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Research Article

Influence of the Vibration Caused by Bus Circulation on the Built Heritage in the Center of Ponta Grossa – Brazil

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ABSTRACT

Ponta Grossa is a Brazilian medium city where the dynamics of urban development has always been conditioned to its privileged geographic location. The implantation of the railroad system has transformed the town completely. Among with the rapid development subsequent to the railroad arrival, on the early 20th century, the architecture in Ponta Grossa has also advanced. Thus, many of the buildings that are heritage protected today are from this period, especially eclectic style palaces. The nuisance caused by the vibration of heavy vehicles in the surroundings of historical buildings is one of many quotidian urban issues that are accentuated with time passing. Not only does such vibration impact on life quality of citizens, but it also may occasion structural damage to heritage architecture. The main goal of this paper is to analyze how susceptible the local historical architecture is to pathology caused by the vibration of heavy vehicles, mainly buses, in Ponta Grossa, Brazil. Seven buildings have been analyzed, all of them protected due to their historical importance. The list of protected buildings, additional information from the local municipality and the transportation department have been used for this analysis, as well as data from the local mobility plan. Heat maps have been produced, illustrating the number of daily trips on each bus line. Additionally, professionals that operate on the field of building restoration have been interviewed, as to obtain information related to the susceptibility degree of diverse elements and constructive methods, for the lack of specific legislation on the matter. With use of the information obtained, analysis methods have been developed by the authors as to identify the susceptibility of the buildings based on their characteristics. The methods made possible to identify the fragilized spots on historical buildings related to bus circulation in their surroundings. The results indicate high susceptibility of traditional building methods to vibration and significant impact on buildings near to intense traffic.

Keywords: Damage to historical heritage, Ponta Grossa – Brazil, Susceptibility of historic buildings, Traffic-induced effect, Urban vibration.

INTRODUCTION

Accelerated urban development and the disorderly growth of cities lead to their destruction when urban fabrics and forms are not respected. This fact may be related to the increase in the use of automobiles, which leads to the emergence of changes in urban dynamics. (Gevú; Varela; Niemeyer, 2020).

The densification caused by urban development contributes to the problems currently known, such as the emergence of heat islands and discomfort caused by vehicle traffic that causes vibration in the urban environment (Brito; Soares; Nazari, 2013). Thus, the higher the speed of these vehicles, the more damage is caused, resulting in "sharp deformations in the terrain, with risks to the structures of the galleries and the supports" (Resende, 2011, p.38). Environmental vibration is little considered in urban analyses, especially those related to historic buildings, where the effects arising from this vibration can address a classificatory analysis both in relation to its discomfort and its damage to the buildings (Brito; Kamimura; Santos, 2015).

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Damage that may be caused by urban vibration must be considered when planning the surroundings of more susceptible buildings. According to the Washington Charter for the Conservation of Historic Places (1987), which highlights problems related to the free movement of heavy vehicles in Historic Centers, there must be regulations to limit traffic and/or its speed in the surroundings of these protected buildings.

Knowing that the accumulation of motor vehicle circulation generates significant impacts on historic buildings, among which pollution caused by vibration and noise can be highlighted, given the rapid development of road infrastructure which results in a decisive impact on the durability of historic buildings (Kowalska-; Stypuła, 2016). The main goal of this study is to analyze the level of susceptibility of historic buildings in Ponta Grossa, Brazil, to pathologies caused by vibration from heavy vehicles, mainly buses.

METHODS

In order to achieve the established goal, a bibliographic and normative survey was carried out regarding the influence of vibration from heavy vehicles on historical buildings, especially eclectic ones from the beginning and middle of the 20th century. Professionals with experience in restoration, requalification and interventions in buildings similar to those studied were also consulted, in order to obtain an overview of the construction elements with greater susceptibility.

The locational cartograms of the buildings, as well as the heat maps related to the proximity of bus circulation, were produced with the Quantum Gis tool. The routes of the public transport lines were obtained in a shapefile file through the database of the Municipality of Ponta Grossa, and the update of the bus stops was verified with the help of Google Maps. For the data related to the buildings, the inventories of the buildings were used, data obtained through field surveys.

HISTORICAL HERITAGE AND THE IMPACT CAUSED BY VIBRATION OF MOTOR VEHICLE TRAFFIC

A city has its own characteristics, related to its evolutionary process, through its buildings, way of life and adaptation of standards (Dropa et al., 2012). However, even if there is a need for constant updating and adaptation of the city, building and rebuilding spaces, there are ways to protect assets considered historical heritage through safeguarding at the municipal, state and federal levels. Among the Heritage Charters, documents of global interest regarding heritage preservation, there are the “Valletta Principles”, which indicate that the infrastructures that support urban traffic need to be planned so as not to damage the “historical fabric” or its surroundings, encouraging the creation of arterial roads, with fast circulation (CIVVIH, 2011, p.11). According to that document, the buffer zone has the role of “defending the cultural values of the protected area against the impact of activities produced in the surrounding area”, whether this impact is physical, visual or social (CIVVIH, 2011, p.3).

One of the effects of urban densification is the discomfort caused by the vibratory energy generated by the urban environment, mainly related to the exclusion of planning guidelines that provide for the distance between buildings and the building alignment (Brito; Soares; Nazari, 2013). Due to the lack of restrictions and the increased use of motorized transport, combined with the accelerated development of modes and the slow technological development in relation to the composition of roads, impacts occur, which directly affect buildings (Brito; Soares; Nazari, 2013).

According to Zini, Betti and Bartoli (2021), there are two types of vibration: short-term, where vibrations are transient, and long-term, with continuous vibrations, the latter being capable of producing fatigue damage to structures after several cycles, through structural resonance, and transient vibrations can produce punctual damage according to their power. The damage caused by vibration to historic buildings can be classified into two types. Structural damage affects the function or use of the building, while architectural damage affects the most fragile and aesthetic elements, being “more annoying than dangerous and starting at a much lower level of movement than structural damage” (Chiostrini; Marradi; Vignoli, 1995, p. 70).

It has been found that vibration waves caused by road traffic are continuous for a period of eight hours or more, are long-term and recurrent, causing vibration in both vertical and horizontal directions (Urushadze; Pirner, 2020). In addition to structural damage, vibrations can cause cosmetic or architectural damage, constituting a serious threat

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to Heritage, where this damage is accentuated by several factors, such as the low level of maintenance, the effects of pollution, the growing demand for public transport leading to massive use of heavy vehicles, pavement irregularities and the proximity of these buildings to heavy vehicle flows (Zini; Betti; Bartoli, 2021).

According to Zhu et al. (2023), vibrations caused by heavy vehicles are more sensitive to changes in speed, given the "shock effect", in which the energy generated is attenuated during its propagation. Therefore, the further away the vibration source, the lower the intensity of the vibration at the point where it is measured. Bus traffic emits vibrations similar to those of freight vehicles. Speed affects vibration impacts, and the higher the speed, the more damage is caused. Vibrations result in sharp deformations in the terrain, with risks to the structures of the galleries and supports (Resende, 2011).

The effect of vibrations is presented through lesions or cracks present in the building's panels. This damage is caused in historical buildings, but not only in them, also occurring in modern buildings, the latter being more resistant, considering their construction techniques and use of materials, such as braced structures (Resende, 2011). ISO 4866:1990 highlights that the relationship of the construction with the dynamic excitation caused by this vibration leads to cumulative effects which must be considered at high levels and long exposure times, with fatigue damage being a possibility of degradation of the building.

According to Kowalska-Koczwara and Stypuła (2016), there are three main ways to protect historic buildings from vibrations, acting on the source of the vibration, promoting isolation of this vibration, in the propagation path, creating physical barriers preventing these waves from reaching the element and in the building itself through insulation systems on the floors, the first being the most appropriate when dealing with historic buildings.

LOCAL CONTEXT – PONTA GROSSA – BRASIL

The history of Ponta Grossa dates back to indigenous occupations. The same location later became part of the troops' routes and later became an important railway junction (MADALOZZO, 2015). Today, in addition to remaining an important hub for railway traffic, Ponta Grossa is characterized as a fundamental point for road traffic in the south of the country. More than a crossroads of roads, the Municipality acted and acts as a crossroads of "culture, peoples and opportunities for living" (MONASTIRSKY, 2006, p.3).

The urban occupation of Ponta Grossa, as in many other Brazilian cities, began in the area around the main church of the town. The first records of the region where the municipality of Ponta Grossa is located today, in addition to the indigenous presence, come from Castilian travelers on their way to Paraguay. At the beginning of the 16th century, the Jesuits also passed through the region, and in the mid-17th century, troopers arrived at the second Plateau and began to populate the region, already known as Campos Gerais, due to the abundance of water and pasture (CHAMMA, 2007). The most common routes used by each of these groups adapted to the terrain conditions – they preferably passed through the terrain's ridges, using them to create traffic routes and avoiding large portions of land corresponding to valley bottoms, with steep slopes and little viability for establishing roads and buildings. As a result, Ponta Grossa's road system, both rail and highway, developed around the terrain's ridges, approximately radial axes in relation to the city center.

Even today, this situation is reflected in the circulation of people and vehicles through the urban center: the main roads are all approximately radial in relation to the urban center, connecting it to the neighborhoods through ridges in the terrain. The layout of some of these roads coincides with the railway lines. This relationship can be seen in Figure 1, where the red lines represent these main roads and the active railway sections are represented by dashed lines. Due to the intense hydrographic network and the difficulty in crossing streams and other topographical features, there are few connections between neighborhoods. Since Ponta Grossa is a mononuclear city, with a highly attractive urban center, the same roads are targeted by all modes of transport, and the heterogeneous and undersized road network makes mobility challenging.

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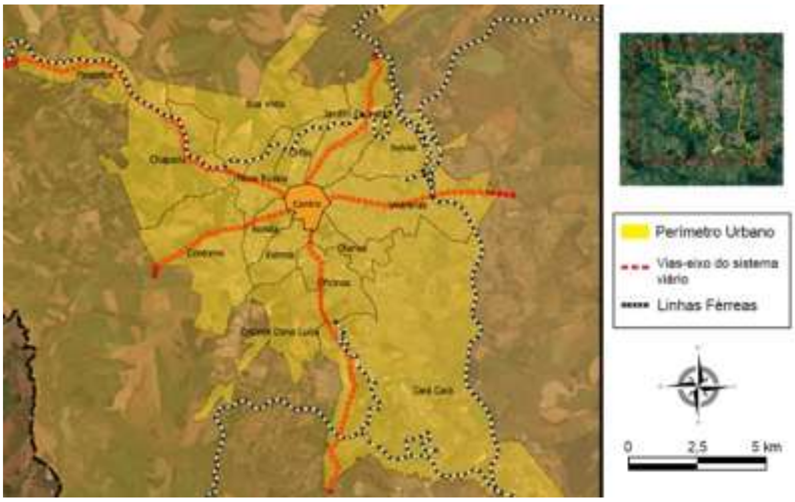

Figure 1. Location of the city center and main roads.

Source: authors, 2025. Data and aerial image obtained with PMPG.

In the 1990s, with the encouragement of road transport throughout Brazil, investment in the railway system was reduced, as was the amount of cargo and the number of passengers transported (MONASTIRSKY, 2006). Since the 1990s, therefore, there has been a significant increase in the circulation of both passenger vehicles and heavy vehicles, such as buses, around the buildings produced during the period of conformation of the urban center, during the 20th century.

RESULTS

Currently, there are over 60 buildings listed for protection at municipal level, and 7 at state level, and one building listed at both levels. This study delimits the 7 historic state level buildings. The age of the buildings studied varies between 92 and 131 years – all of them are from the peak period of eclectic palace construction in the city center. The map in Figure 2 indicates the location of the Municipality of Ponta Grossa in the State of Paraná, the boundaries of the Municipality and the urban perimeter, in addition to the location of the buildings and their proximity to each other. The buildings listed at the state level are highlighted in black on the map and are mostly concentrated in the city center. As an example, the format of the analysis carried out in the building of the former Hospital 26 de Outubro, one of the buildings studied, is presented. All buildings were analyzed in the same way.

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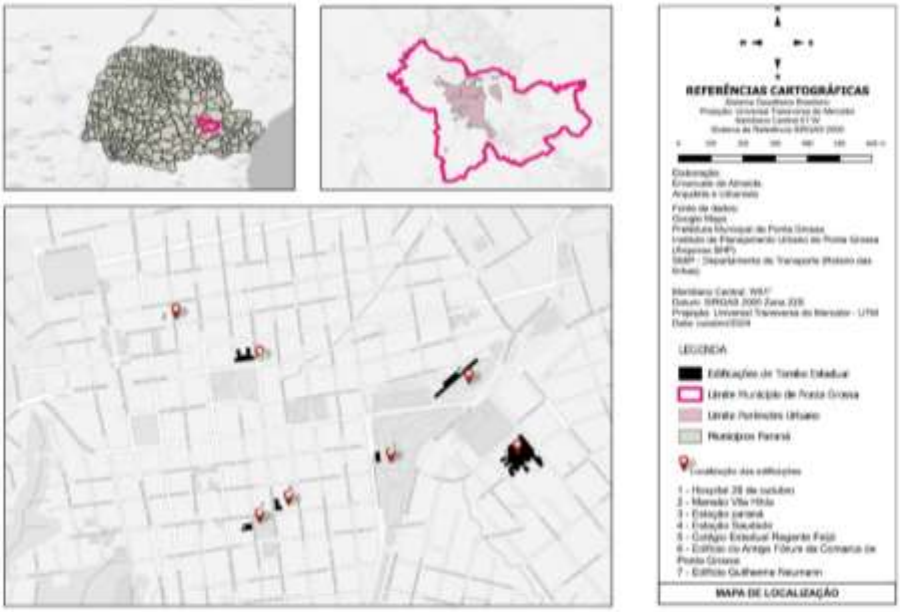

Figure 2 – Location of the selected buildings. Source: Authors, 2025.

The 26 de Outubro Hospital (Picture 3) is a listed building by both municipal and state levels. Located in the city center, it is an eclectic-style building with front and side setbacks and large wooded gardens. Its main façade is approximately 15 meters high. A visual analysis revealed that the structure of the building is elevated, allowing air to circulate through the loopholes located in the building's basement. It has protruding bases, wooden and tile or ceramic floors, and ceramic masonry walls, wood, and partitions. It is located near a shopping center, and its front street is heavily trafficked by passenger and cargo vehicles. Three bus lines currently pass around the building, including the Princesa via Coronel Claudio, Jardim Giana, and Cachoeira lines.

On Picture 4, the influence of the bus lines that run parallel to the building street is demonstrated. Even though the traffic may be considered light, it directly affects a large area of the building's projection, causing greater impact on the main facades, parallel to the roads, due to the building being located on a corner providing access to the shopping mall. The area of influence of the circulation of the circular bus lines reaches a radius of 20 meters, considered the critical distance of direct influence of vibration on the architectural and structural elements of a historic building, where the building absorbs light vibration almost in its entire projection area.

Figure 3 – Main facade of the 26 de Outubro Hospital
Source: Authors, 2025

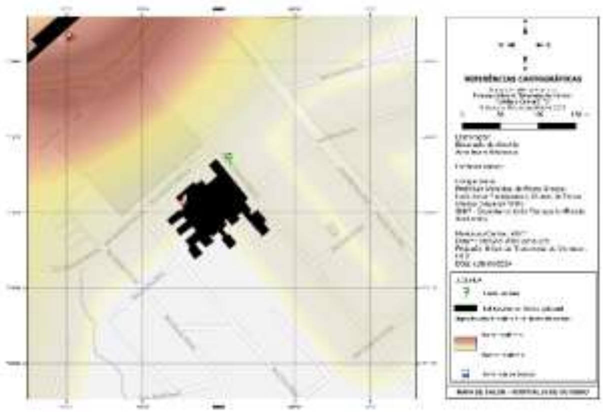

Figure 4 – Heat Map of the influence of bus circulation surrounding 26 de Outubro Hospital
Source: Authors, 2025

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Based on the normative analyses and the consultation carried out with professionals with experience in Brazilian historic buildings, the authors arrived at a susceptibility indicator for each element of the building. The table below (Table 1) presents these values for all the buildings analyzed, with the average value being the arithmetic mean between the degrees of susceptibility of each element of the building.

Table 1.1 Susceptibility of the buildings according to professional perception

Building	Element (foundation)	Foundation material	Constructive system	Material for each element of the constructive system				Average
				Wood	Masonry	Stucco	Rock	
Hospital 26 de Outubro	3,14	3,29	4,07	3,36	3,86	x	x	**3,54**
Mansão Vila Hilda	3,14	3,29	4,07	3,36	3,86	4,64	x	**3,73**
Estação Paraná	3,14	3,29	4,07	3,36	3,86	x	3,29	**3,50**
Estação Ponta Grossa	3,14	3,29	4,07	3,36	3,86	x	3,29	**3,50**
Colégio Estadual Regente Feijó	3,14	3,29	4,07	3,36	3,86	x	x	**3,54**
Edifício do Antigo Fórum da Comarca de Ponta Grossa	3,14	3,29	4,07	3,36	3,86	x	3,29	**3,50**
Edifício Guilherme Neumann	3,14	3,29	4,07	3,36	3,86	x	x	**3,54**

Source: Authors, 2025.

Based on this data, it is possible to observe that some materials used in the buildings studied contribute to the possible degradation that may occur due to the vibration of motor vehicles, with stucco being the most impacted according to the degree of susceptibility given to it (4.64 out of 5), followed by masonry, wood and stone, respectively. The chosen buildings have a certain similarity in relation to the materials used in their construction, do to their dates of building being all similar. The roof structure also stands out as one of the elements that may suffer from these impacts generated in a rigid structure, due to its workability, which may move due to the impact on any point of the building's construction system. Table 2 demonstrates the degree of susceptibility related to the age of the buildings, the number of trips per day on the city's public transport lines that directly impact the surroundings of these buildings, in addition to the degree determined by the setback, measured from the building alignment to the face of the building.

Table 2. Susceptibility of the buildings based on fixed determinations

Building	Age (y)	Susceptibility – age (1 to 5)	Trips per day	Susceptibility - vehicles per day (1 to 5)	Setback (m)	Susceptibility – setback (1 to 5)	Average
Hospital 26 de Outubro	93	2	145	1	10	3	**2,39**
Mansão Vila Hilda	104	2	44	1	20	1	**1,93**

Building	Age (y)	Susceptibility – age (1 to 5)	Trips per day	Susceptibility - vehicles per day (1 to 5)	Setback (m)	Susceptibility – setback (1 to 5)	Average
Estação Paraná	130	3	593	2	3,4	4	**3,13**
Estação Ponta Grossa	124	3	2090	5	52	1	**3,13**
Colégio Estadual Regente Feijó	97	2	1442	4	2	4	**3,39**
Edifício do Antigo Fórum da Comarca de Ponta Grossa	96	2	58	1	2,5	4	**2,63**
Edifício Guilherme Neumann	91	2	184	1	4	4	**2,64**

Source: Authors, 2025.

From the application of data related to the degree of susceptibility, it is possible to observe that the volume of vehicles and the setback have a significant impact on buildings and that the age of these buildings is similar, generating similar analysis parameters in relation to this item. Taking into account the items listed in Table 2, Colégio Estadual Regente Feijó, despite not having the largest volume of daily public transport trips, is the most impacted by its physical factors, such as the setback, as it is close to the road where a large volume of vehicles circulate on three of the four streets that surround it.

The Estação Ponta Grossa building is the second most impacted by the volume of vehicles circulating daily in its surroundings, together with Estação Paraná – both former Railroad Stations, nowadays located significantly near the Central Bus Terminal. It is observed, though, that the setback of this building has a low degree of susceptibility. Considering its advanced age, the building is listed as one of the most susceptible considering the general parameters. Paraná Station, which has the same construction characteristics as Estação Paraná differs in its setback, in addition to having only about 28% of the volume of vehicles passing through its main street. The less susceptibly buildings listed, as may be noted on Table 2, are 26 de Outubro Hospital, a Vila Hilda Mansion, o Former Comarca de Ponta Grossa Forum and Guilherme Neumann Building.

CONCLUSIONS

The main goal of this study was to analyze the level of susceptibility of historic buildings in Ponta Grossa, Brazil, to pathologies caused by vibration from heavy vehicles, mainly buses. During the research, it was possible to observe that there is no way to eliminate discomfort caused by heavy bus traffic, but rather to reduce the damage that may be caused by it. One way to mitigate these effects would be efficient urban planning that considers all urban conditions, such as the location of buildings most susceptible to damage caused by this vibration, in addition to an analysis of the conditions of the roads, correlated to the proposed Urban Mobility Plan.

It is possible to verify that the impacts generated by vibration in historic buildings may compromise their structure and architectural integrity. In order to mitigate these impacts, public authorities responsible for managing the city might create safe traffic zones and limiting the passage of cargo vehicles around these buildings. In order to complement this study, materials that were not subject to analysis but that impact buildings, such as pavement and soil, might be evaluated on future studies.

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