REGIONAL FORCES AND URBAN FORMS: GROWTH DIRECTION

FORÇAS REGIONAIS E FORMAS URBANAS: DIREÇÃO DE CRESCIMENTO

FUERZAS REGIONALES Y FORMAS URBANAS: DIRECCIÓN DE CRECIMIENTO

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ABSTRACT
The possibility of influence that the regional system may have on the urban forms that cities tend to assume is discussed. The difference in scale involved in this vision, which ranges from the regional scale, passes through the municipal scale, and given this situation that presents the way in which urban form, city and region are approached today, it appears that the Studies lack greater connection and assessment of influences between different scales and impacts. This research is carried out through the proposal of a methodological guide, and the instrument developed to obtain results was the collection of data and construction of variables of interest, which can provide a useful tool to study the influence of spatial effects on aggregation of spatial interaction models and how much they can contribute in different ways to substantial achievements in spatial econometric studies, in addition to suggesting statistical tools that infer the value, intensity and probable hierarchy of average flows at certain levels of aggregation of real and estimated available variables. As a way of illustrating the research, data collection with empirical research was chosen as an evaluation instrument, based on the Metropolitan Region of Serra Gaúcha (MRSG), made up of 14 municipalities that present very different forms and urban structures.

KEYWORDS
Forças regionais, formas urbanas, estrutura interna da cidade.

RESUMO
Discute-se a possibilidade de influência que o sistema regional pode ter sobre as formas urbanas que as cidades tendem a assumir. A diferença de escala envolvida nesta visão, que vai desde a escala regional e passa pela escala municipal, colocada esta conjuntura que apresenta a maneira como hoje se aborda forma urbana, cidade e região, verifica-se que os estudos carecem de uma maior conexão e avaliação das influências entre as diferentes escalas e impactos. O encaminhamento desta pesquisa se dá através da proposta de um roteiro metodológico, e o instrumento desenvolvido para obtenção de resultados foi a coleta de dados e construção de variáveis de interesse, que pode fornecer uma ferramenta útil para estudar a influência dos efeitos espaciais sobre a agregação de modelos de interação espacial e o quanto podem contribuir de diversas maneiras para realizações substanciais em estudos econométricos espaciais, além de sugerirem ferramentas estatísticas que inferem o valor, intensidade e hierarquia provável de fluxos médios a certos níveis de agregação de variáveis disponíveis reais e estimadas. Como forma de ilustrar a pesquisa, foi escolhido como instrumento de avaliação a coleta de dados com pesquisa empírica, baseado na Metropolitan Region of Serra Gaúcha

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(MRSG), composta por 14 municípios que apresentam formas e estruturas urbanas bastante distintas entre si.

PALAVRAS-CHAVE
Fuerzas regionales, formas urbanas, estructura interna de la ciudad.

RESUMEN
Se discute la posibilidad de la influencia que el sistema regional puede tener sobre las formas urbanas que las ciudades tienden a asumir. La diferencia de escala involucrada en esta visión, que abarca desde la escala regional hasta la escala municipal, plantea una coyuntura que muestra cómo, hoy en día, se aborda la forma urbana, la ciudad y la región. Se observa que los estudios carecen de una mayor conexión y evaluación de las influencias entre las diferentes escalas e impactos. El desarrollo de esta investigación se lleva a cabo mediante la propuesta de un esquema metodológico, y el instrumento desarrollado para obtener resultados fue la recolección de datos y la construcción de variables de interés, lo cual puede proporcionar una herramienta útil para estudiar la influencia de los efectos espaciales sobre la agregación de modelos de interacción espacial y cuánto pueden contribuir de diversas maneras a logros sustanciales en estudios econométricos espaciales. Además, sugiere herramientas estadísticas que infieren el valor, la intensidad y la jerarquía probable de flujos medios a ciertos niveles de agregación de variables disponibles, tanto reales como estimadas. Como una forma de ilustrar la investigación, se eligió como instrumento de evaluación la recolección de datos con investigación empírica, basada en la Región Metropolitana de la Serra Gaúcha (MRSG), compuesta por 14 municipios que presentan formas y estructuras urbanas bastante distintas entre sí.

1. INTRODUCTION

The pursuit of understanding the spatial transformations generated by the increasing number of people living in cities, the consequent expansion of urbanized areas, the impacts on space consumption, and thus, the emergence of new urban forms. This accelerated growth of urban areas has a direct impact on the structure and organization of a city and has therefore become a subject of interest in various studies.

In this research, we discuss the potential influence that the regional system may have on the urban forms that cities tend to assume. The scale differences involved in this perspective, ranging from the regional scale to the municipal scale, down to the intra-urban scale, present a context that reveals the current approach to urban form, city, and region. It becomes evident that studies lack greater connection and evaluation of the influences between these different scales and their impacts.

The direction of this research is guided by the proposal of a methodological framework, along with statistical and spatial verifications, as well as studies projecting city growth trends based on a 40-year time series (1970-2010). In this context, the tool developed to obtain results involved data collection and the construction of variables of interest, which could provide a useful tool for studying the influence of spatial effects on the aggregation of special interaction models. This approach allows for understanding the extent to which these effects can contribute in various ways to substantial advancements in spatial econometric studies. It is also possible to obtain statistical tools that infer the value, intensity, and probable hierarchy of average flows at certain levels of aggregation of available real and estimated variables—thus enabling a more refined and detailed analysis that could be overlooked in traditional models that do not consider spatial factors.

To illustrate the research, data collection through empirical research based on the Metropolitan Region of Serra Gaúcha (MRSG) was chosen as the evaluation instrument. The MRSG consists of 14 municipalities with significantly different urban forms and structures (Image 1). This diversity introduces varying levels of complexity in the region's interactions, providing an opportunity for the study to assess how distinct spatial factors develop within each municipal specificity, followed by an evaluation of the set of interactions as a whole.

Figure 1: Metropolitan Region of Serra Gaúcha map.
Source: elaborated by the authors

2. REGIONAL FORCES AND URBAN FORMS

We can say that in a given region, cities grow according to their own criteria and exhibit different urban forms, some more dispersed and others more compact. There are various reasons for these urban forms to differ, which are associated with the production and consumption of urbanized space, such as the efficiency of the spatial structure, and the consistency between infrastructure, regulations, and the space occupied by a particular urban form (Bertaud, 2003).

However, cities within the same region, with similar urban and economic structuring characteristics, often display distinct urban forms. A fundamental aspect to consider is the influence that the regional system exerts on the urban forms that cities tend to assume. This discussion is relevant because it is assumed that factors within the regional system play a decisive role in how cities spatially structure themselves over time.

According to Favaro & Pumain (2011), cities must be related in some way because they belong to the same statistical distribution, involving a specific average growth rate and standard deviation, which implies an inherent interdependence between them. Gersmehl (1970) notes that there is a problem of scale in identifying the factors that affect the interaction between two cities, as barriers to the occurrence of flows must be considered, and there is significant influence from neighboring cities and the existing routes between them. This stems from the fact that the interaction between two cities can occur on various levels and at different scales.

The term 'urban form' is associated with various situations, ranging from intra-urban issues to regional concerns. In this research, the term will be used to refer to the overall form of the city, that is, the macroscopic state resulting from the process of adaptation and transformation of the environment at a given moment. Thus, a region is presented where cities grow and assume distinct forms, and these forms are driven both by internal forces within the cities, dependent on locational factors, and by the cities' own location within the region.

3. GROWTH DIRECTION

The measurement of the urbanized area refers to the entire portion of the territory occupied by the urban sprawl, forming a visible patch, and is therefore considered a measure at the municipal scale. At other scales, the measurements of internal structures refer to the internal spatial differentiations of each city, such as the evolution of its centralities, polarizations, and densities.

The measurements of geometric deformations pertain to the overall shape of urban settlements, whose evolution is directly linked to the regional tensions within the system. In this way, deformation would select certain directions, extending the urban areas in those directions. Such deformations could be described by proper geometric measurements, such as variation of the urban perimeter, gross increase in the urbanized area, proportional deformation, directional deformation, among other metrics (Image 2).

The rate of growth of cities over the studied period is being evaluated through a supporting measure, referred to in this work as a measure of geometric deformation. Deformation is a change in the shape and dimensions of a body when a certain force is applied to it. Considering the existence of a force "pulling" a city in a particular direction, we could assume that, by correlating this principle with Hooke's Law, the deformations are extensions or compressions of a segment per unit length.

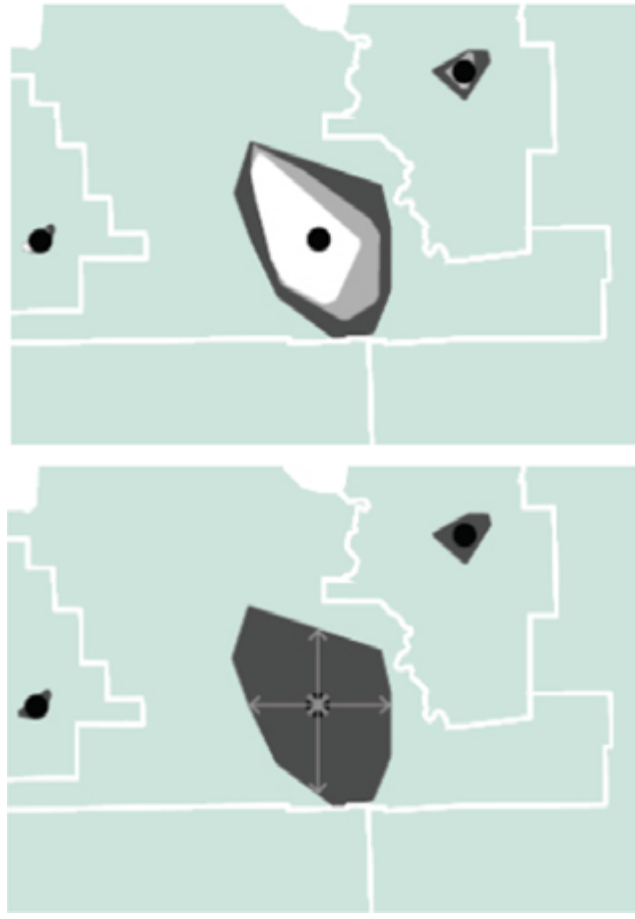

Figure 2: Example of geometric deformation mesure for the city of Bento Gonçalves: In a lighter color, the urbanized area in 1970, calculated towards the shape's vertices; in a stronger color, the urbanized area in 2010, also calculated towards the shape's vertices.
Source: article Forças regionais, formas urbanas e estrutura interna da cidade: UM ESTUDO COMPARATIVO, Autor(es): Manuela Letícia Huppes, Raquel Werner de Vargas e Tamires Lenhart Orientador: Izabele Colusso.

4. METHODOLOGICAL PROCEDURES, GROWTH PROJECTION ELABORATION

Initially, in the preliminary stages of this research, data collection was conducted with information pertaining to the Metropolitan Region of Serra Gaúcha. The objective was to gather a set of data for subsequent analysis, one of which was the growth direction from the centroid (the geometric center of each city). The data were collected in a time series spanning 40 years, with regular intervals of 20 years. This type of temporal approach allows for identifying trends in urban development that limit growth in a particular direction.

To enable a better understanding of the data and facilitate analysis, a second series of tables was created, containing only the growth direction data for each municipality in the MRSG, as shown in Table 1, in this

case illustrating only the municipality of Antônio Prado. Table 1 presents the data regarding the growth direction, represented by the letter "U," corresponding to each orientation (N for North, S for South, W for West, and E for East) for the years 1970, 1990, and 2010, followed by the growth difference for each series: from 1970 to 1990, from 1990 to 2010, and finally, the total from 1970 to 2010. The dimensions were computed in linear meters, and the differences were expressed in percentages.

Subsequently, in Excel, the Forecast Sheet command was applied, which generates predicted data based on the historical data previously presented. This tool can be used to analyze various types of projections, and in this research, we utilized it to analyze the growth direction of each municipality through the measures of its existing urban form. In this way, it was possible to establish a growth trend—based on the past period from 1970 to 2010 and its already defined growth. As a result, we have new phases of urban expansion for the periods of 2030 and 2050. In the next stage, the obtained data were added to the reorganized data table, allowing the command to be applied again to forecast growth for 2070, as shown in Table 4. The Forecast Sheet command was reapplied, this time including the data obtained for 2030 and 2050, as presented in Table 2 and Image 3.

Antônio Prado							
	1970	**1990**	**2010**	**70-90**	**90-10**	**70-10**	**Direction**
UN	665	848	861	27,52%	1,53%	29,47%	-
US	794	967	1518	21,79%	56,98%	91,18%	South: Farroupilha
UE	959	1333	1771	39,00%	32,86%	84,67%	Southeast: Caxias do Sul
UW	1168	1328	1677	13,70%	26,28%	43,58%	Southwest: Bento Gonçalves

Table 1: Synthesized data of Antônio Prado
Source: by Authors.

Timeline	Data	Prediction	Inferior Trust Limit	Superior Trust Limit
1970	665			
1990	848			
2010	861			
2030	980,9639			
2050	1085,704	1085,7043	1085,70	1085,70
2070		**1189,0338**	**1120,29**	**1257,78**

Table 2: Reorganized data including growth projections from 2030, 2050 and 2070, of Antônio Prado .
Source: by Authors.

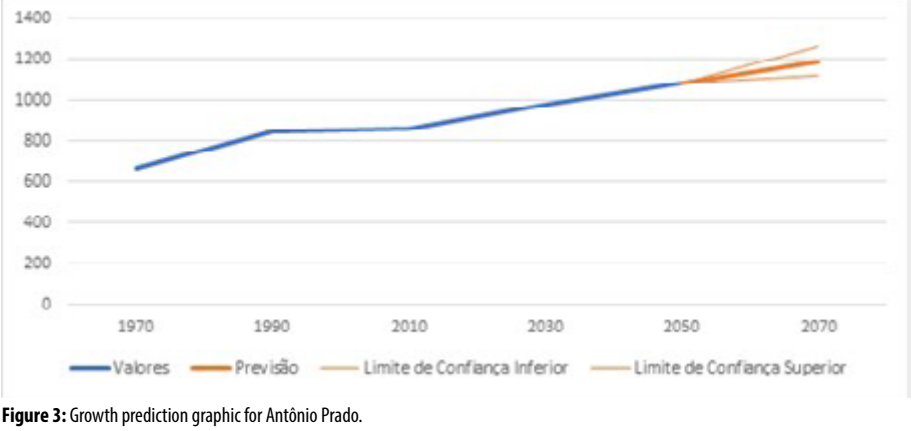

Figure 3: Growth prediction graphic for Antônio Prado.
Source: by Authors.

After obtaining all the necessary data, they were reorganized into a new Total Projections table, where the growth differences became visible through the application of a percentage formula, as shown in Table 3.

The final step was subtracting the data to measure the distance in meters on the map for each growth direction during the analyzed time intervals, ultimately generating a forecast table for each municipality, as shown in Table 4.

To achieve this, maps were developed using QGIS software. Initially, a general map was created, encompassing all 14 cities and their growth patterns over the selected time intervals for visual analysis of growth trends (1970, 1990, and 2010), as shown in Images 4, 5, and 6.

	2030	2050	2070	10-30	30-50	50-70
North	980,96	1085,70	1189,03	13,93%	10,68%	9,52%
South	1831,16	2178,18	2528,32	20,63%	18,95%	16,08%
East	2168,73	2572,19	2976,19	22,46%	18,60%	15,71%
West	1907,08	2154,09	2402,66	13,72%	12,95%	11,54%

Table 3: Total projections for Antônio Prado.
Source: by Authors.

Growth in meters			
	2010 to 2030	2030 to 2050	2050 to 2070
North	119,96	104,74	103,33
South	313,16	347,01	350,15
East	397,73	403,46	403,99
West	230,08	247,01	248,57

Table 4: Growth projection in meters for each direction of Antônio Prado.
Source: by Authors.

This process was conducted for all the municipalities in the MRSG, thereby creating a sequence of data. Subsequently, the spatial behavior of the obtained metrics was analyzed.

5. SPATIALIZATION, ILLUSTRATION AND SPATIAL VERIFICATION ANALYSES

Based on the tables presenting urban growth forecasts generated through Excel, a visual representation of these data was created to understand the spatial behavior of each city over each time series. The objective was to highlight key characteristics, such as the growth direction towards the North, South, East, and West, as well as the urban shape assumed by each municipality and the potential conurbation areas resulting from this growth.

To further facilitate the understanding of the data and forecasts obtained, individual maps were created for each of the 14 cities that make up the Metropolitan Region of Serra Gaúcha (MRSG). These maps provide a clear perspective of the projected expansions in the urban growth areas over the selected time transition periods. These cover the periods from 2010 to 2030, 2030 to 2050, and finally, 2050 to 2070, as shown in Images 7, 8, and 9.

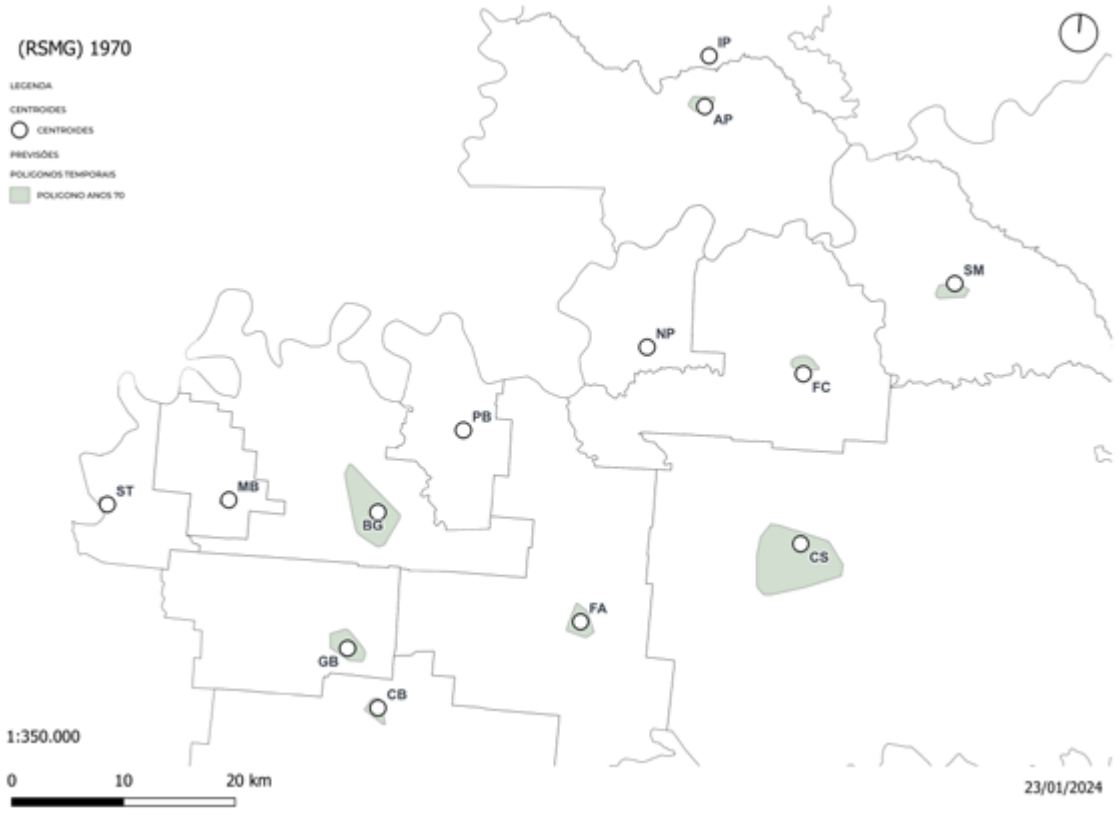

Figure 4: Growth geometry for the cities in the MRSG in the year of 1970.
Source: by Authors.

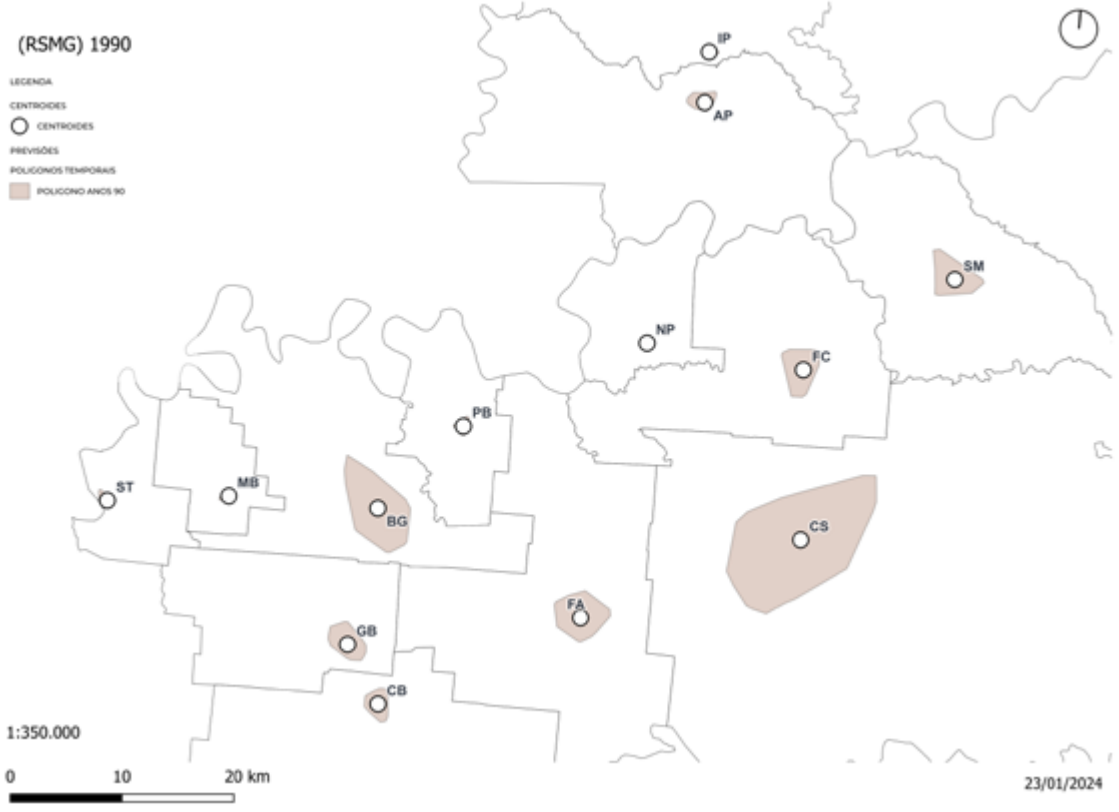

Figure 5: Growth geometry for the cities in the MRSG in the year of 1990.
Source: by Authors.

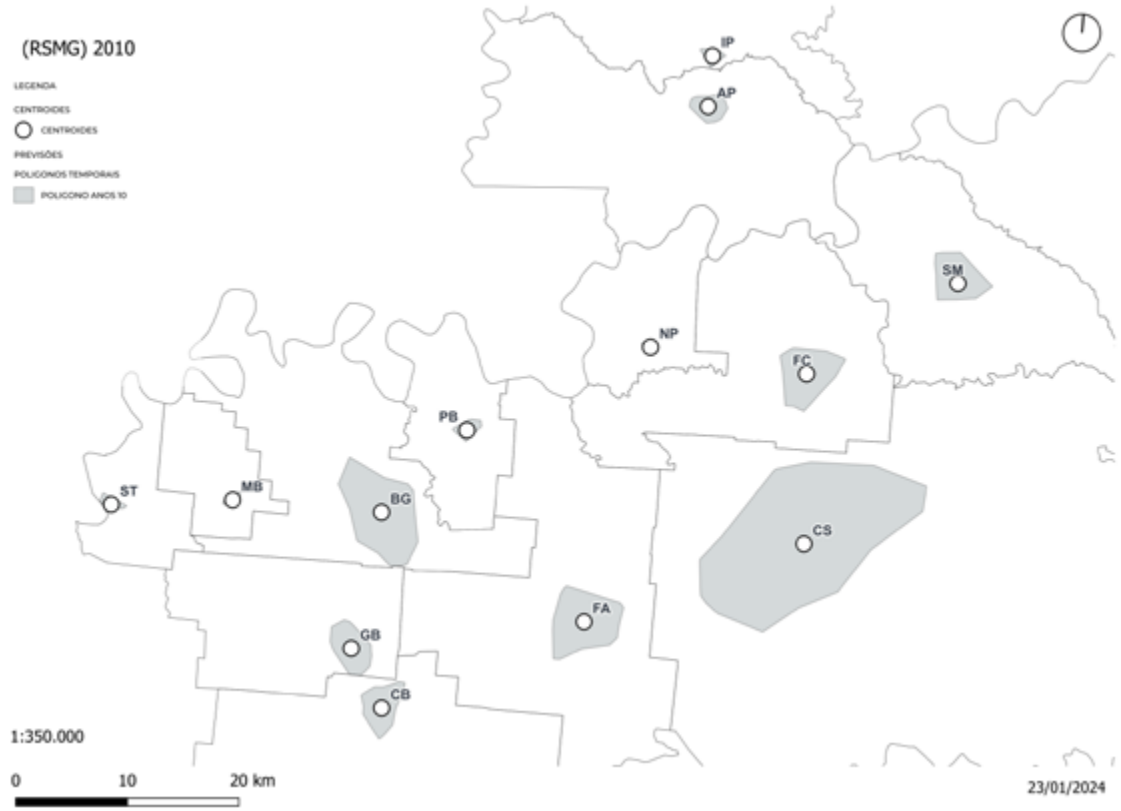

Figure 6: Growth geometry for the cities in the MRSG in the year of 2010.
Source: by Authors.

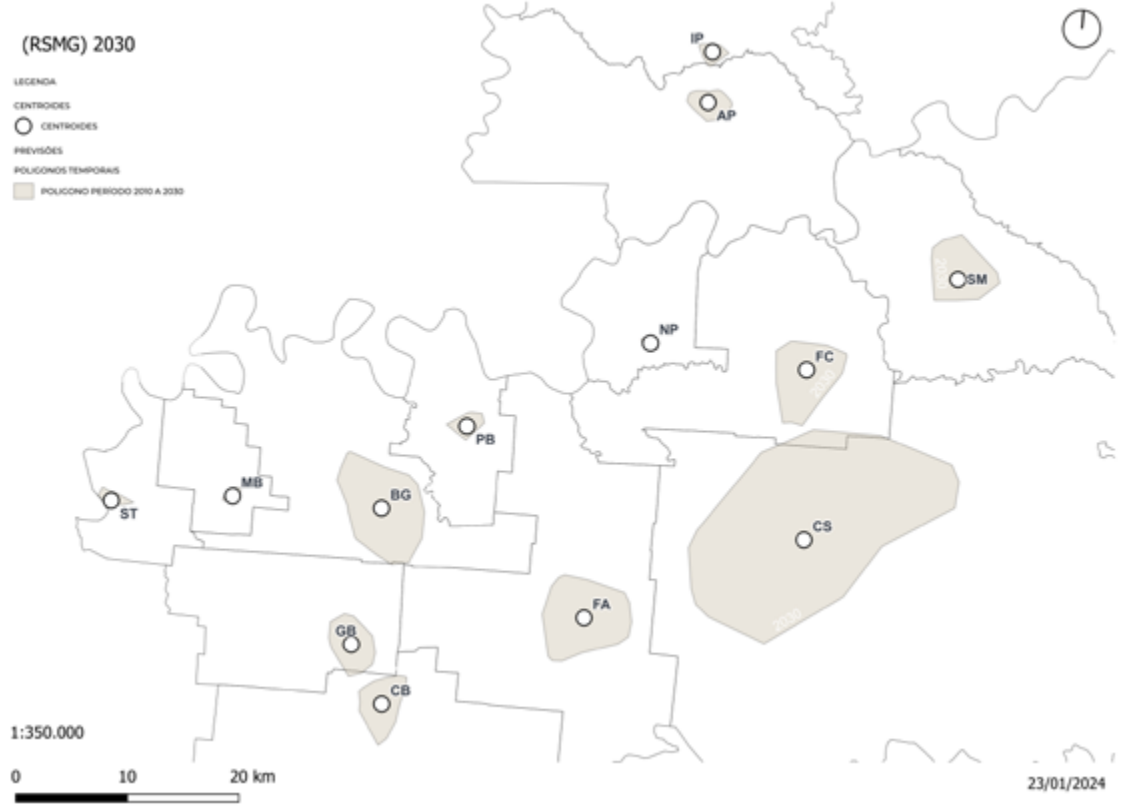

Figure 7: Growth projection geometry for the cities in the MRSG in the year of 2030.
Source: by Authors.

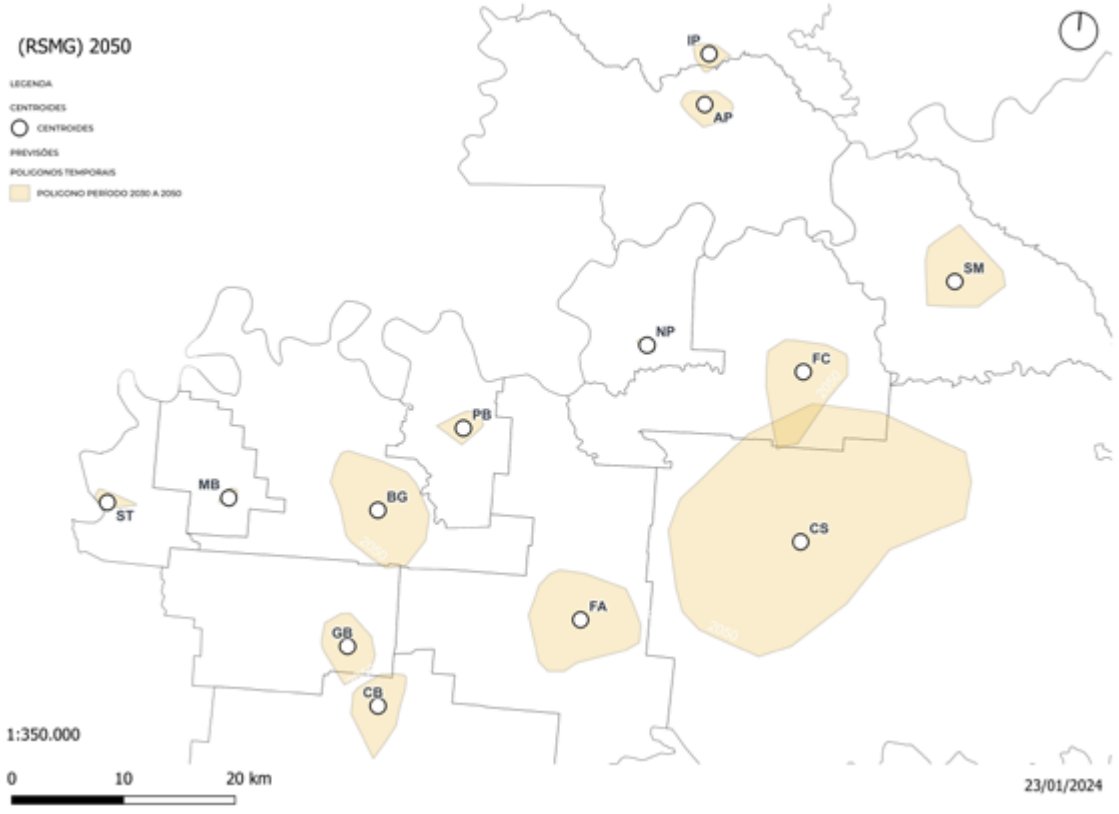

Figure 8: Growth projection geometry for the cities in the MRSG in the year of 2050.
Source: by Authors.

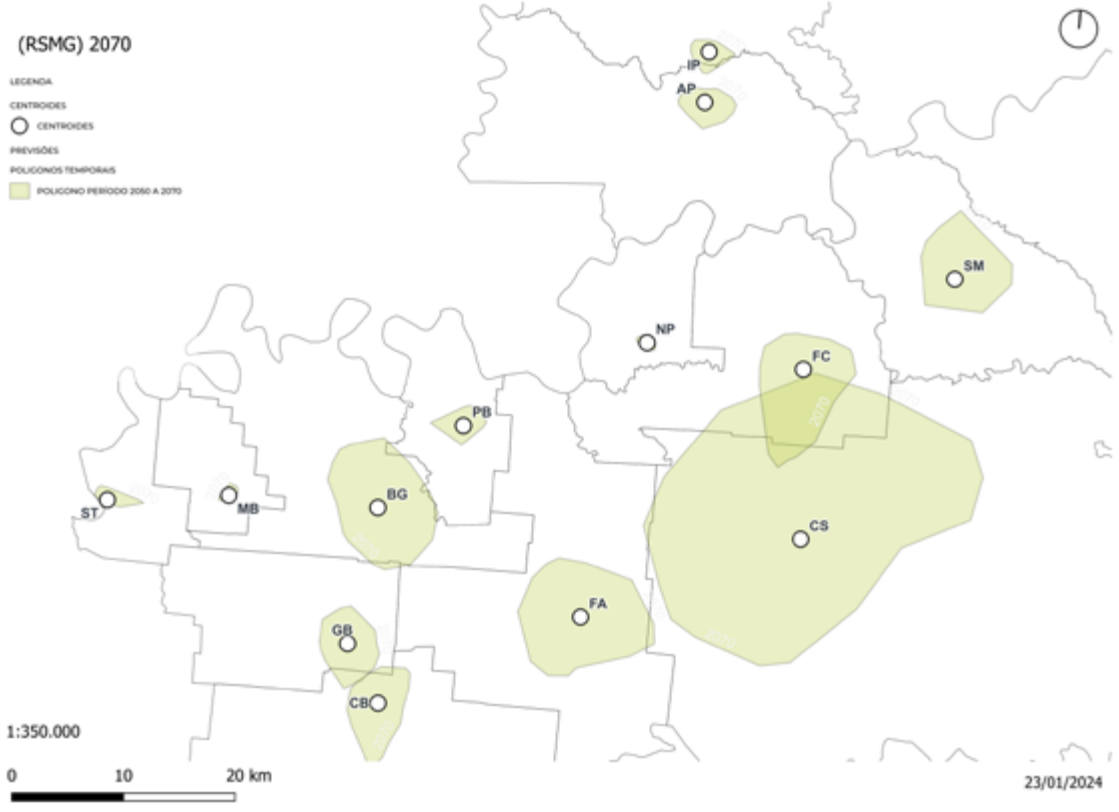

Figure 9: Growth projection geometry for the cities in the MRSG in the year of 2070.
Source: by Authors.

Through these individual representations, it was possible to closely examine each city and how its urban development is projected at different points in time. As a result, this study provides crucial information for understanding the future growth of cities in the Metropolitan Region of Serra Gaúcha, as illustrated in Image 10, using the example of the city of Bento Gonçalves.

Through these maps, it was possible to analyze the direction of growth in four distinct directions: north, south, east, and west. This approach enabled a comparison of the changes observed over the selected time intervals. Additionally, the analysis identified neighboring municipalities near the growth zones, highlighting their pull factors and corroborating previously calculated centrality data from other studies. The maps also provided forecasts of future conurbation regions, where expanding urban areas crossed municipal boundaries and extended into other areas, as exemplified in Image 11, which pertains to the cities of Caxias do Sul and Flores da Cunha.

The Image clearly demonstrates the pull effect that the city of Caxias do Sul exerts on the region. For this reason, it is possible to observe that the city of Flores da Cunha, located to the north of Caxias, tends to significantly expand its urban sprawl southward, towards the municipality of Caxias. This growth pattern is projected to form a conurbated region by the 2030s.

By consolidating the individual maps into a general map encompassing the entire region with the 14 municipalities studied, as shown in Image 12, it became possible to analyze the overall relationship between all the municipalities. This provided a more didactic and direct visualization of the centrality and global integration data discussed in this research, allowing for a better understanding of the region as a complete system.

Additionally, through the application of the methodological framework, it was possible to determine the growth projections for each of the cities in the MRSG (Metropolitan Region of Serra Gaúcha), thereby developing conclusions and hypotheses regarding how this growth occurs in each municipality. In the following Image, we can observe the marking of the centroids of each city, the municipal boundaries, and the growth patterns expressed in colored tones.

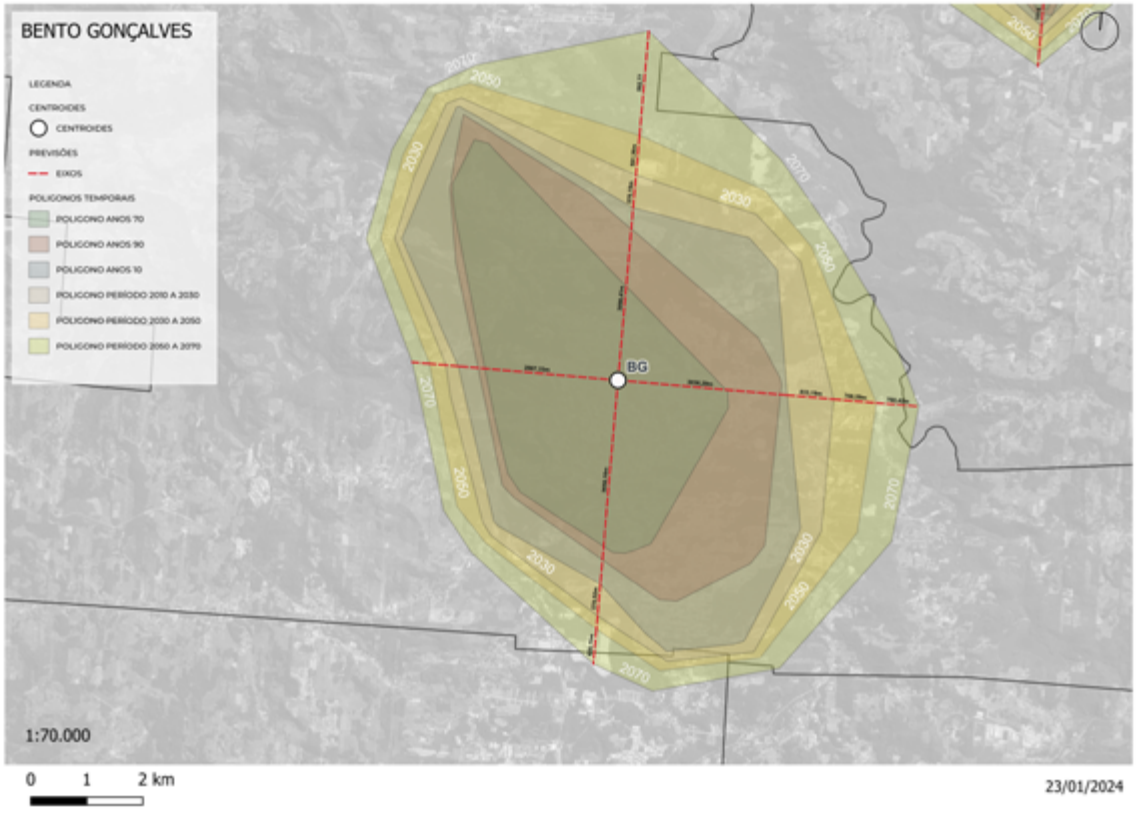

Figure 10: Growth prediction map for Bento Gonçalves.
Source: by Authors.

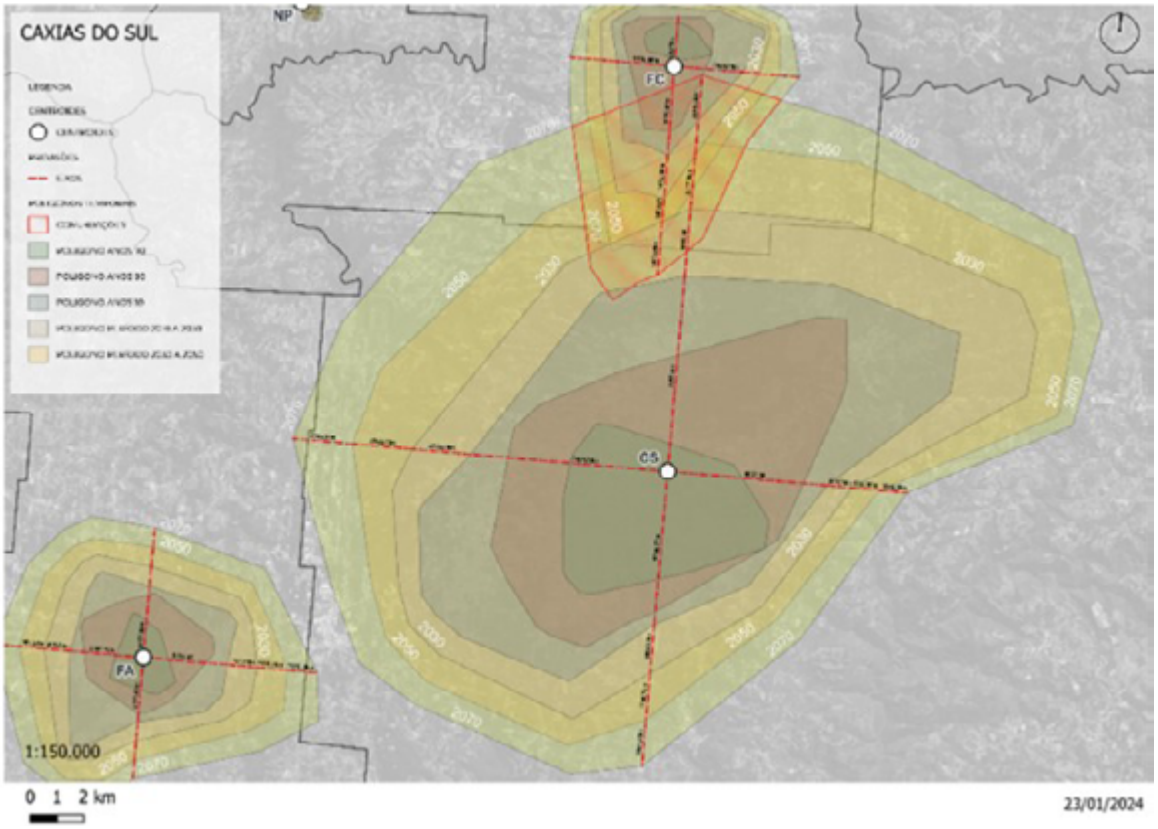

Figure 11: Conurbation prediction between Caxias do Sul e Flores da Cunha.
Source: by Authors.

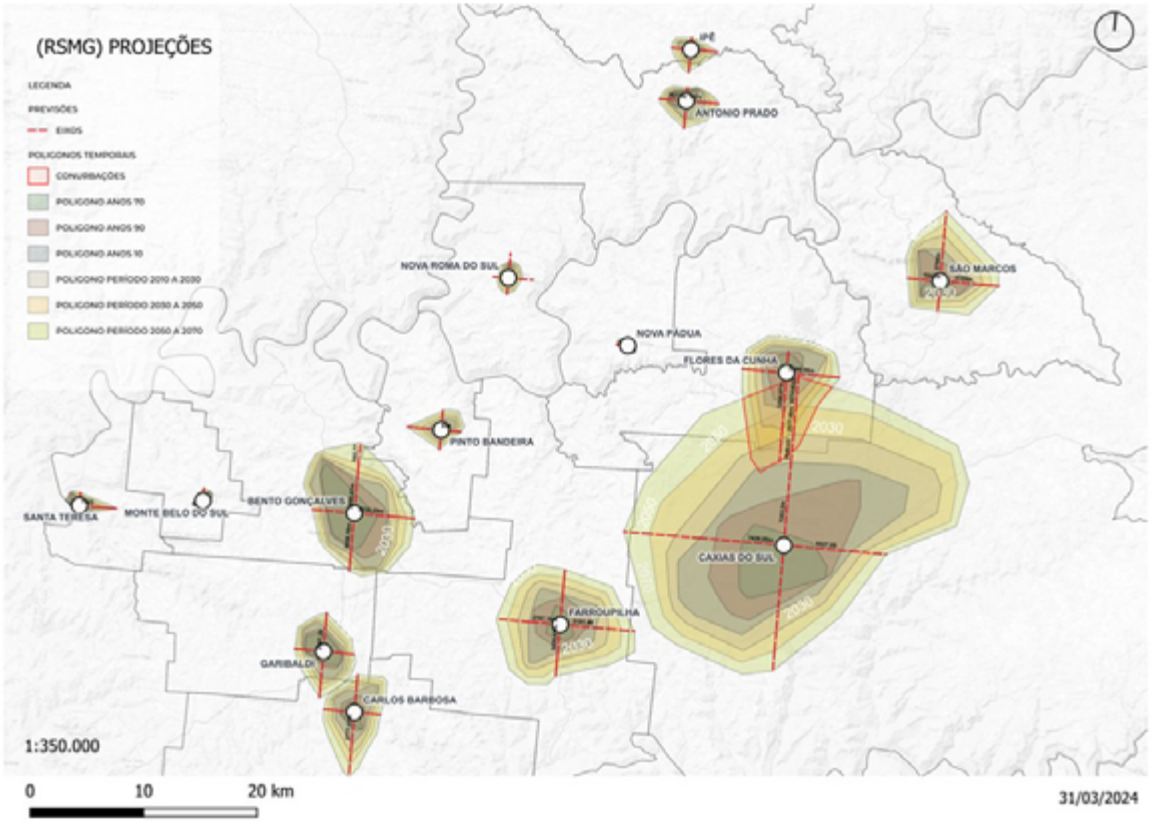

Figure 12: Growth prediction throughout the years.
Source: by Authors.

By analyzing the city of Caxias do Sul, it was determined that the primary direction of growth is towards the north, in the direction of the city of Flores da Cunha, while growth towards the west is directed toward the cities of Farroupilha and Bento Gonçalves. Growth to the east is more limited compared to the other directions, and the phenomenon of conurbation is projected to occur between Caxias do Sul and Flores da Cunha between 2030 and 2050. Based on the conclusions visually expressed in the map, hypotheses were developed to explain this growth behavior, such as the limitation of expansion towards the east. This growth barrier can be attributed to the more rugged topography in that direction, which makes urban expansion more difficult compared to flat areas, in addition to the presence of the Piaí River, which acts as a physical boundary.

The conurbation phenomenon observed between the municipalities of Caxias do Sul and Flores da Cunha occurs due to the mutual attraction between these two cities. This same attraction can also be observed between the cities of Caxias do Sul, Farroupilha, and Bento Gonçalves. Each of these cities tends to grow towards one another, demonstrating that the interaction between them is significant.

Regarding the city of Farroupilha, it was observed that its urban growth is relatively uniform. This reflects the city's high centrality in the region, as its central location connects different points, making it, along with Caxias do Sul and Bento Gonçalves, one of the largest urban areas, both currently and in future projections. However, despite its relatively uniform growth, the primary growth direction for Farroupilha is eastward, toward Caxias do Sul. Growth to the west is directed toward the BR453 highway, in the direction of Bento Gonçalves, while growth to the north is toward the city of Caravaggio (which is not part of the MRSG). Growth to the south, however, is limited.

The following hypotheses were developed based on the conclusions drawn: the city of Caxias do Sul has a direct influence on the growth of Farroupilha, along with the BR453 highway, which also contributes to the city's expansion. Growth to the south is limited by the more rugged topography.

From the map analysis, it was concluded that the main growth direction for Garibaldi is southward, towards the municipality of Carlos Barbosa. Due to this growth direction, conurbation is expected to occur between Garibaldi and Carlos Barbosa by 2070. Growth to the north of Garibaldi is directed toward Bento Gonçalves, while growth to the east and west is more limited.

For Carlos Barbosa, the primary growth direction is southward, with growth to the east and west being constrained. Conurbation between Carlos Barbosa and Garibaldi is expected by 2070, as the main southern growth follows the RST470 highway, which connects the region, while growth to the east is limited by the RS446 highway, and growth to the west is restricted by the rugged terrain, shaping a more elongated urban form.

Regarding the municipality of Bento Gonçalves, it was concluded that the most significant growth occurs to the north and east. Conversely, growth to the south and west is more limited. Growth to the north is driven by the presence of the Rio das Antas and the RS470 route. Southern growth is limited by the boundaries created by the RS444 highway, while growth to the west is constrained by the Arroio Pedrinho stream. Additionally, there is an apparent attraction factor towards the cities of Farroupilha and Caxias do Sul.

For the city of Ipê, the main growth occurs to the east and south, due to the proximity of the ERS 122 highway. Another relevant factor for this growth direction can be attributed to the attraction between the cities of Ipê and Antônio Prado. Therefore, it was concluded that the primary growth direction for the city is eastward, while growth to the north is more restricted.

In the city of Monte Belo do Sul, it was observed that the main growth occurs to the north, while growth to the east is directed toward Bento Gonçalves. On the other hand, growth to the south is limited.

In Pinto Bandeira, it was concluded that growth to the north, east, and south is similarly limited compared to growth to the west. This limitation is due to the more rugged topography in the north, east, and south, while the predominantly flat terrain to the west encourages urban expansion in that direction.

From the analysis of the city of Nova Pádua, it was concluded that the primary growth direction is westward, driven by the attraction of the Rio das Antas. Growth to the south and east is limited by rugged terrain, while growth to the north is encouraged by the more favorable, flat topography.

Regarding the city of São Marcos, the main growth directions are northward and eastward. Once again, there is a tendency for cities to expand toward flatter areas, a factor frequently observed in the cities analyzed. The flatter terrain to the north and east determines a growth trend in these directions, as seen on the map.

Analyzing the growth projection map for the city of Santa Tereza, it was observed that the main growth is eastward, towards Monte Belo do Sul, while growth to the west and

south is limited. From these analyses, two hypotheses were developed: there is an attraction factor between Santa Tereza and Monte Belo do Sul, and growth to the west and south is constrained by the Taquari River, which acts as a physical barrier, limiting the city's development.

6. FINAL CONSIDERATIONS

Based on the points raised in each of the municipalities, it was possible to identify certain patterns in the growth of urban forms in the cities of the Metropolitan Region of Serra Gaúcha. Initially, it is worth highlighting two crucial limiting factors that recur in several of the analyzed cities: the factor of topography and the presence of the ERS-122 highway. The rugged topography, characteristic of the altitude of the region as a whole, represents a significant challenge for urban expansion and becomes a limiting factor for growth, as it complicates organic expansion due to the complexity of construction – a point that ultimately concentrates urbanization in flatter and more accessible areas. The uneven terrain leads to increased costs for infrastructure development and building projects, making it less feasible to expand into hilly or mountainous zones. As a result, urban growth is funneled into more level, easily developable areas, which can lead to higher population densities and an uneven distribution of resources and services across the municipalities. Additionally, these geographical constraints can slow down development projects and increase the time required for expansion, further complicating the overall planning process.

On the other hand, another limiting factor playing a fundamental role in the analysis is the ERS-122 highway. As one of the main traffic routes in the region, this road – which passes through several of the mentioned cities – has become a growth-limiting factor. Although important for the connectivity of the cities, it has turned into a physical barrier to urban growth, as it forces expansion in directions that do not conflict with the road's extension. The highway, while essential for trade and mobility, divides urban areas and restricts how cities can grow on either side of it. This constraint creates an imbalance in the distribution of urban land and development opportunities, as some parts of the cities become more isolated or harder to access, leading to less investment and slower growth in those areas. Moreover, the need to build infrastructure around this highway adds another layer of complexity to urban planning efforts, as cities must navigate the physical limitations imposed by the road while also considering the environmental and socio-economic impacts of expanding into previously undeveloped regions.

Moreover, considering the results obtained, a relevant growth pattern was identified: the expansion of cities in the Serra Gaúcha towards the Rio das Antas. This commonality in the NE (Northeast) direction opens new hypotheses suggesting that the Rio das Antas could be an important axis of development for the Metropolitan Region of Serra Gaúcha in subsequent analyses. The natural resources and landscape around Rio das Antas may present new opportunities for economic activities, tourism, and residential expansion, thereby positioning the region as a future growth hub. The movement toward this area suggests a gradual shift in the cities' focal points, likely motivated by the search for less restricted land for expansion, as well as the potential for developing new economic centers away from the more congested central areas. This trend also indicates that future urban growth may need to integrate sustainable practices to ensure that development along the river corridor does not lead to environmental degradation or imbalances in local ecosystems.

If the direction of greatest growth is considered, the growth of the cities over the indicated time series could be evaluated, as well as future trends explored, acting in accordance with predictive planning. As an ongoing research, there are still other measures to be explored, but the methodology used thus far proves to be promising for further projections, considering physical constraints, for example. With these analyses, urban planners and policymakers could create more effective growth strategies that align with the natural landscape, addressing not only the limitations imposed by geography and infrastructure but also identifying new opportunities for sustainable growth. Regional planning could benefit from such measures when developing integrated regional public policies, such as planning new highways or identifying the location of a major attraction hub that extends beyond the borders of a single municipality. Through a collaborative and multi-municipal approach, governments could work together to create a cohesive development strategy that leverages the strengths of each city while mitigating the individual challenges they face. These coordinated efforts would be critical in creating a more balanced and prosperous future for the entire region.

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