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FRAMEWORK FOR INFRASTRUCTURE RISK ANALYSIS TO PEDESTRIANS IN A UNIVERSITY CAMPUS PARKING

Barbara Stolte BEZERRA
São Paulo State University (UNESP), School of Engineering, Department of Civil and Environmental Engineering, Bauru, Brazil
barbara.bezerra@unesp.br

Gustavo Garcia MANZATO
São Paulo State University (UNESP), School of Engineering, Department of Civil and Environmental Engineering, Bauru, Brazil

Silas Volpon de MELLO
São Paulo State University (UNESP), School of Engineering, Department of Civil and Environmental Engineering, Bauru, Brazil

Anna Silvia P. PEIXOTO
São Paulo State University (UNESP), School of Engineering, Department of Civil and Environmental Engineering, Bauru, Brazil

Mariana Dias Chaves BATISTÃO
São Paulo State University (UNESP), School of Engineering, Department of Civil and Environmental Engineering, Bauru, Brazil

Abstract
This paper presents a framework to analyze the pedestrian's risks due to infrastructure problems in a university campus parking. A geographic information system (GIS) database was created containing data about: cartographic, parking spots, problems of infrastructure and field observations notes. In addition, an analysis of parking capacity and demand was performed, resulting in an Average Occupancy Rate (AOR) of the campus parking. A checklist for field observations was created for the pedestrian's risk analysis, where critical locations could be observed in a thematic map by applying spatial analysis tools. This framework created the first campus database, which has already supported the implementation of some actions for reducing risks to pedestrians. This fact highlights the importance of the framework for the future planning and management of the campus's traffic and parking systems, which can be replicated to similar cases involving risk analysis at university campus parking, due its straightforwardness and low cost for implementation.

Keywordsuniversity campus, parking lot, pedestrians, risk analysis, road infrastructure.

1. INTRODUCTION

In the last decade, the vehicle fleet in Brazil has doubled and continues to grow. According to the National Traffic Department data (DENATRAN, 2013) the fleet in 2000 was approximately 30 million and in 2010 the vehicle fleet reached almost 65 million. In September of 2018 the vehicle fleet reached 99,742,877 vehicles. The Southeast region of Brazil has 50% of the national vehicle fleet and only the State of São Paulo is responsible for 30% of all national vehicle fleet. The main reason for this boom was the economic growth around the year 2010 combined with a government policy of reducing taxes for new automobiles purchases. Thus, the automobile industry had sales records and the number of vehicles circulating increased considerably. However, investment in road infrastructure did not follow this growth, resulting in an increase of the fleet of vehicles without increasing their physical space.

In the case that we investigated in this study, that is, the parking lot of the São Paulo State University (UNESP) campus in the city of Bauru is a reflection of this significant increase in the number of automobiles. In some areas of the campus, the physical space for parking vehicles no longer supports the demand. As a consequence, several vehicles can be found parked irregularly, compromising the circulation of other vehicles and pedestrians. For that reason, there is the need to study the traffic phenomena that take place on the campus.

McIntyre (1990) did a research in several community colleges in California and suggested some guidelines for upgrading the campus parking ambience. Carl and David (2001) developed mathematical models to study the effects of some campus parking politics. Leng and Yan (2003) carried out a study at the Tongji University's campus parking system. Song and Wang (2004) conducted some surveys focusing on campus traffic problems and listed some suggestions. Shang et al. (2007) made a research at the Beijing University of Aeronautics and Astronautics parking and traffic systems focusing on the outflow and inflow of vehicles, parking lot locations, their respective capacity and driver's behaviors.

Miralles-Guash and Domene (2010) conducted a survey to investigate which types of transportation the community of the Autonomous University of Barcelona uses in order to achieve a sustainable transport system. The authors showed that 54% of the university community would choose different modes of transportation. Aoun et al. (2013) investigated parking demand and traffic jam at the American University of Beirut and proposed a solution by encouraging people to use taxi-sharing services.

Riggs (2009 and 2014) analyzed parking problems at UC Berkeley and proposed to charge a price for parking vehicles and incentives with low price for bus trips, in order to reduce solo-driver's trips.

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Moeinaddini et al. (2013) introduced a practical method for the evaluation of parking efficiency at the Universiti Tecknologi Malaysia (UTM) and found critical areas.

Despite the above, there are few research reports aiming at investigating problems in university campus parking systems, especially involving risks to pedestrians. This work suggests a feasible model for the analysis of potential infrastructure risks for pedestrians when circulating in parking lots of an university campus.

2. METHOD

Figure 1 presents the location of the study area. The development of this work involved a data collection on the number of parking spaces on the campus of UNESP and a count of vehicles parked at peak times. These two data sources have been raised according to some pre-established criteria which are described hereafter. Then these data were tabulated and organized, allowing the importance into the geographic information database system for posterior analysis. Also, a checklist for infrastructure risk to pedestrians in parking areas was elaborated.. These steps are described in more detail in the following subsections.

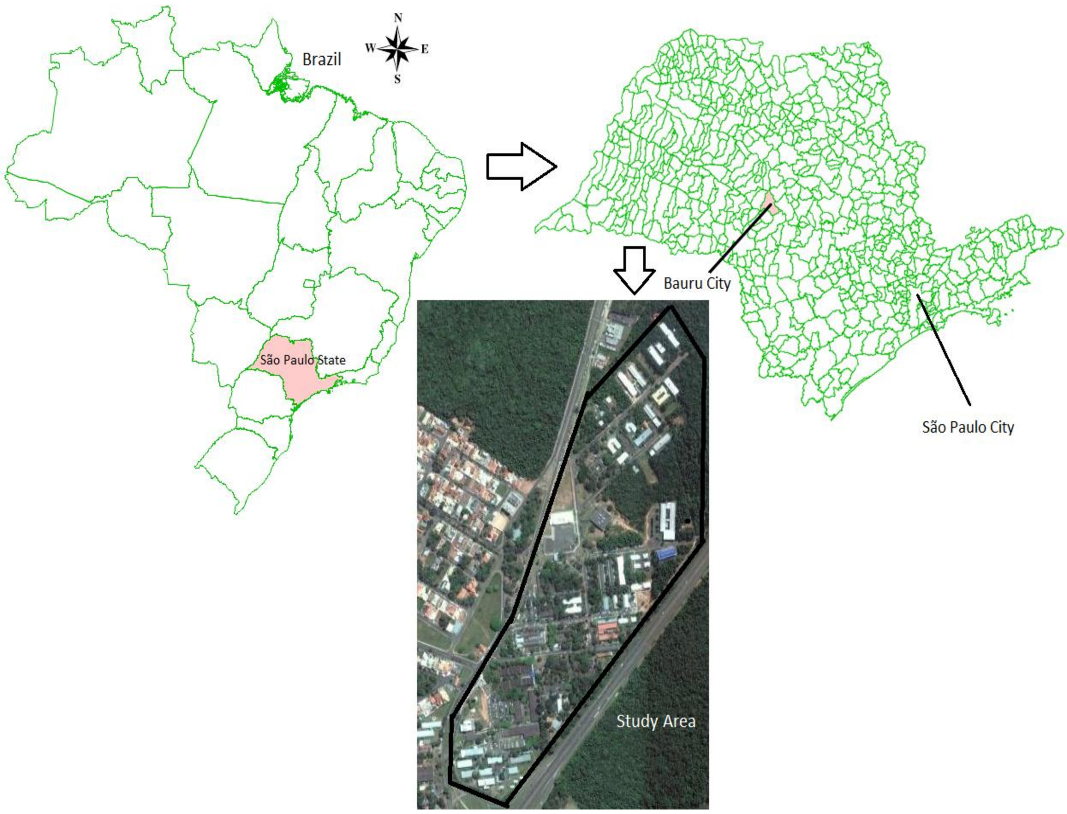

FIGURE 1 - STUDY AREA AT THE UNESP BAURU CAMPUS.

2.1. Parking supply data collection on campus

Vehicle parking places are distributed throughout the campus and are composed of two types. The first type is formed by agglomeration of many car spots constructed specifically for parking called pocket parking lot. The second type, called hallways, is formed by car spots that are located along the campus streets. The campus has a large number of car spots, i.e., more than one thousand, and it became evident the need to subdivide this space for organization and orientation purposes. To subdivide the parking lots, the location of entrances (gates) and campus buildings were taken into account since they are already defined. For this research, six subdivisions of parking lots were considered. These parking lots were subdivided again into smaller areas called pockets or hallways, depending on their characteristics. With this, an identified and georeferenced parking system could be created, since each area had a label for identification and location. Figure 2 shows this procedure.

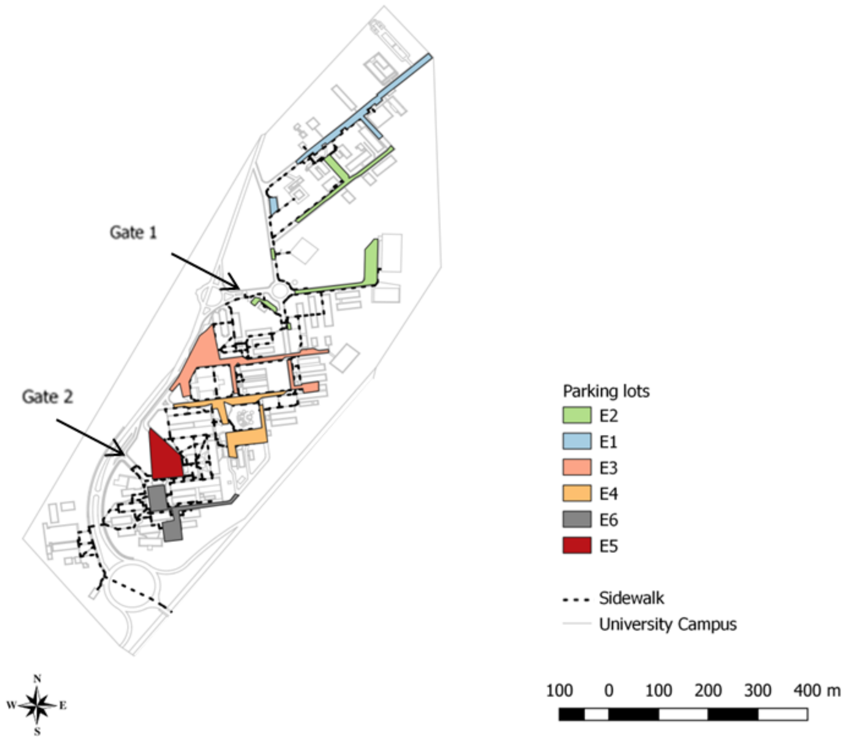

FIGURE 2 - PARKING LOTS AND GATES OF THE UNESP BAURU CAMPUS

To label the parking lot, a nomenclature composed by an alphanumeric system was used. First the letter E is followed by the identifier number of each parking lot, for example E1, E2, E3 (Fig. 2). Then, a sub-label could be added for the identification of the type of parking, i.e., letter P for pocket or letter H

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for hallway. For example, a hallway parking lot could be described as E3-H2 that means hallway two of the third parking lot. And a pocket parking lot could be described as, for example, E4-P3 meaning pocket three of the fourth parking lot.

2.2. Parking demand data collection on campus

In order to collect the demand data, on-site counts were performed to obtain the number of parked vehicles. As the university campus is a large traffic generating pole (DENATRAN, 2001), attracting students and employees daily, in addition to people from all over the São Paulo State and even from other states of Brazil on a regular basis, the days chosen for the best accomplishment of this count were Tuesday, Wednesday and Thursday. This was to guarantee more normal situations in the campus user's routine, since Monday and Friday are days when many people are arriving or leaving due to hometown trips.

The most favorable hours of the selected days for the count were those that represent the highest occupancy or peak of cars. Shang et al. (2007) detected three vehicles inflow peak times corresponding to: 7am to 8:30am, 1:40pm to 2:30pm, and 6:40 to 7:30pm.

The campus we studied is open from 7am to 11:30pm, but the number of people and consequently the number of cars on campus tends to be higher during business hours, that is, from 8am to 6pm. This occurs because in addition to the students, professors and researchers, several employees work on campus for the university administration, banks and other services offered.. In view of this restriction, two schedules were chosen for data collection: from 8:30am to 9am and from 2:30pm to 3:00pm, when the campus users were expected to have already arrived and parked their cars.

The car demand count was carried out on April 23, 24 and 25 of 2013. After concluding the counts, a spreadsheet was elaborated with all results. With the demand results obtained for each day studied, the average demand for each parking lot was calculated. The results were incorporated into the geographic information system to perform the spatial analyses.

2.3. Average Occupancy Rate

With the two data sources above, an Average Occupancy Rate (AOR) for each parking lot could be created and determined by simply dividing the Average Occupancy data by the number of parking supply.

$$\mathrm{AOR} = \frac{\text{Average Occupancy}}{\text{Parking Supply}} \text{(cars/spot)}$$

Combining the average occupancy with the number of parking supply, the average occupancy rate results in an estimate of how many vehicles per parking spot the parking lot operates at peak times. This result measures, in cars per spot unit or percentage, how requested the parking lot operates.

2.4. Assessment of Infrastructure risk to Pedestrians

To identify vulnerable points for pedestrians due to infrastructure, a checklist was elaborated. The checklist contains the main infrastructure elements that can contribute for pedestrian risk in parking lots. These infrastructure elements were identified by an expert panel, composed by 11 road safety professionals. The main infrastructure elements were classified in three dimensions: layout of the parking lot, pavement and drainage, and provision for pedestrian. The final checklist is presented in Table 1. In addition, for the infrastructure risk analysis to pedestrians, a sidewalk GIS database was used.

TABLE 1 - CHECKLIST ELABORATED TO ASSESS THE INFRASTRUCTURE RISKS TO PEDESTRIAN

CHECKLIST FOR INFRASTRUCTURE RISKS TO PEDESTRIAN IN PARKING LOTS			
1. Layout	**YES**	**NO**	**COMMENTS**
Adequate access to all vehicle movements?			
Is the parking space adequate?			
- Appropriate width?			
- Appropriate length?			
Are the spots for disabled people adequate?			
Is there enough space for parking maneuvers?			
Are the vertical signs adequate?			
Are the horizontal signs adequate?			
Are there any vehicles parked irregularly?			
2. Pavement and drainage			
Is the parking pavement in good condition?			
Existence of holes?			
Existence of water puddles?			
Proper drainage?			
Can drainage equipment be a risk to drivers and / or pedestrians?			
3. Provisions for Pedestrians			
Is there a conflict with pedestrians during vehicle access in the parking area or during parking maneuvers?			
There are boundaries to the path of pedestrians in the parking area?			
Is there adequate lighting at night time?			
Is there something that prevents the view of pedestrians by drivers who are performing maneuvers or accessing the parking lot?			
Crosswalk in a suitable place?			
Urban furniture preventing the movement of pedestrians to access the parking?			
Street furniture blocking the view of pedestrians by drivers?			
Are the sidewalks in the surroundings adequate?			
Accessibility of sidewalks (ramps)?			

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3 RESULTS AND DISCUSSION

In this section, the analyses to identify and also to improve the availability of parking lots on campus are presented. To this end, an analysis of vulnerable road users about dark locations, crosswalks, blind spots and vertical signaling, drainage system, bicycle parking lots and orientation signs are described.

3.1. Average Occupancy Rate

Firstly, Table 2 presents the results of the average demand and the parking supply for each parking lot. Also it is possible to observe the percentage of parking lot capacity, which indicates that E5 is an overcrowding parking lot. With the acquisition of the data on supply, demand and Average Occupancy Rate (AOR), some thematic maps were generated creating the database of campus parking lots in a GIS. The maps already give the first notion of the concentration of car spots and the demand.

Regarding the Average Occupancy Rate, we can note that some parking lots already operate nearly or over 1.00 car per spot (E5 and E6), agreeing with what was already observed in the beginning of this study, that is, some parking lots are operating with cars parked irregularly.

TABLE 2 - DATA COLLECTION RESULTS FOR EACH PARKING LOT.

Parking Lot	Parking Supply	Average Demand	Capacity
E1	107	65,17	60,90
E2	234	125,67	53,70
E3	239	170,67	71,41
E4	146	119,00	81,50
E5	162	170,33	105,14
E6	137	136,83	99,87

Figure 3a illustrates the spatial analysis generated with the data sheet on the number of existing parking spots resulting in the supply of each parking lot. Figure 3b shows the spatial analysis generated by the data sheet on the demand for parking spots of each parking lot.

From the thematic map (Figure 3a) it is possible to realize the distribution of the number of parking spots according to the divisions adopted for this research. In the central region, near the gate 1, there is a greater supply of parking spaces compared to the peripheral regions. The more the red color becomes darker, the more car spots the parking lot has. In the legend, the parking lots were increasingly placed on the number of parking places offered.

In the Figure 3b the more requested a parking lot is, the redder is its color. A concentration of parking demand is observed below the central region of the campus, different from the position of the concentration of parking supply. This is the first result that may indicate the overcrowding observed in some parking lots. In the legend, the parking lots are increasingly placed on the average occupancy number.

FIGURE 3 - COMPARISON BETWEEN GROSS DEMAND AND AVERAGE OCCUPANCY RATE FOR EACH PARKING LOT.

With the geographic information system, the data were grouped to form a thematic map containing the Average Occupancy Rate of each parking lot, shown in Figure 3b. The result of this analysis is curiously different from the "crude" analysis of demand and gives a true notion of which parking lots are overloaded or tend to this. For example, the E3 parking lot was appointed as the most requested by the demand analysis, but the average occupancy rate analysis puts E3 in fourth place.

3.2. Infrastructure Risk Analysis to Pedestrians

After processing the data obtained through the checklist, a thematic map was generated containing the main risks to pedestrian due to infrastructure problems and their respective location on campus (Figure 4). The main risks found in the campus parking lot were: lighting problems that result in the lack of visibility of pedestrians and drivers; damaged drainage system that can cause accidents with pedestrians; drainage problems in some streets that make the flow of people and vehicles infeasible; lack of crosswalks, access ramps and vertical signaling that may cause collision risk between pedestrians and vehicles and between vehicles each other; sidewalks obstructed by lighting posts that force pedestrians to walk in the street.

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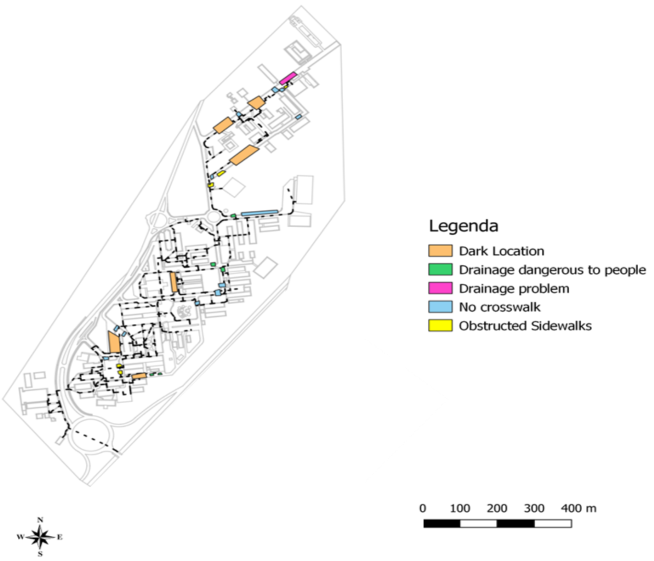

FIGURE 4 - MAIN INFRASTRUCTURE PROBLEMS FOUND AFTER PERFORMING THE CHECKLIST.

A careful observation of these results is necessary since they can greatly assist in making the right decision for the future design of parking areas and the improvements in the existing parking areas as it can be observed in Figure 5.

Analyzing the Figure 5 it can be observed the locations of the main infrastructure problems that are described below:

1. Lighting problems that lead to lack of visibility for pedestrians and drivers.
2. Damaged drainage system that can cause pedestrian accidents.
3. Drainage problems in some streets that make the flow of people and vehicles unsafe and not accessible to pedestrians.
4. Lack of crosswalks, access ramps, vertical signage and occurrence of blind spots that cause collision risk between pedestrians and vehicles and between vehicles.
5. Sidewalks obstructed by light post that force pedestrians to walk in the street.

6. Shortage of parking spots to accommodate certain regions of the campus, which had irregular parked vehicles that created unsafe situations to pedestrians.

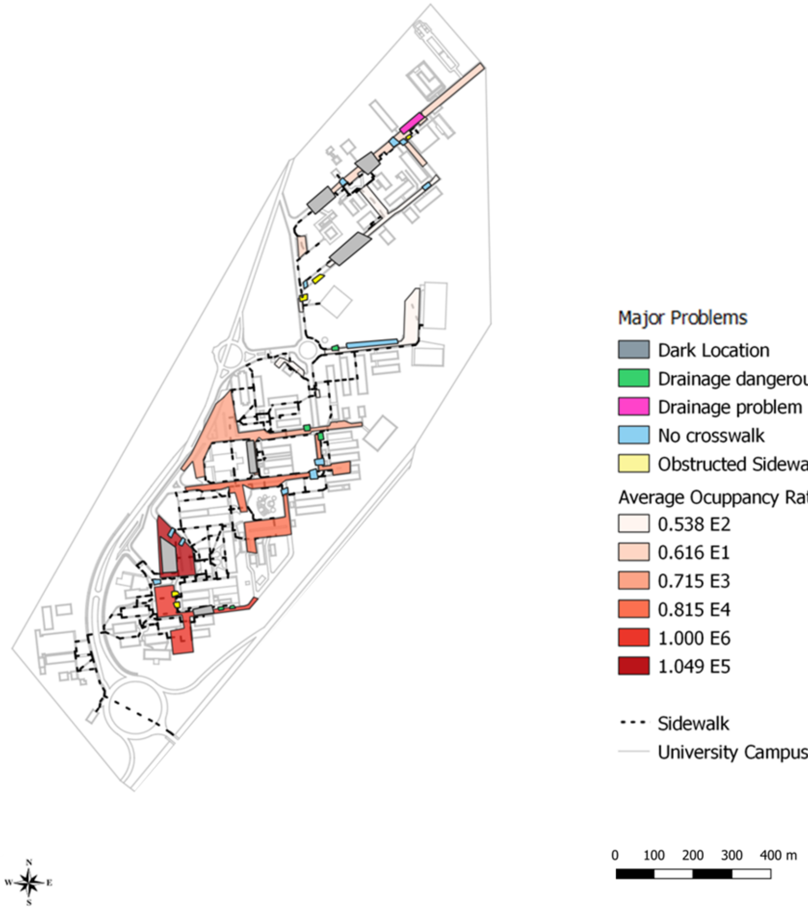

FIGURE 5 - SPATIAL VISUALIZATION OF AVERAGE OCCUPANCY RATE AND MAIN INFRASTRUCTURE PROBLEMS.

3.3. Improvements made through this research

The results of the implementation of the framework helped the campus manager to make the most cost benefits improvements regarding the infrastructure risks to pedestrians. Also the improvements were based on low cost measures due to budget constraints. The supply/demand analysis helped the construction planning location for 200 to 300 new parking spots in the overloaded locations indicated by the AOR, which are under way.

3.3.1. Dark Locations

A new lighting system was installed on the locations indicated in this study as shown in Figure 6.

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FIGURE 6 - (A) BEFORE AND (B) AFTER THE INSTALLATION OF LIGHTING SYSTEM.

3.3.2. Crosswalks, blind spots and vertical signaling

Crosswalks were painted on the locations indicated in this study. Blind spots for cars and people were blocked by yellow concrete bars. A new vertical and horizontal signaling was installed on several crossings, like stop signs and crosswalks signs (Figure 7). It is important to highlight that all improvements were design with low cost budget constraints.

FIGURE 7 - LOW COST IMPROVEMENTS TO REDUCE RISKS FOR PEDESTRIANS

3.3.3. Drainage System

A new design for the drainage was made, for reducing risks of injures as shown in Figure 8.

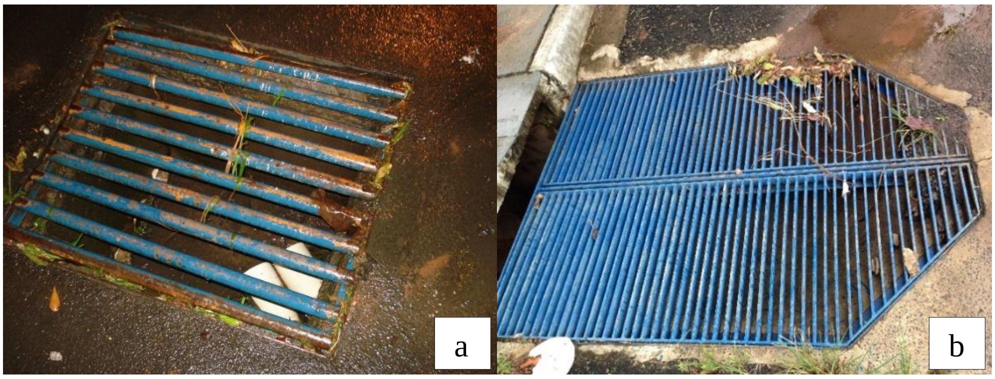

FIGURE 8 - DESIGN OF THE DRAINAGE SYSTEM (A) BEFORE AND (B) AFTER.

3.3.4 Bicycle Parking Lots and Orientation Signs

Some bicycle parking lots were installed for encourage people to use alternative transportation modes. For better circulation, signs that indicate the directions for several buildings on campus were placed on the main entrances (Figure 9).

FIGURE 9 - (A) BICYCLE PARKING LOT AND (B) ORIENTATION SIGN.

4. CONCLUSIONS

The present work had the objective to create a feasible and low budget framework to carry out an analysis on pedestrian's risks due to infrastructure problems in a university campus parking, and was developed s database in GIS (Geographic Information System). This is a way to assist in campus planning, as it is constantly growing and changing, with the intention of improving the quality of mobility and coexistence of the community that use the campus.

Also this framework can be replicated to other university campus. For future works, the GIS database can be improved to add data about the vehicles and pedestrian accidents, in order to conduct a safety assessment in those locations.

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