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***Abstract**: The main objective of this study is to elaborate a tool for evaluating the sustainable urban expansion in rural areas. Such evaluation is carried out through multicriteria analysis, where aspects such infrastructure and the probability and challenges for the region to have sustainable expansion. Through this tool it will be possible to evaluate the occupation of rural areas, with an easy-to-operation analysis instrument using the multicriteria analysis. The use of this technique helped to validate the tool with the consulted specialists, bringing an even broader view to it due to the multidisciplinary of the respondents. The tool allows us to carry out this survey using the bibliography, public documents and field visits, thus being able to have actualized information of great importance for the construction of action plans for an expansion in rural areas, contemplating the socio-environmental and economic needs.*

***Keywords:** Urban development; Sustainability; Cities.*

***Resumo**: O objetivo do estudo é elaborar uma ferramenta para avaliação da expansão urbana sustentável em áreas rurais. Tal avaliação se dá pela análise de multicritério, onde é avaliado aspectos como infraestrutura, saneamento assim como aspectos sociais e de governança local, irá elencar e destacar os principais desafios para que se tenha expansão sustentável. Através desta ferramenta será possível avaliar a ocupação de áreas rurais, com um instrumento de análise de fácil operação utilizando a análise multicritério alinhada com o método Delphi de confirmação. A ferramenta elaborada permite analisar áreas rurais com foco na expansão urbana para estas regiões. Para o estudo de caso foi utilizado a cidade de Novo Hamburgo e sua área rural: Lomba Grande, onde a qual foi avaliada utilizando a ferramenta.*

***Palavras chave**: Sustentabilidade; Desenvolvimento Urbano; Cidades.*

1. Introduction

The expansion process always be continuous and makes municipalities to seek to create guidelines for that safe and sustainable growth could be possible, for both the environment and for people. The planning of expansion of a city must be planned with the support of tools that help the public power to understand its space in an environmental, cultural and socioeconomic way. The

development of an adequate zoning plan brings the necessary information to decision-making and creation of guidelines based on a real context. According with (RIEGEL *et al*., 2019, knowing the environmental, physic, social and economic characteristics can be considered the first step to manage the territory in a sustainable way, focusing on reducing impacts on the environment.

The urbanization process advances quickly and becomes a global problem. An incipient population growth, which brings new questions in the way of living and producing becomes an alert for planners and the sustainability of cities (MATURANA *et al*., 2019)". New sociospatial and organizational configurations are emerging, this phenomenon is called extensive urbanization, which is the extension movement of the urban conditions and lifestyles beyond the metropolises. Due to this movement, we have a new relationship between the rural and the urban, since that urban development takes place in regions considered rural in the municipalities (SANCHO; DEUS, 2015).

The municipality of Novo Hamburgo – RS, located in the metropolitan region of Porto Alegre, faces with the populational growth in its rural region. There is an extensive rural area, with a large part of vegetation also being contemplated with marshes and areas of environmental preservation. What is worrying is the possibility of expansion in this region without an appropriate guideline for its environmental planning, with a focus on minimizing the impacts of urbanization in the rural region (RIEGEL, 2021).

Thus, it is necessary to have a plan for use of these areas, taking for consideration the best way of using and occupying the land and quality of life for the community, observing the delimitation of areas of environmental preservation and the adequate infrastructure for the regions already occupied. This way, the object of study of this research consists on elaboration of a tool to evaluate the sustainability of urban expansion in rural areas, so that the ordering of this occupation causes the least possible environmental impact. It is considered fundamental the construction of cities more resilient, with actions to be considered in urban design and in the strategies focused on the sustainable development of cities (AVERSA, ROTGERE; SENISE, 2020).

2. **Material and methods**

2.1 *Study area*

The methodology adopted in the research was initially through bibliographical research, using already published materials, which address urban expansion in general and later its impacts in rural areas. The use of multicriteria analysis for posterior use of the technique in the elaboration of the expansion sustainability analysis tool was also a focus of the research. The bibliographical research occurred through articles, books, periodicals and specialized websites. The Scielo, Google Scholar, Meu Pergamum and Scopus digital platforms were used for the research base. To carry out the search, the following keywords were used: urban, rural expansion, multicriteria analysis.

For the construction of the multicriteria analysis tool, the theme was studied through the bibliography. The Multicriteria Analysis or also called Multicriteria Support to Decision (MSD) is a tool applied when there are situations which decisions need to be guided by objective and transparent technical criteria, as well as taking into account the political and subjective nature of the decision makers (REIS, 2015). The use of multicriteria analysis techniques in situations involving management policies and territorial planning is widely used, as this method allow the hierarchical visualization of certain interests over others (COSTA, 2021). With the perception of the population growth in rural areas for housing purposes, a multicriteria analysis model (MCA) was built, with the aim of being used as a general analysis tool for evaluating urban expansion.

The aspects adapted were selected with a view to using the tool in a general scope, domains that are common to different contexts and fundamental for the possibility of housing were formulated, for example issues of land occupation, urban management and social aspects. In this way, the tool becomes of general use, serving for analyses in different places. The greatest adaptation was made in the technical aspects, where more detailed of evaluation items were opened, such as basic sanitation, where in the 21 st century Brazil still faces major challenges in assistance sanitation services (OLIVEIRA *et al*, 2019). But this is a global challenge, according to reports from the Joint Monitoring Programme, the group that monitors sustainable development goal number six. Five years after the creation of the SDGs, the world is not on track to achieve the objectives for water and sanitation. To achieve what was proposed by 2030, it would be necessary to quadruple the progress that has been made so far. Table 1 presents all the items that were addressed in the tool.

Table 1. Analysis tool elements.

Subdomain	Indicator	Sub-indicator	
Social aspects	Urban safety	Crimes (robberies, murders, etc.	Q1
		Road accidents	Q2
		Police and fire stations	Q3
	Basic Education	Child Education	Q4
		Elementary School	Q5
		High School	Q6
	Health		Q7
Urban equipment	Patrimony, Public and green spaces	Patrimony	Q8
		Public spaces	Q9
		Green spaces	Q10
	Basic infrastructure services	Eletric energy	Q11
		Circulation routes	Q12
		Street Lighting	Q13
		Public transportation	Q14
	Basic sanitation	Water	Q15
		Sanitary sewage	Q16
		Solid waste	Q17
		Urban drainage	Q18
Urban growth	Land use and occupation		Q19
	Risks and damages	Floods and overflow	Q20
		Landslides	Q21
	Preservation áreas		Q22

Source:

This way, the aspects were selected due to the importance found for construction of a society. The subdomain of social aspects is important in the analysis because in cases of urban expansion, socioeconomic vulnerability is associated to the process (QUEIROZ, MORAIS, ALOUFA, 2019). Therefore, considering these aspects becomes fundamental in the evolution of municipalities, as well as the subdomain of planning and urban equipment management, analyzing the existing or necessary infrastructure or guarantee decent housing. Basic sanitation for people's quality of life is an important element (GONÇALVES, SILVA, NUNES, 2016), in addition to being in full agreement with the objective of sustainable development of number six, which deals exclusively with ensuring the availability and management sustainable water and sanitation for all. The subdomain Configuration of urban growth and Land use and occupation is used to be able to represent the conflicts

appropriation of spaces that can be generate in the municipality and achieve greater order in land use (BRANDANI, 2018).

2.2 Validation of the Multicriteria tool

For validation of the sustainability analysis tool in rural areas, it was sent by electronic mail between the months of November to January to thirteen specialists who contributed to the tool with their technical knowledge (MATZNAUER, 2003). After analyzing the tool, ten of the specialists with positions and different backgrounds from each other (Table 2), returned with the analysis and their respective suggestions, comments, besides values that represents the level of adherence of the topics in relation to the importance of the subject for the sustainability analysis of a region, as well as, in ascending order, the degree of importance of each subdomain.

Table 2. Specialists.

Profession of Specialists	
Profession	**Quantity**
Autonomous	3
Professor	3
Project Analyst	2
Specialist in Sanitation	1
Environmental Manager	1
Specialists formation	
Background	**Quantity**
Biology	1
Law	1
Civil Engineering	3
Pedagogy	1
Architecture and Urbanism	2
Environmental Management	1
Administration	1

After the specialists' evaluations, the subdomains were ranked in order to be able to help in the construction of the weights of each indicator, that is, each specialist listed the position from 1 to 4, with 1 bring the most important to be considered in the analysis 4, according to in Table 3.

Table 3. Subdomain Ranking Example.

SUBDOMAIN	POSITION
Land use and occupation	1
Planning and Management of urban equipment's	2
Configuration of urban growth	3
Social aspects	4

To obtain the results, the scores given for each subdomain of all evaluators were added, then multiplied by the sum of the results of all scores, thus obtaining the percentage that each subdomain represents, as seen in the following equation (1):

$$Weigt(\%) = \frac{X^{n+1}.100}{Z} \qquad (1)$$

Being,

X^{n+1}: sum of specialists scores for each subdomain;

Z: sum of all subdomain results;

Weight %: value in % of subdomain reference weight;

In addition, a scale from 1 to 5 was used, so that the specialists could assess the importance of the indicator listed for the analysis that the tool is proposed to carry out, where 1 means that the indicator has no adherence and 5 total adherence to the subject. After the specialist's feedback, Kendall's correlation coefficient was used, a statistic method that measures their correlation between two quantities. Kendall's coefficient has properties that make it more robust to extreme data, greater capacity of population inference and lower estimation error. The correlation is represented by the coefficients, which assume values of -1 and +1, representing the greatest possible extension and the smallest acceptable distance (MIOTT, 2018). To analyze the reliability and the adherence of the scale, Cronbach's Alfa coefficient was used, it was a technique used to asses reliability, having a good application in questionnaires (GASPAR; SHIMOYA, 2017).

After sending the specialists answers, the tool maintained every domains and subdomains initially proposed, however each of these items will no longer be scored, but will be evaluated qualitatively. The tool will bring a qualitative report of the region raising characteristics and local needs. With the tool, the evaluators will be able to analyze, research and report all the demands and needs of the region. This information can be found through public documents, bibliographic research, interviews and field visits. The tool was applied in the city of Novo Hamburgo, which served as a case study for the present work.

The tool, evaluators will be able to analyze, research and report all the demands and needs of the region. This information can be found through public documents, bibliographic research, interviews and field visits and analysis of the occupied area through photogrammetry. The tool was applied in the citu of Novo Hamburgo, which served as a case study for the present work. The municipality has a large rural area. That is undergoing growth, so the region of Lomba Grande will be used to apply the concepts of the tool designed to assess the potential for expansion of the locality. The case study was carried out through the application of the tool in the region of Lomba Grande, considering: Field study carried out between September and October 2022, in the main access roads and qualitative interviews with residents of the region; survey with remotely piloted system, using DJI Mavic 2, model drone; and diagnosis of Lomba Grande in the Environmental, Economic and Social dimensions presented in the Environmental Urban Master Plan of Novo Hamburgo -2022.

3. Results and discussion

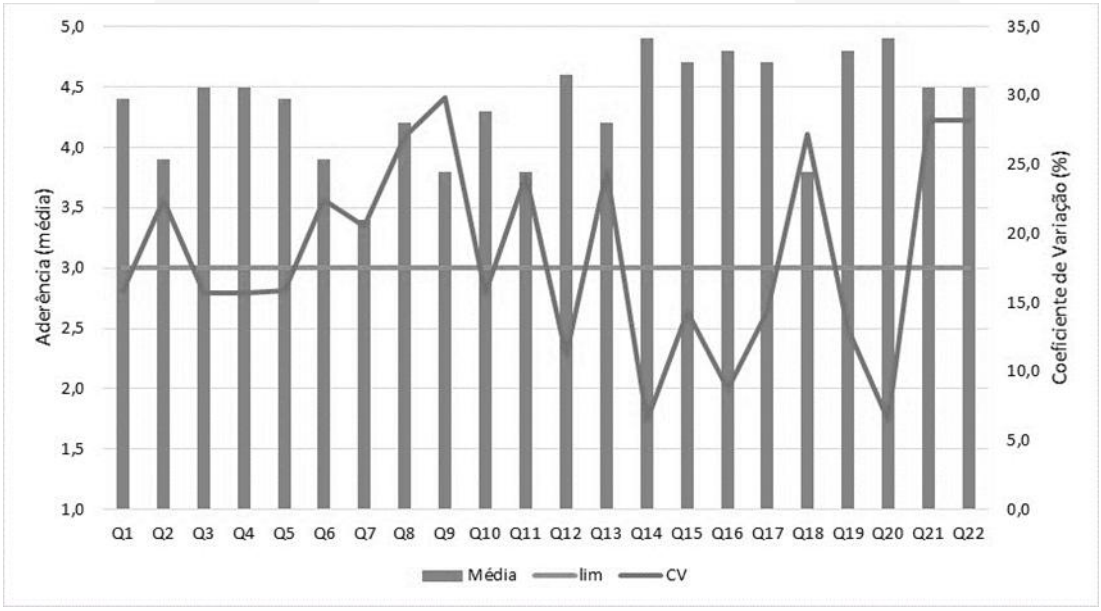
3.1 Multicriteria assessment tool

Through multicriteria analysis it is possible to come to an evaluation considering the performance of urban expansion, using sustainable development parameters (SOARES, FONSECA, RAMOS, 2018). The analysis was carried out by 10 specialists, which is called Delphi Technique. In this evaluation, specialists from different areas of study evaluated the importance of the subdomains that were used with grades from one to five, with grade one representing that the subdomain has no adherence to the subject and five total adherences to the subdomain. The specialists took into account that this tool will be structured for use in different regions, and for this work, the AMC model applied to the case of the municipality of Novo Hamburgo in the rural region of Lomba Grande as a case study. Kendall's W test was applied. It can be observed that exist a certain agreement regarding the adherence of the attributes realized by the evaluators, when analyzing the correlation of the sent answers (WK=0,339), which is significant ($p < 0,001$). As for the reliability of the scale used to evaluate the adherence of the questions by the specialists, it was possible to considered high (0,881), through the Cronbach's Alpha test.

The graph shows the average level of adherence to the questions presented to the specialists, the coefficient of variation (CV) and the intermediate value of the scale used (3). Observing the graph, the question with the lowest adherence on average is the Q7. This presented mean adherence lower than the other attributes, but equally above what is considered moderate (3). The questions with the greatest divergence among the specialists are Q9, Q18, Q21 and Q22, where they have the highest CV. The questions with the highest agreement regarding adherence by the specialists were Q12, Q14 a Q17, Q19 and Q20, with lower CV.

Figure 1 displays a map of environmental degradation represented from four parameters analyzed and weighted by the AHP method, demonstrating that the greatest potential for risk categorized as "very high" are related to dams. This is related to two issues, the first refers to the use of exposed soil, increasing the inefficiency of the grain production system, causing losses in the production process. The management styles adopted by these farmers at some point leaves the land without vegetative cover, leading to possible impacts such as soil erosion, silting of water resources and loss of soil productivity (DAL MORO *et al*., 2021). The environmental system sometimes does not support certain cultivation techniques, causing erosion, soil movement and areas with lack of nutrients.

Figure 1: Risk of environmental degradation



Source: Elaborated by the authors

In order to calculate the weights through the specialists' responses, it was possible to make the respective assignments feasible (RIBEIRO; COSTA, 2014), where the proportional weighting was attributed to the importance scores assigned by the specialists. From the analysis of each return, it was possible to verify that the tool serves as a roadmap for gathering information, as it leads to reflection on various aspects necessary for urban expansion in rural areas. With the discussions brought by the specialists is possible to perceive that after the application of the tool to analyze the area, several new questions can be generated to verify the possibility of this expansion. Since these new points raised cannot be translated into a sustainability value and do not serve as topic inclusion in the tool, after all, each discussion can be different according to the place that will be worked on.

However, topics such as those raised by the specialists arise after analyzing the results achieved with the tool: age group, social class, investments, etc. Points like these helps to define the importance of having more schools or having more health centers. Each targeted group has different life needs, in the real state market there are vector terms of expansion and real state valuation. These are factors that have a great impact on the decision to expand a city, and it is necessary to evaluate this taking into account the needs of the municipality, the local characteristics and who already inhabits the place, in this way a debate is born to discuss the challenges, limits and potentialities for the creation of a less exclusive and more democratic city (BARCELLA; MELAZZO, 2019).

By analyzing the survey carried out in Lomba Grande and using the subdomains as a reference according to the weights ranked by the specialists, it was verified that there are several challenges to be overcome so that urban expansion can occur in this region in a sustainable way. The attributes that should be highlighted in a Master Plan, should be Land use and occupation and Planning and management of urban equipment, which represent a total of 64% of the attributions of the specialists. Land use and occupation: this topic is the one with the greatest weight according to the experts' responses and even though this subject is defined in a master plan, it is possible to verify in the region, through field visits carried out by the authors, that land use does not occur of the occupations within the current norms, the occupation of the soil decreases the permeability index that leads to bigger problems such as floods (SANTOS, RUFINO, FILHO, 2017). It is possible to verify an inadequate growth of housing and land use in marsh regions and preservation areas, these actions can result in compromising the quality of water resources in the region, as well as constant flooding (MAIA, STROHAECKER, GUASSELLI, 2017).

Planning and Management of Urban Equipment: this is the most challenging item, especially in terms of basic sanitation. As already mentioned in the course of the work, the city of Novo Hamburgo already has a study of service to the rural location, which was revised in 2022, where the four axes that make up the municipal sanitation plan were reviewed (water, sewage, waste and drainage urban). For the rural region of Lomba Grande, supply will continue with individual, private or community wells, which must be granted or explored according to specific legislation. For the already urbanized region of Lomba Grande, it foresees the development of supply projects guaranteeing the universalization of treated water. The most convenient and economical technical projects would be the capture of groundwater, however this format of use for water distribution must be carried out with caution and planning, after all it is a methodology that impacts on the recharge of aquifers, which can generate long-term problems in regarding the sustainability of this action and continuity of supply (OLIVEIRA *et al*., 2019). Basic sanitation is an important element for people's health in addition to the quality and preservation of the environment (GONÇALVES, SILVA,

NUNES, 2016), being a great challenge to be faced so that Lomba Grande can have an adequate and sustainable urban expansion.

Configuration and urban growth: The city of Novo Hamburgo has a history full of events facing problems with floods. It is noticed that the expansions occur in humid areas and of environmental preservation, in the great part of these occupations it is possible to verify enterprises or constructions of medium and high standard. In cases such as the housing of these spaces that do not occur only due to irregular occupation, it ends up not only with the omission of the public power by the urban planning, but also a deliberate action that grants them the necessary authorizations for the implantation of the enterprises (FERREIRA, 2019).

Social aspects: in a field visit, it was possible to verify that the region's growth is due to people who have a more stable financial position and a higher age group. In this way, a more in-depth study of the resident profile is necessary to verify the need for more schools, as well as health centers. The process of urbanization in rural areas is a phenomenon that promotes real estate speculation, generating an appreciation of areas, promoting the event of gentrification, which is the process of socio-spatial segregation, which characterizes the accentuated appreciation of a certain area culminating in the departure of old residents due to the cost of living and excluding people with lower purchasing power or in vulnerability (FILHO; MARTINI, 2021).

The rural region of Lomba Grande had an expressive growth, where there was an increase in the already urbanized area as well as a population growth in the rural area. The development of a region without the correct follow-up can bring harm to both the population and the environment. It is necessary to invest in more sustainable cities, using modern structural measures and non-structural instruments, planning cities in an environmentally integrated way the regions that are inserted (FERREIRA, 2019).

4. Conclusion

It is possible to identify a change in people's behavior in relation to quality of life. The way you live and where you live is a very important factor in improving the way you live. With the Covid-19 pandemic, this factor was even more relevant, as the house became the center of everything in people's lives. The search for homes in areas of connection with nature becomes the desire of many families and with that is seen a high search for real estate in rural areas and small towns, leading these regions to have an unplanned population growth. Most of these rural areas do not have adequate planning or the capacity to absorb major changes, after all, with the arrival of more people, the need for urban management equipment becomes indispensable to guarantee decent housing. In addition, with the accelerated pace of real estate pressure, the inappropriate use of land in the regions occurs, which may generate complications for residents and the environment in the future.

The developed tool allows a dynamic and complete assessment to be carried out, addressing all the axes necessary to have urban expansion in rural areas in a sustainable way, aligning the needs of the place and the demands generated by the people. The tool makes it possible to carry out a survey of the area that intends to be used for this expansion and makes it possible to measure the future needs for this action to occur in a safe and sustainable way. The tool was used to evaluate the rural area of the city of Novo Hamburgo, which experienced rapid population growth, especially during the pandemic period. The region faces major challenges to be resolved, which demonstrate that care with expansion is needed. The use and occupation of the soil predicts low intensity of occupation due to

wetland areas and environmental preservation, however it is possible to verify an occupation around areas of risk that have already suffered and may suffer again from flooding problems.

The tool brought to the discussion several topics that need to be seen by the public administration so that the expansion in rural areas is carried out due to a real need for city growth and, if necessary, carried out in a sustainable way for the region. Lomba Grande has potential for expansion, however it is necessary a more active inspection by the government so that the issue of land use and occupation is respected by entrepreneurs and residents. With the correct use of the soil and projects that are aligned with the master plan, it will be possible to foresee the necessary actions for the creation of urban equipment and configuration of healthy and economically viable growth.

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