Assessment of sustainability of the built environment in Latin American neighbourhoods: five cases in southern Chile.

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Abstract. This article aims to show the results of the evaluation of the sustainable potential of the built environment in five neighborhoods in Southern Chile, to deal with the complex agenda of urban transformations in intermediate cities. Five neighborhoods in Isla Teja district, in the city of Valdivia, are evaluated in this research. The methodology considers five dimensions widely discussed in scientific literature: Accessibility, Connectivity, Density, Diversity and Vitality. The results show that certain neighborhoods have greater degree of adaptability in their morphology to generate diversity of uses, which in turn promote greater sustainability of the urban form. Mixed-use development and graded densities in urban blocks show best response to promote social life and collective activity in urban space. The article concludes with respect to future challenges to promote the development of more sustainable urban conditions in Latin American cities.

1. Introduction

Lack of planning has especially placed South American cities at the center of 21st Century development (UN-Habitat, 2017). In Latin America, evidences indicate that cities are following a pattern of change similar to that observed in European and North American contexts. This mainly refers to changes in two basic aspects of the city: form and function. For Salinas and Pérez (2011), this transformation is characterized by a morphological modification in relation to attributes of contiguity, compactness and limits of the historical model of the city, by those attributes of discontinuity, fragmentation or diffusion of the contemporary urban development, which subsequently produces the dispersion of the city. The literature also suggests that one predominant element is the massification of private residential projects, which have transformed the landscape and urban lifestyles (Borsdorf and Hidalgo, 2013; López-Morales et al., 2015). Other studies suggest that these same processes have generated new forms whose main features are fragmentation and privatization of the space, reducing social polarization and increasing segregation on a reduced scale (Inzulza and Gatica, 2018). In this way, urban units such as the neighborhood -bases of a city microstructure- where the community articulates the private space of the family with the public space, gradually lose their structure, identity and vitality (Zumelzu, 2016). There is very little evidence of these processes in intermediate cities, especially in southern Chile, which today represents a great range of potential and interest to promote sustainable urban development (UN-Habitat, 2016).
The principal objective of this article is to apply a methodology to explore and evaluate the sustainable potential of the urban form in five neighborhoods in Southern Chile. Sustainability is used as an operational concept to face urban problems, where the strength of the concept consists of integration of different aspects – economic, social, mobility, accessibility, land use, environment, among other. The methodology establishes the application of five dimensions of sustainable urban form -widely discussed in scientific literature- to evaluate the potential of some places to be catalysts for an improved -more sustainable- urban form: accessibility, connectivity, density, diversity and vitality. To do so, it conducts a critical review of the concept of urban form, sets out its key dimensions and understands their claimed relationship with sustainability. Building on the comprehensive study of Isla Teja, a district located in Valdivia in Southern Chile, five neighborhoods are identified and evaluated. Both quantitative and qualitative research methods are adopted to test the associated sustainability outcomes. Finally, we use our results to highlight critical aspects and future challenges to promote the development of more sustainable urban conditions in Latin American cities.

2. Sustainability as an operational concept

The concept of sustainability in urbanism is broad, complex and even ambiguous, for which there is no single definition, leading to a variety of perspectives and visions. Due to its complexity, the term “sustainability” is often used unsustainably. The stigma of “sustainable city” or “sustainable development” is a metaphysical ideal and a utopian myth -powerful but problematic (Davidson, 2010). There is no pragmatic model, only partial visions (Frey and Yaneske, 2007). While there is evidence of progress, it has been at the level of policymaking. The concept has shown its vagueness in terms of action and implementation, in which the relationship with the purpose of planning is lost (Zumelzu and Doevendans, 2016, p.2).

Application of sustainability in the urban form has been widely discussed during last two decades, in which debates have focused mainly on the search for “ideal” urban models which contribute more to sustainability than others (Jabareen, 2006; Ehlers, 2011). These views suggest that sustainable urban form must be compact from the center to the edges (Breheny et al., 1996; Burton, 2002; Artmann et al., 2019). Other authors suggest that the city could consist of different compact units which are decentralized but connected by a public transport networks (Jenks and Dempsey, 2005; Neuman, 2005). The debate has been, in discourse and in practice, confusing, inconclusive, in which researchers have focused only on a limited number of aspects (Naess, 2014; Jenks and Jones, 2010; Sakamoto et al., 2018). However, urban models can play a determining role because they contain interesting elements which can be applied in an existing city. But often, these models are theoretical constructs, and, in practice, they are still a long way from solving the real problems of cities -mainly related to high levels of energy consumption and urban areas dependent on cars, social and spatial segregation, high levels of pollution, among others.

We believe that discussions and debates on a sustainable urban form should follow a more heuristic trajectory, broadening and interrelating the debate towards the development of methods, instruments and tools instead of producing optimal solutions or models, such as the compact city for example (Kärrholm, 2011; Zumelzu, 2016). It is very important to study the causes of city problems and the development of methods and tools for the practical application of sustainability (Säynäjoki et al., 2015).

3. Dimensions of sustainable urban form

The definition and measurement of sustainable urban form -sometimes referred to as “sustainable urban neighborhoods” or “sustainable urbanism”- has advanced and evolved significantly in the last two decades (Frey, 1999; Song and Knaap, 2004; Karimi, 2013; Luederitz et al., 2013; Zumelzu and Doevendans, 2016; Hemani et al., 2017; Mouraditis, 2018). The application has demonstrated the importance of the concept of sustainability as a tool for integrating economic, environmental, social and morphological issues to deal with urban problems. In spite of this, its direct use in developing countries is debated, due to a lack of clarity regarding how to sensitize these aspects to local problems,
not to mention the lack of a database with the magnitudes and specificities required to apply them. It should be mentioned, however, that there are many other needs, aspirations and dimensions to promote a place that are more specific in terms of sustainable development. This challenge has prompted planners, architects, and local and international governments to propose new frameworks for restructuring and redesigning urban areas to achieve sustainability at different spatial levels.

In scientific literature, discussions of urban form related to sustainability encompass a number of physical and intangible characteristics, which are related not only to morphological elements but also to the configuration of the social environment and its interaction within neighborhoods and districts (Dempsey et al., 2010). Accordingly, we propose five key dimensions, broad and interrelated, that have been identified -usually in scientific literature- and that can be measured and evaluated. The scientific evidence shows that these dimensions are most demanded to influence sustainability and human behavior in the city.

3.1. Accessibility
Accessibility is a long-standing theme among the theories of “good” urban form (Lynch, 1981; Sternberg, 2000). The sustainable urban form is defined by the degree to which it is compatible with the needs of pedestrians and cyclists over car drivers. This has been motivated by a concern about negative effects generated by the built environment on the physical activity and health of inhabitants. It is believed that pedestrian-oriented streets have a positive effect not only on the quality of the place, but also on the degree to which people are willing to walk (Talen and Koschinsky, 2013). A pattern of sustainable settlement should increase access among residents, their workplaces and required services in an equitable manner, considering inhabitants with displacement problems -older adults, disabled, pregnant women and households without car (Barton et al., 2010; Sigh, 2016). Accessibility measures have been used in recent times as part of an effort to assess built environment for health effects (Frey and Bagaeen, 2010; Jun and Hur, 2015; Kowaleski-Jones et al., 2018). Walkable access to services and equipment is an essential part of urban sustainability, because people who live in places with services at pedestrian reach tend to reduce car-dependent mobility and generate a smaller carbon footprint.

3.2. Connectivity
Urban form plays an important role in promoting or limiting connectivity. Connectivity refers to the degree to which local environments offer connection and contact points -to people and resources- in a variety of scales and for multiple purposes. This quality promotes sustainability in which the highest connectivity leads to higher levels of interaction between people, the environment, society, economic and cultural activities, all of which are believed to improve the long-term stability and community of the neighborhood (Talen, 2011). The social connection at neighborhood scale is seen as pedestrian phenomenon, in which networks of “neighborhood relationships” are related to interconnected pedestrian streets and to the internal access to the neighborhood generated by these street networks (He et al., 2019). The importance of maximizing connectivity in the urban space has been a vitally important aspect in studies of urban form, wherein the focus has been to maximize opportunities for interaction and exchange, and increase the number of routes -streets, sidewalks, and other throughways. There is a common agreement in the literature that urban block of great length or scale, cul-de-sacs, and dendritic street systems are less likely to provide good connectivity (Sevtsuk et al., 2016).

3.3. Density
Density is an essential component of sustainable urban form. This criterion has been one of the main factors in maintaining pedestrian access to the basic services and equipment needed in a neighborhood. It is known that an increase in carbon emissions causes declines in density and mixed use (Cervero, 2013). However, no specific rules exist about how density form or the mixed-use level should vary given different regions and contexts (Zumelzu and Doevendans, 2016). In the literature, in relation to neighborhoods, values of total population size are generally established between 4,000 to
10,000 inhabitants, gross population densities between 50 and 58 inhab/he, and net dwelling densities between ranges of 43 and 85 dw/he (Frey and Bagaeen, 2010; Dempsey et al., 2010). The average density of housing must reflect, and is conditioning, to local situations. These may vary depending on the local conditions, either near the edge or the center of the neighborhood. The objective is to support the development of local services and equipment within the neighborhood.

3.4. Vitality
Vitality, also referred as “neighborhood vitality” or “nodality” in urban form, is understood as fundamental for community sustainability. Some authors characterize urban vitality at the neighborhood scale according to three main factors: the continuous presence of people on streets and in public spaces, their activities and opportunities, and the environment in which these activities are carried out (Zarin et al., 2015; Zeng et al., 2018). In urban form, the idea of nodality suggests that urban development should be organized around nodes of various levels and sizes (Frey, 1999; Kärrholm, 2011; Talen, 2011). While expansion tends to segregate the territory, the urban sustainable form tends towards a distinguishable hierarchy: from regional nodes of development to neighborhood centers or even public spaces at urban block level. At neighborhood level, nodes of activity promote sustainability of the urban form, providing there are public spaces around which the buildings are organized, where shops, local services and facilities, and social interaction can take place. Centralized nodes of activity at neighborhood scale might initiate physical interaction among the community, by giving the surrounding residents a common destination. These types of spaces support other aspects of sustainable urbanism, such as an increase in the density of surroundings, mixtures of types of housing anchored by a centralized space, or the commerce viability at neighborhood scale (Ellin, 2006).

3.5. Diversity
Diversity, as a dimension of sustainable urban form, relates to two aspects. In the first, the diversity of land use -understood as balances in the development of residential and non-residential land- is related to promoting a number of benefits: economic vitality, social interaction between individuals, and walkable provision of various services and equipment that a neighborhood requires (Talen, 2008; Tarbatt, 2012). In the second, socially diverse neighborhoods, it continues to be seen as essential for the well-being of a community and the goals of social equity, where the relationship with sustainability is made through a combination of income as well as races and ethnic groups which are believed to form the basis of an “authentic” sustainable community (Dempsey et al., 2011; Landry, 2016). The diversity and mixture of types of housing units is also important, from single family detached, semi-detached, etc. Studies of socially mixed neighborhoods -either through individuals and typologies- have consequently identified the urban form as a key factor in sustainable diversity (Talen, 2008; Zumelzu, 2015).

4. Materials and methods

4.1. Study area
To study the sustainable potential of the urban form, we carried out a case study in the district of Isla Teja in the city of Valdivia, Southern Chile, which represents an area of important spatial transformations from the beginning of 20th Century. Isla Teja represents one of the pioneering districts of industrial principles during the 20th century in Chile. Isla Teja is a residential and service district, which covers approximately 15 km² and contains several residential areas. The growth and urban development of Isla Teja has been generated in a dispersed and fragmented way, given the natural geomorphology of the territory composed of natural systems such as wetlands, rivers, lagoons, forests and hills, generating "residential islands" within the same island, adapted to the natural borders (figure 1).
Figure 1. Location of Isla Teja district (1) within the city of Valdivia, Chile.

Despite its early occupation, the real urban development of Valdivia began with the arrival of German settlers in the late 19th century, bringing their entrepreneurial spirit and extensive knowledge of industrial processes and labor division. Industrial development and the subdivision and specialization of work creates the need for large labor forces, and therefore, the development of neighborhoods for workers came about in the early 1930s. These neighborhoods were developed in Isla Teja in close proximity to the industries, taking advantage of the connected areas.

Despite the efforts made by families descended from German settlers, the great earthquake of the year 1960 abruptly ended the industrial development of the island and may have implied an end to the urban development of Isla Teja. The 1960 earthquake not only altered the economic development of the island, but also redirected its productive role to a residential and service role. These changes were accompanied by morphological variations, including the descent of extensive areas which currently make up wetlands considered nature sanctuaries. The original types of housing with social character also stopped developing along with the end of industry, being replaced by residential complexes for the middle class and later, the upper class. In this sense, due to the varied construction phases and applications of planning concepts, substantial differences in urban form can be noted among the neighbourhoods of Isla Teja.

4.2. Methods
Table 1 summarizes the methodological structure to evaluate and measure sustainability. To study the sustainability of urban form in Isla Teja, the identification of activity nodes that provide neighborhood vitality is realized, to select which places and types of nodes could provide “nodality” dimension. To measure neighborhood vitality, the intensity of occupation is calculated through surveys to measure the count of pedestrians in an area, by using Gate method from Space Syntax theory (Vaughan, 2001).

Specifically, density is a measured by calculating gross population and net dwelling density, considering groups of urban blocks close to the node of activity. Accessibility is measured based on distance between residential lots and retail. In addition, the method of Following People (Vaughan, 2001) was incorporated to assess two aspects: the relationship between one movement route and another one within the system; and the distance that a person walks between their points of interest and their route choice. Connectivity is measured by counting the number of intersections per area unit by using Depthmap analysis from Space Syntax Theory. Finally, diversity is measured by Simpson’s diversity index for housing units’ types and socio-economic group. According to Talen (2008), greater mix of housing units from single-family detached to apartment buildings would have an urban form more supportive of social diversity, a key feature of sustainability. It expected to obtain varying levels about places that could potentially be more sustainable than others in terms of urban form.
Table 1. Dimensions of sustainable urban form and how these are explored and measured. Source: authors, based on Talen (2011).

| Dimension   | How is measured                                                                 | Spatial unit          | Result                                                                 |
|-------------|---------------------------------------------------------------------------------|-----------------------|----------------------------------------------------------------------|
| Vitality    | Intensity of pedestrian occupation and movement in the urban environment.        | street, lots, squares | To qualify and localize nodalities                                   |
| Density     | Population per hectare and dwellings per hectare.                                 | Block group           | To distinguish and characterize variations in households’ size and factors of land uses. |
| Accessibility | Count of residential lots within 400 mts of services and facilities, divided by area of tract. | Unit area or tract    | To evaluate the pedestrian access to daily-basic needs.              |
| Connectivity | Number of intersections per area of tract.                                       | Unit area or tract    | To evaluate the degree in which the environment offers points of connection to people and resources. |
| Diversity   | Diversity of housing types and socioeconomic groups.                             | Unit area or tract    | To quantify the diversity of typologies and social mix of an area.   |

5. Analysis of results

5.1. Identification of potential nodes

Figure 2 shows the potential nodes that provide vitality, together with the neighborhoods of Isla Teja that had highest levels of intensity of pedestrian occupation and movement. Through the “Gates” method, the intensity of occupation was measured (Vaughan, 2011). Several captures were taken in the field for three days in the morning, three days in the afternoon, and one in the evening. Moreover, the captures were taken during two days of the week and one of the weekend.

The identified nodes correspond to neighborhoods Prochelle, Santa Ines, Teja, Raulies and Teja Sur. These areas reveal a mixture of urban occupation and grain types, from a predominantly urban fabric to those that are largely culs-de-sac. Several activity nodes were identified, ranging from parking areas and public squares to supermarkets and green open spaces. Figure 2 shows five types of places that could provide nodes of greater vitality in the neighborhoods of Isla Teja. These nodes serve as the "focal point” of some neighborhoods, presenting diverse uses and activities. Criteria for selection including places that provide a mixture of uses, high density of housing and a meeting place with pedestrian activity.

Figure 2. Potential nodes of activity within neighbourhood areas that provide high levels of vitality.
5.2. Results
Table 2 presents the results numerically. Accordingly, several observations about these data can be made. First, the results show that the most sustainable areas do not seem to have much relation to potential nodes which have greater loads and high values of intensity of use. But rather, they relate to places with a higher mix of building use and higher diversity of activities in their nodes, which are oriented towards open spaces such as squares and green areas, and not towards streets with high intensity of use. Second, it is observed that in neighborhoods with gross housing densities between 35 and 65 houses per hectare, and gross population densities between 50 and 65 inhabitants per hectare, they show a greater graduality of density between their blocks, offering a higher variety of types and size of housing. This promotes greater functional exchanges in the nodes, increasing pedestrian access to opportunities and services. From the net values, it is observed the development of two types of density: density of vertical type and density of horizontal type. The density of vertical type generates higher positive effects within the neighborhoods, especially in Teja and Santa Inés neighborhoods. The high horizontal density, on the other hand, due to the growth of rental housing in residential plots, decreases the pedestrian accessibility in the inner streets.

Table 2. Five measures of sustainable urban form in neighborhoods in Isla Teja. Source: authors.

| Measure              | Isla Teja Neighborhoods |
|----------------------|-------------------------|
|                      | Teja | Prochelle | Santa Inés | Raulies | Teja Sur |
| Vitality (intensity of pedestrian use, average per week) | 7129  | 6370     | 9344      | 1540    | 1430     |
| Population density (mean block group density)       | 155   | 62       | 81        | 46      | 16       |
| Dwelling density (mean block group density)          | 63    | 35       | 59        | 21      | 25       |
| Accessibility                                          | 0.35  | 0.25     | 0.34      | 0.11    | 0.07     |
| Connectivity                                          | 5     | 7        | 4.4       | 3.7     | 3        |
| Diversity                                            | 0.55  | 0.46     | 0.3       | 0.15    | 0.12     |

A high accessibility is observed in neighborhoods with a high vertical housing density and a greater balance between their land uses, such as the Teja and Santa Inés neighborhoods. The pedestrian accessibility decreases in places with greater horizontal density of housing due to the expansion of single-family house that generates effects on the public space. Elements such as blind walls, the lack of front yard, the low distance between street fronts, the absence of green areas, and the decrease in the size of the sidewalks in the inner streets, they negatively affect the choice of routes, and consequently pedestrian accessibility. Moreover, the routes with higher pedestrian accessibility are observed in streets conformed by shorter blocks in their façade dimension, which do not exceed 100 m on average. These routes have a high quality of built environment in all its categories, from wide sidewalks, presence of green areas and good quality of infrastructure of shops and services, as it happens in the nodes of Teja and Prochelle neighborhoods.

Regarding diversity, most of the diverse areas are generally located in areas of higher connectivity and in nodes that show a greater diversity of uses, as in the case of the nodes in Teja, Prochelle, and Santa Inés neighborhoods. These neighborhoods show more balanced average values of diversity among the four categories analyzed: land use, dwelling size, typology of housing and socio-economic group. Furthermore, these “diverse” neighborhoods are positive because of the functional exchanges they offer, promoting greater effective access to opportunities, goods, and services. In addition, it is observed a greater diversity of socio-economic groups (per block), especially in places of greater mixture of building use, through high-rise housing with services on the first floor or the adaptability of
an existing building (transformation of existing typology) to a new use. The mix of housing types and the combination of different shapes and sizes provide multiple opportunities for access in the neighborhoods. In Teja and Prochelle neighborhoods, for instance, the mix of housing types has generated opportunities for the arrival of immigrants and university students, which has led to the appearance of new services and local economies. In these neighborhoods, the commercial activities coexist with residential areas (mixed use), with rental properties that not only provide greater purchase options, but are also essential to retain low-income people in the neighborhoods.

6. Discussion
The maps in figure 3 show the most and least sustainable areas within neighborhoods that show a better balance between their values. Some of the most interesting aspects observed, according to the results, is that the nodes with the highest load of use are not related to places that provide a greater diversity of activities, and in turn, greater social interaction.

![Figure 3](image)

**Figure 3.** Areas scoring high in three dimensions of sustainable urban form, in neighborhoods Teja (left) and Prochelle (right).

For instance, in Santa Ines neighborhood the node is generated due to the high topological accessibility of the street, which, in addition to be the main connector, has a preferably vehicular use intensity. Thus, this has generated the appearance of new uses such as a supermarket and a fire station, which have modified the size of the original plots and have transformed the scale of the neighborhood. Despite being the node with the highest recorded load, there are no activities associated with social interaction and collective life in the space. These constraints do not promote the generation of vibrant nodes with a greater diversity of activities. On the contrary, what is observed in the Prochelle and Teja neighborhoods is interesting in terms of the grouping of activities. In the node of Prochelle neighborhood, it is observed a high pedestrian overlay within the neighborhood. This is mainly given by the average size of their blocks, 98 meters, which are very convenient to promote pedestrian activity. These neighborhoods are those that show a higher degree of adaptability in the morphology of their nodes in order to generate diversity of uses, which in turn promotes greater sustainability of the urban form (figure 4). The presence of front yards, transformed into terraces with commercial use and
services, generate a greater diversity of activities, being the place of greatest pedestrian attraction of Isla Teja. The places of high sustainable potential occur in general around nodes of activity that promote greater diversity of activities and greater adaptability in the building morphology to adapt new uses. In this places, local activities are promoted in the structure of the neighborhoods, such as, grocery stores, bakeries, greengrocers, small restaurants, local commerce, and green areas.

These nodes are generated mainly in open places with greater visibility, such as green areas or squares (figure 4). This condition allows to increase the opportunities for social interaction between people, since there is a bigger temporality of the meetings, and in turn, increases access to opportunities and resources within the units. That condition is strongly observed in Teja, Prochelle and Santa Ines neighborhoods. Besides that, the places that tend towards an "unsustainability" or low sustainability according to the analyzed dimensions are places with low diversity of socio-economic groups, and low diversity of typology and size of housing. Furthermore, they are places which tend to be mono-functional areas with low pedestrian accessibility, high horizontal density, and sizes of blocks much larger, as is the case of Teja Sur and Los Raulies neighborhoods.

Figure 4. Morphological adaptability of the urban fabric in potential node in Prochelle neighborhood (left); Teja Neighborhood square, potential node that provide high levels of pedestrian vitality (right).

7. Conclusions
In general, it is concluded that there is no single neighborhood that is more sustainable than the other in all its categories or dimensions analyzed. Rather, there are specific places within the analyzed units that show values that indicate a greater potential for sustainability given by particular situations of urban development. The places with the highest sustainable potential are mainly related to two factors: one, to units that present a higher mix of building use in their neighborhoods and a greater diversity of activities in their nodes, oriented towards open spaces and not towards streets with a high load and intensity of use. Second, the vertical mixed use and the high variation of densities in blocks continue to be the best response to promote social life and high collective activity in the space.

The five dimensions measured and evaluated are shown to promote greater sustainability in this type of context. Sustainability implies the ability to endure. In this sense, the scope of urban design is particularly broad because it includes not only the capacity of the natural environment to endure, but also the built environment: the place, its community and economy. This parallel focus, having to simultaneously consider maintenance of nature and the economy, is a source of tension when it comes to interpreting what sustainability means in practice. It has also been noted that the neighborhoods in transformation in medium-scale cities of southern Chile still have the human scale, which justifies taking measures to avoid repeating the errors of big cities. Continuing in this line, one challenge in urban morphology is to strengthen the physical-social dimension, which can serve as a strategy for sustainable planning in the 21st century. This dimension complements scalar hierarchy related to the forms of spatial organization of the city (home, block, neighborhood, district) with the forms of social-civil organization (from families to urban communities). Furthermore, this association between spatial and social organization positions the neighborhood as the basic "sustainable unit" of the city.
This research recommends that the initiatives associated with urban design in this context should be oriented, on one hand, to improve the morphological conditions of neighborhoods, understanding their potential and weaknesses in terms of vitality; and on the other, that they promote human development and the generation of necessary conditions for sustainable social and economic development. The sustainable city of the 21st century should not be conceived as a neutral machine with zero carbon emissions, but rather, as the maximum expression of complex social, economic and cultural fabrics, in which the constant interaction of these is what determines, to a large extent, the success or failure of a sustainable urban experience.

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