Automatic verification of urban index compliance: A case study for Brazilian buildings

F S Villaschi1*, J P Carvalho2,3 and L Bragança2,3

1 FSV Projetos, Vila Velha, Espírito Santo, Brazil*
2 Institute for Sustainability and Innovation in Structural Engineering (ISISE), University of Minho, Guimarães, Portugal
3 University of Minho, School of Engineering, Civil Engineering Department, Guimarães, Portugal
*Correspondence: fsvprojetos@gmail.com

Abstract. Urban planning has become an essential tool for regulating the cities' growth, maintaining the local urban identity and providing a good quality of life for its inhabitants. In Brazil, the master plan is the primary policy instrument for urban development and expansion. It defines the common requirements that designers must follow when preparing building projects. Up to date, such projects are verified in project latter stages and eventually approved by the city halls, with a manual calculation and assessment process. This procedure creates both the need to assess project compliance earlier to avoid rework and changes, as well as to automate project verification compliance, to reduce human errors. With the emergence of new technologies and computational systems, such as Building Information Modelling (BIM), creates the opportunity for process automation, by providing the required data to support decision making, as well as to automate the calculation process both for designers and municipalities. Thus, this research aims to develop an assessment procedure which automates the compliance assessment of a set of urban requirements from Vila Velha, Brazil. A BIM model was developed in Autodesk Revit to prove the procedure functionality and Dynamo was used to automate data collection and the calculation of three different indexes from Vila Velha’s building code. By providing a fast and reliable analysis, the research framework provides designers with a real-time decision support tool, which indicates building compliance in the project's early stages. It also provides municipalities with a calculation tool, which can be used to assess the compliance of submitted BIM models, sparing time and avoiding assessment errors. Overall, the procedure has the potential to support building project design, increase process efficiency and accelerate the verification of mandatory requirements. It also offers the possibility for replication by adapting the routine to the mandatory requirements of each location.

Keywords: BIM; Automatic code compliance; Computer Design; Urban Index

1. Introduction

Building design and construction processes are usually oriented by several regulations and guidelines. The requirements for those regulations are constantly evolving and include a set of data that must be complied by construction projects. Automatic code compliance has been widely addressed over the past years, given the need to adapt building projects to the mandatory regulatory requirements. Following
the recent emergence of Building Information Modelling (BIM), automated code verification has once again attracted researchers' attention, as BIM offers a set of potentialities to improve the analysis [1-3]. BIM can be described as a working method that allows managing all the project design and data in a virtual environment during the project life cycle [4]. It has the potential to support project design and analysis, as it allows to store different multi-disciplinary information into a single digital model, improving process efficiency and reducing project errors and incompatibilities. Following the need for building projects to comply with the local regulations, both designers and city halls experts must guarantee that submitted projects always consider the regulation requirements. Such procedure is usually made with a manual process, requiring time and opening a gap for assessment and calculation errors. With the increasing design and project complexity [2], together with the increasing number of building requirements for different types of buildings [5], manual compliance analyses tend to be very time consuming, requiring deep knowledge about the building, often leading to many analyses errors and delaying the verification procedure [6-7]. With the support of BIM, new approaches for automatic code compliance have been developed, allowing for better and more comprehensive procedures. In 2009, Eastman et al. [8] have defined the main four tasks which must be followed when performing automated code compliance: (1) Rule interpretation, which consists of the identification of applied requirements and translation to computer-processable language; (2) Building model preparation, which is the designing of a digital BIM model; (3) Rule execution (3), which consist on the execution of the identified rules, using text format coding or Visual Programming Language (VPL); and (4) rule compliance report, which summarizes the analysis result. As in previous successful studies [9], this research will adopt this same procedure to carry out this study. For the rule execution task, VPL language was used through Dynamo software, as it is more transparent and easier to understand, especially for architecture, engineering and construction stakeholders who usually have limited knowledge of information technologies.

1.1. Legislation
As the present research will focus on Brazilian buildings, the local regulation will be considered. The main instrument to regulate Brazilian construction is the urban master plan, which defines several rules for buildings, depending on the building type, location, and use. Figure 1 summarizes the Brazilian regulation [10], where the municipal master plan was developed to define the mandatory requirements for urban development and expansion. It comprises a set of guiding principles and rules for designers to plan quality and comfortable construction for citizens. City halls are responsible to verify the project's compliance to certify if the building can be built in that location, with its specified characteristics. The city hall approval is mandatory to issue construction permits. Along with the land use plan, the Brazilian master plans include city zoning and building codes. City zoning usually determines what building types and uses can be built in each identified zone. Building codes establish the rules for organising the building interiors and requirements for habitability. These rules apply to new and existing buildings and aim to provide occupants with a healthy indoor environment. Under the scope of the local building codes, the most notorious requirements are the minimum window area, to ensure proper lighting and ventilation, the minimum room area, and the minimum ceiling height. This study will focus the research on Vila Velha’s building code, addressing and evaluating these three main indexes.
The requirements limits are usually defined locally by each municipality, depending on the building type. Every municipality must guarantee that the master plan requirements are being complied with, usually with a typically time-consuming process. Many municipalities are looking for innovative systems and improvements to reduce the bureaucracy of internal procedures and increase the convenience and agility of such construction processes [11]. Therefore, this study aims to develop an automatic analysis method to minimise time and avoid errors when performing automatic code compliance for building projects in Brazil. By using a characterised BIM model and a routine created in Dynamo, the required data for the analysis is automatically collected and processed to quickly provide designers and municipalities with a compliance report of the local building code.

2. Materials and Methods
To achieve the research objective, the specific case of Vila Velha’s (Brazil) building code is considered. As stated earlier, currently, city halls usually adopt a manual procedure to verify building code compliance and Vila Velha municipality is no exception. Despite the need to submit a digital process, the building code compliance is made manually, requiring each analyst or expert to carefully review each project according to the current legislation, which costs time, delays the approval process, and creates room for calculation and misunderstanding inaccuracies. Combined with the need to provide designers with a real-time decision-making tool, this research aims to develop an automated evaluation method to verify the building code compliance of Brazilian construction projects.

2.1. Methodology
An automated routine will be developed and applied to a building case study to accomplish the research objectives. The methodology is divided into four different stages, as presented in Figure 2 and according to the identified procedure made by Eastman et al[8].

Figure 1. Brazilian legislation.
The first step will be the rule design, where the building code requirements will be identified and translated to software code [11]. Then, the case study BIM model will be created within Autodesk Revit, which was selected due to its capability to develop personal interfaces through Dynamo (VPL). Moreover, Autodesk Revit is also the most used BIM platform among researchers on the topic [12,13]. To carry out the modelling procedure, an Autodesk Revit template was used, containing predefined schedules of room types, windows, and rooms, to facilitate data collection from Dynamo to quickly proceed with the analysis. After that, the Dynamo routine will be developed to collect and compare the schedule data for the analysis and perform the intended calculations. The results for each parameter are compared with the local building code requirements to assess building compliance. After running the Dynamo routine, a compliance report is generated, indicating if the building project can be approved and a construction permit can be issued.

2.2. Case Study
The selected case study (Figure 3) is a single-story residential building in Vila Velha, Brazil. It has some of the most representative features of Brazilian houses - a detached single-family house with a colonial tile roof and brick masonry. The house has 2 bedrooms, a kitchen, a laundry room, a dining room, a living room, a balcony, and a garage. The building’s total useful area is 72.23 m² and each compartment name, area and ceiling height are described in Figure 3. The total window area is 9.12 m², corresponding to 12.63% of the floor plan area.

3. Results
The first step was the identification of Vila Velha’s building code requirements. For a residential building, the following requirements must be fulfilled: Minimum ceiling height, minimum compartment area and minimum window area for ventilation and lighting. These minimum limits are defined in Annex VI of the local building code, according to Table 1. The building code defines the minimum area and
ceiling height for each compartment type, as well as the minimum window area based on the compartment floor area.

### Table 1. Vila Velha building code minimum requirements

| Minimum requirements | Hall | Service Bathroom | Social Bathroom | Living room | Kitchen | Pantry | Laundry | Garage |
|----------------------|------|------------------|-----------------|-------------|---------|--------|---------|--------|
| Area (m²)            | 1.00 | 1.60             | 2.50            | 10.00       | 4.50    | 1.60   | 1.60    | 10.35  |
| Window area          | -    | 1/8              | 1/6             | 1/8         | 1/10    | 1/10   | 1/10    | 1/20   |
| Ceiling height (m)   | 2.30 | 2.30             | 2.30            | 2.60        | 2.60    | 2.60   | 2.30    | 2.30   |

During the modelling stage, a set of guidelines must be followed for the proper functionality of the Dynamo routine: a personalised template should be used, previously characterised with the local building code requirements; the user must create rooms for every compartment and characterise them accordingly; and the building walls must be segmented in every intersection, as the routine will associate windows area to each compartment wall. The personalised template was created to automate the compilation and collection of the required building data for the local code analysis. By organising the information, the template quickly provides all the input data for the Dynamo routine. For each compartment, schedules identify whether the room should have a window, the minimum floor area for each room type, the minimum window area, and the minimum ceiling height. This process has been automated in the Autodesk Revit template by converting the model rooms into a list that contains sub-lists of information for each room, including the required data for analysis. This data is then used to verify if the building compartments comply with the building code requirements. Thus, the applied template has created specific schedules of windows and rooms (Table 2 and 3), which lists all the required data (dimensions and number of windows, room area, and the ceiling height) to proceed with the analysis in the Dynamo routine.

### Table 2. Case study window schedule

| Type Mark | Mark | Width (m) | Height (m) | Sill Height (m) | Quantity |
|-----------|------|-----------|------------|-----------------|----------|
| J1        |      | 0.80      | 0.60       | 1.50            | 1        |
| J2        |      | 1.50      | 1.20       | 1.10            | 4        |
| J3        |      | 1.20      | 1.20       | 1.10            | 1        |

### Table 3. Case study room schedule

| Name       | Room Type                | Ceiling Height (m) | Area (m²) |
|------------|--------------------------|--------------------|-----------|
| Kitchen    | Kitchen/dinning room     | 2.50               | 8.26      |
| Bedroom    | Bedroom                  | 2.60               | 8.91      |
| Bathroom   | Social Bathroom          | 2.40               | 3.19      |
| Living room| Living room              | 2.70               | 12.98     |
| Laundry    | Laundry                  | 2.70               | 2.99      |
| Balcony    | Undefined                | 2.70               | 4.20      |
| Hall       | Hall                     | 2.70               | 1.27      |
| Dining room| Kitchen/dining room      | 2.70               | 11.76     |
| Garage     | Garage                   | 3.00               | 32.40     |

The local building code requirements for each room type were previously introduced in the Autodesk Revit template (based on Table 1) and organised into a schedule (Table 4). After that, the Dynamo routine will use this data to compare it with the properties of the BIM model (from Tables 2 and 3). The results will certify whether the BIM model meets the local building code or not. If a room is not required
to meet any of these requirements, the "Key Name" should not meet any of the listed names. Also, if a room is not required to have windows, the user can deselect it and exclude it from the analysis. The user must prepare the project and name each compartment according to the names specified in the local building code (and in the Autodesk Revit template).

Table 4. Room schedule

| Key Name             | Include in analysis? | Minimum Area (m²) | Minimum Windows Area (m²) | Minimum Ceiling Height (m) |
|----------------------|----------------------|-------------------|---------------------------|---------------------------|
| Bedroom              | Yes                  | 7.00              | 0.17                      | 2.60                      |
| Garage               | Yes                  | 10.35             | 0.05                      | 2.30                      |
| Hall                 | Yes                  | 1.00              | 0.00                      | 2.30                      |
| Kitchen/dining room  | Yes                  | 4.50              | 0.13                      | 2.30                      |
| Laundry              | Yes                  | 1.60              | 0.10                      | 2.30                      |
| Living room          | Yes                  | 10.00             | 0.17                      | 2.60                      |
| Pantry               | Yes                  | 1.60              | 0.13                      | 2.60                      |
| Service Bathroom     | Yes                  | 1.60              | 0.13                      | 2.30                      |
| Bedroom              | Yes                  | 7.00              | 0.17                      | 2.60                      |
| Garage               | Yes                  | 10.35             | 0.05                      | 2.30                      |

After characterising the model, the dynamo routine of Appendix 1 was developed to carry on the analysis. Overall, it captures the information from the BIM model and automatically performs the model verification according to the building code requirements. The analysis is made by comparing the building code requirements for the minimum window area, room area and ceiling height (Table 4) with the BIM model characteristics (Tables 2 and 3). The adopted case study has failed in complying with the minimum window area, as the laundry compartment has no windows, while the minimum requirement is to have 0.10 m² of windows. For the remaining two indexes, the case study has been successfully approved.

The result of the routine consists of a compliance report indicating if the building complies with the local building code. If a negative output is reached, the Dynamo routine identifies which criteria is not being met, according to the considered regulations. The compliance report output summarises the results for minimum window area, minimum room area, and minimum ceiling height.

4. Discussion

The applied methodology has successfully automated the building code compliance criteria for a case study in Vila Velha, Brazil. The procedure was significantly faster than the typical analysis process, as it automated data collection and processing, proving reliable results. It has also avoided common human errors in assessing data and performing calculations. This method can effectively support designers by providing a real-time decision support tool, allowing for design optimisation. Municipalities can also take advantage of the research outcomes, with an automated process to verify building compliance and reduce the required time to issue build permits.

The workflow created in Autodesk Revit and Dynamo has considered specific modelling guidelines to properly collect the required data from the BIM model. A personal template with predefined schedules was used to facilitate and improve data collection. The template is mandatory for the analysis, as the Dynamo routine uses schedules data to perform the calculations. To avoid the template, a new Dynamo routine can be made, replicating the same actions. However, Dynamo routines must be executed separately and by order (1st create schedules; 2nd perform analysis).

Despite the useful successful analysis, the applied method seems to have a couple of limitations. The compliance report presentation must be assessed directly in Dynamo, requiring the need to open the routine to assess results. To avoid this need, a node from “datashapes” [14] can be used, which allows presenting a given result or information directly in the Autodesk Revit environment. The template is already characterised with Vila Velha building code data. For replicability, the template must be manually adapted. Once again, the development of a new Dynamo routine to replicate the template can be a possible solution. Such routine can create new “shared parameters”, so the users would be able to introduce their local building code limits.
Another key factor is the use of Autodesk Revit 2022 in English and Dynamo version 2.10. As software is continuously receiving new updates, the functionality of the template and routine must be carefully evaluated in different software versions. Authors can assume that the routine will work properly in newer versions since only base nodes were used.

For the method replicability for other Brazilian locations, minor efforts are expected. The Autodesk Revit template must be updated with the local building code limits. As building requirements may change in other countries, international replicability is not guaranteed but insights can be taken.

5. Conclusion
This study has developed a workflow for the automation of building code compliance of a case study in Brazil. By using Autodesk Revit and Dynamo software, the adopted methodology can support building design by evaluating its compliance with the local regulations. The use of BIM provides the required resources for faster and more reliable data collection and analysis, as well as important data for decision making in the design phase. Municipalities can also use it as an innovative tool to quickly assess building compliance with the local building code.

The applied software has the potential to store the necessary multidisciplinary information and perform the required analysis. It can significantly support design, as well as reduce the administrative processes of issuing construction permits. Despite the limitations, it has proven to be quite reliable and offers a few ways to overcome them. Overall, it has been concluded that automatic code compliance with BIM will become an essential tool for designers and municipalities, as administrative institutions and construction companies are increasingly integrating digitalization into their procedures. In future works, it is suggested the automation of new urban indexes, as well as the inclusion of different building types and distinct locations.

Funding: This research was funded by the Portuguese Foundation for Science and Technology, through the Regional Operation Programme of North (Grant number SFRH/BD/145735/2019).

References
[1] Miettinen, R., & Paavola, S. (2014). Beyond the BIM utopia: Approaches to the development and implementation of building information modeling. Automation in Construction, 43, 84–91.
[2] AIA. AIA Document G202-2013; Project Building Information Modeling Protocol Form; AIA: Washington, DC, USA, 2013.
[3] N Marco Häußler, Sebastian Esser, André Borrmann, Code compliance checking of railway designs by integrating BIM, BPMN and DMN, Automation in Construction, Volume 121, 2021.
[4] Succar, B. Building information modeling framework: A research and delivery foundation for industry stakeholders. Autom. Constr. 2009, 18, 357–375.
[5] Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM Handbook A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors (2nd Edito). New Jersey: John Wiley & Sons.
[6] Eleftheriadis, S.; Mumovic, D.; Greening, P. Life cycle energy efficiency in building structures: A review of current developments and future outlooks based on BIM capabilities. Renew. Sustain. Energy Rev. 2017, 67, 811–825.
[7] Solihin, W., & Eastman, C. (2015). Classification of rules for automated BIM rule checking development. Automation in Construction, 53, 69–82.
[8] Eastman, C., Lee, J. min, Jeong, Y. suik, & Lee, J. kook. (2009). Automatic rule-based checking of building designs. Automation in Construction, 18(8), 1011–1033.
[9] Peter Burggräf, Matthias Dannapfel, Matthias Ebade-Esfahani, Florian Scheidler, Creation of an expert system for design validation in BIM-based factory design through automatic checking of semantic information, Procedia CIRP, Volume 99.2021, Pages 3-8.
[10] Rezende, Denis Alcides, and Clovis Ultramari. "Plano diretor e planejamento estratégico municipal: introdução teórico-conceitual." Revista de Administração Pública 41.2 (2007): 255-271.
[11] Najjar, M.; Figueiredo, K.; Palumbo, M.; Haddad, A. Integration of BIM and LCA: Evaluating the environmental impacts of building materials at an early stage of designing a typical office building. J. Build. Eng. 2017, 14, 115–126.
[12] Acco Tives Leão, H., & Canedo, E. D. (2018). Best practices and methodologies to promote the digitization of public services citizen-driven: A systematic literature review. Information, 9(8), 197.
[13] Tan, X., Hammad, A., & Fazio, P. (2010). Automated Code Compliance Checking for Building Envelope Design. Journal of Computing in Civil Engineering, 24(April), 203–211.
[14] “UI. Multipleinputform ++ update”, https://data-shapes.io/2017/04/02/ui-multipleinputform-update/ (accessed Apr.29, 2022).
Appendix 1. Routine.

get valid rooms

get the dimensions of rooms

Room Analysis

Analysis result