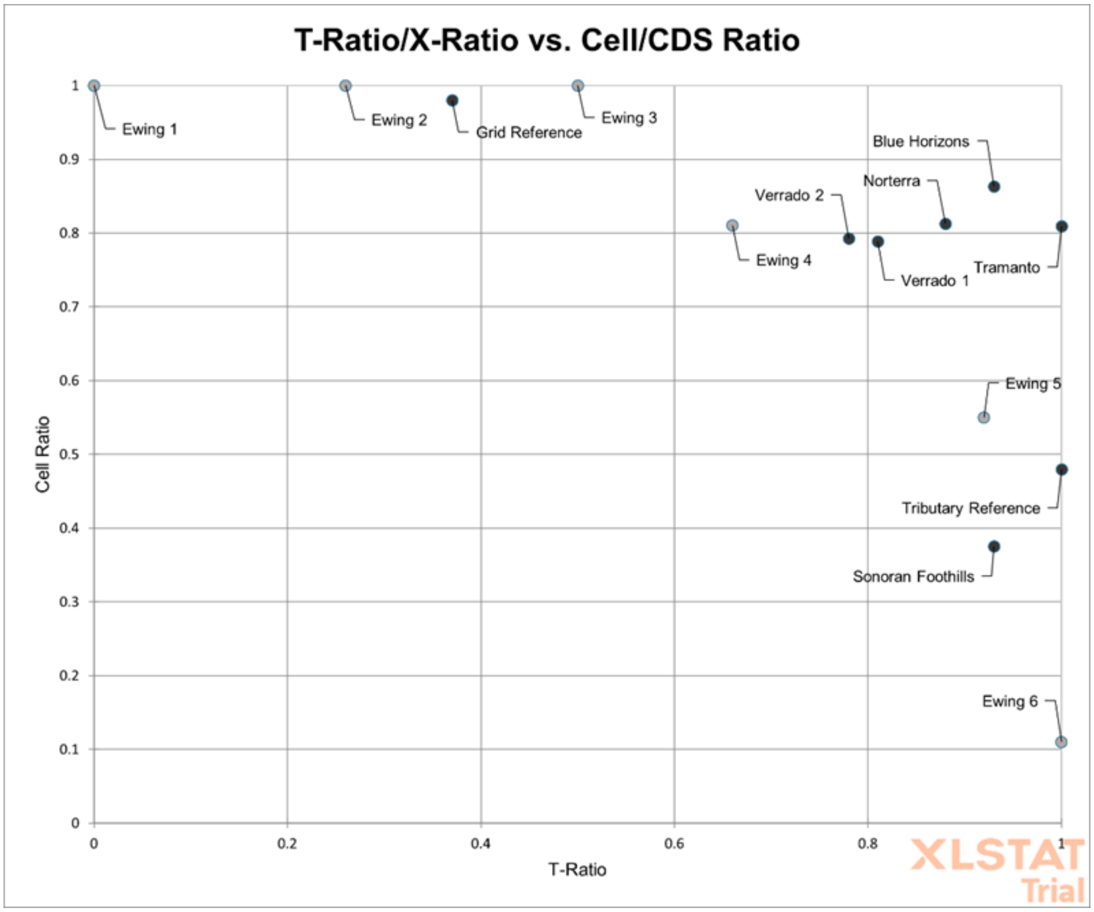


Figure 6. Comparing Intersection Type and Network Structure by Case Study

Ultimately, the case study communities from Phoenix relied on small numbers of cul-de-sacs and lacked clearly disconnected network routes. The Sonoran Foothills network shared characteristics with the tributary reference, with a high number of cul-de-sacs and T-type intersections and thus featuring a true “T-cell” network per Marshall (2005). Verrado and Norterra, neotraditional communities designed to facilitate the benefits of a connected transportation network, had more cul-de-sacs than Blue Horizons and Tramanto, which are communities more indicative of homebuilder community types, but maintained a noticeably higher percentage of X-type junctions.

See **Table 10** for a full reference table with basic analysis results.

Space Syntax Analysis Results

High continuity is indicative of true grid networks, where individual routes traverse large swaths of the network area and connect with many other routes. Most of the communities in the study represented low to moderate continuity through developments (**Figure 6**). All of the case study communities from the Phoenix area represented continuity levels more akin to tributary, dendritic networks (such as the tributary grid network) than gridded networks, which feature far higher continuity linked to low depth networks. Low continuity was independent of cul-de-sac ratio and cul-de-sac percentage, representing networks which are not fully discontinuous (as seen in a single-segment cul-de-sac) but are disjointed and have short segments where each route connects to very few other street segments in the community; this phenomenon is observable in the Sonoran Foothills, Tramanto, and Blue Horizons subdivisions, which have significantly lower levels of connectivity that represent the fact that each route connects to a limited number of other routes.

Greater connectivity frequently accompanies high continuity (though not in all network designs), given the connectivity measure analyzes how many other routes which are connected to each discreet route. A network where each "route" connects to many other routes on continuous stretches leads to a high connectivity score. Connectivity scores were widely variable in this analysis, as demonstrated in **Figure 6.** Many of the networks feature moderate connectivity scores; the most connected communities were found in Norterra, Verrado and its Heritage District, and the grid reference network, which all had connectivity scores indicative of moderate connectivity. Low-to-moderate connectivity was found in the Tramanto, Blue Horizons and tributary reference communities, and the Sonoran Foothills development had a far lower level of overall route connectivity.

Network depth was illuminating in demonstrating how connectivity is being developed in each community. A gridded network, such as the grid reference network in this study, will feature very low network depth, as most routes connect to “datum” routes, which were arterials in this analysis of Phoenix transportation systems. Depth was variable between communities, but overall remained far higher than the grid reference value of 0.188 (**Figure 6**). Tramanto, Verrado, and Blue Horizons all featured moderate connectivity but high depth, indicating a bias toward internal connectivity in these communities. Norterra had the lowest depth of the case study communities, representing a high level of external connectivity and higher access to the arterial “datum” route in the analysis than most suburban communities. Most communities’ depth value reflected that of a “tributary” network, with most routes in the network requiring several turns to reach the arterial “datum” route, and most connections found deeper in the network with less overall relationship to surrounding communities.

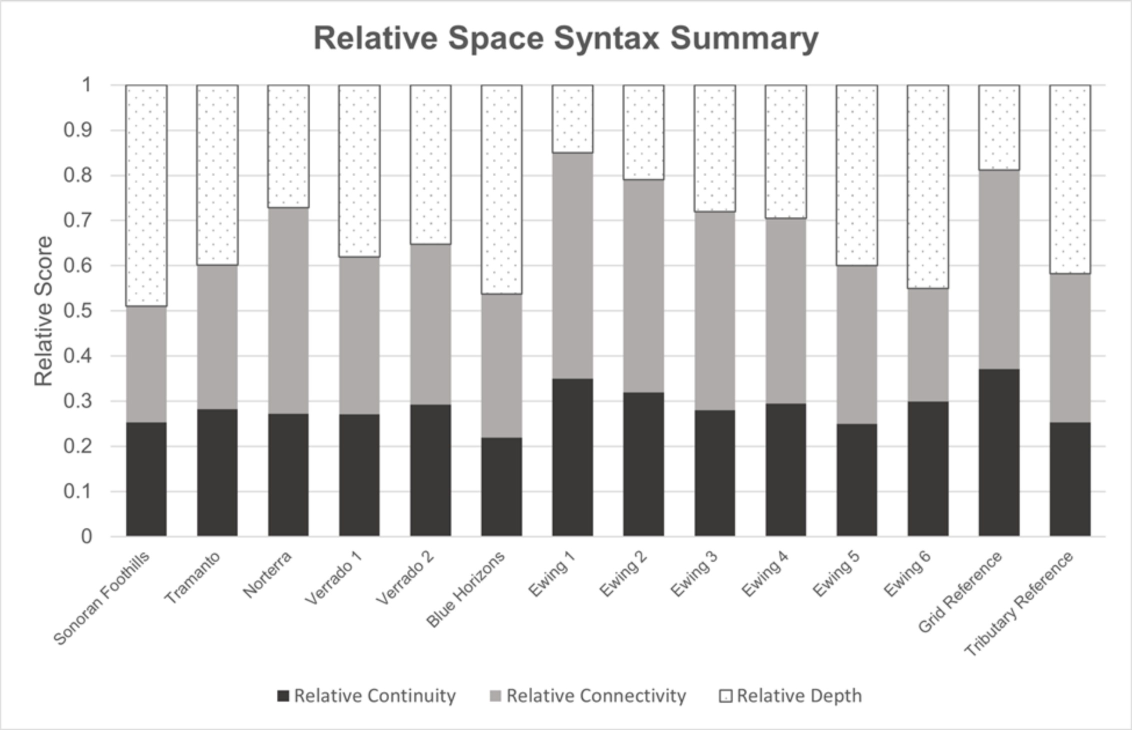


Figure 7. Relative Space Syntax Scores Between Case Studies

Ultimately, case study communities performed similarly to the tributary reference network in the space syntax analysis. **Figure 7** illustrates the composite relationships between continuity, connectivity, and depth. Additionally, this diagram adds sample communities from a seminal paper utilizing similar methods (Ewing, 1996), which includes six sample reference street networks to compare values from this study against. Figure 7 demonstrates that most communities in the study remain similar to a tributary pattern of development, such as the tributary reference network used in this study or the Ewing 5 and Ewing 6 networks from previous studies (Ewing, 1996). Networks from this study feature the higher relative depth and lower relative connectivity and continuity than that found in more gridded and integrated transportation networks. The Norterra development was the lone case study which reflected the network properties found in the grid reference network and in Ewing's more integrated grid street network examples.

See **Table 10** for a full reference table with space syntax results.

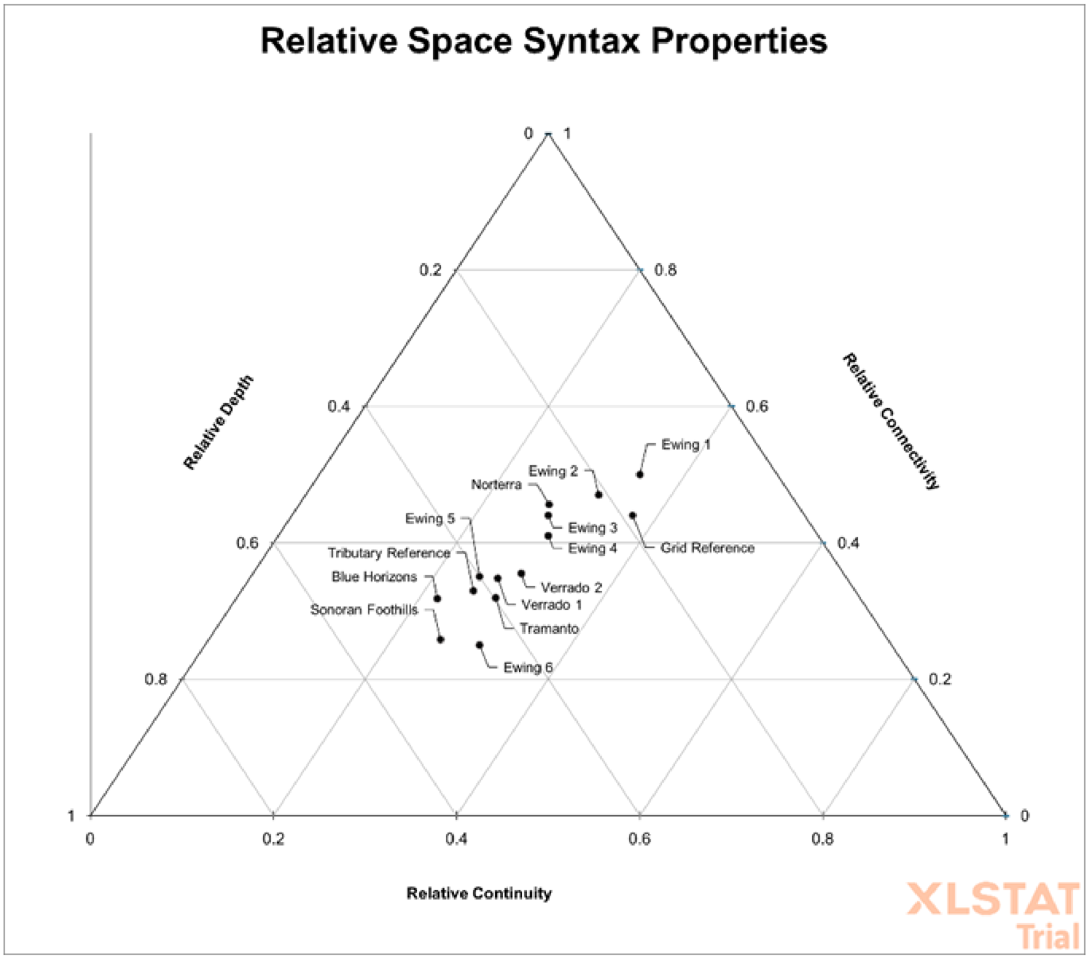
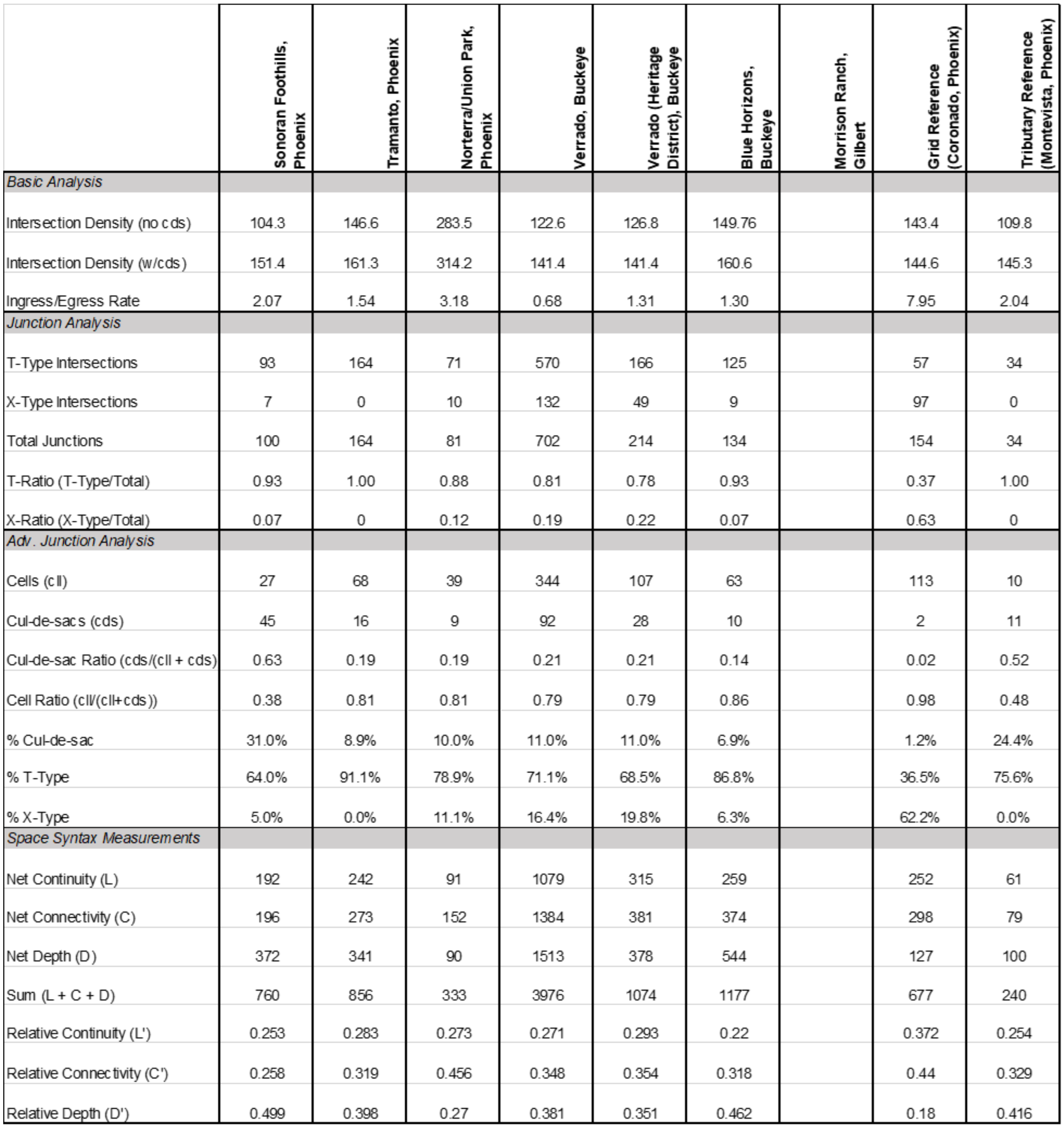


Figure 8. Comparing Relative Space Syntax Results Between Case Studies



	Sonoran Foothills, Phoenix	Tramanto, Phoenix	Norterra/Union Park, Phoenix	Verrado, Buckeye	Verrado (Heritage District), Buckeye	Blue Horizons, Buckeye	Morrison Ranch, Gilbert	Grid Reference (Coronado, Phoenix)	Tributary Reference (Montevista, Phoenix)
Basic Analysis									
Intersection Density (no cds)	104.3	146.6	283.5	122.6	126.8	149.76		143.4	109.8
Intersection Density (w/cds)	151.4	161.3	314.2	141.4	141.4	160.6		144.6	145.3
Ingress/Egress Rate	2.07	1.54	3.18	0.68	1.31	1.30		7.95	2.04
Junction Analysis									
T-Type Intersections	93	164	71	570	166	125		57	34
X-Type Intersections	7	0	10	132	49	9		97	0
Total Junctions	100	164	81	702	214	134		154	34
T-Ratio (T-Type/Total)	0.93	1.00	0.88	0.81	0.78	0.93		0.37	1.00
X-Ratio (X-Type/Total)	0.07	0	0.12	0.19	0.22	0.07		0.63	0
Adv. Junction Analysis									
Cells (cll)	27	68	39	344	107	63		113	10
Cul-de-sacs (cds)	45	16	9	92	28	10		2	11
Cul-de-sac Ratio (cds/(cll + cds)	0.63	0.19	0.19	0.21	0.21	0.14		0.02	0.52
Cell Ratio (cll/(cll+cds))	0.38	0.81	0.81	0.79	0.79	0.86		0.98	0.48
% Cul-de-sac	31.0%	8.9%	10.0%	11.0%	11.0%	6.9%		1.2%	24.4%
% T-Type	64.0%	91.1%	78.9%	71.1%	68.5%	86.8%		36.5%	75.6%
% X-Type	5.0%	0.0%	11.1%	16.4%	19.8%	6.3%		62.2%	0.0%
Space Syntax Measurements									
Net Continuity (L)	192	242	91	1079	315	259		252	61
Net Connectivity (C)	196	273	152	1384	381	374		298	79
Net Depth (D)	372	341	90	1513	378	544		127	100
Sum (L + C + D)	760	856	333	3976	1074	1177		677	240
Relative Continuity (L')	0.253	0.283	0.273	0.271	0.293	0.22		0.372	0.254
Relative Connectivity (C')	0.258	0.319	0.456	0.348	0.354	0.318		0.44	0.329
Relative Depth (D')	0.499	0.398	0.27	0.381	0.351	0.462		0.18	0.416

Table 10. Quantitative Analysis Results Master Table

ViaCity Analysis Results

ViaCity scores were collected between parcel origins and commercial destination points; high ViaCity scores represent a higher degree of connectivity and proximity suitable for overall site accessibility. Case study communities demonstrated high levels of variability in the output of ViaCity scores.

Sonoran Foothills featured good returns on ViaCity scores for approximately 13.5% of parcels, mostly concentrated in small pods near arterials or at the base of collectors connecting to roads. Network depth was closely related to the overall ViaCity score output; scores close to collectors and near the entrances of “pods” of development featured high scores, while large numbers of parcels deeply embedded in separated parcels of the development featured lower scores. Tramanto had a higher performance in the ViaCity scoring system, with approximately 29.6% of parcels with a “good” or “excellent” score. A similar pattern of scores was reflected in the Tramanto development, which parcels located near collectors which run through the development having relatively high ViaCity scores.

Verrado demonstrated very high ViaCity scores for commercial destination access for most parcels in the development, with over 50% of parcels exhibiting a “good” or “excellent” score. Over 90% of parcels in Phoenix’s Norterra featured “good” or “excellent” destination scores, far higher than other assessed subdivisions. Verrado and Norterra, which featured more continuous grids with a greater integration of uses, both featured high scores between commercial destinations and most parcels. Blue Horizons failed to provide a meaningful output for commercial parcel measurements due to data errors caused by the extremely young age of the subdivision and transportation networks immediately surrounding the development.

Results from the commercial destination analyses are detailed in **Figure 8** and summarized in **Table 11.**

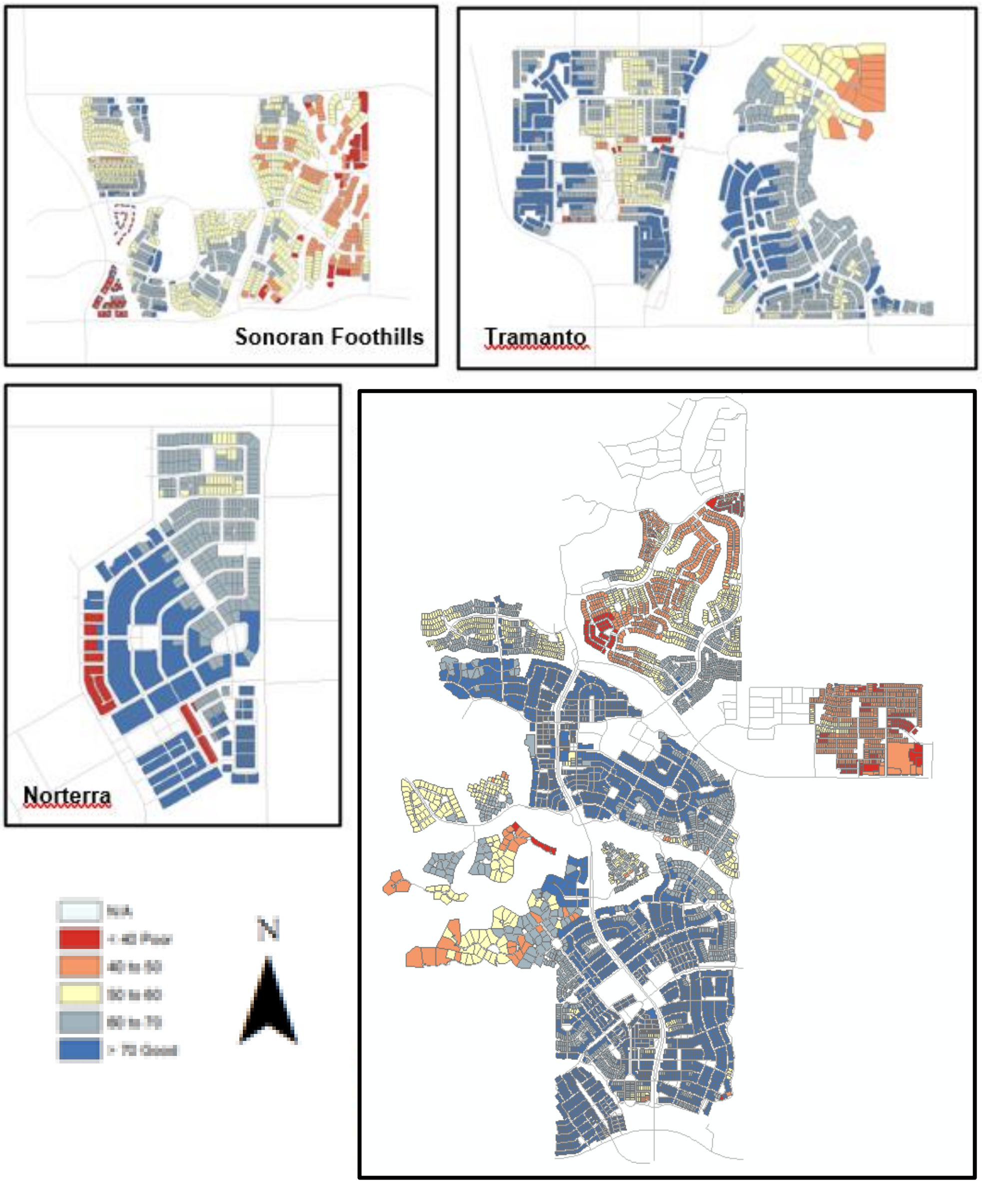


Figure 9. Parcel-to-Destination Analysis Results for Case Studies

ViaCity scores were collected to reflect the connectivity and proximity relationships between ween a single parcel and all other parcels in a subdivision. These data intensive analyses provided a rich analysis of the effects of connectivity and street network design in each case study community. Communities performed variably in this analysis, with high variation within each subdivision and relatively poor scores assigned to many parcels in each case study community.

The "parcel-to-parcel" analysis completed for Sonoran Foothills revealed moderate accessibility to other parcels in the development. The larger block units and disconnected vehicle and pedestrian networks found in the northeastern portion of the development harmed scores significantly, as did the lack of proximity to routes which provide through access to multiple portions of the development. Only 16.3% of parcels were assigned a "good" or "excellent" score (60 or greater) in the parcel-to-parcel analysis.

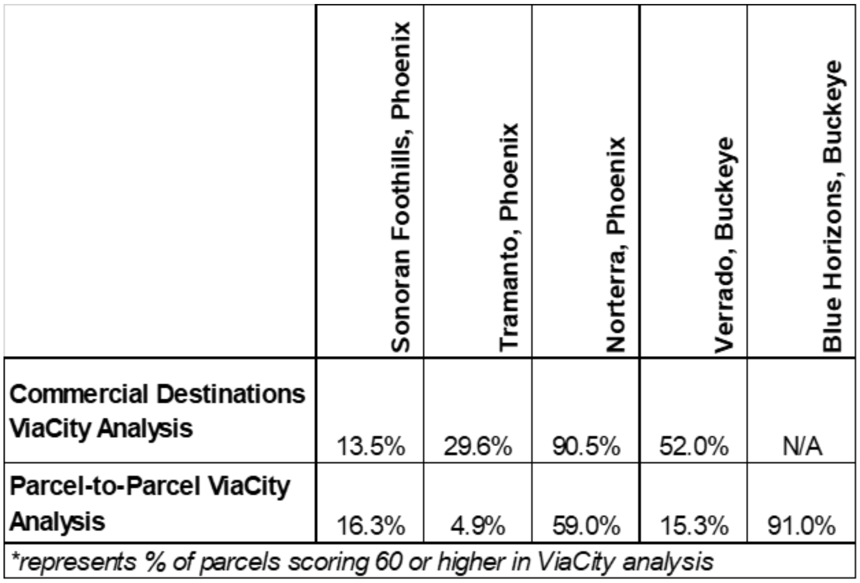
Tramanto also reflected very poor analysis scores in the parcel-to-parcel analysis, with less than 5% of the parcels in the development being assigned a "good" or "excellent" score (60 or greater). Large lot subdivision areas in the northeastern portion of the development were poorly connected to other parcels in the community and were spread significantly further away from other portions of the community by lot size and topography. Only parcels on routes with direct access to collectors in the development had moderate or high scores (40 or greater).

Norterra had relatively high ViaCity scores from the parcel-to-parcel analysis. Approximately 59% of parcels had a "good" or "excellent" ViaCity score (60 or greater) assigned to them, with lower scores concentrated on the ends of the development where more direct collectors and continuous local roads in the development terminate and the network creates a greater number of turns to produce accessibility, triggering some distance decay effect. The Norterra development reflected robust internal connectivity.

The large-scale parcel-to-parcel analysis at Verrado revealed highly variable rates of connectivity and accessibility within the community. Approximately 15% of parcels were assigned a "good" or "excellent" ViaCity score (60 or greater) in the analysis, but these parcels were heavily concentrated in the Heritage and Main Street districts of the community where connectivity was an explicit design goal for land use planners and homebuilders. The internally compact networks of the subdivision's neotraditionally-themed areas create a high level of accessibility between parcels, deeply shaped by the higher rates of connectivity and directness found in routes. Most parcels were rated with moderate accessibility to other parcels in the development. Suburban, curvilinear networks in the recently constructed northern portion of the development revealed poor connectivity. Some skew to the results was caused by the phasing of the Verrado subdivision, which has resulted in the isolation of some parcels in the eastern portion of the subdivision which lowers overall ViaCity scores.

The Blue Horizons development had extremely high levels of overall accessibility between parcels, improved by the high numbers of pedestrian connections within the development and the close access to the collector ring road which provides access to all smaller phases, or "pods," of the development. Approximately 91% of the parcels in the Blue Horizons development featured "good" or "excellent" ViaCity scores (60 or greater). Some parcels located in highly connected but deep networks within the development received moderate or poor ViaCity scores (60 or lesser). The development reflected the highest parcel-to-parcel ViaCity analysis returns of the case study analyses. Results from the parcel-to-parcel analyses are detailed in **Figure 9** and summarized in **Table 11.**

Figure 10. Parcel-to-Parcel Analysis Results for Case Studies



	Sonoran Foothills, Phoenix	Tramanto, Phoenix	Norterra, Phoenix	Verrado, Buckeye	Blue Horizons, Buckeye
Commercial Destinations ViaCity Analysis	13.5%	29.6%	90.5%	52.0%	N/A
Parcel-to-Parcel ViaCity Analysis	16.3%	4.9%	59.0%	15.3%	91.0%

**represents % of parcels scoring 60 or higher in ViaCity analysis*

Table 11. ViaCity Analysis Results

5 DISCUSSION

Assessing Connectivity Outcomes

This study provides an opportunity to perform an initial assessment of the properties of new urban transportation networks being developed through the creation of subdivisions in the Phoenix metropolitan area.

Modern Phoenix subdivisions feature statistical levels of internal connectivity consistent with gridded patterns of development found in older portions of urban Phoenix, but have less external links to the surrounding urban environment than older gridded developments. Such an observation reveals consistent results with recent studies (Barrington-Leigh and Millard-Ball, 2019; Boeing, 2021), demonstrating street networks returning to moderate levels of connectivity increasingly consistent with historic patterns of development. However, this also illustrates a pattern of consistently low external connectivity on par with past studies of suburban network development (Stangl, 2015, Ewing and Hamidi, 2015), warranting further exploration into how external connectivity is being shaped by policy and the action of planning stakeholders.

New subdivisions are dominated by three-way intersections, a trend which continues to deviate from the historical gridded pattern of development in the Phoenix metropolitan area. Even neotraditional communities used as case studies, such as the district-scale Verrado and the smaller Norterra developments, utilized far lower proportions of four-way intersections than historic gridded developments. Since literature has demonstrated that three-way intersections may be less effective at promoting the transportation benefits of increased connectivity (Berrigan et. al., 2010; Grasser, van Dyke, and Titse, 2017; Hatamzadeh, Habibian, & Khodaii, 2017), this is an important indicator determining the effectiveness of connectivity in walkability. As demonstrated in advanced statistics of this study, three-way intersections play a role in increasing relative network depth and decreasing relative network continuity; deeper and less continuous networks are less likely to create robust conditions for route choice, direct routemaking, and walkability (Marshall, 2005; Kashef, 2021).

In addition to a high number of three-way intersections, most case study networks demonstrated high cell ratios, indicating a low number of cul-de-sacs and full discontinuities in local transportation networks. Paired with the high number of T-intersections, it can be ascribed that a pattern of “T-cell” street networks is common, with irregular but enclosed block structures demonstrating moderate connectivity but limited opportunities for direct routemaking or continuous route creation (Marshall, 2005; Ewing and Cervero, 2010; Stangl and Guinn, 2011). As uncovered in the interview research of this study, this irregular gridding is achieving by maintaining alignments for utilities and lot development efficiency, but minimizing infrastructure and opportunities for through traffic by reducing the number of continuous blocks on a particular alignment. The local transportation efficiency and sustainability benefits of implementing four-way intersections is poorly understood in the practice of subdivision development, as discussed later in this chapter.

Ultimately, networks in this study were revealed to have commonalities with both grid and tributary developments, creating a hybrid between these models which reflects the moderate grids found in Ewing’s landmark study on network typology (1996). Most developments, including the neotraditional communities surveyed in the study, featured the connected and enclosed design of more gridded developments but employed the discontinuity and high three-way intersection counts of tributary styles of developments which have characterized previous sprawling development patterns (Aurbach, 2020).

Communities showed low-to-moderate relative continuity, moderate relative connectivity and moderate-to-high relative network depth, indicating patterns of developments more gridded and functionally connected than tributary, dendritic development patterns but far from achieving the level of connectedness and griddedness of a more traditional pattern of development in American cities. The neotraditional communities in the study successfully reduced network depth with a greater overall griddedness and higher level of overall connectivity in developments, as evidenced by the lower relative depth scores and higher relative connectivity scores in the space syntax analysis. Network continuity remained low in all communities studied, with no community scoring above the gridded control for this study. These networks had space syntax properties in line with the moderate grids of Ewing's 1996 analysis, representing fused and discontinuous gridding in their development. The case study reflective of homebuilder-oriented master-planned communities (Blue Horizons) and the suburban community heavily influenced by topography and organic community design (Sonoran Foothills) demonstrated high depth and low continuity, with moderate connectivity. These communities shared space syntax measures which suggest that these communities operate similar to tributary networks in their design.

When the advanced ViaCity analysis was completed on each subdivision evaluating overall route directness and connectedness to commercial destinations within and adjacent to case study communities, clear patterns emerged. Proximity to collector roadways crossing through developments and connecting to arterials (where Phoenix commercial development is often concentrated) resulted in high "parcel-to-destination" scores, reflecting the role which connections to the more continuous collector streets planned through subdivisions play in creating routes with a greater potential for walkability and efficient route creation. Most developments which were assessed in the "parcel-to-destination" analysis demonstrated full distance decay in some portions of the community (Sonoran Foothills, Tramanto, Verrado), reflecting sites greater than two miles of network distance from a commercial destination and demonstrating a lack of land use integration into communities in a manner which produces the potential for active transportation trips. Norterra, the community which features omnidirectional connections to other nearby land uses, was the single community with uniformly high "parcel-to-destination" scores which reflected high functional connectivity to commercial destinations near the subdivision. The design of the Norterra subdivision may provide a path forward for more sustainable suburban development patterns which are achievable within the existing paradigm of greenfield development.

While the ability for networks in neotraditional communities to support functional connectivity was less noticeable in the space syntax analysis, it was presented with far greater clarity in the commercial "parcel-to-destination" ViaCity analysis. More than half of parcels in both neotraditional communities received "good" or "excellent" scores in the ViaCity analysis suggesting an ability to support active transportation trips through the design of the local transportation network. Neotraditional network patterns with more integrated land uses may provide pathways toward more sustainable transportation network function for greenfield developments. Restrictions to the development of the street networks found in the denser centers of these neotraditional communities may serve as an impediment for realizing neighborhoods with functional network connectivity which can support higher numbers of active transportation and a lower reliance on the vehicle necessary to overcome shortcomings in network capability to support active transportation trips.

The “parcel-to-parcel” ViaCity analysis revealed the limitations of the “T-cell” street development pattern indicative of modern suburban development in the Phoenix metropolitan area. Only the Norterra and Blue Horizons developments achieved large numbers of parcels with a “good” or “excellent” score indicating a capability of supporting internal active transportation trips amongst parcels within the development. Robust pedestrian networks evenly distributed throughout the development, such as the network found in the Blue Horizons development, and proximity to collector networks with greater continuity resulted in significant improvements in overall “parcel-to-parcel” scoring. Poor connectivity via trail networks linking disparate portions of the Sonoran Foothills and Tramanto developments furthered the proliferation of poor scores for internal functional connectivity in these developments. The Verrado development had high overall connectivity to other neighborhood parcels in dense, gridded portions of the development, but had low scores elsewhere in the development which reflected less connectivity between various phases of construction. While internal connectivity scores from the basic spatial analysis of case study communities were statistically similar to the control grid used in the study, the design of networks between connections indicates less functional internal connectivity in many new suburban communities.

New street networks are being constructed in a manner which exhibits a mixture of design elements from grids and tributary developments, coincident of studies conducted at a global level assessing changes in connectivity in American communities over time (Barrington-Leigh and Millard-Ball, 2019; Boeing, 2020). This development pattern results in a moderate capacity to support active transportation trips. This study provides a glimpse in the functional outcomes of such developments. The quantitative study also provides a vocabulary for more precisely identifying barriers to the development of more sustainable transportation networks in greenfield communities.

Quantitative analysis can demonstrate which network properties in current networks may be inhibiting the opportunity for better functional connectivity and which policies and mechanisms in the planning process may be creating such inhibitions to the support of potential active transportation trips.

Thematic Review and Analysis

In addition to the results and quantitative findings from this study, numerous themes emerged from both qualitative and quantitative analysis which must guide future conversations surrounding connectivity in local communities.

Connectivity as Scalar

Addressing multiple scales of connectivity is exceedingly difficult in the studied region of Phoenix. With arterial streets in Phoenix largely handled by the regional transportation planning body (MPO) and planned far in advance of local initiative, and local streets planned almost exclusively by private sector action, local governments are left to manage the collector roads between these two classifications. While important for promoting a greater degree of overall connectivity and continuity through new proposed communities (as evidenced in ViaCity case studies from the study, where collectors heavily impacted the results of overall community accessibility analyses), local planners who are most in charge of broader land use and transportation planning in American communities are left with few options for affecting connectivity. The local streets which comprise the overwhelming mileage of roads in urban transportation systems often have only indirect control from local planners, resulting in a significant barrier to connectivity without significant changes to planning authority of local streets and the planning procedures surrounding transportation design in new communities.

Single-Site Development Paradigm

At the center of the diverging scales of connectivity is a planning paradigm which treats new subdivisions and developments as individual sites in isolation of one another. As two planners in the study stated, the processes creating connectivity outcomes are found at the intersection of planning and engineering reviews for new proposed subdivisions; these reviews are almost exclusive for measuring the effects of a particular subdivision on immediate surroundings and the mitigation of externalities within the site. Traffic analysis is designed to control the flow of trips into and out of developments, and connectivity to surrounding areas is dictated by the perceived traffic creation from a particular new subdivision (1, 9). Collectors are "increasingly designed" to create internal traffic flow for subdivisions while limiting all opportunities for through traffic and less manageable flows of new traffic into surrounding areas (1, 3).

Beyond the immediate reviews of traffic, open space and trail amenities are reviewed for sufficient presence within the confines of a particular subdivision, with few opportunities for connections or integrating open space with surrounding communities. Adjacent land uses are interpreted based on their potential negative effects on a proposed site, and site planning is adjusted to mitigate externalities within a single site rather than performing more robust integration with surrounding land uses. Neighborhood governance fortifies this single-site paradigm long after the completion of the community, as noted in this study in examples avoiding cost, possible negative externalities and limited any effects from surrounding neighborhoods for community control. In short, planning is done to maximize the opportunity for realizing private vision and minimize change and externalities from new development. As one public planner stated, “the tradition of subdivision development is where you do not have to be dependent on other communities to do what you want to do” (6).

The result is the high variability and prescient opportunity for improved connectivity within subdivisions, but an unsupportive paradigm for creating meaningful connectivity between uses and destinations which can support active transportation as articulated in past studies (Berrigan, Pickle and Dill, 2010; Ewing and Cervero, 2010). Most policies directly affecting connectivity (such as block length requirements, intersection density requirements, and General Plan guidelines) “remain concentrated on how connectivity is implemented on single sites” (10). Two planners noted problems with inefficient street patterns and other challenges associated with avoiding broader connectivity in order to maintain separation between sites and a “single-site mindset which harms neighboring processes in unanticipated ways” (4, 5). Current planning policies and processes in local government in Arizona may be failing to create opportunities to manage relationships between sites and require more dynamic planning between new communities and developments, sharing services and providing greater connectivity between sites.

Strategies emerged in this study which may suggest possibilities for future change to the single-site paradigm which deeply influences connectivity outcomes in cities. Multiple private sector stakeholders identified Phoenix’s sub-regional “village core” model for promoting connectivity in sites in areas planned for greater density and requiring greater dynamism between sites (11, 12). A public transportation planner and a public planning leader noted how the General Plan and other guiding documents can create widespread discretion for advocating for and negotiating better connectivity, providing space for managing the possible externalities and more challenging relationships between sites (2, 3). More broadly, communities such as Laredo, Texas and Bastrop, Texas are taking steps to override the current model of single-site transportation and service planning to create uniform grids and street networks where high connectivity at multiple scales is the starting point for development proposals (2) (Viva Laredo, 2017; City of Bastrop, 2019). This paradigm must be challenged to create the diversity of origin and destination points required to create true gains in active transportation.

Lagging Public Arguments for Connectivity

Connectivity was revealed as embedded within a complex political economy without a clear stakeholder capable of advocating for it successfully. The private sector stakeholders in this study revealed how the private sector has some motivations to provide more robust connectivity within new subdivisions being created, such as providing greater accessibility to neighborhood amenities and recreational elements, designing a neighborhood to reflect a particular theme, or enabling certain types of housing products. Residential design standards and efforts to improve subdivision design have resulted in calls for promoting equal access and connectedness to amenities and services within a subdivision. This provides increasing raw connectivity overall as more communities participate in the provision of more connected street and pedestrian networks.

But the benefits of connectivity are inherently public in nature. Connectivity is designed to provide greater route choice, direct routemaking, and additional connections in urban space. The full benefit of connectivity emerges when many attributes of an urban place, including land uses, destinations, and even various groups within the city, are connected within urban space. This defies the current overwhelming planning paradigm in modern American cities emphasizing self-contained development and functionally separated land uses. Connectivity requires an embrace of relationships beyond any single site which private sector stakeholders will find themselves concerned with; as one land use planner stated, "[private actions] right now will not represent a shift in increased connectivity, but rather creating better connectivity and rethinking neighborhood connectivity" (12).

Early sentiments from this study reveal that the public sector may lack clear and concrete pathways for translating the theoretical argument for broader connectivity into the practice of greenfield development. Multiple public sector officials stated difficulty in convincing powerful public players in the development process, particularly commissioners and councilpersons involved in approvals, of the benefits of broader connectivity. Private property rights remain a salient barrier toward being able to consistently provide greater connectivity between sites as Phoenix grows. Numerous land use policies continue to articulate the incompatibility of commercial, industrial, and institutional uses with residential uses, creating less incentives for providing connectivity which can bind various uses and different developments together. As stated by public planners in the study, the sense of costs imposed on developers by increasing connectedness and infrastructure linkages can result in severe challenges in implementing connectivity most advocated for by public planners (4, 6). Automobility remains a tool which can overcome many shortcomings in broader connectivity, resulting in less possibilities for political support of connectedness given the powerful attachment to traffic efficiency in the sphere of local planning politics. The juxtaposition of an inherently public good (that is, a broader scale of connectivity) being provided through the private development of subdivisions remains politically difficult to manage.

Clear stakeholders to own advocacy for improving connectivity between sites are far more difficult to find than politically salient opponents. However, local and regional public planning agencies must step up to construct arguments for better intra-site connectivity in greenfield communities. As one public planner stated, “we need to have our toolbox sharpened in countering arguments [against connectivity] by developers and public officials” (6). More study is needed to create better arguments and practice-oriented research which overcomes the concerns surrounding connectivity, such as detailing how costs increase for the private sector and how the public sector can take on the costs of private development improving an overall public good with the increase in connectivity. The public sector will need to gain tools for overcoming the barriers to connectivity, including a more robust set of transportation routes beyond the automobile-oriented hierarchy and transportation design tools.

Automobility Remains a Practical Barrier for Connectivity

The experience of connectivity remains constrained by the heavy emphasis on the automobile in urban space. Traffic management standards are designed to both promote high-speed travel along the exterior of developments (access management standards requiring long distances between intersections) and limit through traffic in developments (intersection standards including required T-intersections and limited connections for collector streets). Both of these properties hamper the ability to produce connected and legible urban space.

The long distances between intersections for collectors or local streets along outer arterials and collector streets may promote vehicle safety but causes a severe decrease in the possible routes exiting a subdivision and can significantly add distance to trips. Regulations designed to reduce through-traffic increase network depth (as evidenced by the high relative network depth values in most of the new subdivision case studies selected in this study), which is a sign of a significant increase in the number of turns required to reach destinations and generally an increase in the distance required to reach destinations (Marshall, 2005; Yin, 2013). Regulations tied to intersection type (such as limited four-way intersections for traffic safety) can also add to reductions in network continuity when paired with connectivity regulations such as reducing overall block length, resulting in truncated gridded streets found in developments such as Blue Horizons and Tramanto, both which exhibited poor continuity scores.

Further evidence for the effects of street layout regulations designed to limit throughput of automobile traffic is found in the three case studies from Phoenix which were constructed in a similar development policy environment; while the Norterra development was intentionally designed with amendments and careful work alongside local leaders to promote four-way intersections as a part of a neotraditional design (6) and realized high ViaCity and overall connectivity scores, Tramanto and Sonoran Foothills had lower ViaCity and overall connectivity scores. Even with other policies in place, such as maximum block lengths and some connectivity requirements, efforts to reduce through-traffic can result in gains in connectivity being cancelled out without a greater set of tools to increase potential connectivity. Policies to promote connectivity which are tied to automobile infrastructure alone may cause shortcomings in the experience and effectiveness of connectivity in urban space.

Neighborhood as Commodity May Hurt Connectivity

Developers, homebuilders, and other private sector stakeholders utilize a set of strategies for selling new neighborhoods as saleable products for other developers and residential consumers, which can lead to severe barriers to connectivity. As referenced in interview data, neighborhoods are frequently sold as “distinctive places,” and separation between communities enhances the sense of buying into a particular product and improves marketing outcomes from developers (12, 13) With full room to provide the level of connectivity most suitable for product and community type within the boundaries of the new neighborhood, developers and builders may choose to separate their product to build “emotional connection to neighborhood” and see tangible loss in requiring high degrees of connectivity between land uses and other communities, perceiving greater risk and lesser distinctiveness in the product.

At a smaller scale within each neighborhood, master-planned communities are often developed in “pods” which are split into “compartments of housing” which “create enclaves” to sell lots to different homebuilders or development agencies within a single master-planned community (5, 13). These “pods,” often laid out as unique parcels, are often intentionally disconnected from one another to ensure “limited influence from surrounding parcels, which may have different housing types unified only by some overall design standards” (13). While some communities are created with a single builder, which may achieve “some opportunities for greater integration,” many communities will use the parcel model to achieve maximum profit and home product performance throughout the entire development (13, 14). Communities of varying lot sizes “are often separated by the collector and arterial road systems in communities, only connected via secondary connection requirements.”

The current state of neighborhood commodification is written about at length by other scholars (Lake and Townshend, 2006; Chamberlain, 2012; Parker, 2019). Blending the single-site planning paradigm of minimizing effects (including any effects from additional direct physical connections) from surrounding developments with the private control of street network development, packaging neighborhoods as unique commodity and saleable product to multiple levels of consumers can result in lessened connectivity in neighborhoods and barriers to future implementation of such a property without significant changes in local planning processes.

Limitations of Study

While this study provides a suitable introduction to the political, social, and economic currents affecting the production of transportation network connectivity in one region of the Sun Belt, there are several limitations to this study which must be account for, and which offer opportunities for further research into this subdiscipline of transportation planning.

Quantitative Analysis and the Modifiable Areal Unit Problem

As discussed previously in this section, the very concept of connectivity is continuously scalar; how connectivity is defined and analyzed can change dramatically based on the scale of analysis. However, embedded in this property of connectivity is a common bias known as the Modifiable Areal Unit Problem (MAUP). This bias, which describes how the validity of statistics such as summaries, ratios, or other statistics created from geographical data is impacted by the unit (area) of analysis chosen, is common in most GIS analyses. This bias was apparent in the studies of intersection density, ingress and egress, and the creation of base layers for space syntax analysis in the study.

The MAUP bias was mitigated by creating consistent rules for developing case study areas for analysis. Each case study was developed using official subdivision boundaries provided by the Maricopa County Recorder's Office, selecting all subdivision parcels or phases which were related to a single larger master-planned community name in the GIS software used in the study. Consistent rules were also followed between subdivisions, including rules for selecting intersections and other phenomena on the periphery of case study areas (i.e. intersections on perimeter of study area selected if connecting directly to internal streets within a subdivision, but not at the intersection of two arterials adjacent to subdivision, etc.).

While the use of consistent methodologies between case study communities can mitigate much of the bias embedded in quantitative GIS analyses, this bias remains and must be offset by completing larger-sample analyses at differing scales to account for variations caused by different geographical units. Additionally, connectivity analyses are particularly susceptible to being swayed by even minor changes in the boundaries of the analysis area (Stangl, 2015). This phenomenon has been written about at length by several scholars as a limitation of any quantitative analysis in this subdiscipline (Stangl, 2015; Buzzelli, 2020).

Quantitative Analysis and Limited Sample Size

Available resources for this thesis study limited its scope to a handful of case studies, which were selected to be representative of various master-planned community types being constructed in the Phoenix metropolitan area but may not capture all types of communities or nuances between community designs. This study is designed to provide a starting point for the integration of qualitative data with findings from quantitative connectivity analysis. Creating stronger causal relationships and links between stakeholders in the political economy of subdivision development will require a greater sample size which promotes in-depth statistical analysis and an assurance of the ability to capture further nuances of the design of various communities.

Quantitative Analysis and Model Assumptions

Assumptions in any study built on quantitative models and more complex quantitative analysis must be challenged. In this study, there are numerous assumptions which are worth analyzing further:

1. **Space Syntax and Route Analysis:** The space syntax analyses of this study were built on network datasets that were constructed using consolidation, or combining continuous segments of a street network as defined within a street centerline shapefile and combining them to describe a more practical experience of street network properties. However, while consistent rules were defined for consolidating these segments into individual routes within each case study community, the definition of a "route" is a difficult concept to capture. Developing these "routes" as the individual pieces of analysis requires the investigator conducting the study to use discretion to determine which continuous street segments should be counted as a singular route (Figure 5.2). The difficulty in determining true route structure of a street network is examined in several of the works from which the methods of this paper were derived from (Ewing, 1996; Marshall, 2005; Boeing, 2019). While space syntax methods used in this study are deemed robust and capable of responding to some definitional changes in route structure (footnote), the route structure is based on assumptions which may have caused minor effects on the outcome of analysis.

2. **ViaCity Aggregate Scoring:** The ViaCity Score is a route directness score which uses a distance decay effect and search tolerance for other parcels in a given study area, both which require user inputs. As described in the Methods section of this paper, the ViaCity Score was used with a search tolerance "z-setting" and distance

decay parameter of two network miles. This may be unrealistic for capturing a property designed to measure built environment characteristics which affect active transportation uses (who rarely travel greater than one mile, per Moudon et. al., 2005; Ercan et. al., 2017; INRIX, 2019). However, a larger search distance and slower distance decay affect allows for a greater ability to analysis changes in the effects of street network design on connectivity and route directness over a wider area, which was the purpose of this study. These values are based on study assumptions which can change the outcome of the study; depending on the use of the metric, the outcome of ViaCity scores and other values from the quantitative analysis could change significantly.

Qualitative Analysis and Necessary Stakeholder Redundancy

There is a need for an analysis of finer-grained differences between members of the same stakeholder groups, as defined in the qualitative interview methods of this study. This study only included one to three members from a particular stakeholder group or community, creating a sample size of 16 interview participants. While this can provide insight and a foundation of new knowledge to build further inquiry upon, such a sample size may miss finer details, disagreements and tensions between members of the same stakeholder groups (footnote: For example, how two homebuilders may have dramatic disagreements on pertinent topics discussed in interviews, such as gating or preferred street network design). This study would further benefit from a greater sample size which can handle more advanced corpus linguistic analysis and statistical measurements. Adding participants and asking questions which explore the differences in sentiments between members of the same stakeholder group could provide a more robust qualitative analysis, though the 20 hours of interview data included in this study are sufficient for telling a descriptive story of street connectivity dynamics in Phoenix.

Directions for Future Study

The barriers to connectivity and quantitative assessment of connectivity outcomes in Phoenix subdivisions provided a roadmap to future research in the planning discipline on the application of connectivity to the modern urban fabric. This research paper presents a non-exhaustive but carefully selected list of research needs which may be deemed as most urgent based on the results of this study.

Localized Analysis of Connectivity

This study is designed to illustrate the potential of qualitative study and localized case study analysis exampling connectivity at the local and regional level. Computing capabilities for quantitative analysis has advanced, allowing for global analysis of connectivity and other urban network properties at an unprecedented scale (Barrington and Millard-Ball, 2019; Boeing, 2020). Since the advent of geospatial network analysis using programs such as ESRI's Network Analyst extension and other advanced network analysis software, academic literature has been saturated with robust analysis of the quantitative effects of connectivity, as illustrated in the literature review of this study. There is a need for further local analysis to supplement the knowledge of planners seeking to improve local and regional connectivity, with further study of the experiences of connectivity and urban network design and to capture changes in the effectiveness of connectivity with local nuance and detail that large-scale coded analyses cannot capture. Discovering new methods of measuring the experience of connectivity, and subsequent tools for providing greater experiences for those most likely to use provided connections, may be a critical piece of practical literature to support the work of planning practitioners seeking to increase community connectivity and transportation sustainability.

Political Economics of Urban Network Development

There is a need to further explore the political economics surrounding connectivity and urban network development in a manner further removed from quantitative analysis. Given the intimate role which urban networks play in achieving various positive social and environmental outcomes, it is critical that a more pronounced exploration of the political of planning which lead to less sustainable urban networks be completed, and that lessons be quickly broadcast to planning scholars and practitioners alike. As demonstrated in this study, particular needs within this political economics research are the discovery of the most salient political arguments for connectivity which can be leveraged for connectivity as a public asset, the exploration of the role of risk, liability, and devaluation avoidance behavior in the development of community street networks, the analysis of emotional and political channels surrounding arguments for modern traffic and access management which steers connectivity, and the further application of the benefits of connectivity to real stakeholders in the development process of new subdivisions.

This research will provide understanding of how practicing planners, developers, engineers, and other stakeholders involved in the development of new urban space can implement meaningful changes in overall community network design. Finding patterns in political discourse surrounding connectivity is a critical step toward implementing street network design outcomes in American cities.

Cellularity and Updates to Understanding Modern Urban Space

Finally, further research needs emerged from the quantitative analysis of this study, highlighting the need to study more closely how "cellularity" is impacting the ability to create truly sustainable and cohesive urban development. Cellularity is the production of urban street "subnetworks," such as subdivision street networks, which create network "cells" which are disconnected from one another, functioning as "cul-de-sacs" at the scale of entire neighborhoods, with streets in the network only capable of servicing other destinations within the defined neighborhood "cell" and failing to create external connections and the subsequent diversity of route options and ability to create more direct connections in multiple directions in urban space (Aurbach, 2020).

Networks may be well connected within each cell, but this connectivity is deeply embedded within street networks and fails to be connected to strong external connectivity which must be achieved for the creation of well-integrated and connected urban space. This property was exhibited in the networks with low external connectivity and high depth but moderate connectivity in the quantitative analysis featured in this paper. Studying the property of "cellularity" in the modern street network has ramifications for not only producing more direct and connected urban networks, but challenging modern frameworks of the development of neighborhoods which result in neighborhoods being treated as commodities to be fully distinct and traded between one another (Graham and Marvin, 2001), single-site development and the inefficiencies of producing cities by creating sites to contain parking and services to mitigate all external site effects (King and Krizek, 2020a), and the implicit and explicit privatization of other urban amenities and services (McKenzie, 1994; Kohn, 2004).

Continuity and Urban Legibility

In addition to the property of connectivity, where the premise of this paper began and was largely focused upon, the properties of network continuity and depth must be explored, as well. Continuity is essential for creating direct routes, allowing for routes to move through urban space without changes in direction which disorient or distract those moving through urban space. Network depth can harm urban legibility by requiring a large number of turns to reach destinations in areas far removed from major routes (arterials) and clusters of activity which require placement on network areas of lower depth where more route traffic is concentrated. As has been articulated in past research of various types, these properties are essential for urban legibility and the development of vital urban places (Lynch, 1964; Hamilton-Baillie, 2004; Taylor, 2009; Boeing, 2021). Greater attention must be paid to these attributes in the analysis of the production of new urban networks, such as those in emerging suburban communities.

6 CONCLUSION

Summary

Streets are essential for the proper function of a city. Streets play a central role in determining the social, political, and environmental outcomes of the modern city, as the primary convening point for transportation and movement, political action, and the handling of environmental externalities of the city (Jacobs, 1993; Lopez, 2014; NACTO, 2017; Environmental Protection Agency, 2021; Fagg, 2021). Few have surmised the role of the street so succinctly as 20th century urban advocate and author Jane Jacobs, who wrote in her treatise *The Death and Life of Great American Cities* (1961)*,*

> *"Streets and their sidewalks-the main public places of a city-are its most vital organs."*

Connectivity is a central property of functional and integral street networks. As Jacobs (1961) quickly added to her belief in the importance of streets to urban life,

> *"...frequent streets and short blocks are valuable because of the fabric of intricate cross-use that they permit among the users of a city neighborhood."*

A great deal of academic literature has coalesced into widespread agreement about the benefits of a connected street grid, including improved rates of active transportation, recreation, public health outcomes, and urban economic accessibility. The studies completed on connectivity within the wider body of planning literature are heavily quantitative, leaving a potential gap in understanding of other topics related to connectivity, such as the qualitative results of a connected and integrated urban fabric and the political economics surrounding the properties of transportation network design.

Connectivity has become an increasingly dominant priority amongst transportation planners. However, while implementation of connectivity has increased amongst street networks in the United States in the 21st century, overall rates of street network connectivity and integration remain far below historic peaks, and the rate of increase remains slow. Greater knowledge from academics and planning practitioners is needed about how connectivity is being shaped by various stakeholders in the process of planning greenfield communities, and what barriers exist in the implementation of street connectivity. This study engaged with the problem of identifying barriers to the implementation of street connectivity in the Phoenix metropolitan area, a rapidly growing urbanized region with growth and urban development patterns similar to those in other cities in the "Sun Belt" growth corridor of the United States.

Through qualitative analysis, numerous barriers to the implementation of connected street systems were identified. Traffic management remains a key barrier, as split authority between levels of streets within a divided functional hierarchy, access management standards designed to promote high speeds and regional accessibility, and methods of ensuring limited through-traffic and isolating neighborhoods from flows of traffic result in limits to the level of connectedness street networks in Phoenix can achieve. Divided priorities within planning bodies of local governments and limitations in the potential for positive advocacy for connectivity result in lagging local government action to support connectivity. Numerous barriers, including the cost of infrastructure over perceived value of installing additional infrastructure to connect neighborhoods, market demands for privacy, security, and exclusivity, private property rights and heavily privatized control over the outcomes of street networks can serve as barriers to overall connectivity in new Phoenix neighborhoods. Private sector pushes for connectivity are common at an internal level, and signal changing attitudes toward connectivity in some markets. Site conditions, such as the site, scale, and potential overall lot yield for a particular type of housing product, will heavily influence and shape connectivity as the properties of street network design are both sold with homes and are secondary to the plan to maximize yield, lot count and community value. The issue of connectivity lies within a thick political economy, and policies aimed at implementing simple metrics of connectivity at the subdivision level will fail to unravel the dense set of barriers to more robust urban connectivity which stretch across stakeholder groups.

Quantitative analysis discovered insights into how connectivity is being shaped in the Phoenix metropolitan area. Internal connectivity in many new subdivisions is slightly lower than or consistent with the historic grid of Phoenix, which features larger block sizes in a coherent grid; this connectivity is heavily impacted by the large number of T-intersections present in many modern subdivisions. External connectivity, in comparison, has dropped significantly and remains very low in most subdivision communities. Phoenix subdivision networks feature enclosed networks with few cul-de-sacs and hard discontinuities. However, many of these networks also have a high network depth and low network continuity, reflecting the current policy environment which is heavily shaped by traffic management policy and various impacts from stakeholders participating in a decentralized and highly market-driven planning process for building new transportation networks.

Communities in this study featured varying levels of overall accessibility to commercial destinations and other parcels, shaped heavily by location near continuous network routes (i.e. collector streets) and pathways which provided more direct access to various portions of a particular development. Some communities have completed significant work in improving overall connectivity and reflecting the function of a grid network in space syntax and accessibility analyses; however, these communities are difficult to build and are not the overall product of the current system of the production of urban space and networks in new subdivisions. Current planning policies are creating an enclosed and moderately connected street network which features significant cellularity, discontinuity and network depth; such properties harm outcomes of active transportation and may hamper efforts to improve connectivity and its attendant benefits in Phoenix communities. The barriers identified in this study serve as reasons for the creation of discontinuous, deep and only moderately connected street networks which may not be achieving goals for urban sustainability and efficiency.

Numerous themes emerged in this study of barriers to connectivity in the Phoenix street network. Connectivity is inherently scalar, and the current planning process is best designed to promote internal connectivity within new subdivision communities. Phoenix is achieving sound macro-scale connectivity, particularly for vehicle users along its large arterial and freeway network, but while accompanying improvements are being made to internal connectivity within the confines of subdivisions, other scales of connectivity such as between land uses and adjacent sites or within sub-regions of the Phoenix metropolitan area remain significantly lacking. Methods for maintaining automobility and high speed, uninterrupted travel through cities and preparing neighborhoods as unique commodities to be bought and sold by builders, developers and consumers alike can lead to breakdowns in connectivity at smaller scales and contribute to an overall fragmentation of the urban street network.

Ultimately, connectivity across the Phoenix region remains hampered by a “single-site” planning paradigm which accounts only for improvements in connectivity and accessibility *within* the confines of a particular community. Street network design and connectivity metrics, provisions for open space and trail connections, and other urban features which affect connectivity are planned at the level of the individual community, with only negative “spillover” externalities managed between sites. Factors intimately known to private sector stakeholders in new community development, such as effects of neighboring communities on land values and the perceptions toward connectivity by many potential residential consumers, can cause hesitancy toward connectivity. As such, neighboring communities often exist in isolation from one another. Few incentives likely exist to break away structurally from the single-site planning paradigm within a heavily privatized framework for planning new neighborhoods and street networks, which may remain as a barrier to improved overall connectivity which serves to improve overall urban integration and accessibility. This single-site planning paradigm lies at the heart of the challenge in providing connectivity in Phoenix and many other American cities in the 21st century.

The public sector requires the support of robust arguments for connectivity which can counter the perceived cost of infrastructure, and there are missing connections between the publicness of connectivity and how costs are distributed in the development process. Tools are missing which can provide functionally effective connectivity in new communities. Developing these tools and arguments will be immensely difficult due to the complex political and economic systems surrounding the property of connectivity, especially given the difficulty in discerning how important connectivity actually is to urban benefits such as active transport, improved health and social cohesion (as written about in the literature review.) However, such work will be necessary to provide leadership toward more sustainable street networks in the future, as connectivity is generally believed to play a role in creating more resilient transportation networks in some form.

Action Steps for Planning Practitioners

For planners today, immediate opportunities to improve connectivity can be found by pragmatically challenging the current paradigms of planning decision-making found in many local governments. Evaluating and drafting regulations which focus on the *experience* of connectivity can improve connectivity outcomes in new communities for future sustainability. Planners should ask "to what am I connecting, and for whom?" Such questions can build a foundation for more salient arguments for connectivity, pulling them from abstract to practical for particular groups who stand to benefit from such a property, and begin to build a more robust toolset of methods for connecting communities. Planners can use these questions in the planning process to build on increasingly positive notions of connectivity amongst developers and builders responding to market demands and shifting patterns of development.

This study confirmed that there is great opportunity for increasing connectivity in greenfield communities in Arizona. The research presented here suggests a theory of change with numerous opportunities to immediately improve connectivity in "new build" neighborhoods of Arizona. These function as practical takeaways from this thesis research to be applied to the planning practice of Arizonan cities and similar built environments (such as those in America's Sun Belt region).

The concept of connectivity enjoys increasing support (though likely far from universal support) amongst both public sector planning practitioners involved in greenfield development and private developers and builders with vested interest in new urban development. Public planners increasingly seek to gain the benefits of increased community connectivity and continue to increasingly pass policies regulating properties of transportation networks, such as intersection density, maximum block length, and other (generally quantitative) measures. Private development and planning practitioners advocate for connectivity to meet new market demands, increase lot yield and maximize access and visibility of local amenities.

While both methods of support generally focus on improving internal connectivity within proposed subdivisions and new communities, a smaller number of stated barriers were revealed which may make internal connectivity a suitability starting point for breaking down barriers to network connectivity implementation. A primary barrier to increases in connectivity to take advantage of shared public and private goals is the role of other public departments regulating a specific pattern of service delivery, such as sanitation and fire. The regulations often advocated for and managed by these departments, including wider right-of-way and turning radii, can “severely curtail the necessary trade-offs” (6) mentioned in the study as needed to avoid burdening a single party with the costs of connectivity implementation. These trade-offs include narrowing streets to create connectivity without large novel infrastructure burdens (2, 12). Playing off of the synergies between public and private stakeholders desiring to improve connectivity may be possible by challenging the efficiency of such regulations in achieving service delivery, developing new tools for amending standards (such as Morrison Ranch and Verrado in this study) and innovating within connected street networks to provide services while maintaining a feasibly connected street network.

The development of new tools for increasing connectivity (which remains overwhelmingly tied to streets and vehicle transportation networks in local planning practice) is tantamount. Trails and other non-motorized connections can serve as a vital tool with which can be used to connect local residents to surrounding arterials and portions of neighborhoods separated by various political and economic forces and unlikely to be grafted together with the use of streets accessible to vehicles. As identified in the study, barriers such as site topography (arroyos, etc.) and site phasing within subdivisions play a severe role in reducing connectivity and accessibility, as seen in the Sonoran Foothills and Tramanto case studies. Street network concepts such as the "fused grid," which integrate non-motorized pathways to create a cohesive gridded urban form, are demonstrating how non-motorized routes can achieve the benefits of modern street networks in limiting traffic and reducing liabilities for road infrastructure without causing burdens to active transport users. Integrating trails into a framework of transportation, rather than a framework of amenity and recreation, may provide an opportunity to overcome difficult site topography and master-planned communities without uprooting the current pattern of subdivision development.

New development in Europe provides a pathway forward for imagining the implementation of new tools such as shared use and pedestrian paths and limited vehicle access streets as a tool for promoting connectivity while alleviating potential concerns with traffic and overall safety. Many European cities have promoted new neighborhood development with circuitous routes, slower traffic designs and longer distances between access points for vehicles, pairing such network design choices with high numbers of links for active transportation users in all directions. This results in a far more diverse array of transportation designs which create direct routemaking and a greater overall experience of connectivity for active transport users while slowing or blocking vehicle traffic. Such tools in European cities develop a paradigm which limits traffic in new neighborhoods not simply for the purpose of protecting a low-traffic residential environment, but creating an incentive for active transportation by leveraging connectivity and requiring vehicles, which are far more capable of overcoming the barrier of low connectivity and indirect routes, to utilize indirect routes. Integrating pedestrian and non-motorized networks elements into the transportation system can enable the construction of connectivity for users which most benefit from such connectivity without creating widespread opportunities for vehicle access and free vehicle movement which will always compete with active transportation use.

The current planning environment produces a complex set of political and economic forces which will raise the challenge of producing connected street networks beyond what can be achieved by requirements for quantitative connectivity in communities. This finding from the experience of members of the Phoenix development community and case studies from the Phoenix region validate the need for a systemic approach to sustainable street network development (Talen, 2011; Winters, Buehler and Gotschi, 2018). A more holistic approach to promoting connectivity in new neighborhoods will be required which involves shifting costs and responsibilities between stakeholders in the development process and overcoming challenging political and economic incentives to resist connected networks. However, there are immediate opportunities to promote connectivity in a manner which likely appeals to most stakeholders in the greenfield development process, which should provide planning practitioners with hope for the development of more sustainable street networks. Planners must analyze local planning contexts to determine the greatest opportunities for collaboration to produce connectivity between stakeholders. Planners should take advantage of opportunities which lie beyond basic regulations which may not challenge overall street network composition in a manner which achieves the benefits of connectivity, as revealed in this study, and consider more politically and economically comprehensive methods of securing connectivity in new communities. As cities face unprecedented social and environmental challenges at local and global scales, creating transportation networks to support sustainable transportation and land use futures will be essential to securing a more stable and resilient future.

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APPENDIX A

INTERVIEW SCHEDULE

The sixteen semi-structured interviews conducted for this study were performed between March 6, 2021 and October 12, 2021. This appendix details the interview schedule from this study. Names remain anonymous to maintain the integrity of the data presented in this study.

- City of Phoenix, Site Development – March 6, 2021
- City of Casa Grande, Planning – March 20, 2021
- City of Buckeye, Planning and Entitlements – April 7, 2021
- Lennar Homes, Home Construction – April 29, 2021
- Espiritu Loci – May 5, 2021
- Norris Design – May 12, 2021
- AB/LA – May 23, 2021
- Town of Gilbert, Planning – July 12, 2021
- Town of Gilbert, Transportation – September 30, 2021
- Hilgert and Wilson – October 1, 2021
- T.Y. Lin International – October 6, 2021
- Maricopa County/City of Maricopa – October 12, 2021

APPENDIX B

INTERVIEW KEY

The sixteen semi-structured interviews conducted for this study provided an array of insights necessary for answering the research questions proposed in this paper. In this paper, numbers are used to properly cite quotes from interview transcripts used to build the qualitative narrative. Each number refers to an interview participant from the study. The key is provided below with anonymity to protect data quality.

Maricopa County/City of Maricopa – 1

Town of Gilbert – Transportation – 2

Town of Gilbert – Planning (Retired) – 3

City of Casa Grande – Junior Planning – 4

City of Casa Grande – Senior Planning – 5

City of Phoenix – Site Planning and Development – 6

City of Buckeye – Planning – 7

City of Buckeye – Planning – 8

Hilgart Wilson – Transportation Engineering/Planning – 9

Hilgart Wilson – Engineering/Planning – 10

Hilgart Wilson – Land Use Planning – 11

AB/LA – Land Use Planning – 12

Norris Design – Land Use Planning – 13

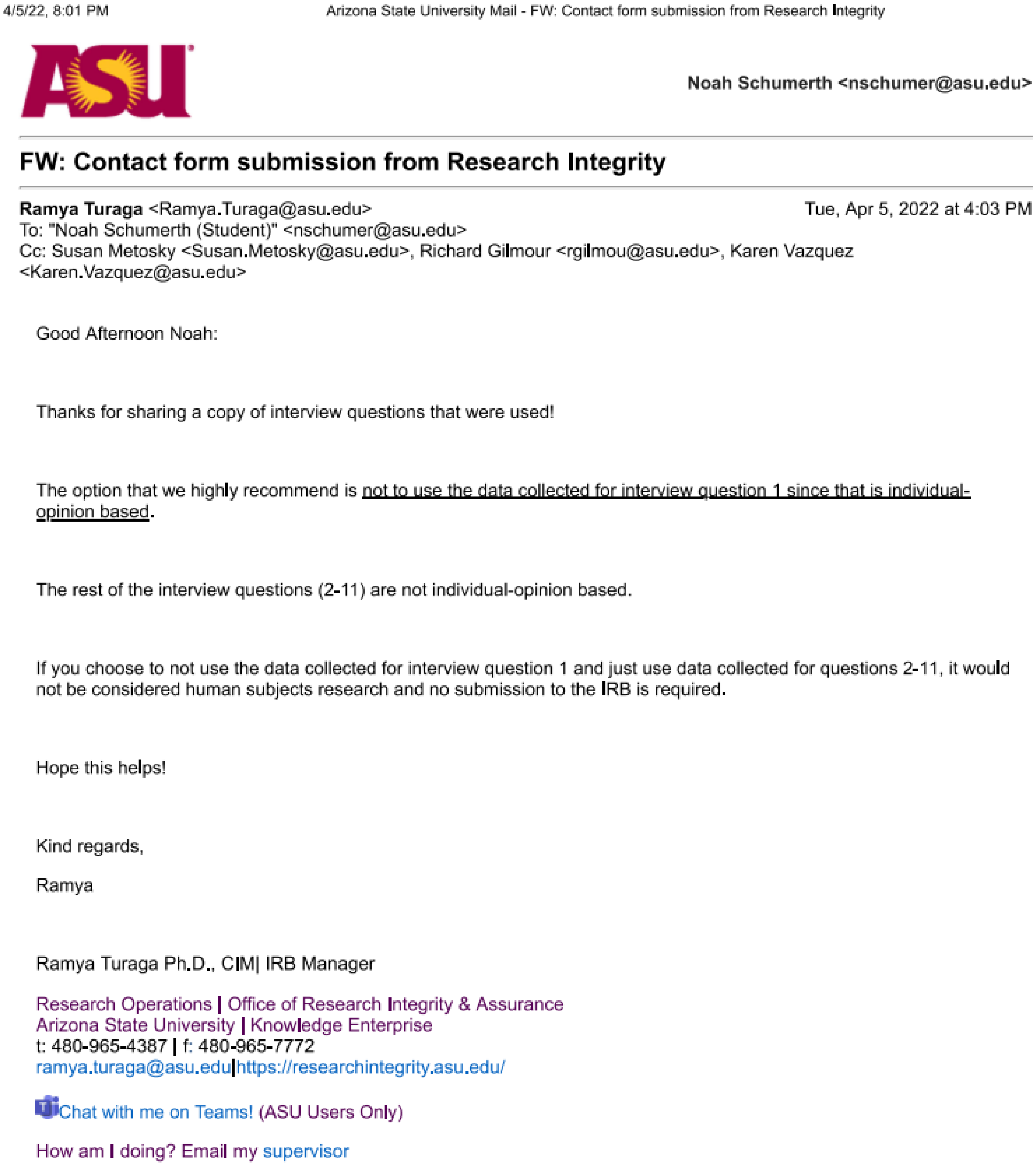
Espiritu Loci – Land Use Planning and Development – 14

Lennar Homes – Homebuilding – 15

T.Y. Lin International – Transportation Design - 16

APPENDIX C

IRB WAIVER AND DOCUMENTATION



4/5/22, 8:01 PM Arizona State University Mail - FW: Contact form submission from Research Integrity

Noah Schumerth <nschumer@asu.edu>

FW: Contact form submission from Research Integrity

Ramya Turaga <Ramya.Turaga@asu.edu> Tue, Apr 5, 2022 at 4:03 PM
To: "Noah Schumerth (Student)" <nschumer@asu.edu>
Cc: Susan Metosky <Susan.Metosky@asu.edu>, Richard Gilmour <rgilmou@asu.edu>, Karen Vazquez <Karen.Vazquez@asu.edu>

Good Afternoon Noah:

Thanks for sharing a copy of interview questions that were used!

The option that we highly recommend is <u>not to use the data collected for interview question 1 since that is individual-opinion based</u>.

The rest of the interview questions (2-11) are not individual-opinion based.

If you choose to not use the data collected for interview question 1 and just use data collected for questions 2-11, it would not be considered human subjects research and no submission to the IRB is required.

Hope this helps!

Kind regards,

Ramya

Ramya Turaga Ph.D., CIM| IRB Manager

Research Operations | Office of Research Integrity & Assurance
Arizona State University | Knowledge Enterprise
t: 480-965-4387 | f: 480-965-7772
ramya.turaga@asu.edu|https://researchintegrity.asu.edu/

Chat with me on Teams! (ASU Users Only)

How am I doing? Email my supervisor

APPENDIX D

SAMPLE INTERVIEW INSTRUMENTS

This appendix features three randomly selected interview instruments designed to demonstrate the design and structure of interviews used in this study. Interview instruments were utilized directly when conducting interviews with panel participants. Names and other identifying information on the interview instrument used by the principal researcher have been redacted for this appendix. Please contact principal researcher (Noah Schumerth) for additional access to interview instruments or other data.

Interview Instrument Sample

[redacted]

October 6, 2021

Total Time: ~60 minutes (45 + 15)

Procedural Notes:

- All answers suppled in this interview are to be used for academic purposes only. No portion of this interview shall be used for commercial purposes or other purposes by which compensation may be received from the content of this interview.
- Personal anonymity will be provided for any and all answers during this interview. All references to responses in paper will associate to your organization – in no way will personal names or details be revealed in the final thesis document. Interview participants will have a formal opportunity to review the thesis document to ensure clarity and accuracy in any quote or answer from this interview used in the final paper.
- All questions following the interview may be forwarded to nschumer@asu.edu.

Questions:

[redacted]

2. What are the primary documents, policies, and standards used to determine subdivision street layout in a given community? Where do you see the most variation in guidance between communities? (3-5 min)
3. What are the principal ideas which drive subdivision street layout, in your experience? To put it a different way, what goals are generally embedded in neighborhood transportation design for new communities in Phoenix? (4-7 min)
4. How do members of your discipline approach street connectivity? (3-6 min)
5. What variables tend to affect street connectivity in a new neighborhood? (5-8 min)
6. How do market dynamics affect neighborhood layout and transportation design? How might it affect connectivity? (5-6 min)
7. What are barriers to producing greater street connectivity in new developments, both a) within developments and b) outside of developments connecting to surrounding areas? (8-11 min)
8. What are situations where a community may be built with increased connectivity? (4-7 min)
9. Do you see new trends in connectivity going forward? Is there a demand for communities becoming more or less connected?

Closing the interview (see checklist)

- Reiterate anonymity and verify status of anonymity for interview subject.
- Reiterate permission from interview subject to use data for academic, non-commercial purposes
- Thank the interview subject for their time (Deirdre said – make sure they feel their time was well spent and will contribute to a body of research work).

Interview Instrument Sample

[redacted]

[redacted]

July 12, 2021

Total Time: ~60 minutes (45 + 15)

Procedural Notes (see checklist)

- All answers suppled in this interview are to be used for academic purposes only. No portion of this interview shall be used for commercial purposes or other purposes by which compensation may be received from the content of this interview.
- Anonymity may be requested for any and all answers during this interview. Interview participants will have a formal opportunity to review the thesis document to ensure clarity and accuracy in any quote or answer from this interview used in the final paper.
- All questions following the interview may be forwarded to nschumer@asu.edu.

Questions:

General: 1. Briefly describe your role with [redacted] – in particular, your role and what issues particularly animated your work? (4-6 min)

Stakeholder Specific: 2. This interview centers on exploring the pattern of development [redacted] took on from 2000-onward, which features more gridded streets, higher-density housing products and some neighborhood [redacted] which integrate land uses in a manner which is unlikely to be seen in many other Valley communities. What documents or policies does [redacted] use to regulate and guide subdivision and neighborhood design? (3-5 min)

General with Stakeholder Specific Introduction: 3. This project is largely focused on street network design. [redacted], statistically demonstrate a far higher level of street connectivity and "griddedness" than surrounding Valley communities. Has the Town made active policies to encourage this griddedness, or was that the result of other factors? (i.e. private development interest, incentives, unforeseen policy outcomes, etc.) (5-8 min)

General: 4. What role does the Town take in managing the layout and design of local streets? How much of this authority does the Town cede to private developers? (5-7 min)

General: 5. What does [redacted] process look like for subdivision design? (beyond the obviously required platting processes in Maricopa County, etc.) (5-7 min)

Stakeholder Specific: 6. With [redacted] more gridded street patterns and more connected neighborhoods, how did you see that tying into broader market trends? Why were developers agreeing to develop this way or actively design neighborhoods in this manner? (5-7 min)

General with Stakeholder Specific Introduction: 7. What are the primary variables that change street design patterns between neighborhoods (i.e. what makes a neighborhood such [redacted] (4-6 min)

General: 8. How does the Town approach external connectivity to subdivisions? What factors affect the spacing of external connections to subdivisions?

General: 9. What degree of flexibility does the Town offer for different street designs (i.e. different street sections) and setting their own standards for streets? How does this impact connectivity from the Town's perspective? (5-7 min)

Closing the interview (see checklist)

- Reiterate anonymity and verify status of anonymity for interview subject.
- Reiterate permission from interview subject to use data for academic, non-commercial purposes
- Thank the interview subject for their time (Deirdre said – make sure they feel their time was well spent and will contribute to a body of research work).

Interview Instrument Document

[redacted]

April 7, 2021

Total Time: ~60 minutes (45 + 15)

Procedural Notes (see checklist)

- All answers suppled in this interview are to be used for academic purposes only. No portion of this interview shall be used for commercial purposes or other purposes by which compensation may be received from the content of this interview.
- Anonymity may be requested for any and all answers during this interview. Interview participants will have a formal opportunity to review the thesis document to ensure clarity and accuracy in any quote or answer from this interview used in the final paper.
- All questions following the interview may be forwarded to nschumer@asu.edu.

Questions

General: 1. Describe your roles with the [redacted], and briefly explain your experience with greenfield development in Arizona.

General: 2. Describe the city's review process for street networks – between planning, public works and other city agencies, who is making the decisions in the city on where street will go? Which agencies/individuals are responsible for designing each tier of the functional classification system? Is the tier largely overseen by public or private decision-making?

General: 3. Describe the relationship between public and private sectors in designing street networks in the city?

General: 4. What design standards does [redacted] use for determining street design and street sections?

General: 5. What is the greatest factor in the ultimate layout/design of street networks in [redacted] subdivisions? (security, marketability, efficiency, profit, other variables, etc.)

Stakeholder Specific: 6. Describe the main goals for future subdivision development in Buckeye:

a. What (if anything) would the city like to do to improve the quality of subdivisions in the city?

b. What processes might the City use to realize those goals?

General: 7. How prevalent are private street networks in the City of Buckeye? Do private streets expand private sector flexibility for street design and/or layout?

General: 8. How does the city approach external connectivity to subdivisions? What factors affect the spacing of external connections to subdivisions?

General with Stakeholder Specific Introduction: 9. What trends do you see in the street network designs being applied to subdivisions in [redacted]? How are local streets or other subdivision features evolving?

Stakeholder Specific: 10. Let's talk about [redacted] known for its greater degree of connectivity, increased density and land use integration. How did the city approach DMB's new subdivision design idea? What did the city do to accommodate the project? What barriers did DMB and other private sector actors run into when building this subdivision? Were there other aspects of the development which ended up not becoming a reality?

General: 11. In your experience as a planner, what are the primary barriers to increased connectivity in Phoenix cities, or in U.S. cities as a whole? (6-10 min)

Closing the interview (see checklist)

- Reiterate anonymity and verify status of anonymity for interview subject.
- Reiterate permission from interview subject to use data for academic, non-commercial purposes
- Thank the interview subject for their time (Deirdre said – make sure they feel their time was well spent and will contribute to a body of research work).

APPENDIX E

INTERNAL INTERVIEW POLICIES

This appendix features internal policies designed to maintain the integrity of the qualitative methods employed in this study and meet IRB standards for interviews without opinion-based analysis of human subjects.

Internal Policy Directive

Semi-Structured Interviews, Master's Research Thesis

Noah Schumerth (David King, Chair)

April 2021 – October 2021

Checklist:

- Provide background for project covering the following points:
    - For Master's thesis research to complete Master of Urban and Environmental Science degree
    - Selected from sample of participants from each stakeholder group – if referred by ASU faculty committee member, provide name. Tell participant that group of 15-20 interviewees will be involved.
    - Designed to provide semi-structured interview format for participants to respond to specific planning questions while providing unique insights
    - Research is inductive in nature and designed to explore the processes, complexities and attitudes surrounding street connectivity.
- Receive **explicit verbal consent** from interview subject upon sharing the following information
    - Data treatment (anonymous, stakeholder group membership as primary identification)
    - Ability to request specific anonymity for any or all comments made during interview
    - Interview will be recorded for transcription and notetaking purposes and will not be distributed or published in any manner, to be deleted at end of project tenure.
    - Commercial purposes clause (academic purposes only, not to be used for commercial purposes, for sale or profit, or other means not rooted in research)
    - Contact information (nschumer@asu.edu)
- Complete interview (see instrument)
- Close the interview
    - Reiterate anonymity and verify status of
    - Reiterate permission from interview subject to use data for academic, non-commercial purposes
    - Thank the interview subject for their time (Deirdre said – make sure they feel their time was well spent and will contribute to a body of research work).