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Urbanistic code compliance checking tool based on geospatial data for building licensing

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ABSTRACT
The licensing process of real estate developments is regulated by technical standards and legislations. The compliance verification against such regulations, and their reference parameters, is a complicated task. Automating this process, using computational resources, can make it more efficient. The addition of geospatial data in urban code compliance checking can incorporate new methods into territorial planning. Thus, this paper aims to develop a computational geospatial tool to assist in the city of São Carlos' building licensing process, adopting the code compliance checking method. A GIS plugin was developed for this purpose, where, based on vectorial data, the tool performs a parameter verification based on the Municipal Master Plan reference values. This tool brings public benefits as it can reduce the licensing process time and ensure sustainability and transparency. Moreover, using geospatial data enables a plethora of new urban analyses based on the same inputs of the developed tool, evolving to new government processes models.

Keywords: Code Compliance Checking. Geographic Information System. Real Estate Licensing. Urban Planning

1 INTRODUCTION

A building project's licensing process is guided by a range of regulations and standards, such as legal parameters and environmental performance recommendations. Compliance checking against these regulations is a complex task, and is primarily practiced in many governments (BEACH; REZGUI; KASIN, 2015). In many cases, digital methods can offer advantages over conventional ones (HÄUßLER; ESSER; BORRMANN, 2020). Furthermore, implementing computational and automated tools allows the government to rethink traditional processes and sustainably articulate the demand for resources (OJO; DZHUSUPOVA; CURRY, 2016). In this context, digital technologies can be the basis for the evolution of governance models, making their operations and processes more transparent, participatory, and democratic (SILVA; FERNANDES, 2020).

Automated compliance checking is an area of research that aims to provide computational support in verifying building projects compliance against the applicable building and urban standards in a time and cost-effective manner (İLAL; GÜNAYDIN, 2017). Among the computational tools available, Geographic Information Systems (GIS) can be mentioned due to the wide range of spatial and numerical operations on geographic objects. Moreover, it can operate with tabular data, allowing the incorporation of new techniques and methods into urban planning (NAKATA-OSAKI; SOUZA; RODRIGUES, 2018).

Many code compliance checking systems are developed using a Building Information Model (BIM) basis, such as building interior design rule checking (SYDORA; STROULIA, 2020) and research aimed at addressing common issues, such as low availability and accessibility of essential data (SOLIHIN et al., 2020). However, while BIM models represent a rich source of information in the scope of design, GIS models can provide adequate support for city planning, using geospatial data based on the principles of locations, conditions, trends, and patterns (Liu et al., 2017).

FLOSS (Free/Libre/Open-Source Software) projects are frequently used for collaborative work, involving multiple institutions with different interests and organizations. Its success, which overlaps with agile methodologies, reinforces the potential of applying their practices in collaborative scenarios. FLOSS methodologies can lead to great collaboration, especially in governments and academia (WEN et al., 2020). This kind of partnership is an essential part of geospatial tool development by academia for government use.

This paper aims to develop a computational tool that helps in the building licensing process. To do this, a geospatial tool is developed based on the concept of automated code compliance checking. The municipality of São Carlos, in São Paulo state, Brazil, is adopted as the study area. The urbanistic parameters presented in the São Carlos Master Plan (2018) are used as the reference for the code compliance checking process.

This paper is organized as follow: Section 2 presents the theoretical basis regarding subjects covered in this article; Section 3 introduces the proposed methodology, including the law review and the study cases; the results are presented in Section 4 and discussions are carried out in Section 5. Finally, Section 6 summarizes the findings of this paper.

2 THEORETICAL BASIS

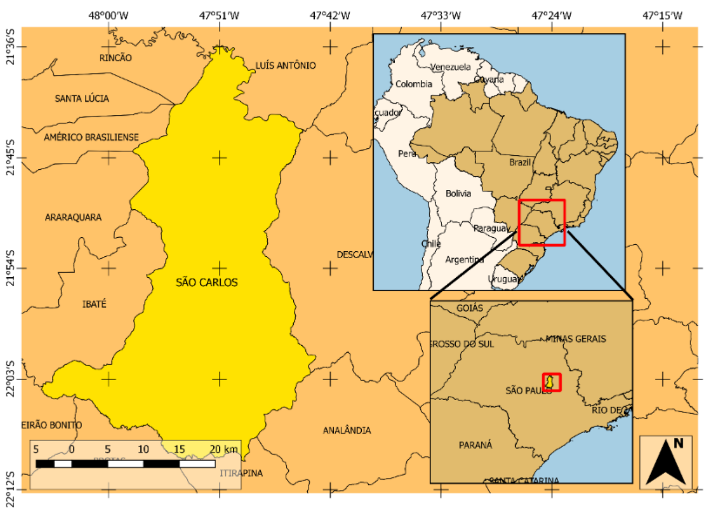
This section presents some approaches concerning the study area and a review regarding code compliance checking and its applications.

2.1 Study area

The city of São Carlos (Figure 1) is located in São Paulo state (BRAZIL). It has an area of 1,136,907 km² (IBGE, 2011) and a population of 244,036 inhabitants in 2021 (SEADE, 2021). Furthermore, according to SEADE, the degree of urbanization in the municipality is 96%.

As elucidated by Stanganini and Lollo (2018), São Carlos' urban area has undergone rapid and disorderly growth over the last decades. This fact is due, to a large extent, to the real estate valuation of specific areas, increasing the environmental problems due to the lack of planning.

Figure 1 – Study area location



Source: IBGE, (2011)

When dealing with the laws that govern the urban environment in the studied municipality, the main instrument is given by the latest version of the São Carlos Master Plan of 2018 (SÃO CARLOS, 2018). Among the urban instruments, the Study of Neighborhood Effects (SNE – Estudo de Impacto de Vizinhança, in Portuguese) is a document that must be prepared by real estate developments that significantly impact the environment or infrastructure. It must previously inform about the effects and impacts on the quality of life resulting from the development's implementation and democratize the urban and environmental licensing process. The SNE can be an effective tool when compiling project data and when reporting the impacts on the quality of life of the population residing around the development's influence area.

2.2 Existing code compliance checking tools

So far, there has been no adoption of automated compliance checking as part of official government processes of real estate licensing, except for Singapore, which implemented an automated system. However, this has now been discontinued (BEACH; HIPPOLYTE; REZGUI, 2020). This system, called CORENET (Construction and Real Estate Network), comprises subsystems that aim to share information between the parties involved in a real estate project (NARAYANSWAMY; LIU; AL-HUSSEIN, 2019).

The CORENET project is the earliest production of building code compliance checking, which was initiated in 1995. At the beginning, the system was based on bi-dimensional drawings, but later, Industry Foundation Class (IFC) data started being used. The CORENET project developed a platform called FORNAX to collect the required building code information (İLAL; GÜNAYDIN, 2017).

Among the academic research of code compliance checking tools, Melzner et al. (2013) implemented an automated fall hazard detection and protection platform based on BIM. The tool uses IFC design models to detect routines and recommends safety protective equipment based on predefined rule sets. The system could help construction managers to understand and plan to prevent potential fall hazards. The authors point out that if such a project were carried out manually, it would cost more time, labor effort, and, consequently, more capital than a computational tool operated by a single professional.

Hussnain et al. (2016) developed a planning support system to save time and costs in approving private housing projects in two territories in Pakistan (Punjab and Islamabad Capital Territory). This research was motivated by identifying, in the study areas, the demand for housing, the occurrence of irregular private housing developments, and the lengthy licensing process (13 months on average). The authors state that this process, which was carried out manually and through paper documents, was subjective and not transparent. To do this, a system was proposed in order to reduce the time and cost involved in analyzing documents for housing licensing.

By integrating computational routines into the approval process, open-source tools can make this objective more reliable. It allows adaptations, modifications, and the development of new versions, seeking the proposal's improvement and reproducibility for other places. This system was based on open-source and geospatial tools, which were integrated through equations related to the type of project, area, location, access to the road network, among other parameters. The authors claim that using such a tool can make the licensing process faster, more transparent, and more understandable.

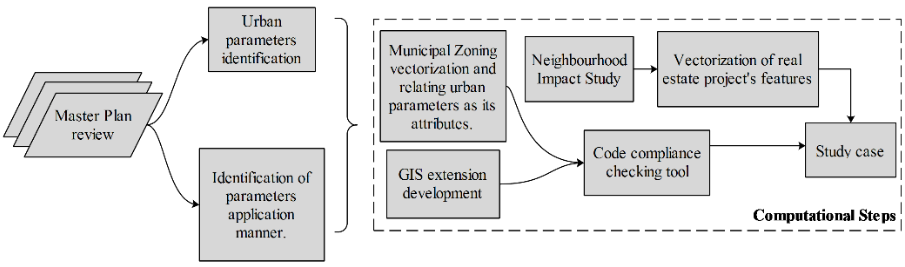
Nawari (2020) developed a generalized framework to reduce deficiencies of the current code compliance checking approaches. These deficiencies are related to high maintenance costs and poorly adaptable methods, which could be useful only in specific applications (NAWARI, 2019). The author provided a schema based on an open standard for a computable model used to express building regulations and rules, enabling the code compliance review process' computerization.

However, as Hussnain et al. (2020) pointed out, there are examples of developed planning support systems that are not well disseminated, even at the local level. Thus, the results of the researches cited in this section remain in the academic sphere. The authors highlight the importance of open access to such tools, sharing them for broader applications.

3 METHOD

Due to the need for a computational tool that can help the public sector in the real estate licensing process, a geospatial tool is proposed. Based on geographic information systems (GIS), such a tool is responsible for verifying compliance in georeferenced projects. Regarding its application, it was developed in Python programming language and applied as a plugin for the QGIS® platform, in version 3.10.11. Figure 2 depicts the flowchart of the proposed GIS extension for the urban code compliance checking method.

Fig. 2. Flowchart showing methodology.



First, the primary urban legislation, the Master Plan of the study area (SÃO CARLOS/SP, 2018) – Brazil, was revised to identify the applicable urban parameters and how they are applied to real estate projects. Then, the Municipal Zoning was vectorized to be used as the plugin basis, indicating, in a geospatial way, in which zone the project is located and the applicable parameters for that zone. The GIS extension was then developed, and to validate it, a real estate project was vectorized, based on its SNE, which contains the project's information, parameters, and values. Moreover, since only the SNE approved by the government is available, a hypothetical development was created to validate the plugin's behavior upon non-conformities and specific zones of the municipality.

3.1 Master Plan review

From the Master Plan analysis, the criteria imposed by the municipality can be observed. During the review, the parameter values were identified to integrate them in the proposed tool. In other words, the main parameters were identified to enable subsequent feeding of the proposed system with the reference values for the municipality. Also, the parameters application manner was identified to enable the development of routines that ensure compliance with legislation. The possibility of legislation revisions over the years was considered, so that the tool can quickly adapt in case of changes in the reference parameters, updating the set of stored parameters in the vector's attribute table.

The urban parameters found throughout the São Carlos Master Plan (SÃO CARLOS, 2018) were defined as the study object. Therefore, the parameters used in the present research are those related to land occupation, which correspond to:

1. Soil Occupancy Coefficient (SOC): proportion between the area of the building projection on the ground and the land area of the lot;
2. Soil Use Coefficient (SUC): proportion between the building area and the land area, which can be divided into Basic Use Coefficient (BUC) – the proportion between the building area and the land lot area, without needing a counterpart - and the Maximum Use Coefficient (MUC) – a factor by which the lot area must be multiplied in order to obtain the maximum building area allowed in this same lot, upon the application of certain urban instruments defined in the São Carlos Master Plan (Onerous Grant of the Right to build or Transferable Development Rights);
3. Permeability Coefficient (PC): the ratio between the permeable area and the land area;
4. Vegetation Coverage Coefficient (VCC): the ratio between the area covered by tree or shrub vegetation of a given property and its total area.

As well as the aforementioned urbanistic coefficients, the Master Plan also establishes limits for the Minimum Lot Area and Minimum Frontage length. All parameters and their respective values are arranged in the sections that comprises Chapter II (of the municipal zoning) of Title II (of the territorial ordering) of the São Carlos Master Plan. Each section of the chapter is responsible for describing the zone, declaring the objectives, listing the urban coefficients and their values, and pointing out the applicable instruments of urban policy.

Although the urban parameters used in the present research are from the São Carlos Master Plan, complementary legislation needs to be consulted to identify the non-computable areas to calculate SOC and SUC. To do this, the Building Code – Law No. 15.958, of December 29, 2011 (SÃO CARLOS, 2011) was consulted. According to such legislation, the non-computable areas are:

1. Garages, vehicle parking, and their respective traffic and maneuvering lanes;
2. Reservoirs, hydraulic structure, and engine room;
3. Swimming pools;
4. Stairs repetitions, pit elevators, ducts, and shafts.

Once the licensing process is understood and mapped, and the reference values and legal parameters are raised, the tool’s development becomes more assertive.

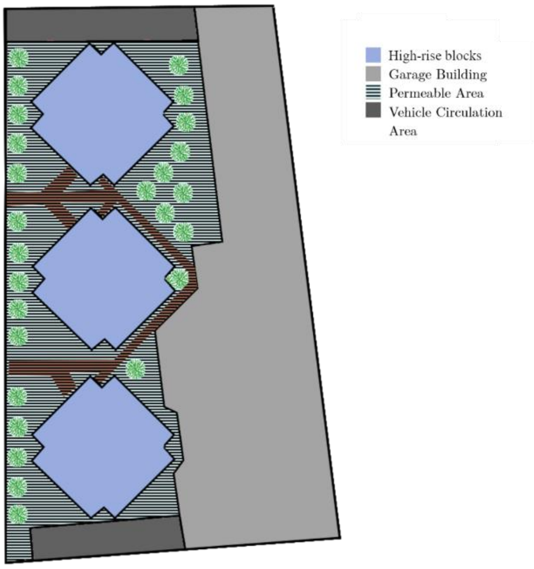
3.2 Study object

To validate the effectiveness of the tool, it was applied to a case study in the municipality of São Carlos, simulating the requirements verification procedures in the licensing process. To do this, the Parque dos Girassóis Project was selected (Figure 3).

This project is a social housing project, part of the Brazilian program Minha Casa, Minha Vida, responsible for promoting better real estate financing conditions. This project, implemented in an area of 6,113.72 m², is located in Zone 2 (Induced Occupation), according to the São Carlos Master Plan (2016).

The Parque dos Girassóis project has three high-rise blocks, each with 142 apartments, on 17 floors, and an upper floor for leisure activities. It also has a garage building with four floors (basement, ground floor, and two more floors above). According to its SNE, the project in question is a housing alternative as the city of São Carlos meets demands for housing fairly quickly. It can be observed that land occupation does not represent potential conflicts with land use (i.e., loss of production and jobs in the agricultural sector).

Fig. 1. Parque dos Girassóis project presented in its SNE



Source: Parque dos Girassóis project (2020)

A hypothetical development was considered to evaluate the tool through non-conformities of the project and specific locations. To do this, such a project was vectorized on the Structuring Axis zone and subjected to parametric verification. This zone, once is determined by some of the main urban roads in the municipality, encompasses more than one of the other zones. Thus, when identifying a land lot that lays on two zones simultaneously, the tool gives preference to the Structuring Axis, as in cases where there is overlap, one of the zones has to be the Structuring Axis. Moreover, the hypothetical development was guided to force the existence of non-conformities. Therefore, in terms of the primary variables, the plugin measures the magnitude of the disagreement with the legislation.

3.3 GIS extension

The proposed tool was developed for the QGIS® platform, version 3.10.11, using its resources and extensions for plugin creation. First, the plugin called “Plugin Builder” was installed, responsible for creating all the necessary files and the basic structure for creating a QGIS® plugin. This extension creates a folder containing all the essential files necessary for the program operation.

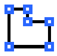
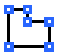
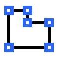
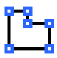
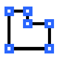
Then, its graphical interface was developed through the “Qt Designer” tool, which also accompanies the QGIS® package. To do this, the file with the extension “.ui”, created by the Plugin Builder, was then opened and modified by the Qt Designer. Such a tool provides multiple options of widgets that can compose the plugin interface to be created according to the desired functions and operations.

When assembling the desired interface for the plugin, it was necessary to develop the Python language routines. For that, the ".py" file, which contains the entire Python structure of the plugin, must be modified. The tool was developed based on the São Carlos' Zoning vector and its attributes table. These vectorial data were used as the reference to check in which zone the development is located and verify compliance with the reference parameters defined for that zone.

The real estate project, created in a GeoPackage structure, must contain the necessary features for each part of the project, such as polygon for the lot, line for the frontage, polygon for the building, polygon for the permeable area, and so on, as described in Table 1. Although there are two non-obligatory features (permeable and vegetation cover area), the others represent components that every real estate development must have in its project, even if some zones do not indicate parameters for such obligatory features.

From the two main structures (zoning and real estate project), the plugin requires the user to indicate the features associated with each structure. The plugin also allows the user to mark possible restrictive cases, such as social housing, single-family housing, or mixed-use. The restrictive cases are important as such cases imply different reference values. Then, the tool must retrieve the correct parameters from the attribute table.

Table 1
Data requirements for the proposed GIS tool.

Dataset	Type	Description
Land Lot		Polygonal vector representing de project's land lot.
Building Computable Area		Polygonal vector containing only the computable area of the building, according to applicable legislation.
Permeable Area		Polygonal vector of the project's permeable area. It is non-obligatory data
Vegetation Cover Area		Polygonal vector containing the area covered by vegetation. It is non-obligatory data.
Frontage		Line vector covering the project's frontage.
Municipality Zoning		Polygonal vector of the municipality zoning. It should contain all the parameters for each zone on the attributes table, where each zone can be represented by a line of the table.

Source: Authors

Thus, from the Python routines, the plugin checks in which zone the project is, retrieving the respective reference parameters. Then, after automatically calculating the area and length of each project component, the tool computes all applicable parameters and checks them according to the reference values for the zone. Finally, it creates a report, containing the conformities and, if applicable, the magnitude of the non-conformities. It is essential to mention that, although the verification is carried out in terms of the urban coefficient, the non-conformities are presented in terms of primary variables (area or length). Thus, there is a better understanding by the parties involved in the real estate licensing process, that is, the public power, private sector, and, especially, the civil society.

This tool is interesting when analyzing the parameters from a file frequently used in projects: the vector files and the geospatial data. Furthermore, it can integrate the real estate project with other geospatial information, allowing several urban analyses considering its geographical position and the characteristics of its surroundings.

4 RESULTS

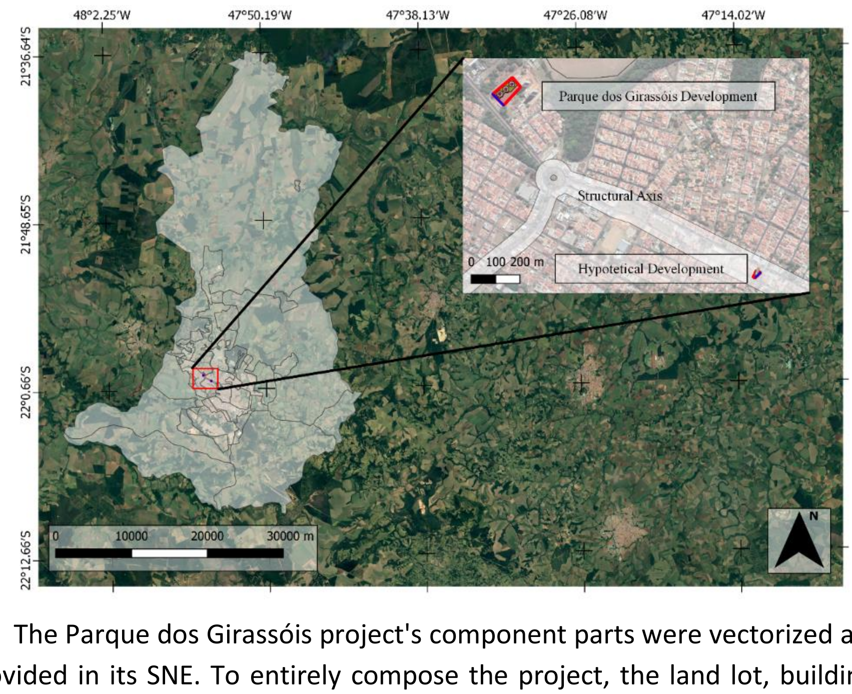
This section describes the results obtained for each component that comprises the geospatial tool. This was conceived for the public sector's use, allowing the composition of a georeferenced real estate system, enabling various urban studies. The developed plugin behaves as a tool that can help the housing and real estate licensing process, verifying the urban design coefficient conformity. For this paper, the urbanistic parameters from the São Carlos Master Plan were used.

The developments described in Section 3.2 were used as the case studies, enabling to analyze the licensing according to the applicable urban parameters.

4.1 Vectorial data

Zoning was vectorized (Figure 4). When analyzing the zoning, geographically separated zones can be observed but with the same classification (and consequently the same parameters). For this purpose, multipart polygons were used, which associate spatially separated polygons as a single feature, so that only one line appears in the attribute table. The attributes table of the zoning vector, containing every parameter, can be checked in Table A.1.

Fig. 2. São Calos zoning vector.



The Parque dos Girassóis project's component parts were vectorized according to the plan provided in its SNE. To entirely compose the project, the land lot, building, garage, and

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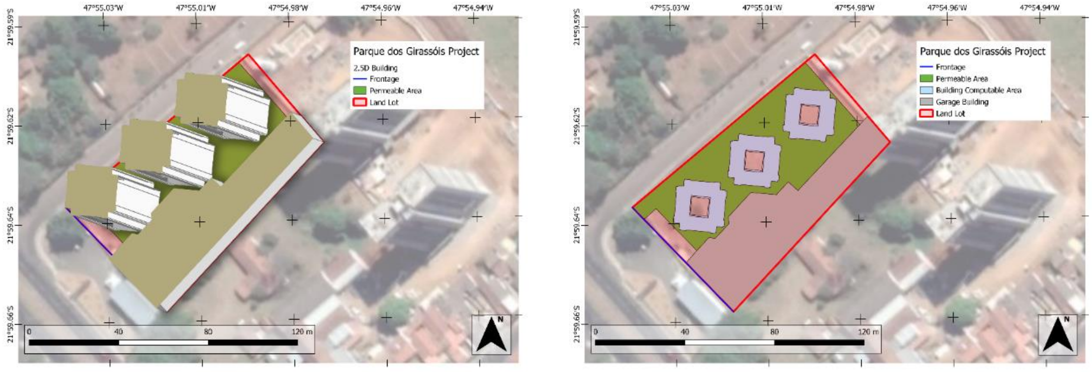
permeable area were vectorized as polygonal features, in addition to the linear feature for frontage. According to the high-rise block's shape, the building features were replicated for each floor, enabling to calculate the SUC, which considers the entire constructed area. However, for the correct calculation of the coefficients, each building floor was vectorized discounted from the non-computable areas, as specified in the project's SNE, and governed by the Building Code, presented in Section 3.1. Figure 5 illustrates (a) a 2.5D representation of the housing development, and (b) the features used in the study case, with the building feature discounted from the non-computable areas.

Fig. 3. Parque dos Girassóis development GIS project.

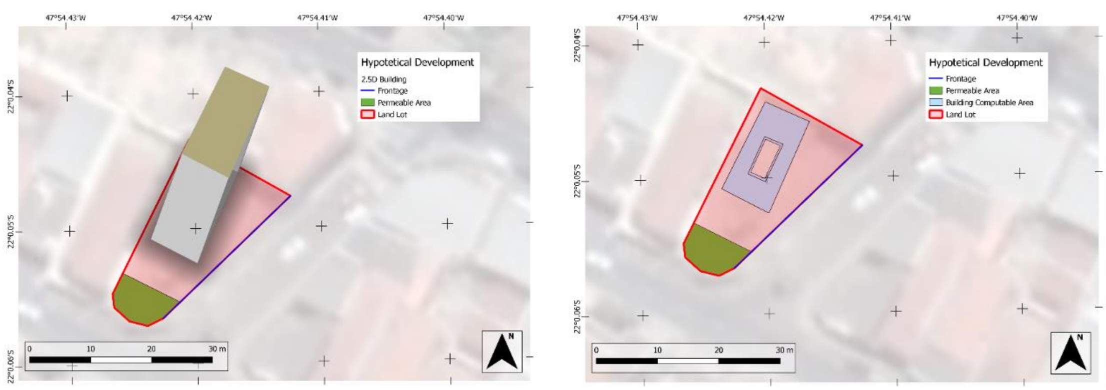
(a) 2.5D representation of the development (a) Features used in the study case



Similarly, a hypothetical development was vectorized over the "Structural Axis" zone to ensure the tool's operation in areas with more specific characteristics. This zone, by definition, is superimposed over the others, as it represents areas delimited by traffic routes that consider more than one zone. For demonstrative purposes, the building of the project was considered as a 15-story high-rise block, forcing the tool to identify non-conformities. This project is illustrated in Figure 6, where, similarly to the representations of the Parque dos Girassóis development, Figure 6(a) presents a 2.5D representation of the project, and Figure 6(b) illustrates the features used for automated requirement verification of the hypothetical development.

Fig. 4. Hypothetical development project.

(a) 2.5D representation of the development. (b) Features used in the study case.

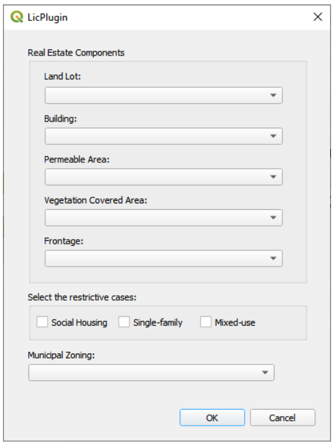


4.2 GIS code compliance tool

The plugin interface developed in Python language for the QGIS® platform, to automatically check the project's compliance with the parameters described in the São Carlos Master Plan, is illustrated in Figure 7. Its interface was entirely created using the Qt Designer tool.

The Permeable Area and Vegetation Covered Area parameters have the option of not being associated with any vector file, since not all zones and not all projects have such characteristics. However, the land lot, the frontage, and the building are the basic parameters necessary to verify compliance with the real estate licensing, based on the São Carlos Master Plan parameters.

Fig. 5. QGIS® code compliance checking tool interface.



After configuring the plugin parameters, according to the project’s features, and selecting the “Ok” button, the tool first identifies in which zone of the municipality the land lot is located. Next, the calculation of the areas and lengths of the features is performed to compute each coefficient then. For the Soil Occupancy Coefficient, the tool performs a merge operation to join the building features to calculate only the area of its projection on the land lot. For the Soil Use Coefficient, the tool calculates each feature's area and makes the sum of them to calculate the total constructed area.

After calculating all applicable coefficients, the plugin retrieves the data from the attribute table associated with the project's zone, allowing the parametric compliance checking step. At the end of the verification, a report is generated, shown to the user at the Python Terminal of QGIS®. For the case of the Parque dos Girassóis Project, the report is illustrated in Figure 8.

To verify the functioning of the “Structural Axis” zone, and the tool's behavior in the face of non-conformities, a case study was carried out from a hypothetical development (Figure 6). Therefore, a hypothetical project was vectorized on the Structuring Axis and subjected to parametric verification. In that case, when identifying a land lot that focuses on two zones, the plugin gives preference to the Structuring Axis, since in cases of overlap, one of the zones is necessarily the Structuring Axis. Moreover, the case study on the hypothetical development was guided to force the existence of non-conformities. Then, the plugin measures, in terms of the primary variables, the magnitude of the non-conformities. The report generated for the hypothetical case is illustrated in Figure 9. The use of a hypothetical project to verify non-conformities, instead of a real project, occurred because the SNEs made available are only approved projects, that is, their projects have already been adapted to the legal parameters values.

Fig. 6. Report of the QGIS® code compliance tool for the Parque dos Girassóis development.

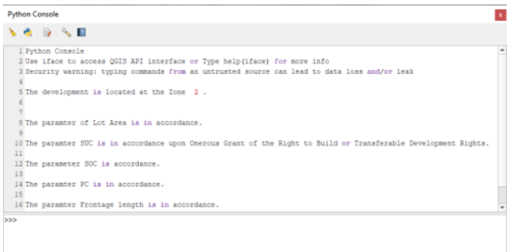
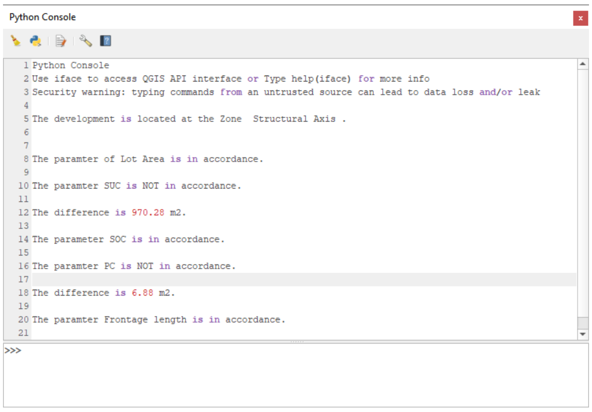


Fig. 7. Report of the QGIS® code compliance tool for the hypothetical development.



In this way, the geospatial tool allows housing and real estate developments to be automatically evaluated by the incident urban parameters. Moreover, it can be observed that the use of vector files, as it proves to be an essential resource in project design, allows the quick and robust calculation of the urban land use parameters and its compliance verification.

The proposed tool can present better results when integrated into government processes, mainly if used as the official real estate licensing method as it would require real estate projects to develop geospatial models. Thus, besides the verification of legal parameters, other forms of geospatial analysis would be possible, constituting a complete and multi-analysis planning support system, especially for the public sector.

5 DISCUSSIONS

When developing a tool from the FLOSS approach, the possibility of the public application becomes greater. Moreover, cooperation between academia and the public sector can be promoted, as methodologies based on cooperative procedures, in conjunction with open-source developments, make it viable (WEN et al., 2020).

According to the study developed by Shahi, McCabe and Shahi (2019), the most complete electronic system level to analyze real estate developments is given by the integration between GIS and BIM. This integration would allow building evaluation according to its design, considering the urban context in which it is found.

Tools that perform the verification of parameters in real estate projects are mainly focused on BIM use. Such focus generally represents expensive and complex resources, generating a gap in the urban analysis of projects and not harnessing the potential of integrating computational tools into the urban environment. In this way, a geospatial tool developed for the QGIS® platform (which is free) allows its use by the government sphere without the restrictions of private licenses. Eastman et al. (2011) point out that manual and automatic verification should be complementary.

The presented case, where the project is located in the Structural Axis, allows an expansion of the methodology, since it is an area that overlaps the others. Thus, areas of special interests can be modeled, which are specific regions destined for certain purposes, which consequently overlap with the zones defined for the municipality. Although the tool was applied to the city of São Carlos, it is worth mentioning that it can be adapted to other municipalities as long as the specificities found are modeled according to the need.

GIS models promote efficient support for urban planning, using geospatial resources based on the fundamentals of geospatial location, patterns and trends (LIU et al., 2017). Moreover, according to (YAAKUP et al., 2007), the integration of GIS models with government procedures allows users to follow projects, create databases, perform project analyses, share data and reduce the recurrence of redundant data.

By using vector data for project evaluation, other geospatial analyses can be developed for any project phase. Moreover, an integrated public system that uses geospatial data from real estate developments in the municipality can generate new forms of urban planning and management of the built environment. However, the concept of compliance verification using GIS models is underexplored, especially when applied to the real estate and housing developments licensing process. Although the case studies have been guided for housing developments, the tool may be applied to any real estate development as long as the parameters are also applicable to them.

Possible future work can be developed, seeking to extend the scope of the tool and resolve its limitations. It can be expanded in terms of the legislations considered. A greater number of legal parameters can be incorporated into the scope, also integrating the type of development, classifying them as their use (commercial, industrial, residential, or mixed).. Moreover, it is interesting to integrate the tool into a broader system, composing a public geospatial database. Thus, using other GIS resources makes it possible to extend the knowledge about the built environment and evaluate the consequences of implanting a real estate development in its adjacent lands.

6 CONCLUSION

The developed program proves to be of great use for the various parties involved in the licensing process for housing and real estate developments. As public benefits, a geospatial code compliance tool that checks urban parameters for real estate projects against reference values may reduce the delay of licensing, in addition to ensuring sustainability and transparency. Moreover, the results generated by such a tool could facilitate accountability to society, making the approval process more objective, transparent, and using fewer resources. Still, in the long run, the reduction in approval time may meet part of the housing demand in the municipality.

Free and open-source computational tools, when developed aiming at public application, must be articulated through open codes and free platforms. Therefore, it allows the tool to receive updates or incorporations of new methods through participatory developments, involving the scientific community, public authorities, and civil society. Still, the free use of the tool does not require the contracting of licenses for the use of specific models, avoiding that the government needs to purchase such private licenses.

The present research can be an initial stage of developing integrated systems between GIS and urban planning since it is still little explored in the academic scope. The evolution of technological resources enables us to reflect on traditional public sector processes due to the potential to make them more efficient. Furthermore, integrating computational tools in the public sphere can provide a basis for new paradigms of governance models, making their operations and processes more efficient and democratic.

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