Analyzing data on the tree coverage of a large city

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Abstract. *Tree coverage in urban spaces is a theme of great importance for current societies, given all the benefits that green spaces provide to the population, especially in large cities. Trees fulfill a very important role to ensure quality of urban living and urban environmental quality, and as a result trees are considered to be an element of urban infrastructure. In spite of the recognition of the importance of tree coverage, events in which a street tree falls or needs to be preventively cut down are quite frequent, damaging property and causing disturbances in the routine of the population. From a rich dataset on urban trees for the city of Belo Horizonte (MG, Brazil), this paper proposes contributions towards the identification and solution of problems related to tree coverage, with special emphasis on felled trees. Data mining techniques are employed in search of consistent patterns, expressed as association rules or temporal sequences, that are related to felling events. We also seek to identify the information components that should be used to create a volunteered geographic information collection tool for urban tree coverage.*

Resumo. *Arborização Urbana é um tema de grande importância para a sociedade nos dias atuais por todos os benefícios que ela proporciona aos cidadãos, principalmente nos grandes centros. As árvores desempenham um papel muito importante na melhoria da qualidade de vida da população e do meio ambiente, de modo que a arborização vem sendo considerada um dos elementos da infraestrutura urbana. Apesar dessa importância, eventos de queda ou corte preventivo de árvores em áreas públicas têm se tornado frequentes, causando danos materiais e gerando transtornos ao cotidiano das cidades. Partindo de um conjunto expressivo de dados individuais sobre árvores em Belo Horizonte (MG), este projeto busca contribuir para a identificação e solução de problemas de arborização, com especial ênfase na queda de árvores. Técnicas de mineração de dados são utilizadas para procurar padrões consistentes, expressos como regras de associação ou sequências temporais, que se relacionem à queda de árvores. Busca-se, também, identificar os componentes informacionais necessários para a construção de uma ferramenta para a coleta voluntária de informações geográficas sobre a arborização urbana.*

1. Introduction

The availability of trees in the urban landscape represents a long-term concern of local governments. In cities, trees have a very important role in improving the local living conditions, for the quality of the air and for the well-being of citizens, to the point that tree coverage is increasingly considered to be another element of urban infrastructure

[F. Dwyer et al. 1992]. Among the numerous benefits trees provide, there are the positive psychological effect for walkability, aesthetic contribution for the landscape, shade and protection against wind, reduction of noise pollution, absorption of rainwater and carbon, reduction of the temperature, and preservation of small fauna.

Trees are always present in large cities, even if in small densities, and there is a growing search for the harmonization of urban growth and the environment. Like in any other municipal activity, creating and maintaining large numbers of urban trees[1] requires careful planning and attention to technical detail. Keeping trees within the boundaries of public spaces is a complicated task, given several limitations and potential conflicts with other elements, such as buildings, cabling and pavement.

In the attempt to contribute to the local environment, many people take on to themselves the task of planting and keeping trees, shrubs and flower beds in sidewalks and other public spaces. However, the lack of technical guidance may lead to harm in the future. Inadequate species are frequently used in limited spaces, disregarding future interferences and dangers, such as when canopies conflict with electrical cabling or superficial roots break sidewalks.

Some initiatives, such as municipal tree inventories, intend to gather information and enable analyses to understand the relationship between trees and the places where they live, assessing the compatibility between the typical characteristics of the tree species (type of root system, trunk height, canopy diameter) and the available space, the phytosanitary conditions (sunlight, irrigation, soil type) and the adaptation of the specimen to those conditions.

In this context, we realized an opportunity for using data mining techniques over a comprehensive dataset on urban trees to look for consistent patterns, temporal sequences, systematic relationships and other aspects, in order to gather elements that can help solving maintenance and care problems that are becoming commonplace, such as inadequate pruning, unexpected collapses and preventive suppression.

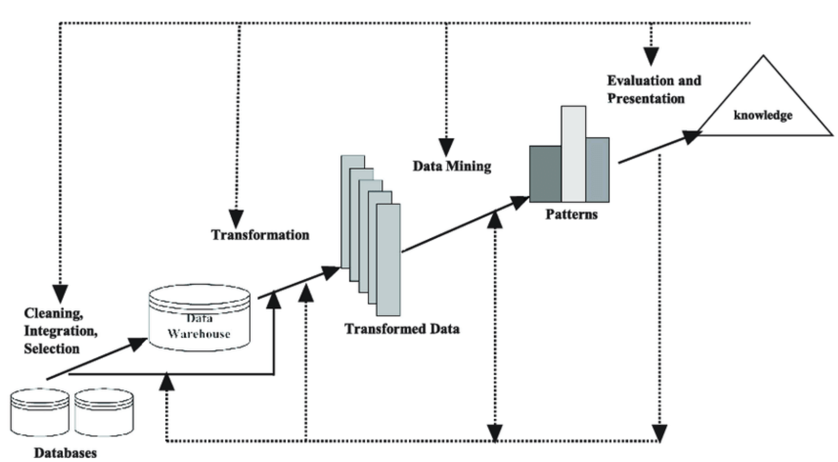

Figure 1. Data Mining Cycle

[1]We use the expression *urban trees* to refer to trees planted in sidewalks and along the thoroughfares of a city, excluding those in wider areas, such as parks and preservation areas

In May 2012, the Brazilian geographic institute (Instituto Brasileiro de Geografia e Estatística, IBGE) published a study based on data from the 2010 Census in which urbanistic parameters around Brazilian homes are considered. One of the indicators presented in this study regarded the presence (or absence) of urban trees in front of or in the vicinity of each residence[2]. Results show that there is a deficit of at least 15 million urban trees in Brazil, and that about 32% of the residences (or almost 50 million people) do not benefit from urban tree coverage. The study also shows that a third of the largest Brazilian cities (population of one million people or more) have between 60% and 77.6% of the citizens have no urban tree coverage in the proximities of their home.

Besides lacking tree coverage, large cities suffer with unexpected tree falls, putting people and property in risk and causing problems in traffic. In Belo Horizonte, about R$ 8 million were invested in 2018 in actions that seek to reduce the number of accidents with trees. Between January and July, 22,437 prunings and 4,451 cuts were executed. Throughout 2017, the city promoted 16,445 prunings and 3,041 cuts, in an universe of over 300,000 urban trees[3].

Since tree falls are frequent in Belo Horizonte (between January and March 2018, the Fire Department received 516 emergency calls to remove fallen trees in the city and metropolitan region)[4]). The city's administration maintains a plan to cut down trees that are considered to be at risk of falling[5].

Therefore, the existence of an integrated and up-to-date database on urban trees allows us to follow the data mining cycle to discover new knowledge (Figure 1) and can enable city officials in charge of tree maintenance to direct and organize their work. If made public, these data can also inform citizens as to the characteristics of specimens that live around them.

The remainder of this work is organized as follows. Section 2 presents related work on urban trees. Section 3 describes the data used in this work. Section 4 introduces a case study that involves discovering patterns from the comprehensive tree database available for the city of Belo Horizonte, Brazil (335 km^2, 2.5 million people). Finally, section 5 presents conclusions and discusses future work.

2. Related Work

There are many studies related to urban tree coverage in the fields of Biology and Earth Sciences. [Bonametti 2003] show the lack of organization in cities as to planning and managing trees in urban thoroughfares, and also highlights the importance and benefits of urban greenery. A tree inventory uses sampling to estimate quantitative parameters, such as green volume and base area, as well as quantitative ones, such as trunk quality and species valuation. Inventories are used in many cities as a tool to achieve greater control over the species that exist in their streets. [Dantas Coelho et al. 2004] and [CARVALHO et al. 2010] present examples of tree inventories in Brazilian cities.

[2]http://www.jardimcor.com/arvores/o-deficit-da-arborizacao-urbana-no-brasil/

[3]https://www.em.com.br/app/noticia/gerais/2018/08/17/interna_gerais,9REFORMULAR80874/supressoes-de-arvores-em-bh-ja-superam-todo-o-volume-do-ano-passado.shtml

[4]https://g1.globo.com/mg/minas-gerais/noticia/prefeitura-define-criterios-para-retirada-de-arvores-que-correm-risco-de-queda-em-bh.ghtml

[5]https://prefeitura.pbh.gov.br/sites/default/files/estrutura-de-governo/meio-ambiente/2018/DN92_18_.pdf

In Chicago (USA), [Simpson and McPherson 1996] estimated that planting 50 thousand trees and their maintenance over a period of 30 years would cost US$ 8.4 million, while the benefits provided by such trees would achieve US$23.5 million. In the city of Modesto (USA), which has more than 90 thousand urban trees (one for each two residents), a study was conducted to verify if the benefits from trees would justify the annual budget of about US$ 2 million in maintenance. Results showed that the benefits far outweigh the costs, estimated at US$ 4.95 million.

Power companies suffer a direct impact from urban trees, since they must concern themselves with interference between canopies and aerial cabling to avoid service interruptions and accidents. For that reason, in some cities the power companies share the responsibility for pruning urban trees with local government organizations.

[Biondi 2005] classifies tree maintenance practices in:

- preventive measure: aims to avoid and prevent problems that the trees might have at their location, and to overcome less significant damage;
- correction measure: attenuates a flaw or a blight, acting to repair or correct a problem with the tree in its location, usually damage to the trunk caused by natural factors or physical damage from accidents with vehicles, wind and vandalism;
- suppression measure: directed at cutting down or removing the tree from its location due to problems with the specimen or its relationship with the urban space. It is applicable to trees with disease or blight, in risk of falling down, or certified death, but also to specimens that have unpleasant flowers or fruit that cause allergies, or even at the request of residents.

In the Brazilian scenario, and more specifically in the case of power utilities, tree management processes are formally defined as “greenery handling”, and comprise planning and executing urban tree pruning, and clearing the servitude strip around transmission lines and rural trunks. The process uses about 80% of the budget reserved for preventive maintenance, and its efficiency reflects in the operational budget for correction events, since trees are shown to be the main cause of sustained interruptions of power supply[6], one of the main power utility efficiency indicators. Furthermore, the greenery handling processes represent a significant risk of environmental impact, since there is a direct intervention in elements that legally exceed the company’s mandate. Therefore, improving the management of urban trees is still a challenge for power companies, since there is a direct impact of tree incidents over their quality indicators and overall energy distribution costs. Combined with the potential environmental impact, a successful handling of tree issues minimizes the risk of further financial loss from legal sanctions or environmental fines.

CEMIG is one of the main Brazilian power utilities, managing the power grid for the state of Minas Gerais. According to their Urban Tree Manual (2011)[7], written in partnership with a well-known environmental NGO, interventions in regions covered by urban trees must be planned beforehand, in order to avoid or to minimize damage to trees themselves and to other living beings that interact with them, including humans. The manual lists some criteria to determine whether the tree is at risk of falling down: vegetative strength, elevation from ground level, existence of plagues and trunk deformities.

[6] http://www.cemig.com.br/pt-br/a_cemig/nossos_negocios/Paginas/indicadores_de_qualidade.aspx

[7] http://www.cemig.com.br/sites/imprensa/pt-br/Documents/Manual_Arborizacao_Cemig_Biodiversitas.pdf

Additionally, [PIVETTA 2002] shows that there many characteristics are required from a tree species so that its use in urban areas can be considered free of inconveniences, such as resistance to plagues and blights, strong trunk and branches, and deep roots.

[Grey and Deneke 1986] states that, when a tree is considered to be an element of the urban infrastructure, it should be possible to assign a monetary value to it, as in the case of other forms of physical infrastructure. [Almeida et al. 2006] presents urban tree benefits as measurable entities, estimating the value of each tree. [Nowak 1993] calculates the value of urban trees in Oakland (USA), using a tree-value formula, so that public management of trees can have a basis for planning and prioritization of actions. Furthermore, [F. Dwyer et al. 1992] compares benefits and costs of urban greenery, and shows that costs sometimes are larger than necessary due to inadequate planning.

In Belo Horizonte, a detailed inventory of urban trees exists since the early 1990s, and a recent update is available, as described in the next section. Such an inventory, which includes several attributes for each tree, along with its geographic location, was initially intended as a tool to support maintenance operations. However, by itself and in combination with other sources of information, the inventory can be analyzed in search of unexpected patterns and valuable insights, which should be useful for the overall management effort and to understanding and prioritizing solutions for the challenges regarding urban tree coverage.

For this study, we employ some well-known data mining techniques[Zaki et al. 2014], such as algorithms for determining frequent patterns, association rules and clustering. [Agrawal et al. 1993] and [Agrawal et al. 1994] show how the analysis of frequent patterns and association rules can be useful over large datasets, allowing the discovery of unexpected relationships. Clustering [Berkhin 2006] aims at grouping data elements with similar properties. We extend such techniques by taking location into consideration as well, in order to identify local characteristics and variations in tree coverage, and connections between event concentrations and other geographically located elements. To the best of our knowledge, there are no related publications that use data mining to identify potential problems in urban trees, or to predict the risk of tree-fall events.

3. Dataset Characterization

Data used in this work were obtained from Belo Horizonte's tree inventory system (Sistema de Informações e Inventário das Árvores de Belo Horizonte - SIA/BH). The inventory is the result of a cooperation between the municipal administration and Universidade Federal de Lavras (UFLA) and CEMIG, the state's power utility. The cooperation, dating back to 2011, collected and organized data on about 300 thousand urban trees.

Each tree in the database is geographically located, and characterized by numerous descriptive attributes. Data were collected by forestry engineers and environmental engineers, who visited each tree equipped with portable devices running a specialized application, which also allowed taking photos to complement the descriptive data. The application managed entries for 57 attributes of each tree, including biological (species), physical (height, diameter of the canopy, diameter of the trunk), health (presence of insects or fungi) and locational (interference with buildings or with cabling) characteristics.

Figure 2 shows the number of individuals of the most common species found in

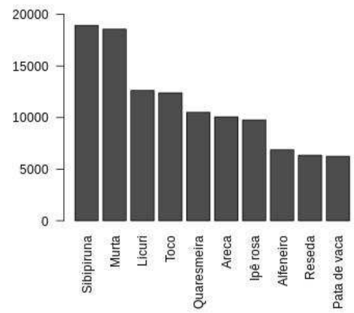

Figure 2. Top 10 tree species in Belo Horizonte

the city. In Belo Horizonte, the most common species has the popular name *Sibipiruna* (*Caesalpinia pluviosa*), a native Brazilian tree, medium to large size, found in most large Brazilian cities. It should be used in pubic squares and large spaces, but should not be used in narrow sidewalks and with overhead cabling, due to its size. Nevertheless, it has a great capacity for shadow and temperature reduction under its canopy, which is useful especially in cities where the urban heat islands effect is observed.

Region	Quantity of trees
Centro-Sul	91,792
Pampulha	63,733
Noroeste	59,320
Oeste	53,880
Leste	31,151

Table 1. Trees per region in Belo Horizonte

Table 1 shows that the largest concentration of trees is found in the South-Central region of Belo Horizonte, which contains the downtown area, the most important economically, which receives intense flows of people daily at its high-density commerce and residential areas.

Table 2 lists some of the attributes of the dataset that were used in the analyses presented in this work, along with their acronyms. Notice the information on epicormic branches and shoots. Epicormic buds lie dormant beneath the tree bark, since the plant concentrates growth hormones around active shoots in its top parts. When damage occurs, or when light levels increase due to the removal of branches or nearby obstacles to sunlight, these buds may become active. However, since the bark around them is already aged, their connection to the trunk or branches is deficient, creating a weak point [O'Hara and Berrill 2009].

4. Case Study

For this work, a subset of the data are used, comprising about 25,000 trees in the South-Center region of Belo Horizonte. This region was selected for being the first to be oc-

Acronyms	Attribute	Observation
PERECIDA	Perished	Fallen tree
PODADA	Pruned	Recently pruned tree
BIFURCADA	Bifurcated	Not a single main branch
ENTOUCEIRADA	Thickened	No longer a sapling
BCA	Elevated base	-
BCBE	Epicormic shooting	-
BCPI	Presence of insects	-
CCGO	Canopy with hollow branches	-
CCGS	Canopy with dried branches	-
PGC	Heavily barked branches	-
CCGE	Epicormic branches in canopy	-
PERFILHAMENTO	Shoots from the root system	-
RCE	Strangled or cut roots	-
AR	Superficial roots	-
TCI	Trunk with insects	-

Table 2. Attributes

cupied when the city was founded in 1897, and, consequently, the site of the many older trees that may be more apt to falling.

We also obtained a list of 127 trees that perished along 2017 in the South-Center region. This list was compiled from records of the city department in charge of picking up tree remains after a fall or cut. From the operational data on retrieving tree parts, we were able to trace back to the inventory records. An order to retrieve a tree was issued with an address, from which we determined a coordinate using geocoding. Next, a geographic query was used to the closest tree in the inventory. Regrettably, the inventory has not been fully incorporated in the routine of the municipal administration, and there is no work process or information system that takes care of updating the inventory.

Next sections present the results of data mining and spatial analyses over the combination of the inventory and the information on fallen trees for 2017.

4.1. Association Rules

This analysis aims at determining if there are any relevant rules that associate perished trees to their attributes, aiming to identify possible causes for tree falls or suppressions. Algorithms for mining association rules generate expressions of the form $A \rightarrow B$, in which A and B are lists of attributes. The rule indicates that, in individuals where attributes in A are true, attributes in B are also true. For instance, the rule $\{AR, PGC\} \rightarrow \{CCGE\}$ indicates that, in trees with superficial roots and heavily barked branches, there are often epicormic branches in the canopy. The assessment of how often this happens, i.e., how important the rule is, is given by the rule's support and confidence indicators. Support indicates how frequently these attributes appear in the database, and confidence indicates how often the rule is found to be true [Dasseni et al. 2001].

However, in datasets where the frequency of attributes varies intensely, support and confidence might not be the best indicators to select association rules. In our case,

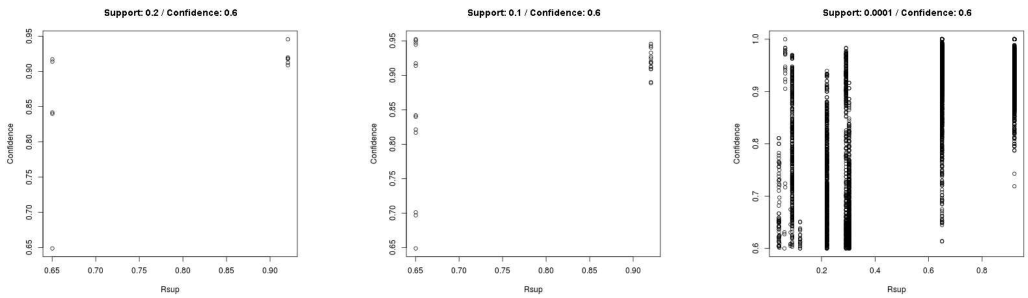

Figure 3. Relation between relative support and confidence

some attributes (PODADA, CCGE) are very frequent, while others (PERISHED) are not. Rules in which the right side is very frequent tend to show up more easily if the rules with the highest confidence values are selected. Figure 3 shows a comparison between three different combinations of the relative support generated by the rules from our dataset and confidence thresholds, in which we show few attributes when support and confidence has high values and more attributes when we reduce the support and confidence thresholds.

We used lift and leverage instead of support and confidence to mine interesting rules from the dataset. Lift indicates how frequent is the right side of the rule when the left side is found. If lift is equal to 1, the attributes are independent from each other, and no rule can be derived. If the lift is greater than one, the higher the lift value, the more higher is the dependency between the attributes, so rules are more important. Lift is useful to find strong associations between less frequent attributes. Leverage, on the other hand, represents the number of additional rules covered by the left and right-hand side attributes, if they were independent from each other. The larger the leverage, the more interesting is the rule.

Figure 4 shows a comparison between lift and leverage for the rules generated from our dataset, with varying support and confidence levels.

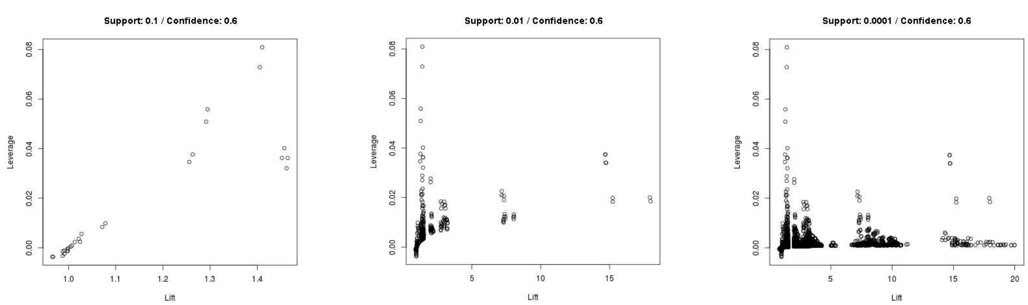

Figure 4. Relation between lift and leverage

Table 3 lists some of the most interesting rules that heve been obtained. Some of them are expected, such as $\{BCPI, CCGS\} \rightarrow \{TCI\}$, since if there are insects at the base of the tree, there is a fair chance that the trunk also has insects. The previously mentioned rule $\{AR, PGC\} \rightarrow \{CCGE\}$ relates factors that may indicate incorrect or harmful pruning.

Association Rule	Confidence	Lift	Leverage
PERFILHAMENTO, BCA, PODADA ->BCBE	0.600	9.756	0.003
BCPI, CCGS ->TCI	0.726	8.048	0.013
CCGO, TCI ->CCGS	0.705	3.209	0.007
RCE, PGC ->AR	0.934	3.204	0.011
AR, PGC ->CCGE	0.947	1.457	0.040

Table 3. Top-lift association rules

Rules with the PERECIDA (perished) attribute in the left or right sides are of special interest in the attempt to find factors related to fallen trees. However, such rules are less frequent, since only 0.5% of the trees in the database were marked as fallen or suppressed, from the 2017 data. The most interesting rule discovered was $\{PERECIDA\} \rightarrow \{CCGE\}$ (confidence = 0.74; lift = 1.5), that indicates that epicormic branches are frequent in fallen trees, which then lead to the hypothesis that badly executed pruning may be an important cause of tree losses. With further data on fallen or suppressed trees, this observation may become stronger in the future.

4.2. Clustering

Clustering algorithms are used to separate fallen or prone to falling trees from the others. Since there is a large number of attributes in the dataset, we selected the ones that are more closely related to the criteria forestry specialists use to indicate a risk of falling, such as strength of growth, height, presence of plagues and trunk deformities [ARAUJO and ARAUJO 2006]. Considering the results from the mining of association rules, we selected attributes on bifurcation, epicormic branches, proximity to cabling, and interference between canopy and cables. If epicormic branches are strongly related to the risk of falling, attributes that indicate frequent pruning or interference with other urban elements should be considered as well.

We used the k-means clustering algorithm, with k = 2, in order to divide healthy trees from prone to falling ones. The algorithm would find the trees whose attributes are closest to the ones from fallen trees to form one group, and include all the others in the second one. Initial centroids were generated using a parallel version of k-means, k-means++ [Bahmani et al. 2012]. The initial centroids generated by k-means++ are guaranteed to approximate the optimal solution. A relative tolerance to terminate the algorithm from the sum of intra-cluster distances was 0.0001.

Table 4 shows the clustering results for k = 2. Notice that a good separation of the perished trees from the others (88.19% in the first cluster). This suggests that this cluster is able to characterize and select trees with a higher chance of falling from the others, thereby requiring closer attention by the maintenance crews.

Cluster	Number of trees (%)	Number of perished trees (%)
0	22,716 (88.36%)	15 (11.81%)
1	2,994 (11.64%)	112 (88.19%)

Table 4. K-means results with K = 2

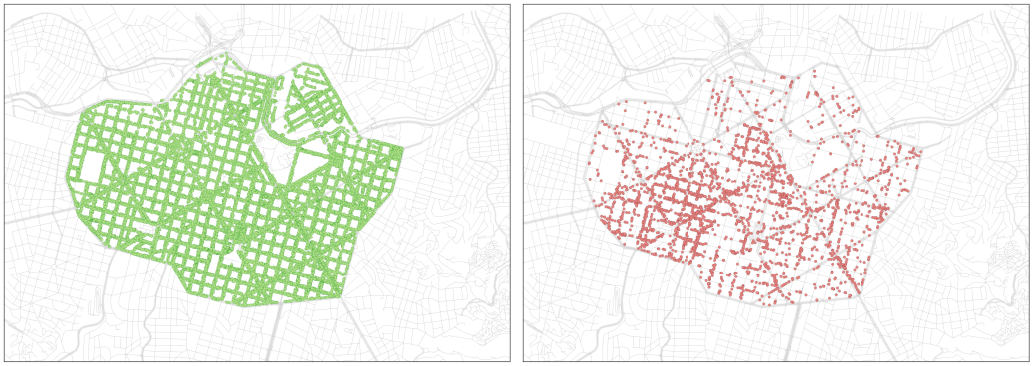

Figure 5. Clusters

Figure 5 shows, on the left side, all the 25,710 trees included in the sample. The right side shows the 2,994 trees from cluster 1. The selection of this smaller number of trees enables city officials to prioritize their inspection in the field.

Figure 6 shows a heat map generated from cluster 1 trees, i.e., trees deemed to have a higher chance of falling down. This enables the visual identification of the regions that require more attention and concentrate the necessary fieldwork of inspection.

Figure 6. Kernel

5. Conclusions and Future Work

This work shows the potential application of data mining to find elements to assist in the maintenance of urban tree coverage, including the identification of risk factors and the prioritization of inspections to prevent accidents with trees. The difficulty in obtaining information on perished trees indicates that a volunteered geographic information (VGI) initiative can be designed and implemented to help in updating and expanding the original dataset. With more information of incidents related to trees, mining results can be much more effective and useful.

Results suggest that some characteristics are more frequently found in fallen trees, and may be useful in directing future inspection and management actions. Additional information on fallen trees, possibly gathered from volunteered contributions, may reinforce these observations and introduce new factors, which may lead to a prediction system to be used by city managers.

Results also show which attributes are to be prioritized, from the 57 characteristics obtained in the tree inventory project, to be supplied by the population in a VGI initiative. Citizens may feel more motivated to contribute in a theme that has a direct relationship with the quality of life in their neighborhoods, in the interest of their safety and of the successful maintenance of a healthy urban environment. For the municipal administration, on the other hand, citizen contributions provide a virtually costless and effective way to obtain necessary information without resorting to public employees that would need to traverse the streets regularly. However, the integration of tree data to the city's administrative processes is a necessary step, which must also include information from the power utility, whenever they conduct pruning or suppression on their own.

Therefore, future work includes expanding the data mining and spatial analyses of tree data, and the study of adequate VGI approaches to obtain current information on trees throughout the municipal territory. Citizen contributions can also be useful in the definition or enhancement of guidelines for managing urban trees and green areas. Education initiatives, comprising information on the suitability of tree species to the characteristics of public spaces, can take place simultaneously. The pioneering work of Belo Horizonte's municipal administration in creating and updating a tree inventory is applicable to other cities, so the analysis techniques and the VGI initiatives proposed here should be replicated and reused.

6. Acknowledgments

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