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Integrating socio-environmental spatial information to support housing plans

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ABSTRACT

The current challenge of promoting the sustainable provision of social housing for the global population requires an integrated evaluation of the infrastructure and service availability across a territory. Few applications are recognized for supporting social housing plans with spatial information, especially regarding the ability to provide room for new initiatives. The aim of this research is to propose a Social Housing Index (SHI) for integrating and quantifying urban spatial socio-environmental information to support social housing plans. To this end, data about land use and sectoral activities are integrated using a standardizing methodological framework. The SHI supports studies on location alternatives for new housing projects and the availability of infrastructure and services for the implemented housing complexes. The proposed index also harmonizes the development of housing plans by making different demands compatible for supporting urban sustainability.

1. Introduction

Social housing plans address the provision of appropriate living conditions for the low-income population. The development of these initiatives consumes materials, energy and resources, causing significant impacts on the environment. These consequences encompass alterations in climate change, public health and urban drainage (Preval, Randal, Chapman, Moores, & Howden-Chapman, 2016). In addition, the social aspects are influenced by the location of the buildings, sometimes reinforcing existing inequalities among low income families (Duren, 2018; Reyes, 2018). Therefore, there are many consequences of social housing plans to address to reach the sustainable development of these initiatives.

To promote urban sustainability, Cohen (2017) notes the need for goal-based frameworks as well as for testing them through empirical studies. The lack of standardized assessments also represents a hurdle in current urban sustainability planning (Geneletti, La Rosa, Spyra, & Cortinovis, 2017). Therefore, to inform the delivery of housing initiatives that ensure sustainable housing, an integrated evaluation of the infrastructure and services available across a territory is necessary (Choguill, 2007).

An index is made up of the individual indicators used for evaluating information and supporting decision-making (OECD, 2008). Both individual indicators and indexes are widely applied in assessments to tackle the effects on the environment (Huang, Wu, & Yan, 2015), and the most widely used methods for evaluating urban sustainability are based on indicators or index-based frameworks (Cohen, 2017). The indexes are used to (i) formulate risk and vulnerability indexes (Beccari, 2016; Siqueira-Gay, Tomasiello, & Giannotti, 2017); (ii) assess the ecosystem services in an urban environment (Alam, Dupras, & Messier, 2016); (iii) evaluate urban sustainability (Huang et al., 2015); (iv) guide land use planning on a regional scale (Marull, Pino, Mallarach, & Cordobilla, 2007); and (v) identify land for human settlements by using Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) (Musakwa, Tshesane, & Kangethe, 2017), among many other applications. Although some studies have presented indicators for supporting social housing plans (Winston & Eastaway, 2008), only a few applications are recognized for supporting social housing plans with spatial information (Marques & Rodrigues, 2013; Rolnik et al., 2015), especially regarding the decision to provide room for new initiatives (Sorrentino, Meenar, & Flamm, 2008).

The aim of this paper is to propose a Social Housing Index (SHI) for integrating and quantifying urban spatial socio-environmental information to support social housing plans. The SHI index encompasses the selection and analysis of socio-environmental spatial information to assist housing initiatives. It can be used as a management tool to identify most suitable locations for social housing programs as well as to evaluate the outcomes of sites that have already been chosen.

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The index formulation comprises the selection of indicators to fit different contexts (Sánchez-Cantalejo, Ocana-Riola, & Fernández-Ajuria, 2008) for housing initiatives. To verify the feasibility of the proposed SHI index, an empirical study has been developed to explore where and how the SHI may be used to feed decision-making with regards to housing plans. To develop the applied step of this research, we selected a city that faces serious problems with social housing provision (Duren, 2018). The metropolitan region of São Paulo presents a housing deficit of half a million housing units (Fundação João Pinheiro, 2016). The primary city in this metropolitan region, São Paulo, presented a shortage of 133,000 housing units in 2009, according to the housing plan (Prefeitura de São Paulo, 2011a). The choice of the São Paulo municipality to address this empirical study is also based on recommendations from the literature that highlight the importance of the problems faced by Brazilian cities regarding substandard housing units with a lack of access to basic urban services, due in part to its zoning and construction regulations (Moreno-Monroy & Ramos, 2015; Acolin & Green, 2017) and the difficulty the low-income population experiences in trying to access appropriate land and basic infrastructure (Ultramari, de Oliveira da Silva, & Meister, 2018).

This paper is organized as follows. First, the data and procedures for the indicator composition are presented in section two. In section three, the sub-items follow the methodological steps, and the results are presented as follows: (i) the primary findings of the document review grounds the conceptual framework and indicator calculation; (ii) the index composition with data analysis and integration; and (iii) the index application with the evaluation of available land to receive social housing and built projects. Finally, the conclusions are outlined in section four.

2. Material and methods

A framework to formulate an index from the gray literature was used to guide the methodological steps related to the index composition (OECD, 2008). Other studies have used this framework; for example, Inostroza, Palme, and de la Barrera (2016) applied this guide to construct an index with a standardizing and formal methodological framework. Through this tested framework, the present research uses this index construction rationale as a method for identifying which variables would be relevant for our purpose. The application of predefined procedures guarantees the replicability and robustness of the analysis. Some technical alternatives, such as missing values imputation and multivariate analysis, were chosen based on the literature review presented by Beccari (2016).

Fig. 1 depicts a synthesis of the methodology. The first three steps formulate the SHI using data and documents from a municipality, but they can be followed in different contexts involving local plans and the available spatial information. The application of the index encompasses the following two levels of analysis: (i) supporting the strategic level by evaluating the demarked areas and (ii) projects that were already built.

The São Paulo municipality is in the southeastern region of Brazil and is home to approximately 12 million inhabitants (Fig. 2); it is the study area of this research.

2.1. Conceptual framework

The housing deficit and the socioeconomic situation of the population influence the affordability and the institutional schemes for housing provision (Gan, Zuo, et al., 2017). In this sense, the indicators should be chosen according to the context of the analysis, especially to consider the social and environmental concerns of the urban environment appropriately (Geneletti et al., 2017; Sánchez-Cantalejo et al., 2008). This work investigates housing planning policy documents to identify the context of the analysis and consider its fit for purpose indicators.

According to Preval et al. (2016), some key policy documents, such as those related to land use, transport and infrastructure planning, are relevant for discussing housing needs. In accordance with Brazilian federal laws, the primary urban sectoral policies are associated with housing, sewage, and transportation. The related policy plans at the municipality level should be articulated with the master plan, which aims at establishing strategic guidelines to guide land use and urban development. Documents on housing, sewage, and transportation plans as well as the master plan were reviewed (for detailed information about these plans, see Table 1 in Supplementary Material) to identify the explained issues related to São Paulo housing planning.

These documents are available for the consolidated sectoral and land use plans in the urban planning context of São Paulo. The document review was guided by the “keyword in context” content analysis using “housing” to identify explicit information on the objectives, guidelines and plan proposals regarding housing provision (Hsieh & Shannon, 2005). Using this strategy, it was possible to identify the explicit relations established in the housing-related plan documents. This analysis builds a conceptual framework with the relevant themes concerning environmental and social quality in relation to housing planning. For each theme, a search was conducted on the website of the São Paulo municipality, and the indicators were calculated.

2.2. Indicator calculation

The data analysis and the index construction integrate information about infrastructure and service provision for the municipal territory. The empirical study case for São Paulo considered census tracts as a unit of analysis, and the indicators were calculated based on 18,953 census units (IBGE, 2011) (Fig. 2). Table 1 depicts the description and details of the indicators used here (for a detailed description of each indicator, see Table 2 and Fig. 1 in the Supplementary material). The choice was made based on the selected themes and data availability. The census data source was the IBGE website. The digital platform on georeferenced data from the municipality of Sao Paulo, which is called *Geosampa* (hyperlink: http://geosampa.prefeitura.sp.gov.br/), was consulted for public and available spatial data. The layers were set by the São Paulo municipality in cooperation with the state secretariats.

The indicators about the water supply, sewage system and garbage collection services were calculated based on the percentage of residences served within a census tract. The variables of sewage and garbage from Census do not indicate the quality, only the presence of service. For the green area coverage, the percentage of green area in each census tract was considered. The accessibility measure was based on the concept of cumulative opportunities (Páez, Scott, & Morency, 2012) and represents the number of opportunities that can be reached within a given travel time. Fig. 3 shows the procedures for calculating the accessibility indicators. An origin destination survey was used to calculate the travel time threshold value for each travel purpose according to the (Department for Transport Business Plan, 2012). This survey indicates the median values of the distribution as the lower threshold and a more conservative one for each type of service. Based on the threshold for each travel purpose, the transit network with the inference of the travel time was used to calculate the service area (Siqueira-Gay et al., 2017; Tomasiello, Giannotti, Arbex, & Davis, 2018).

Although the accessibility measures are considered a good inequality measure (Dadashpoor, Rostami, & Alizadeh, 2016), the indicators applied during this study do not consider the competitiveness, quality, and availability of the urban facilities in their formulation, and the jobs data do not include the informal market.

2.3. Data analysis and integration

The primary steps after the indicators selection are data preprocessing with missing data imputation, multivariate statistics, weighting and aggregation (OECD, 2008). A sensitivity analysis was

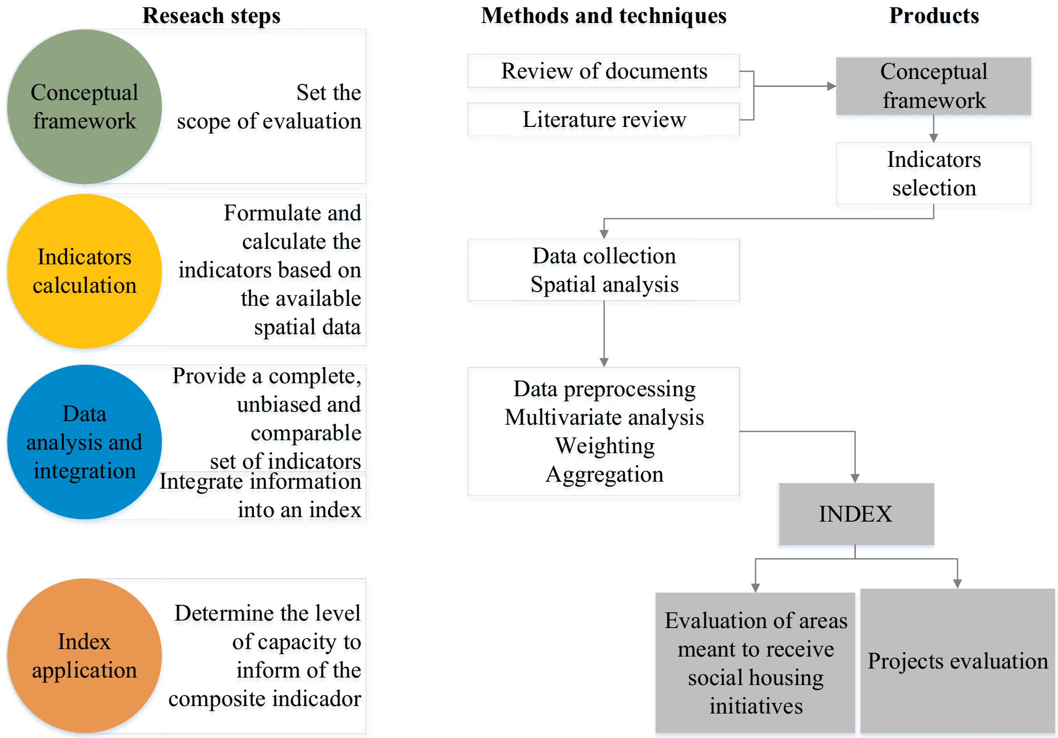

Fig. 1. General methodological framework.

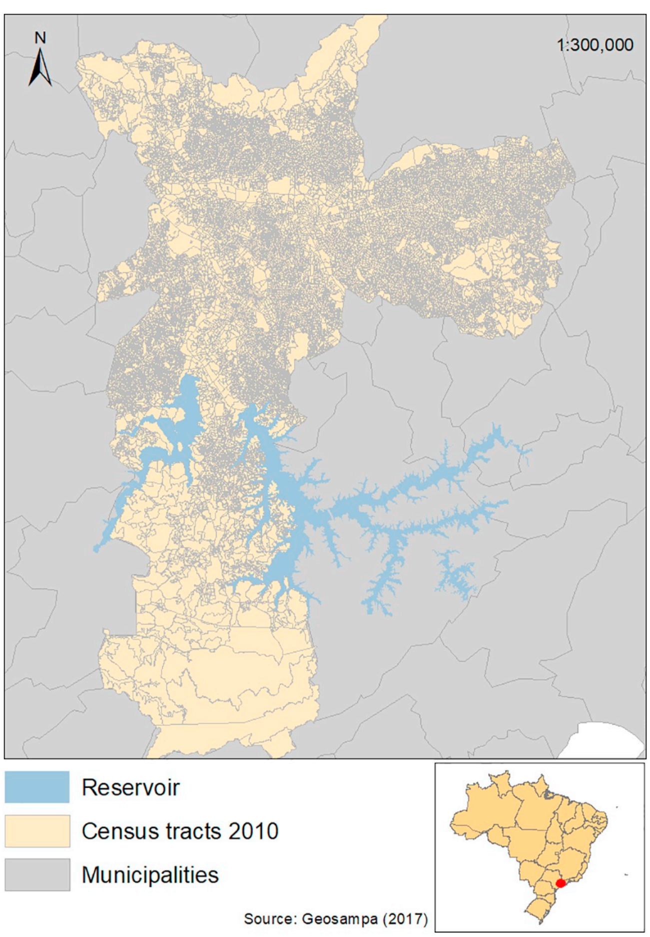

Fig. 2. São Paulo municipality and the census tracts from 2010.

applied to test different alternatives to the missing values imputation, such as instances removal and median value substitution. The census dataset presented 3% of the empty instances, and the other indicators do not present missing values. The replacement of missing census data by using the mean was chosen because it kept the descriptive statistical values of the other four indicators and does not considerably influence the dataset composition.

After preprocessing, a multivariate analysis was performed with the correlation matrix and Principal Component Analysis (PCA). PCA is mostly used to reduce the dataset noise, transforming the dataset into a new set of uncorrelated variables. Some initiatives relating to the index composition and urban analysis applied this technique (Beccari, 2016; Ibes, 2015; Inostroza et al., 2016). This approach provides the eigenvalues of the dataset, which are useful for weighting the components when constructing the index (Beccari, 2016; Gan, Fernandez, Guo, Wilson, & Zhao, 2017). It is thus possible to construct a statistically unbiased indicator for the dataset with high correlated variables (Greco, Ishizaka, Tasiou, & Torrisi, 2018). Although the PCA has been broadly applied due to its ease of implementation, in most of the cases, it results in new components that do not represent the variables of the original dataset (Gan, Fernandez, et al., 2017). To illustrate the transformed dataset better, the maps and a description of the principal components used here are presented in section three. Normalization using the min-max method was only applied at the end of the index composition to visualize the results better. The spatial information was processed in ArcGis 10.5. and descriptive statistics and a multivariate analysis were performed in Weka (Frank, Hall, & Witten, 2016).

2.4. Index application

The evaluation of different infrastructure and service levels can inform the following: (i) ex ante analysis during the strategic phase of the decision making, for example, about locational alternatives (Geneletti, 2010) and (ii) ex post analysis during the monitoring phase, for evaluating the projects already built to inform the performance of

Table 1
Selected indicators.

Indicators	Parameters
Accessibility to public schools	Number of public schools that can be accessed in 45 min by public transportation
Accessibility to jobs	Number of jobs that can be accessed in 60 min by public transportation
Accessibility to leisure	Number of cultural facilities that can be accessed in 50 min by public transportation
Garbage collection system	Percentage of residences with a garbage collection service
Water supply	Percentage of residences with a water supply system
Sewage system	Percentage of residences with a sewage system
Green areas	Percentage of green areas in the census tracts

Table 2
ZEIS categories[1].

ZEIS category	Description
1	Areas with favelas and irregular settlements; land occupied by a low-income population.
2	Underused areas with little or no infrastructure, compatible for urbanization.
3	Area with underused buildings with services, facilities and infrastructure
4	Areas with unbuilt lots or no infrastructure, compatible with urbanization, located in areas close to the reservoir and environmental protection
5	Areas with unbuilt lots or underused areas, provided with services and facilities

[1] For more information see Ribeiro, Daniel, and Abiko (2016).

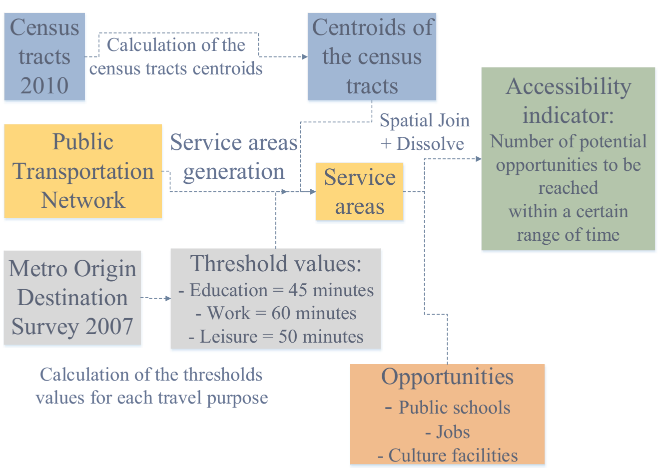

Fig. 3. Steps for accessibility indicator composition.

initiatives that were already developed (Marques & Rodrigues, 2013; Rolnik et al., 2015).

Using spatial information about infrastructure and service provision, the SHI evaluates the areas marked for receiving social housing initiatives during the ex ante analysis. The master plan for the São Paulo municipality to support the development of social housing initiatives creates Special Zones of Social Interest (Zonas Especiais de Interesse Social – ZEIS, in Portuguese) (Ribeiro et al., 2016). Those areas encompass vacant and occupied land with different uses. Fig. 4 depicts the map of São Paulo with the areas (which are also available in Geosampa), and Table 2 shows the description of the predominant land use. Based on the existing marked land, the index is applied to rank the areas set to receive social housing initiatives. With this, it is possible to identify the level of infrastructure in each region that is dedicated to providing new houses for the low-income population. Although the existing demarcated zoning areas can represent an advantage in this context, a more detailed evaluation of the existing infrastructure is required (Ribeiro et al., 2016).

During the ex post phase, the SHI provides information about the performance of the housing policies that were already developed, to evaluate the projects of a Brazilian housing plan. A recent relevant housing initiative is evaluated to inform the performance of the existing housing strategy in Brazil. *My House My Life* (Minha Casa Minha Vida - MCMV) was created in 2009 and reformulated in 2012. MCMV was the

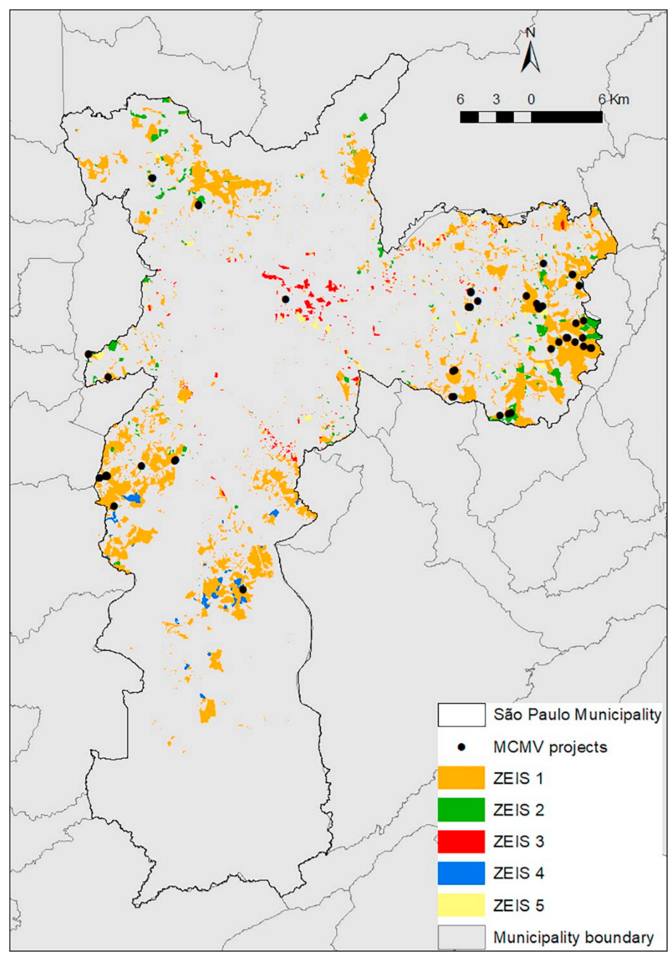

Fig. 4. ZEIS and MCMV projects.

first social housing program to provide funding that included subsidies for the lowest income level segment (Bonduki, 2014; Valença & Bonates, 2010). With many controversial details in the program structure, it produces massive housing construction, considerably impacting the land demand in Brazilian cities (Klink & Denaldi, 2014).

This program is divided into the following three primary segments:

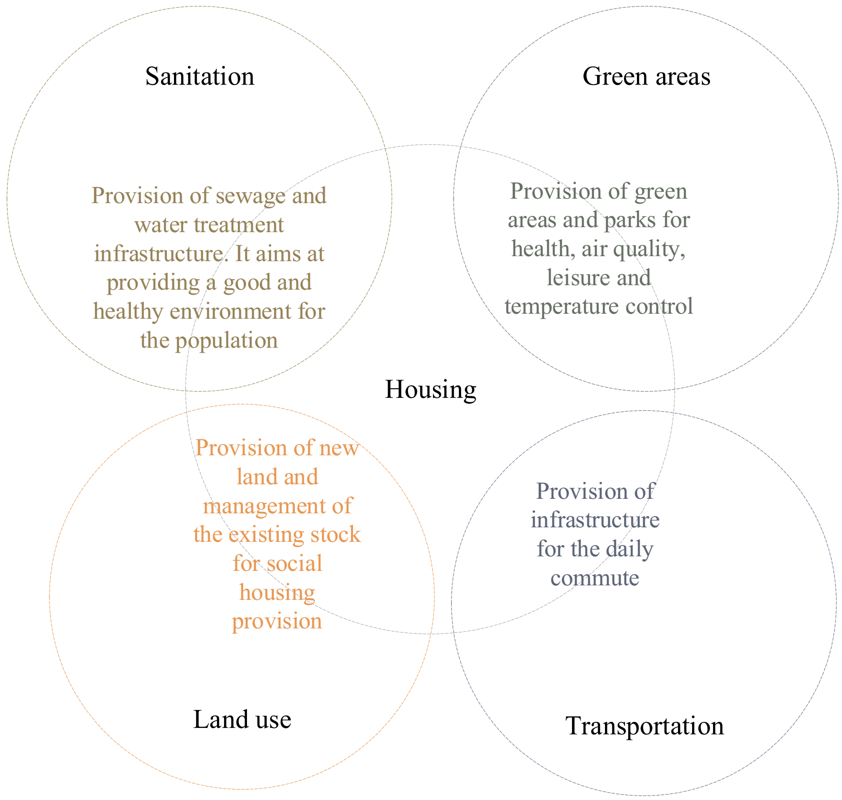

Fig. 5. Conceptual framework of social housing planning relations to other plans.

Table 3
Correlation matrix of the seven indicators.

Correlation matrix							
	Water	**Sewage**	**Garbage**	**Accessibility to culture**	**Accessibility to public schools**	**Accessibility to jobs**	**Green areas**
Water	1	0.15	0.38	0.09	0.19	0.11	−0.33
Sewage		1	0.15	0.03	0.03	0.04	−0.06
Garbage			1	0.05	0.08	0.06	−0.18
Accessibility to culture				1	0.27	0.96	−0.15
Accessibility to public schools					1	0.3	−0.27
Accessibility to jobs						1	−0.18
Green areas							1

(i) the first income level consists of families that earn up to three minimum wage[1]; (ii) the second income level consists of families that earn from three to six times the minimum wage; and (iii) the third level consists of families that earn from six to ten times the minimum wage (Campos & Guilhoto, 2017). Here, we aim to evaluate the first segment, which presents the greatest housing deficit (Campos & Guilhoto, 2017) and represents an innovation in the housing trajectory in Brazil (Bonduki, 2014). The projects built from 2009 to 2014 are shown in Fig. 4. Given the historical development of social housing in Brazil (Valença & Bonates, 2010), some studies show the need to evaluate the proper provision of social housing for the low income population (Marques & Rodrigues, 2013; Rolnik et al., 2015).

[1] 1 US$ = R$ 1.57 (time of reference 2009). The minimum wage was R $510,00, then equivalent to US$ 800.

3. Integrated assessment: Social Housing Index construction

This section presents the results of the index composition. First, the urban sectoral relations to housing plans in the municipality are presented. Then, the index map with the evaluation of the infrastructure and services are presented. Finally, the index application with the outcomes for housing plans is described.

3.1. Conceptual framework

One of the primary guidelines of the National Mobility Policy is the integration of the urban development policy with other urban sectoral initiatives. The São Paulo mobility plan (Prefeitura de São Paulo, Secretaria de Transportes, CET, and SpTrans, 2015) expresses the role played by transportation in providing a more compact and economic city, in which jobs, leisure, and educational opportunities are close to

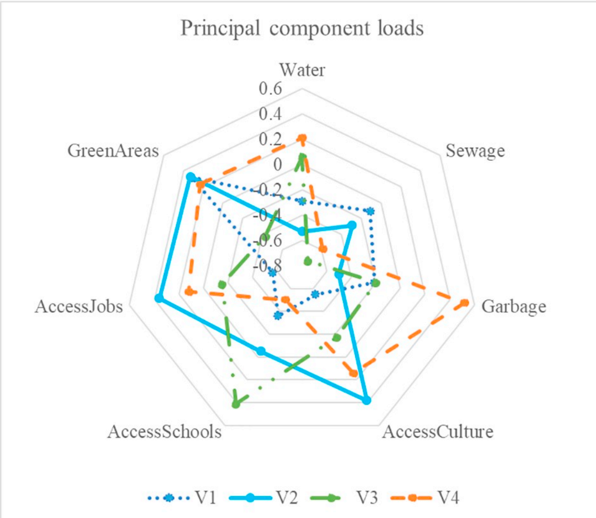

Fig. 6. The loads of each original indicator in the principal components.

the housing areas, especially for the low-income population. Therefore, the existing Brazilian transportation planning structure foresees the integration of policies, plans and programs regarding the quality of life and the daily commute of the city's inhabitants. However, the São Paulo Housing Plan does not present considerations about the provision of transport, which remains in the realm of land use planning.

The São Paulo Sanitation Plan (Prefeitura de São Paulo, 2011b) also highlights the integration of government policies, programs, and actions for sanitation, health, water resources, housing, land use and urban development. This plan explains the interaction, especially with housing initiatives, with the (i) intervention in irregular settlements; (ii) the favela urbanization program; and (iii) the Headwater Protection program. This protection program is aimed at providing the proper infrastructure for sewage and water treatment in areas of irregular occupation along the border of the city reservoir. The housing plan also mentions these programs, showing the integration of the documents.

The São Paulo Master Plan encompasses guidelines and strategies for land management to provide an equitable distribution of goods and infrastructure such as urban facilities, parks, transport, and, especially, social housing. It aims at distributing 30% of the financial resources obtained from taxation to new social housing developments. It also marked ZEIS areas and other zones for environmental protection and urban developments. The document also foresees integration with the Atlantic rainforest municipal plan. This initiative aims at identifying priority actions and areas for the conservation and recovery of native vegetation and the biodiversity of the Atlantic forest, based on a mapping of the remnants of the Atlantic rainforest. The plan was still under development at the moment this publication was written. Fig. 5 summarizes the conceptual framework of urban integration created during the document review. It relates the primary themes identified in the plans that support the choice of indicators.

In general, for new housing development, information on the existing land use, infrastructure and services is necessary for providing social housing in good areas with good environmental quality (Choguill, 2007). Especially in São Paulo, the low income population suffers the most from the housing deficit (Campos & Guilhoto, 2017); therefore, it is the primary target group of social housing initiatives.

Transportation planning shows the need to overcome social exclusion and inequalities (Lucas, 2012). In this sense, to evaluate its distribution, the opportunities and the transportation infrastructure should be considered to better address the integration between land use and transportation plans.

The services involved in sewage collection and treatment, water distribution and garbage collection also influence the quality of life of citizens as part of the available services and infrastructure provision. Environmental licensing requires the provision of sewage collection and treatment in addition to water distribution, and it is a considerable tool for providing the proper environmental conditions for the houses.

The master plan highlights the importance of public parks and green areas. The existence of these parks is also intrinsically related to the well-being of urban citizens. In this sense, the natural areas promote ecosystem services as recreation and the regulation of the air and local climate (Chiesura, 2004). They promote social and psychological benefits for citizens, playing an important role in urban sustainability.

This set of relevant issues forms a basis for the indicator calculation and index composition; and finally, the information on land use, on available land for new housing developments and on social housing buildings that were already constructed is used to test the index application.

3.2. Indicators, data analysis and integration

The indicators presented in Table 1 were calculated using spatial information aggregated into census polygons. A multivariate analysis was then performed to identify the correlated variables of the dataset. The correlation matrix primarily reveals the high dependence, i.e., the higher values of correlation coefficients shown in Table 3. Accessibility to jobs and accessibility to cultural facilities, such as museums and libraries, present a higher correlation coefficient (Table 3) because both present the same spatial pattern (Fig. 1 Supplementary), with high values in the city center.

To compose an unbiased index, a PCA was performed to provide a new set of uncorrelated variables. Four primary components, which explain approximately 81% of the original variance of the sample, were chosen. Therefore, the index will be calculated based on these four components instead of the previous seven. To present the relations with the original dataset, the loads inform the dependence between the original indicators and the new components (V1, V2, V3, and V4) (Fig. 6). The principal component, V1, is positively related to the green areas. The second primary component, V2, is positively related to accessibility to cultural facilities and jobs. The third primary component, V3, is positively related to accessibility to schools and the fourth, V4, is related to garbage services. For more details about the spatial patterns of the components, see Fig. 7.

The parameters from the PCA were used to weight the indicators. It was thus possible to weight the indicators in a reliable statistical way, to avoid biasing the indicator aggregation (Gan, Fernandez, et al., 2017). The eigenvalues multiply the instances of the new components. The final formula of the index composition is as follows:

$$Index = 3.32 * V1 + 1.53 * \mathrm{V2} + 0.99 * \mathrm{V3} + 0.85 * \mathrm{V4}$$

Finally, the SHI represents the evaluation of the infrastructure and services provision in the São Paulo municipality. To visualize the spatial patterns, the map shows the normalized value of the index (Fig. 8). A higher index value represents a higher provision of urban services and facilities. Note the considerable differences when considering the city center and the peripheral region.

The proposed methodology depends on the available public data regarding green area mapping. Although the potential use of services provided by green areas can be positive, associating its beneficial functions with encouraging physical activities and recreation, green areas can also be perceived as negative, risky and unsafe places (Jim & Shan, 2013). For the present study, there were no data available to qualify the vegetation map areas to differentiate if it could be considered as a variable that represented the opportunity to enhance the quality of life, or if the opposite was true. In the empirical study area, the southern region has a larger presence of green areas, but as noted by Duarte and Malheiros (2012), it reflects the proximity of environmentally protected areas that are occupied by precarious settlements. In summary, poorly managed parks can be used as a garbage

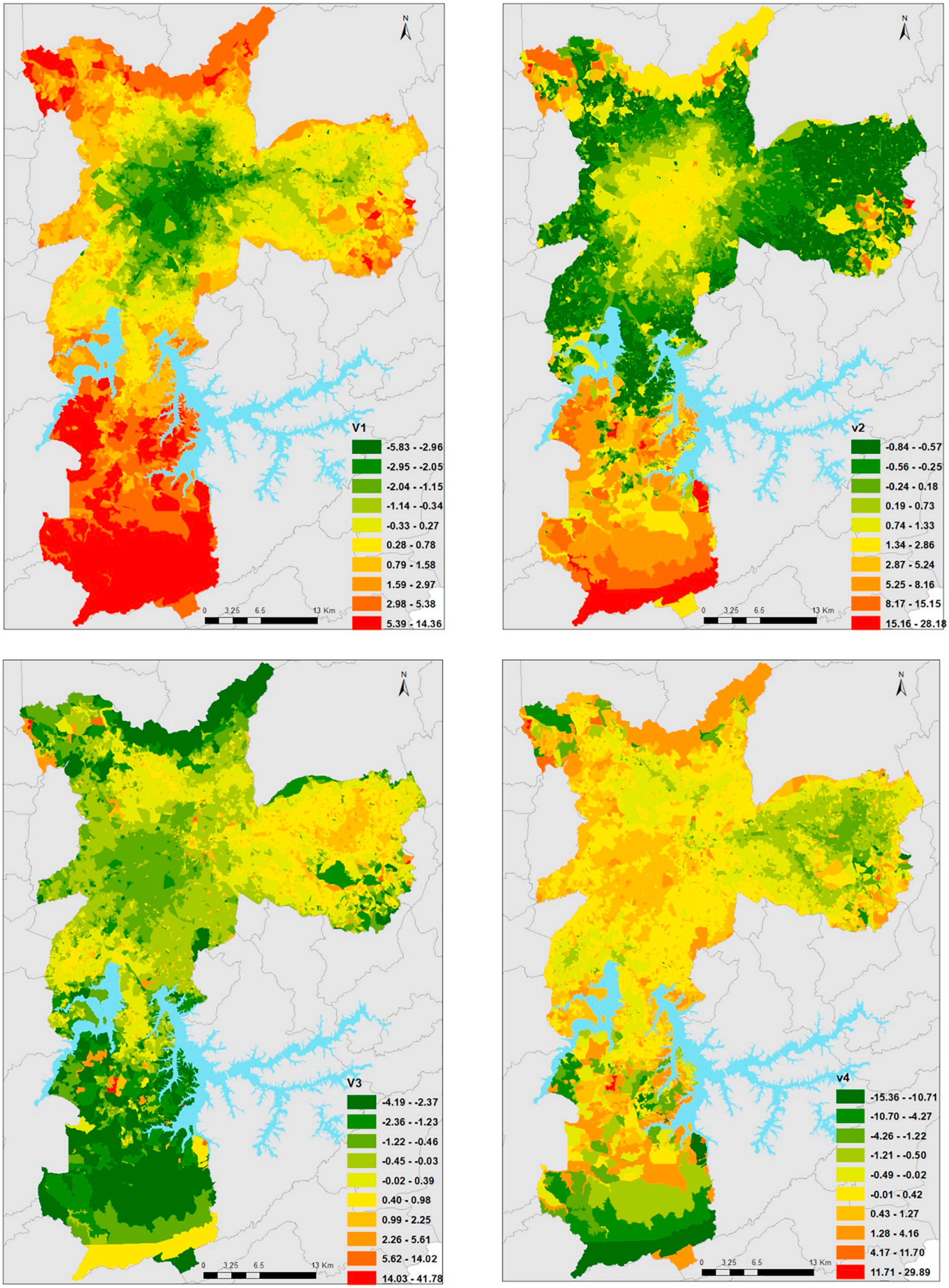

Fig. 7. The principal components of the index.

deposit.

According to Fig. 8, group A is on the urban fringe, in the Headwater Protection area, which is delineated to preserve the watershed supply. However, in accordance with Geneletti et al. (2017), this area needs robust planning. Because it is a green protection area occupied by precarious settlements, it does not provide its potential positive services to enhance the population's quality of life.

Fig. 9 indicates the primary differences between the segments that

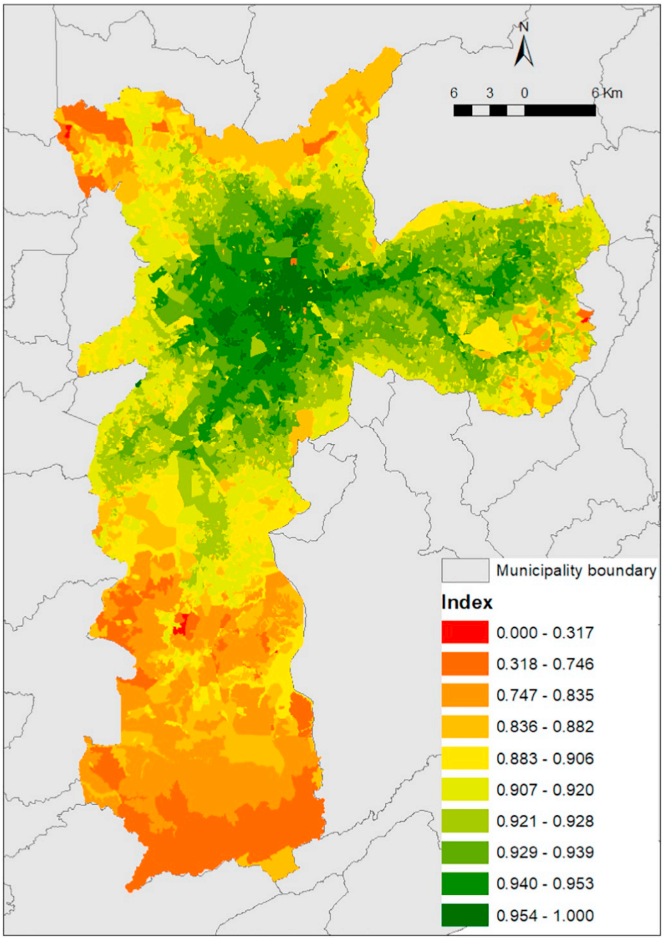

Fig. 8. The proposed index.

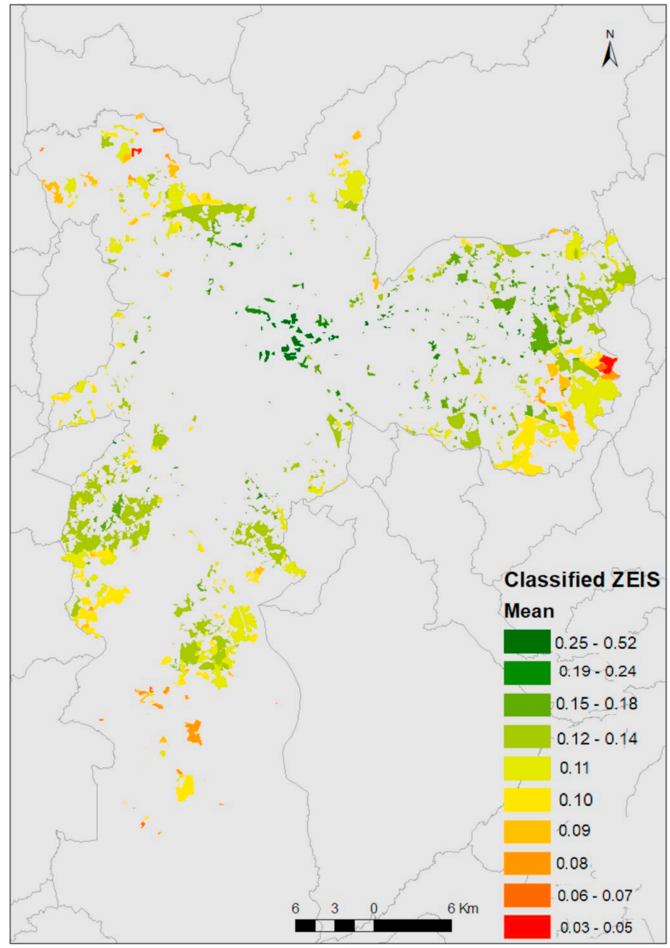

Fig. 9. Analysis of ZEIS categories.

are related to accessibility measures. The differences in accessibility to schools do not change as much as accessibility to jobs and cultural facilities. This result confers an urgency for more transportation infrastructure, cultural facilities and job distribution in the peripheral areas of the city (Fig. 9).

The best-evaluated segment (E) also presents the best service level provision. The values for sewage, garbage, and water do not change considerably between the segments, revealing the high level of the supply across the entire city. However, this measure is conceived from the observation of the census interviewer; areas that are not reachable, such as those located in the urban fringe, should be questioned.

For future studies, it would be interesting to add other dimensions to the proposed index that is not considered in this study due to the lack of available data. The demand considering the existing population that uses the public service as well as the vacancies on offer, for example, for assessing the public school's quality, would enhance the analysis presented here. Applying this methodology in other contexts could help researchers and stakeholders to explore this perspective as well as include other important services such as primary health, different types of leisure as well as the quality of green areas for public use. Although this approach would be a possibility, it is also important to consider that more variables result in more complex indicators. In the case of SHI, more simple indicators facilitate the final interpretation of the results and outcomes. Other weighting methods and different aggregation levels can also be tested.

3.3. Outcomes for housing plans: Index application

This section presents the rank of the existing marked areas that are likely to receive social housing initiatives. In addition, the existing housing projects of one relevant Brazilian program are evaluated according to the index formulation. This section will inform readers about the service and infrastructure provision to identify the regions with worse condition.

The SHI was developed to inform social housing initiatives by considering the infrastructure and service supply. Two levels of analysis were developed as follows: (i) previous decisions about the location of housing initiatives by ranking ZEIS polygons and (ii) decisions about the existing plans and programs for evaluating their results by evaluating MCMV projects.

To make ZEIS polygons compatible with census tracts, the spatial join operation of ArcGIS 10.5 was applied. It resulted in the mean value of the index by considering the polygons that spatially coincided with the ZEIS areas. Fig. 9 shows the rank of the existing land for social housing. According to the index, the worse factor is on the urban fringe and the best is in the city center. The ZEIS category's (Table 2) worst ranking is at number four, which consist of areas with underused land that is adequate for urbanization in the Watershed Protection region. The best ZEIS is number three, with underused or unused buildings that are degraded but found in regions with services, infrastructure, and urban facilities.

As already highlighted by Ribeiro et al. (2016), the ZEIS zoning did not mark the best location. However, in alliance with the index and indicators, it can be useful to better support the housing initiatives. In this sense, the SHI provides measures of transportation, educational, jobs and cultural facilities; it also includes sewage, water, green areas and garbage services, which were not mentioned in the description of the ZEIS condition. For example, this analysis shows that the provision

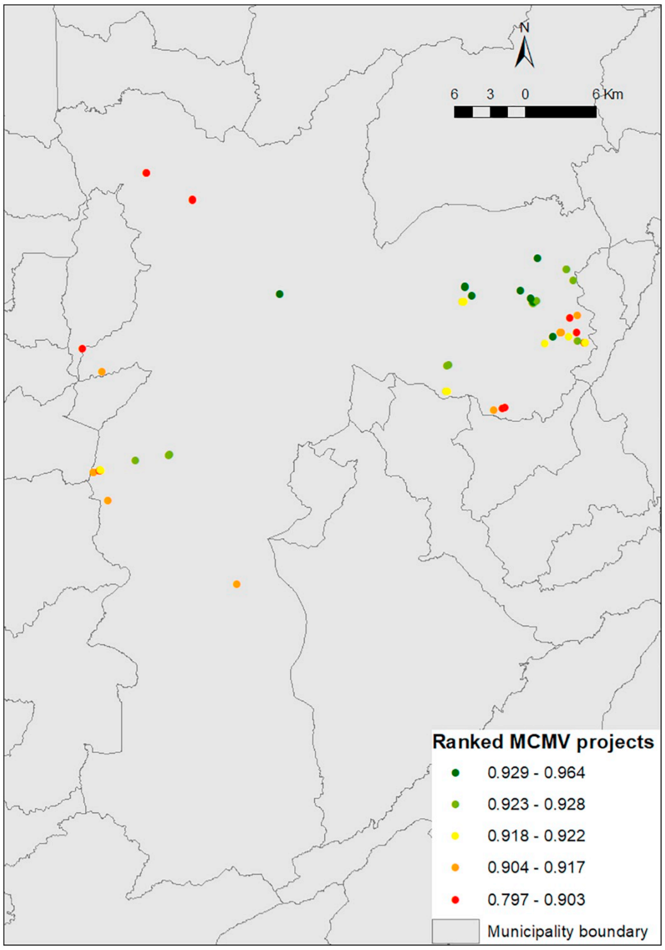

Fig. 10. Analysis of MCMV projects.

of services in some areas of the urban fringe (Fig. 9) will reinforce inequalities among poor families.

In the ex post analysis, the MCMV projects were evaluated. The projects in the worse condition are in the urban fringe, especially in the northern and eastern regions (Fig. 10). The eastern region has been the recipient of a considerable number of social housing initiatives in recent years (Marques & Rodrigues, 2013). It presents a heterogeneous condition of very highly ranked areas, intermediate and urban fringe, and the lowest ranked areas (Fig. 8). The low ranked projects (in red in the map) present the lowest level of accessibility to all facilities. Compared with the highly ranked areas, the lower ranked ones only show a higher percentage of green areas in the surroundings.

Other studies exploring the MCMV note that the spatial patterns of the projects in the first target segment are marked by the same spatial pattern of the previous housing programs (Marques & Rodrigues, 2013; Rolnik et al., 2015). Rolnik et al. (2015) note that the peripheral location of the buildings kept the precariousness and fragmented urbanization pattern of the historical initiatives.

According to the SHI, the most differences between the project evaluations are related to accessibility (See Fig. 1 Supplementary). The jobs and cultural facilities are the urban equipment to prioritize to provide a homogenous condition for the existing housing projects. The SHI also considers green coverage and reveals that the already built projects are close to green areas. Although the protected areas maintain the air quality and temperature, they do not represent more access to leisure, once the region requires special regulations for use and occupation.

The SHI can be used by different stakeholders. The evaluation of demarcated areas could support the government's decisions about the best place for developing new houses by considering good infrastructure and good environmental conditions. The developer and the housing market can also use this information to estimate the land use potential based on social and environmental information. The evaluation of the projects that were already built can inform decisions on future housing policies about opportunities to improve. Especially the SHI, which considers social and environmental information, shows the need to integrate between different urban plans and programs to provide information for use in making decisions. As discussed by Ultramari et al. (2018), the current improvement observed in the infrastructure and the provision of basic public services in Brazilian cities may partially be an outcome of governmental public policies and compliance with new legislation and approved plans, which indicates the potential of the proposed SHI as a tool to bind stakeholders.

Similarly, for the replicability characteristic from Musakwa et al. (2017), the SHI can be applied to other countries and can be used to tackle other problems such as land use potential. To apply it to other contexts, it will be necessary to adapt the indicator selection (Sánchez-Cantalejo et al., 2008) that capture the particularities of the social housing context. The marked areas in São Paulo represent an advantage in relation to another context without this tool. However, another existing zoning approach could be considered for the index application. The evaluation of the existing buildings has the drawback of capturing the infrastructure at the moment the buildings are constructed. However, even so, it is possible to develop an idea of the general condition of the city infrastructure and services and to evaluate the most critical areas.

4. Conclusions

This work proposed a social housing index (SHI) for integrating and quantifying urban spatial information for supporting social housing plans by using robust methodological steps that can be adapted for different urban contexts. The conceptual framework has to fit the local urban conditions by using the primary issues from local sectoral and land use plans. It reveals and addresses the local socio-environmental spatial features to be addressed in supporting housing plans. The index calculation involves a spatial analysis, and its composition encompasses techniques for setting up a statistically reliable measure of infrastructure, services and environmental information.

The application of the SHI shows a way to match different demands of housing plans for more sustainable urban development. The evaluation of areas that will receive social housing initiatives reveals the heterogeneity of services and urban infrastructure. The analysis of built projects in the MCMV program, which is the primary Brazilian program to offer social housing, highlights the priority to increase the supply of jobs and cultural facilities in the surroundings of the buildings on the urban fringe.

The proposed index formulation using spatial information can be adapted by selecting public, relevant and available information about the environment, urban infrastructure and services. For further developments, more information about the quality of services, the number of vacancies and demand, land prices and existing housing stock could enhance the analysis. While using the index to evaluate social housing units that were already implemented, it could be interesting to include architectural standard variables. PCA strengthens the replicability of the procedure, especially in highly correlated datasets, once it presents a reliable statistical method for weighting and revealing the data structure, which can inform users about the relation between the selected indicators, however, other aggregation schemes can be tested.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2018.11.010.

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