Assessing the impact of contemporary urbanization on bioclimatic features of historic architecture through a two-step simulation process

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ABSTRACT: The aim of this paper is to provide a systematic understanding, through simulation-based assessment, of how contemporary urban planning affects the bioclimatic features of existing historic architecture. An emblematic early 20th century Brazilian building, the Casa das Rosas in São Paulo, has been chosen as a case study to see how the deep transformation of its surroundings has altered its indoor conditions. Taking into account both the original and the current urban and environmental conditions, a two-step assessment is conducted by moving between two levels of simulation: the urban- and building-scales. The urban-scale simulations characterize the microclimate parameters (temperature, humidity, and wind speed) that will represent the boundary conditions for the building-scale simulation. EnergyPlus and DIVA-for-Rhino were used to assess the bioclimatic features in terms of indoor thermal and visual comfort levels respectively. Despite the revival of passive design solutions derived from historic architecture, studies of the influence of contemporary urban settlements on their comfort behavior are still quite limited. Outcomes from our simulations show that urban planning can have a significant impact on the indoor light levels of historic buildings, but that the average temperature conditions are not significantly affected. We expect that the results would show a bigger difference if anthropogenic heat sources were taken into account, especially for outdoor comfort conditions.
Keywords: bioclimatic architecture, energy, comfort, daylight, urban microclimate

INTRODUCTION

The concept of bioclimatic architecture integrates an understanding of local microclimate with architecture to improve indoor comfort. In different climatic regions, architecture gave birth to a large repertoire of building typologies developed to mitigate the effect of climatic and environmental conditions, while respecting the cultural and socio-economic frameworks from which they emerged. These structures, which include rural settlements as well as urban historic buildings, constitute an important part of the cultural heritage of contemporary societies. Besides cultural value, they may also be considered sustainable by definition, since they were originally conceived to provide comfort by means of passive techniques, i.e. without the aid of mechanical systems.

The improvement of building techniques and the broad availability of fossil fuels in the second half of the 20th century spread design and construction practices that were, in most cases, characterized by the negation of a holistic design approach. Since then, new projects have risen adjacent to and even amidst ancient neighborhoods in an unsystematic manner, often significantly altering the original natural landscape and/or urban morphology. In some cases, this generated a mixture of architectural languages and technologies without consideration for the connectivity of a community as a whole, disregarding the implication of modern urban interventions and related phenomena, such as the Urban Heat Island (UHI) effect, on the original bioclimatic intentions of an architectural typology. In the last few decades, a number of studies have raised interest in the climate-responsive features of historic architectural types (Coch 1998, Singh et al. 2009, Cardinale et al. 2013). A significant number of studies have also been carried out regarding the sustainable preservation and energy renovation of historic buildings (e.g., Ascione et al. 2011, Nesticò et al. 2015), including methods and techniques for the application of rating systems to improve sustainable performance (Boarin et al. 2014). Despite the revival of passive design solutions derived from historic architecture, studies on the influence of contemporary urban settlements on their comfort behavior are still limited.

This paper suggests the application of a simulation-based methodology to investigate the effect of contemporary city settlements on the urban microclimate and, as a consequence, the bioclimatic features of existing historic architecture. To this end, an emblematic Brazilian building from the first half of the 20th century, has been chosen as a case study to see if, and to what extent, the deep transformation of its surroundings has altered its ability to provide adequate indoor comfort conditions.

METHODOLOGY

Although they provide detailed data to estimate indoor comfort conditions, building energy simulation tools are limited to using outdoor boundary conditions usually derived from long-term observations of local weather stations, therefore ignoring any effect of the surroundings. On the other hand, microclimate simulation tools are able to predict micro-urban scale climate for different urban configurations. In this case, thermal and daylighting conditions at the building scale are either too simplified or totally neglected. Therefore, as suggested also by other studies (Yang et al. 2012, Pastore et al. 2013), the integration of the two kinds of tools allows for the incorporation of microclimate effects on building performance assessments. For this study, a two step-simulation methodology of this kind is proposed to obtain quantitative information about the influence of urban alteration on the bioclimatic performance of historic buildings. To this end, two environmental conditions surrounding a selected case study are compared: 1) at the moment of its construction, and 2) in the present, to observe the effect of altered urban surroundings on the indoor operative temperature and useful daylight illuminance (UDI).

We expect that such methodology could provide new data on thermal and daylighting performance of historic buildings in cities that have undergone massive densification, and where urban development policy has had a relatively limited consideration of building preservation.

The workflow of the study is as follows:

- Starting from TMY weather files, a first micro-urban scale simulation phase is conducted with the software ENVI-met to assess the different processes that occur in, at, and between different elements in the area enclosing the settlement under consideration. These include, for example, urban geometry, surface types and vegetation. These simulations characterize the microclimate parameters (temperature, humidity, wind speed) that will represent the boundary conditions for the next level of simulation.
- Following this urban scale simulation, a building-scale simulation phase is carried out with the software DesignBuilder (EnergyPlus) and DIVA-for-Rhino to assess the bioclimatic features of the building in terms of indoor thermal and visual comfort levels respectively. Finally, the results obtained for both states (original and present day) of the area are compared in order to identify the possible consequences that urbanization has had on the existing architectural case study.

Given the considerable time required for computing ENVI-met simulations, this study was necessarily limited to two sample days which represent a typical cold and a typical warm day.

CASE STUDY

Description of the area

The methodology introduced in the previous section was applied to the historic Casa das Rosas, situated in the city of São Paulo, Brazil. The two-floor (plus attic) building was designed in French eclectic style by the architect Francisco de Paula Ramos de Azevedo in 1930 (Lemos 1987). It was situated in an area of roughly 5,500 sqm in the residential neighborhood of Avenida Paulista which was characterized, at that time, by the presence of aristocratic mansions immersed in open green space (fig.1(a)). In the second half of the last century, as the city's industrial economy grew, the avenue underwent rapid densification (fig.1(b)), becoming the main business artery for the city. The avenue was one of the first to be paved with asphalt and was widened in the 1970s to accommodate increasing traffic loads.

By that time, many of the surrounding mansions were replaced by skyscrapers for a number of financial and cultural institutions with Casa das Rosas remaining one of the few to survive this massive demolition process. The house was later declared a National Landmark by the State, leveraging a restoration and conversion process to revitalize the historic cultural center of the city. The building contains 30 rooms and maintains its original façade. The rose garden, from which it takes the name, has been maintained and the vegetation in the near surrounding still flourishes.

Figure 1: (a) The neighborhood of Avenida Paulista and Casa das Rosas the beginning of the XX century (Toledo 1987); (b) The area and the building as they appear today.

Climate

São Paulo is characterized by a humid subtropical climate (Köppen Cfa/Cwa), with mild and dry winters and hot and humid summers. In summer, the mean low temperature is about 17 °C and the mean high temperature is near 28 °C. In winter, temperatures tend to range between 11 and 23 °C.

MICROCLIMATE SIMULATION

For the micro-urban scale simulations, an area of 250x300m was considered. Two models representing the original and the present state were built according to a 3d-nesting grid of 50x60 (grid size= 5m).

Four receptors (A, B, C, D) were set around the building in order to extract values for temperature, relative humidity and wind speed in the two states. ENVI-met is capable of generating climate data at different heights. In this case, a height of 4.5m has been considered, corresponding roughly to the first floor of the building. The weather data used as input for this simulation phase was taken from the TMY file available on the EnergyPlus website. For each model, two simulations were run corresponding to typical summer and winter days. The typical days are those that had valid wind data (in the IWEC weather file), and whose daily average was closest to the average of that month. The main weather data used as input are reported in table 1.

Table 1: Input data for simulation in ENVI-met. Temperature and humidity profiles were given for 24 hours, while the other values were only for 6 am (initialization).

	Winter (July)	**Summer (January)**
Average temp [°C]	25.30	18.97
Average RH [%]	59.87	62.33
Spec. Hum. at 2500m [gH²O/kgAir]	3.88	6.36
Wind Speed [m/s]	3.30	3.12
Wind Direction [°]	185	185
Cloud cover [Okta]	0.6	1.0

To compare the original and the current microclimatic scenarios around the building, the mean values obtained from averaging the four receptors have been considered. Table 2 shows microclimate differences between the two urban configurations according to diurnal and seasonal variations.

Temperature differences are affected by both season and time of the day. Increases in the temperature attributable to UHI effect are at their maximum value during night time for all receptors. This result is consistent with several studies, which observed that compared to non-urban areas, urban heat islands raise night-time temperatures more than day-time temperatures (Hallet 2002).

Conversely, receptors B, C and D registered cooler temperatures during morning hours in the current urban state than in the historical one. This might be explained by the effect of building density in the surrounding urban fabric and the shading provided by vertical obstructions associated with early morning sun angles, as described also in other studies (Yow 2006). The diurnal variation is in line with temperature trends registered in urban and suburban stations of the metropolitan region of Sao Paulo (Ribeiro et al. 2015), although UHI intensity results are more attenuated in this case. This could be due, in part, to the cloud cover selected for this model and the mitigating effect produced by vegetation surrounding the building (fig. 2).

Differences in relative humidity profiles are negligible during both winter and summer. Urban wind speed values are always between 0.5 and 1.5 m/s, far less than the airport data. Differences between the historical and current scenarios are, however, minimal.

Table 2: Differences of temperature (ΔT), relative humidity (ΔRH) and wind speed (ΔWS) between the two states (Δ = current – historic).

		ΔT [°C]		ΔRH [%]		ΔWS [m/s]	
		Sum.	Wint.	Sum.	Wint.	Sum.	Wint.
Day	Aver.	-0.18	-0.08	-0.15	-0.84	0.00	0.07
	Max.	-0.48	-0.21	-1.48	-1.77	0.03	0.09
Night	Aver.	0.13	0.20	-0.87	-1.48	0.00	0.07
	Max.	0.18	0.24	-1.42	-1.72	0.06	0.08

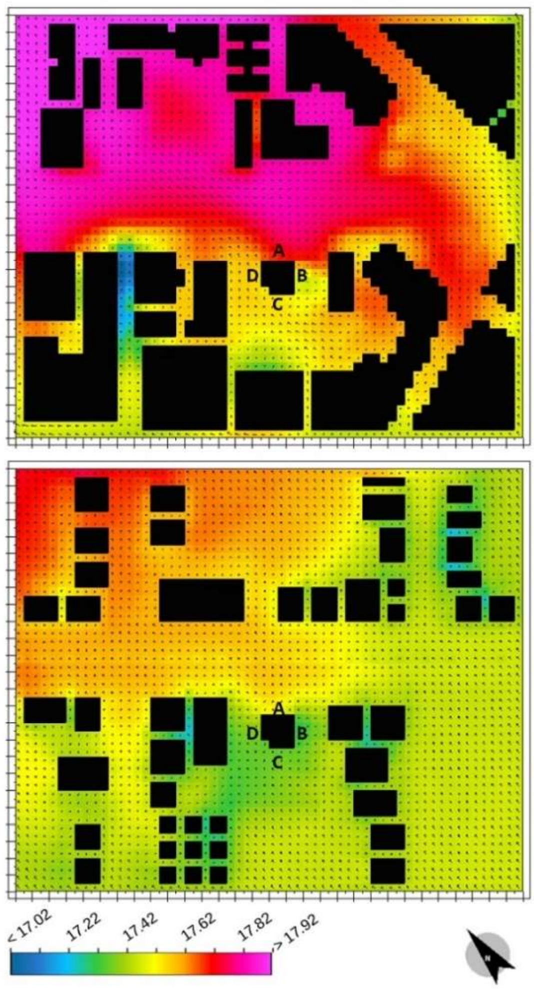


Figure 2: 2D maps of Envi-met thermal outputs in winter at midnight (z=4.5m) for the present-day [top] and historic [bottom] urban configurations.

THERMAL SIMULATION

Only a limited part of the urban context was considered for thermal simulation to reduce computational loads (for external shading calculations), like in the micro-urban simulation. That is, only those surrounding buildings which may directly shade the case study were included (fig. 3). The assumptions about construction and occupancy schedules were consonant with an early 20th century household: a family of four, with domestic staff, on normative schedules based on an assumed usage per room (e.g., master bedroom). The walls are load-bearing masonry, while the roof is a composite of wood and metal sheets (Sato, 2011).

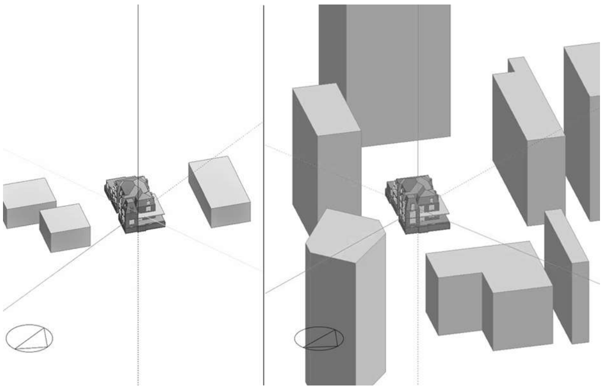
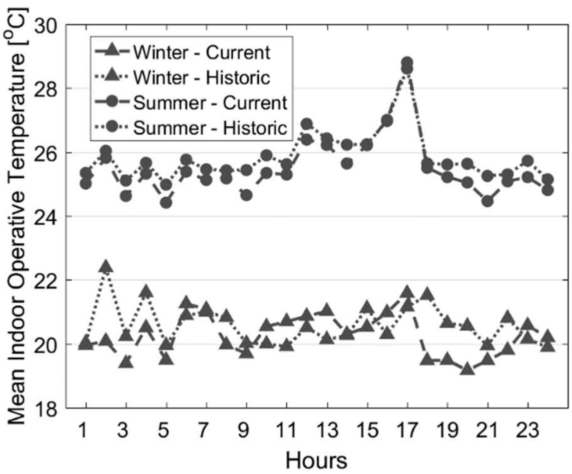


Figure 3: Screenshots of the historical [left] and current [right] urban contexts, as modelled in DesignBuilder.

While the simulations were carried out for the entire months of January and July, only one day per month was used per urban configuration (the same days as the microclimate simulations). EnergyPlus does not integrate microclimate simulations, so the inclusion of context is limited to shading and a wind-pressure factor (suburban for historical Sao Paolo and urban for present-day Sao Paolo). Since these days fall in the typical winter and summer months, they are meant to give an indication of the range of influence generated by changing urban surroundings.

Fig. 4 [top] shows the mean[1] and raw operative temperature across all zones. The difference between indoor operative temperature in the historic and present-day configurations is small and generally greater at night, as evidenced by the marginally higher mean indoor night-time temperature in the historic state. At first glance, it seems counter-intuitive that the present-day (more urbanized) situation gives lower indoor nighttime temperatures (i.e., the house is marginally cooler). This is comprehensible in view of the results for the urban microclimate simulations and the layout of surrounding buildings in fig. 3. The tall adjacent buildings block much of the sunlight before reaching the Casa das Rosas and the small rise in urban temperatures due to UHI do not compensate for that decrease in the quantum of solar irradiation received/stored during the day. Due to this decrease in internal heat addition from solar radiation, caused by the new urban surroundings, the house has slightly cooler indoor temperatures at night. Probably due to the same reason, the winter day is somewhat warmer in the historical case. The histogram of raw temperatures (fig. 4, bottom), indicates that while the temperature difference can be up to 4ºC, the majority of differences are in the ±1ºC range.



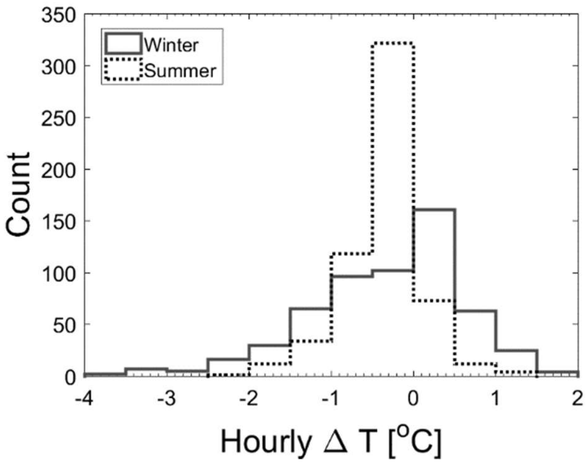


Figure 4: Mean indoor operative temperatures per hour [top], and difference between raw current and historic operative temperatures [bottom]. A negative difference indicates that the current urban context induces a lower indoor operative temperature, and vice versa.

[1] Mean across all zones.

DAYLIGHT ASSESSMENT

To assess the impacts of urban densification on the availability of daylight in the Casa das Rosas, a more detailed geometry model was created in Rhinoceros from existing floor plans and exterior façade drawings found in Prado de Assis (2012). Each surface was assigned a material according to the information provided by literature and a visual assessment of historic and present day photographs (fig.6). The historic and present-day context was modelled to match the ENVI-met simulation models, though only immediate surroundings, which affect the incidence of sunlight, were included. Trees were modelled from a visual assessment of historic and present-day photographs and assigned a material with 20% transmittance to mimic the amount of shading predicted as a result of their foliage.

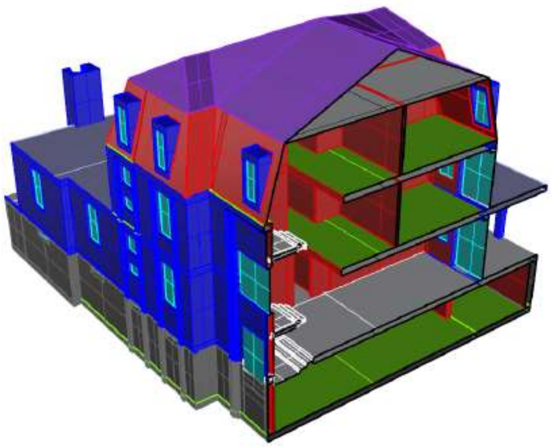


Figure 6: Rhinoceros models showing a section cut through the model with layers representing each material (below).

Illuminance sensors were placed on each level, 0.85 meters from the floor to represent a standard furniture height (table, desk, etc.). Climate based simulations were run to produce useful daylight illuminance maps (UDI) between 100 and 2000 lux (Nabil & Mardaljevic, 2005). Results for the 1st, 2nd, and attic levels are shown in fig.7, with UDI values for historic site conditions shown on the left and present-day site conditions shown on the right.

Mean UDI values for each floor and each site condition are summarized in table 3. Due to the presence of densified urban surroundings, each floor experiences a decrease in average UDI from 5 to 10% of occupied hours. This translates to 8.4% fewer hours a year when illuminance levels fall between 100–2000 lux. This decrease in UDI has the biggest impact on indoor illuminance levels deep within each room and along the circulation spaces.

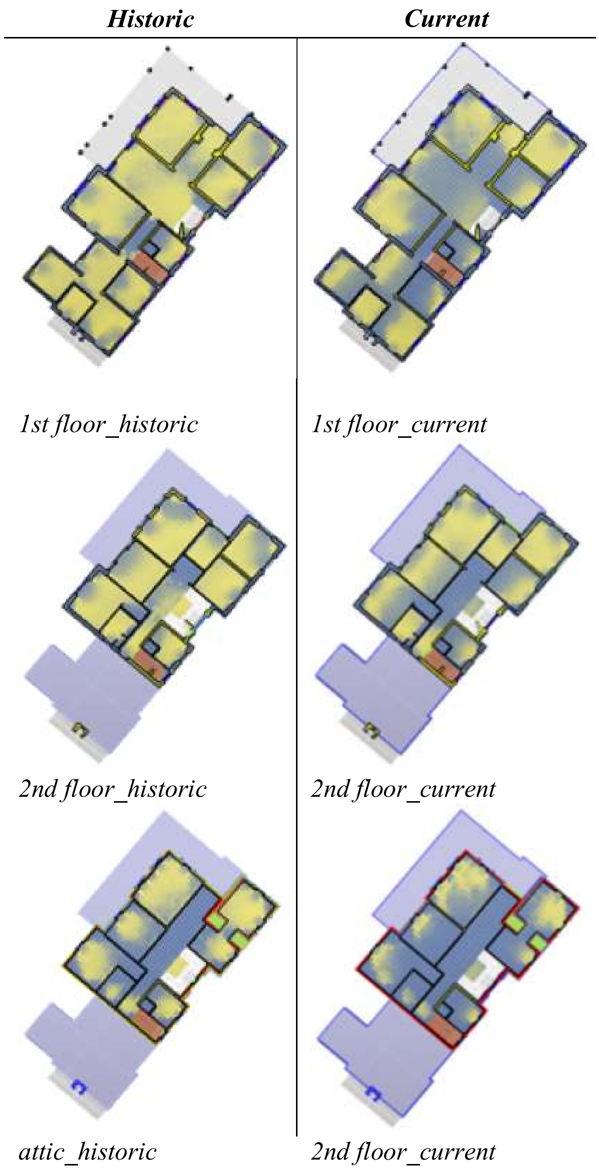


Figure 7: Useful Daylight Illuminance (UDI) 100 – 2000 lux for historic and present-day site conditions for the 1st, 2nd, and 3rd floor levels

Table 3: useful daylight illuminance (100 – 2000 lux) for the 1st, 2nd, and attic levels under historic and current site conditions.

Floors	Historic	Present	Difference in UDI	Relative diff. (%)
First	27.4	17.4	-10	-37%
Second	26.7	21.1	-5.6	-21%
Attic	17.7	9.1	-8.7	-49%
Total	24.6	16.3	-8.4	-34%

CONCLUSION

The simulation results show that the proposed approach is capable of quantifying the effects of different urban configurations – which result in different microclimatic scenarios – on historic building indoor comfort. While the simulations here are limited in their scope and resolution, they point to a need for such analyses in high-impact urban reconfigurations.

The results from the microclimatic assessment of *this* particular case do not show large differences in outdoor temperatures between the original, suburban, and current, urban, scenario. However, the simulations reported here are only for a small range of weather conditions, and we do not recommend extrapolating the same results to other conditions, like clear sky days or weaker wind speed values. In addition, we expect a larger effect of the Urban Heat Island if anthropogenic heat sources such as transportation are included.

Mean operative temperature inside the building is not significantly affected by urban configuration. Nevertheless, individual rooms could experience larger changes. Moreover, it is expected that reduced access to sunlight (because of the height of the new urban context) would change the nature of the indoor environment. The reaction to such a change could be mixed, since it depends on the occupants' preference. Given that Sao Paolo is a mild climate, reduced solar heat gain could be better for thermal comfort, but reduced daylight may not be a welcome change.

The authors do not claim to have extracted generalizable results from this one simulation, since the results from the microclimate simulations in particular are very case-specific. Rather, this paper demonstrates that the change of microclimate (change of temperature, shading, access to daylight, etc.) is quantifiable. The relatively simple simulation procedures and suggests that, along with the issues related to architectural integration and cultural preservation in contemporary cities, a more environment-oriented approach might be needed at the professional and policy level when modern urban development encounters the historic built heritage.

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