(Para)metric Evaluation of Walkability, Diversity and Density in Low-income Neighborhoods

Using the CityMetrics toolbox

Fernando Lima[1], Luiza Vallone[2], Carlos Frederico Costa[3], Ashiley Rosa[4]
[1,2,3,4]Universidade Federal de Juiz de Fora
[1,4]{fernando.lima|ashiley.rosa}@arquitetura.ufjf.br [2]luiza.vallone@arquitetura.ufjf.br [3]fredcosta.arquitetura@gmail.com

This paper describes an implementation of the CityMetrics toolbox, in order to provide a dynamic assessment of metrics related to walkability, diversity and density in remote and low-income urban areas. The applied methodology was used in two remote neighborhoods of Juiz de Fora, which is a Brazilian city, in a case study. The objective was to identify and to evaluate a set of weaknesses in the addressed areas and to propose some improvements in the neighborhoods´ arrangements. The ultimate goal is to contribute to a better understanding of urban problems according to walkability, diversity and density, as well as to contribute to the discussion on the design and implementation of low-income real estate developments, facilitating the management of solutions in urban planning processes in this context.

Keywords: *Urban analysis, Low-income urban areas, CityMetrics, Walkability, Diversity, Density*

INTRODUCTION

The adopted paradigm of sprawling cities is responsible for huge inconveniences in contemporary urban centers (e. g. automobile dependence, fragmented spatial patterns, less social interactions). Planning cities for a more efficient and integrated spatial organization, in turn, is the most effective method to reduce the impact of urban transport and promote a more interactive social life. In this sense, developing planning approaches that consider walkability, diversity and density features for urban areas have become increasingly important, even more important in low-income urban areas. However, it is common to find low-income neighborhoods in remote urban areas, generally distant from basic urban services, which results in the aggravation of a series of social problems. On the other hand, computational design and algorithmic-parametric procedures are shifting design methods, as they enable to address complex situations in design environments, allowing one to explore multiple solutions. Parametrically generated variants of a generative system can provide ways of managing huge amounts of data and process possible interactions between them. Optimization tools can allow decisions to be made efficiently, and this may enable identifying improved configurations for the role that buildings, streets and neighborhoods play in an urban mobility network.

In this context, this paper presents a research, developed within the DOMVS Laboratory of investigation in Architecture, from the Federal University of Juiz de Fora. Thus, this paper advocates the application of the CityMetrics toolbox for analysis and optimization tasks that seeks to identify the addressed neighborhoods´ weaknesses, in order to improve: (i) the location/distribution of amenities, intending to minimize commuting distances and provide greater walkability and social interaction, and; (ii) the balance of living and working places in the urban environment that surrounds the studied low-income real estate developments, aiming at a greater diversity. Besides, we also advocate a computational implementation of Spacematrix density indicators, proposed by Pont and Haupt (2010) for supporting the goals definitions and the decision-making process.

Therefore, this article is structured in the following sequence: i) a short review about walkability, diversity and density, and their importance to help promoting more integrated and sustainable urban areas; ii) a description and a presentation of the CityMetrics toolbox; iii) some reflections about low-income neighborhoods in Brazil; iv) an implementation of the CityMetrics toolbox in a case study that deals with two different neighborhoods in this context; v) a presentation and a discussion about the obtained results, and; vi) an overall discussion and conclusions.

WALKABILITY, DIVERSITY, DENSITY AND COMPUTATIONAL TOOLS FOR URBAN ANALYSIS: A SHORT REVIEW

In summary, this work addresses three basic principles that should be considered in proposing more sustainable, integrated and socially balanced cities: i) walkability - the ability that a particular neighborhood has to connect housing and amenities points through distances that can be traveled on foot; ii) diversity - providing a mix of uses, densities and housing types in the same district; iii) density - encouraging in-fill and redevelopment within existing neighborhoods, allowing the system to run efficiently (Cervero and Kockelman 1997; Calthorpe and Fulton 2001; Dittmar and Ohland 2004; Suzuki et al. 2013).

Walkability

Gehl (2013) argues that the city tends to become more lively as more people are invited to walk, cycle or stay in public spaces, interacting and exchanging information and social and cultural opportunities. Walking in a neighborhood that has basic urban needs that are directly connected at a short distance, is undoubtedly a much more pleasant activity than walking through regions where these are dispersed. Thus, walkability tends to bring more people to the conviviality in the urban space. According to Farr (2013), in summary, walkability consists of the ability of a given neighborhood to connect dwellings, points of commerce and other services by distances that can be walked on foot, thus conferring greater autonomy, less dependence on the automobile and a road network that allows urban life and transportation options.

Diversity

Calthorpe (1993) understands that a diversified use of the neighborhood scale is a key factor for the sustainability of cities, reinforcing the importance of multifunctional neighborhoods. Rogers (1997) advocates mixed use and diversity for a better use of spaces, in a logic where everything happens simultaneously: living, working, consuming and recreating in the same area, which aims to meet the principle of positioning services and trades without the need for large movements. In this sense, neighborhoods with various types of amenities, encourage people to commute, allowing contact and integration of people from different cultures and classes, improving the quality of interaction and social life.

Density

The compactness in urban areas is an idea defended by several authors (Dantzig and Saaty 1973; Rogers 1997; Glaeser 2011; Leite 2012; Chakrabarti 2013; Farr 2013; Gehl 2013; Suzuki et al. 2013). Rogers (1997) argues that compact cities are sustainable because they provide optimum energy performance, reduces pollution and resource consumption, and offers the advantages of living close to the workplace and the other, in a quest for rediscovery of closeness. According to [1], the concept of a compact city is based on three pillars: resource optimization, innovation and sustainability. The optimization of resources occurs as greater urban densities enhance urban infrastructure, streets and transportation systems, cable networks or public fibers and equipment.

Computational tools for urban analysis

Although they are not yet as frequently implemented as in the specific field of architecture, computational applications for urban context have been increasingly developed in the last years (Lima 2017). The constituent components of a neighborhood or a city also share similarities that can be parametrically defined, and there are several tools and models within this context. The works of Duarte et al (2012), Beirão (2012), Montenegro (2015) and Nourian et al (2015), besides confirming the great potential of computational applications in urban situations, address issues related to urban configurations, urban morphology, urban ontology, walkability, among others. There are also other tools in this scenario, like Urban Network Analysis (Sevtsuk and Mekonnen 2012) and urbano (Dogan et al. 2018). However, the approach adopted in this research uses the CityMetrics toolbox, a set of tools elaborated in a parametric-algorithmic environment, that also aims to provide analysis in a more dynamic (grasshopper plugin) computational environment, addressing walkability, diversity and density metrics.

CITYMETRICS TOOLBOX

The CityMetrics Toolbox, developed by Lima (2017) is a set of grasshopper® tools intended to assist on urban analysis and on urban planning tasks. In this context, it consists of specifically designed tools to assess the performance of urban areas from the perspective of walkability, diversity and density metrics and consequently, to help in proposing more socially vibrant and sustainable neighborhoods and cities. It is important to highlight that it is not meant to act as an independent-automatic solver. So, the role of the many players involved in urban planning tasks remains central, and it is still these players that will establish objectives, feed the system and consider "non-programmable" and subjective aspects. In this sense, the CityMetrics toolbox consists of the following tools: (i) Physical Proximity Calculator (PPC) - a tool that measures the distance between a target (an amenity) and one (or all) locations(s) in a neighborhood (origins). In this regard, the proposed algorithm calculates the path(s) with smaller physical distance(s) between a target and one (or all) destination(s) in a district, considering slope(s) in the path(s); (ii) Topological Proximity Calculator (TPC) - a tool that calculates proximity considering topological metrics, using concepts from Space Syntax theory (Hillier and Hanson 1984); (iii) Amenities Variety Calculator (AVC) - a tool that calculates the average distances between a given source and all the nearby targets in a given category of urban services; (iv) Amenities Recurrence Calculator (ARC) - calculates the proportion of the number of targets reported (in each category of services) and the total number of locations in a surveyed area; (v) Mixed-use index calculator (MXIC) - calculates the proportion between the sum of all the residential and non-residential areas of a locality, making a comparison of these proportions (Hoek 2008), and; (vi) Spacematrix calculator (SPC) - calculates density attributes from studied areas, informing three fundamental indicators proposed by Pont and Haupt (2010) Intensity - Floor Space Index (FSI); Coverage - Ground Space Index (GSI) and Network Density (N). (Lima 2017; Lima et al. 2019).

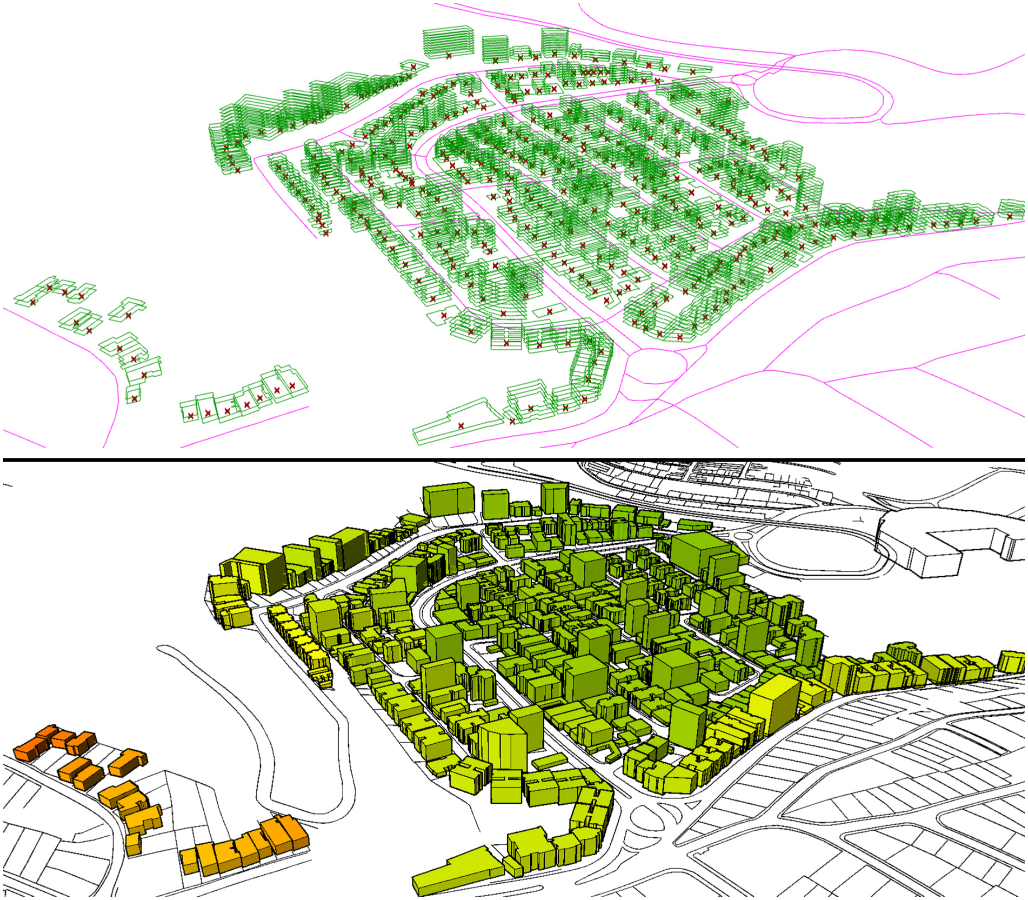


Figure 1
A model used in a CityMetrics approach: points, curves, solids and other geometric entities used for urban analysis related to walkability, diversity and density features. Source: Adapted from Lima (2017)

LOW-INCOME NEIGHBORHOODS IN BRAZIL AND THE "MINHA CASA MINHA VIDA" PROGRAM

The "Minha Casa Minha Vida" program (MCMV) is a policy of the Federal Government of Brazil that has the main purpose of supplying the country's housing deficit, through initiatives that drive the construction industry [3]. MCMV was intended to work in partnership with states, municipalities, companies and public and private institutions, through a growth acceleration program entitled "Programa de aceleração do Crescimento" (PAC). [3].

The first phase of the MCMV comprised the years 2009 and 2010, and the second phase comprised the years between 2011 and 2014. More recently, the third phase, announced in 2016, expected the works completion in 2018. Currently, the MCMV serves families with 4 income brackets (in Brazilian currency - reais): i) band 1, up to 1.800; ii) band 1.5, up to 2.600; iii) band 2, up to 4.000 and; iv) band 3, up to 7.000

[4]. Families that comprise band 1 receive the highest subsidy from the government, and can reach up to 95% of the value of the property. These are the Houses of Social Interest (HSI).

MCMV was very criticized while its implementation, mainly, with regard to: i) the articulation of the projects with the urban space; ii) the reproduction of typologies on a large scale, and; iii) the impact on urban infrastructure, especially those housing the low-income population. (MURAT 2015).

MCMV in the city of Juiz de Fora

The city of Juiz de Fora, the spatial object of our study, is a medium-sized municipality, located in the southeastern Brazilian state of Minas Gerais, in the Zona da Mata Mineira region. The total area of the municipality is 1.429.875 km² and has an estimated population of 564.310 inhabitants[2].

According to Zambrano (2018), Juiz de Fora presents a significant production of MCMV program projects in relation to the Brazilian housing deficit; however, it raises criticisms and questions about its results and impacts for the city. In phases 1 and 2 of the MCMV (2009 to 2014), a total of 16 projects were produced in Juiz de Fora, for program 1, totaling 3.615 housing units. The local criteria for priority at the lottery were: i) families at social risk (no income, social rent); ii) families living in the city for more than two years, and; iii) families with two or more children in scholar age - up to 16 years.

Zambrano (2018) also states that the prevalence of urban infrastructure and services precariousness reports show that the municipality should pay more attention to these aspects when approving the implementation of new MCMV projects. If the places where the projects are implemented were already precarious before the implementation of the MCMV, they end up having this precariousness amplified, with an increase of the demand for services and with the inclusion of a high number of families in these places (ZAMBRANO 2018). In this context, it is possible to state that, in general, the MCMV projects in Juiz de Fora (and also in Brazil) are implemented in areas with low walkability, low diversity and low density. Thus, these low-income neighborhoods have few urban services in their proximity, are located in predominantly residential areas and with low concentration of people and meeting opportunities.

CASE STUDY

This case study is based on the use of the CityMetrics toolbox in two low-income neighborhoods from Juiz de Fora, in order to: a) measure and compare their walkability related indexes (Physical Proximity and Topological Proximity), considering their nearest urban services (health, educational, supplying, food, commerce, entertainment, recreation and others); b) measure and compare their Mixed-use Index; c) measure and compare their Spacematrix indicators; d) propose changes to improve their indexes.

Within this framework, it was created a parametric model using Rhinoceros/Grasshopper, in order to manage geometric and measurable features of the selected neighborhoods. The geometric entities were associated with urban elements, in the construction of the parametric model. Points represented the location of buildings and referred to different urban functions (e. g. educational, commerce, food, recreational). Curves simulated the existing network of streets, and solids were used to play the role of buildings. Thereafter, optimization tools indicated modifications in the organization of the neighborhoods, indicating where new amenities should be located, in order to optimize the neighborhoods walkability and diversity. The analysis also made possible to evaluate the diversity ans density scenarios in both projects.

The identification of amenities within the study area was made through a simple mapping, using data provided within the Google Maps tool, and considering a 1,5 km radius. Thus, the amenities were classified into 8 categories, which were: i) Health - composed of hospitals, emergency care units and basic Health Units; ii) Educational - composed of primary and secondary education institutions; iii) Supplying - including supermarkets, bakeries and gro-

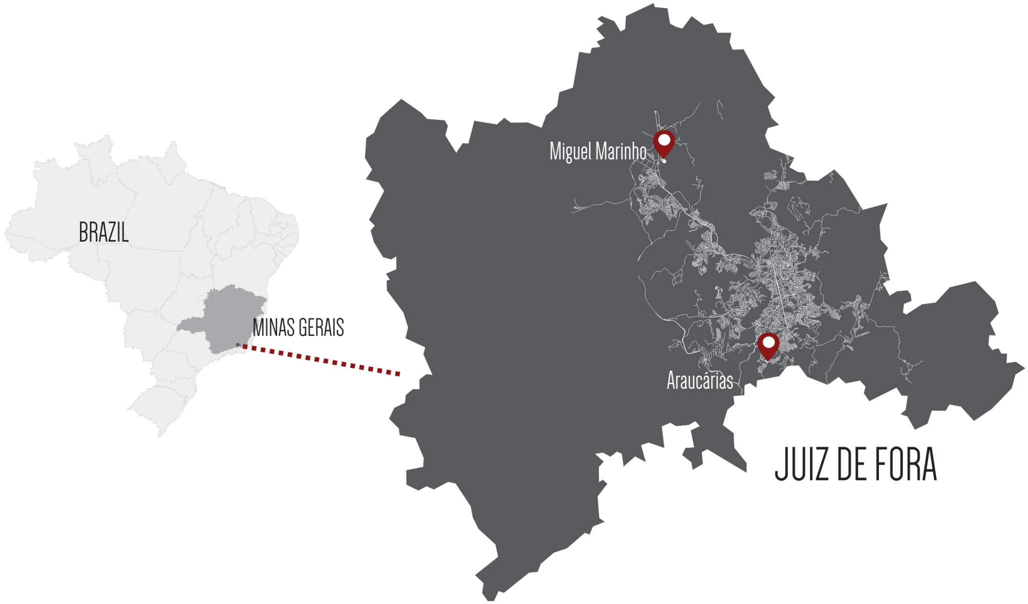


Figure 2
The location of the two addressed MCMV projects (Residential Miguel Marinho e Araucárias Residential) in the city of Juiz de Fora, Minas Gerais state, Brazil. Source: The authors.

cery stores; iv) Food, consisting of snack bars, bars and restaurants; v) Commerce - consisting of pharmacies and stores that sell products of basic need; vi) Entertainment - composed of Theaters, Cinemas, Houses of Culture; vii) Recreation - including recreational spaces such as courts, soccer fields, squares and clubs; viii) Others - containing all other services that do not fall into the previous categories, such as banks and institutional services, for example. Diversity and density analysis were made considering all the buildings in their immediate surroundings, considering a radius of 1 km.

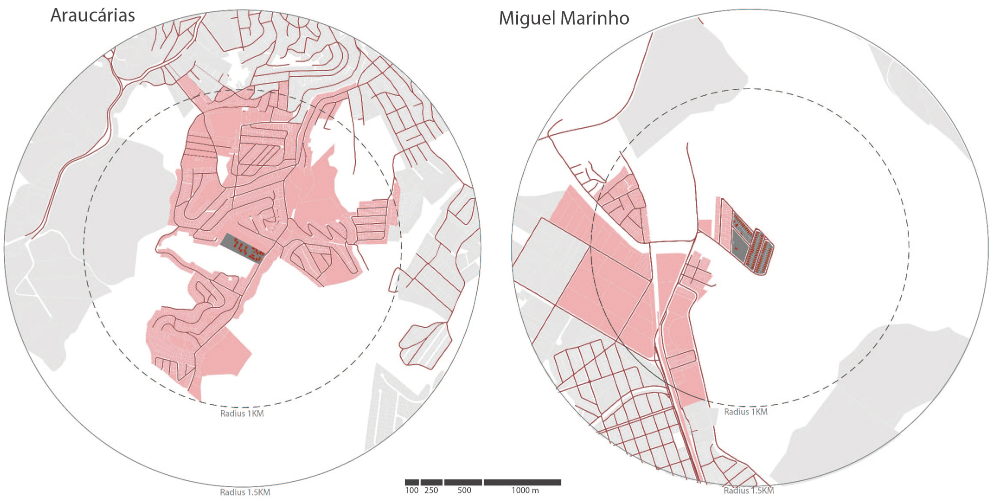
The addressed areas

The addressed neighborhoods in this case study were selected based on their differences in: i) the building typology; ii) the scale of the project, and; iii) the location in the urban network. The Residencial Miguel Marinho is located in the North Region of the municipality, near the edge of the urban area and is composed of 86 houses (two-story) of four units per lot, totaling 344 housing units. The Araucarias residential is located in the South Region of Juiz de Fora. Residencial Araucárias is configured by 380 housing units distributed in 19 five-storey buildings with four apartments per floor. Although they have different typologies and are located in different regions of the city, both projects have similar difficulties regarding walkability, diversity and density issues.

RESULTS

The implementation of the CityMetrics toolbox allowed us to make some analysis and to propose some changes to the arrangement of the addressed neighborhoods, suggesting a better performance from the scope of walkability and diversity and allowing to discuss, with objective data, about diversity and density issues. The analysis with CityMetrics confirmed our perception that both projects are located in areas with low walkability (as shown in Tables 1 and 2), low diversity and low density (as shown in Table 3). Both

Figure 3
The location of the two addressed MCMV projects (Residential Miguel Marinho e Araucárias Residential) in gray and their immediate surroundings. Souce: The authors.



residentials do not have a good proximity to basic urban services (PPI near to 1), besides staying in remote regions of the city. Despite of presenting a balanced MXI index, the Miguel Marinho residential is located in a low diversity area. The obtained results, in this case, were influenced by the fact that there are many industries in its surroundings (what does not mean access to urban services - and so, to diversity). Spacematrix indicators (FSI and GSI) highlight that both areas have low footprints and low verticalization, what suggests some modifications in their arrangements (as shown in Figure 3). Optimization tasks allowed us to identify the better places for suggesting the location for new amenities in both neighborhoods (considering the aforementioned categories). Thus, the insertion of one amenity for each category resulted in greater TPI and PPI indexes, suggesting greater walkability and more diversity for the neighborhoods (see Tables 1 and 2). In some cases, we suggested the insertion of services that did not existed in the vicinity of the Miguel Marinho neighborhood. Although this may seem like an increment (worse performance) in the global TPI index, it means more diversity and walkability for the addressed neighborhood. (see table 1).

Table 1
General information about the addressed areas (Araucárias and Miguel Marinho) and Topological Proximity Indexes (TPI) before and after the proposition of new amenities in the neighborhoods. Lower TPI indexes indicate greater proximity. Source: The authors.

General Information (Araucárias / Miguel Marinho)				
Neighborhood area	171 ha		89,22 ha	
Number of plots	3388		561	
Number of buildings	3982		862	
Topological Proximity Index (TPI) to services (partial)				
Category	Araucárias		Miguel Marinho	
	TPI (average)		TPI (average)	
	before	after	before	after
Health	12,04	11,86	-	12,75
Educational	7,95	7,70	10,01	9,93
Supplying	6,79	6,60	10,28	9,91
Food	10,05	10,02	9,84	9,76
Commerce	5,58	5,52	9,39	9,38
Entertainment	13,27	12,94	-	12,76
Recreation	9,20	8,99	9,62	9,60
Others	15,47	6,57	9,27	9,26
TPI (Global)	10,04	8,77	9,74	10,42

Physical Proximity Index (PPI) to services (partial)								
Category	Araucárias				Miguel Marinho			
	PPI (average)		Distance (m)		PPI (average)		Distance (m)	
	before	after	before	after	before	after	before	after
Health	1,00	1,00	210,56	210,56	0,00	0,94	-	426,77
Educational	0,76	1,00	666,59	347,02	0,60	0,96	734,67	406,60
Supplying	1,00	1,00	364,51	364,51	0,24	0,99	1259,41	331,40
Food	0,97	1,00	434,56	186,57	0,53	1,00	934,50	316,38
Commerce	1,00	1,00	336,99	297,49	0,84	0,99	448,04	341,41
Entertainment	0,47	1,00	1023,03	287,02	0,00	0,98	-	336,84
Recreation	0,91	1,00	506,21	355,73	0,98	0,99	284,15	284,15
Others	0,72	1,00	714,75	342,01	0,90	0,98	337,29	337,30
PPI (Global)	0,85	1,00	532,15	298,86	0,51	0,98	666,34	347,61

Table 2
Physical Proximity Indexes (PPI) before and after the proposition of new amenities in the neighborhoods. Higher PPI indexes indicate greater proximity. Source: The authors.

Diversity and Density (Araucárias / Miguel Marinho)					
Mixed-use Index (MXI)		Non Residential		Residential	
		0,02	0,48	0,98	0,52
Spacematrix					
FSI		GSI		N	
0,2829	0,3043	0,1871	0,1747	0,0150	0,0106

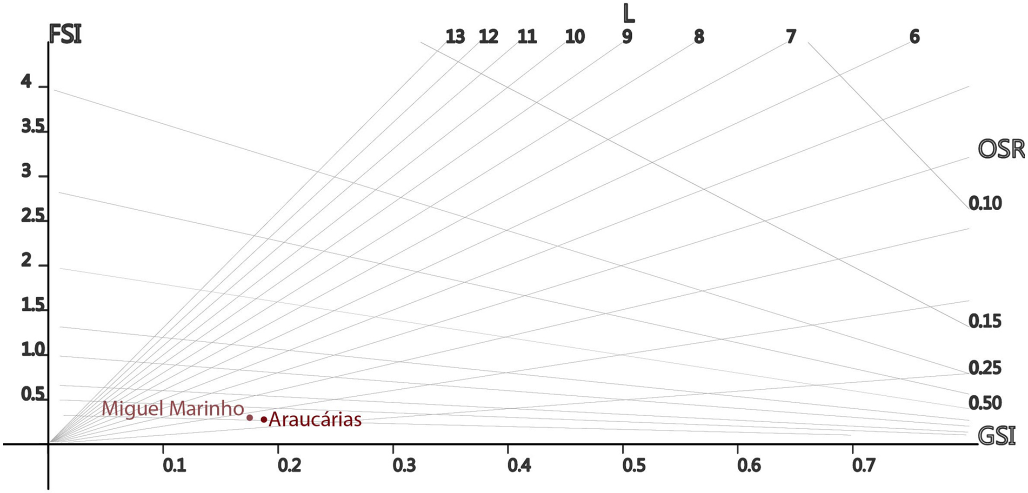
Table 3
Mixed-use indexes and Spacematrix indicators for both projects (Araucárias and Miguel Marinho). Low diversity, very low density and verticalization for both projects. Miguel Marinho has a “false” balanced MXI because it is close to the industrial district of the city. Source: The authors.

DISCUSSION AND CONCLUSIONS

Despite the usefulness of a computational tool for supporting urban analysis, we identify some limitations in the presented approach. First, we recognize that for a more accurate analysis, it would be interesting to adopt a field survey in the case studies, for a confirmation of the data that was considered in the analysis. Secondly, we recognize that Physical Proximity Index and Topological Proximity Index does not fully incorporate the diverse features that can influence the walkability of an urban area. Finally, as shown in our research, density has a fundamental role within the scope of vibrant and sustainable cities. In this context, variables related to populational density and the implementation of modals in a neighborhood should also be tested.

It is also very important to highlight the importance of rethinking the way that MCMV projects are implemented in Brazil. These residentials should be implemented in more consolidated urban areas, with close available urban services and infrastructure. The presented approach, although proved to be helpful in order to improve the neighborhoods´arrangements, helping to make it more walkable, diverse and showing (in a objective mensurable way) the weaknesses of both neighborhoods.

Figure 4
Spacematrix graphical representation of both projects neighborhoods. Areas with low density and low footprints. Spatial and social fragmentation. Source: The authors.



This article seeks to facilitate the management of solutions in urban planning processes, in order to contribute for computational approaches towards more dynamic, sustainable and vibrant urban communities. Therefore, this study demonstrates the CityMetrics' potential towards a more efficient urban planning methodology, that can be used in order to help promoting more social and spacial balanced neighborhoods and cities.

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