

Università Iuav di Venezia
Master's program in Architecture

Built density, solar potential and daylighting

**Application of parametric studies and
performance simulation tools in urban design**

MASTER'S THESIS

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Densità del costruito, potenziale solare e illuminazione naturale
**Applicazione di studi parametrici e strumenti di simulazione
delle prestazioni nella progettazione urbana**

TESI DI LAUREA MAGISTRALE

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«Omniaque aedificia ut luminosa sint oportet curari, sed quae sunt ad villas, faciliora videntur esse ideo quod paries nullius vicini potest obstare, in urbe autem aut communium parietum altitudines aut angustiae loci inpediundo faciunt obscuritates. Itaque de ea re sic erit experiendum. Ex qua parte lumen oporteat inmittere, et si ab ea linea in altitudinem cum prospiciatur poterit spatium puri caeli amplum videri, in eo loco lumen erit sine inpeditione».

«We must take care that all buildings are well lit. However, if for those in the countryside this seems quite easy as they do not have any neighboring walls that can make obstruction, for those in the cities either the height of side facades or the narrowness of the place may cause darkness. In this case we should proceed as follows. From the space in which the light is to be introduced let draw a line up to the source and, if looking upwards, a large area of open sky can be seen, the light will be on that place without any problem».

VITRUVIUS, *De Architectura*, VI, 6, 6

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Abstract (Italian)

Densità del costruito, potenziale solare e illuminazione naturale

Applicazione di studi parametrici e strumenti di simulazione delle prestazioni nella progettazione urbana

L'aumento della densità insediativa contribuisce allo sviluppo sostenibile delle aree urbane riducendo, ad esempio, il consumo di energia legato ai trasporti e limitando l'urbanizzazione di nuove aree. Per non compromettere il potenziale solare e la disponibilità di luce naturale, è necessario però un approccio integrato alla progettazione che garantisca la *performance* ambientale degli edifici anche in contesti urbani densi.

Questa tesi presenta l'applicazione di strumenti di simulazione delle prestazioni dell'edificio in un programma di modellazione tridimensionale parametrica allo scopo di calcolare il potenziale di produzione di energia solare, la domanda di energia per il riscaldamento/raffrescamento degli ambienti e alcuni indici di illuminamento naturale su base climatica per diversi scenari di progetto generati attraverso la combinazione di parametri geometrici di base.

Questa metodologia è applicata a tre casi studio in Svizzera che presentano differenti strategie di densificazione alla scala di quartiere, come la rigenerazione urbana di un'area industriale dismessa a Yverdon-les-Bains e due interventi di "densificazione leggera" a Ginevra: la sopraelevazione di edifici in un'area centrale e un'operazione di *infill* in un quartiere residenziale periferico. Ogni caso studio è stato valutato sulla base di una serie di indicatori morfologici e ambientali comuni evidenziando che il progetto di rigenerazione urbana rappresenta un buon compromesso tra gli obiettivi di densità e quelli prestazionali degli edifici. È stato individuato inoltre un insieme di scenari di progetto ottimali per questa strategia.

Sebbene i risultati di questo lavoro siano riferiti ad una casistica particolare non esaustiva di tutti i contesti urbani, tuttavia, a livello metodologico, la procedura qui presentata può essere applicata come sistema di aiuto alla decisione nelle prime fasi della progettazione urbana anche ad altre realtà e può facilitare nella scelta della strategia di densificazione più appropriata.

Abstract (English)

Built density, solar potential and daylighting

Application of parametric studies and performance simulation tools in urban design

Augmenting built density helps achieve a sustainable urban development reducing, for example, transport-related energy consumption and greenfield urbanization. Yet, in order not to undermine solar potential and daylight, an integrated design approach guaranteeing building performance in dense urban contexts is needed.

This thesis shows the application of building simulation tools into a parametric 3D modeling environment so as to calculate the potential energy production from solar systems, the energy needs for space heating/cooling and some climate-based daylight metrics for several design scenarios generated by the combination of fundamental geometrical parameters.

This methodology is applied to three case-studies in Switzerland presenting different densification strategies at the neighborhood scale: the urban renewal of a brownfield site in Yverdon-les-Bains and two “soft densification” interventions in Geneva, i.e. roof raising in a central area and housing infill in a suburban residential district. Each case-study has been evaluated according to common morphological and environmental indicators, showing that the urban renewal project represents a good compromise between built density and building performance objectives. Moreover, a set of optimized design scenarios has been proposed for this strategy.

Although the results of this work refer to specific case studies which are not representative of all urban contexts, at a methodological level the hereby presented procedure can be used as a decision support tool in the early urban design phase also in other situations and can facilitate the choice of the most appropriate densification strategy.

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Introduction

Using at best the available natural resources in buildings has always been one of the main concerns of designers. Sun and daylight, in particular, are necessary for both the quality of our lives and the energy efficiency of the built environment. However, the incessant development of denser urban environments has often neglected design principles following the sun rhythm. If some ancient and an increasing number of new buildings conform to climate-appropriate design criteria, the form of the cities they belong to, in most of the cases, does not.

In the 19th century, the relationship between sun and city form was studied by scientists and architects of the «hygienist movement» so as to determine street and building proportions that guarantee solar access in densely built urban areas. In the first decades of the 20th century their work influenced in different ways the theories of urban planners and designers, who developed two antithetical models to solve the problems due to overcrowding in modern cities. Solar access was in fact at the basis of both low-density garden cities and suburbs based on Howard's theories and high-density proposals by the modernist movement, culminating in Le Corbusier's *Ville Radieuse*. Nonetheless, these two models showed their limits, mostly because they both presumed radically new design proposals to be imposed on new settlements without really solving the problems of the existing city.

Nowadays, urban density has finally become one of the main prerequisites for the sustainability of our cities, especially because it reduces the energy consumption for transportation as well as the use of green fields for new urbanization. To the opposite of the modernist *tabula rasa*, most of the contemporary efforts are towards densification strategies applied to the existing urban fabric, because of the social, environmental and economical advantages of «making the city on the city». However, as already remarked, built density is indeed determinant for solar access. Furthermore, the concept of solar access has recently evolved into a more exhaustive set of environmental indicators taking into account the whole building performance, whence the necessity of finding the best compromise between built density, solar potential and daylighting using new comprehensive environmental analysis tools. Also, the importance of early-stage design decision for building performance is often underestimated, while it is in this phase indeed that built density is shaped into an actual urban form.

This work aims at critically examining some contemporary densification strategies according to a set of climate-based dynamic environmental indicators. In parallel, a performance-integrated design methodology for the early design phase is developed, focusing on the optimization of fundamental geometrical parameters. This is accomplished by the application of the latest computer simulation tools into a 3D parametric environment, so as to simulate the building performance for several design scenarios generated by the combination of fundamental geometrical parameters. This methodology has been applied to three case studies in Switzerland, offering a wide range of different urban conditions and building typologies. Despite the specificities of the cases, the final ambition is to infer some general planning and design strategies to move towards a sustainable urban form.

Thesis structure

Chapter 1 offers an overview of the historical theories concerning low-density and high-density city models especially in relation to solar and daylight availability, as well as their criticism. Moreover, selected contemporary densification strategies and performance-integrated design tools at the basis of the proposed research methodology are here critically reviewed.

Urban renewal is proposed as a way to densify the city by building a new neighborhood in its inner core, possibly in brown field sites and using sustainable design principles. As complementary/alternative proposals, two different soft densification strategies to increase density in both central and suburban urban areas are analyzed. However, the impact of such densification practices on the building performance has not been studied enough yet. A literature review is therefore conducted on performance-integrated design tools that could be used to evaluate land use and building performance at the urban scale. Thanks to the evolution of computational techniques, some of the simulation engines normally used to analyze the performance of single buildings have been in fact recently applied to a larger scale.

Chapter 2 details the research methodology and presents the building performance simulation tools and the indicators used throughout the thesis. In particular, it illustrates the application of parametric studies within the design process, thanks to the coupling of the 3D modeler Rhinoceros and its visual scripting plug-in Grasshopper, as well as their integration with the performance analysis tools of DIVA, which provide a graphical interface to Radiance/Daysim and EnergyPlus simulation engines.

The results of solar radiation, energy performance and daylight simulations are used to compute building performance indicators, focusing on solar potential and daylighting. The potential for passive and active solar applications is defined, through the assessment of solar radiation on buildings' external surfaces, in terms of suitable area and energy production. The energy needs for space heating and cooling simulated in EnergyPlus are also considered as indicators of the passive performance of buildings (i.e. the balance between solar gains and heat losses), as no particular assumptions are made on the envelope nor on the HVAC systems. Daylighting is evaluated, through the results of climate-based simulations, by calculating daylight availability (on façades) and dynamic daylight performance (on interior workplane), expressed in both spatial and temporal terms. Daylight sufficiency metrics, such as spatial daylight autonomy, are also used to determine if a space is adequately daylit. Finally, built density and other relevant morphological indicators are defined according to current standard indices, like the Floor Area Ratio (FAR), using simple geometric relations to be dynamically calculated from the 3D model.

Chapter 3 deals with the optimization of the urban form after a master plan. A recent urban renewal project in a former industrial area next to the train station of Yverdon-les-Bains, in the Swiss canton of Vaud, is used to test the research methodology applied at the early design phase. All performance indicators previously introduced are implemented so as to find the most relevant ones for the analysis purposes.

Building performance simulations are conducted on up to 768 design scenarios generated as the combination of five design parameters, allowing an environmental analysis on an extensive range of possible building forms respecting the master plan constraints. The study highlights the sensitivity of performance indicators to each design parameter and finally produces a set of optimized scenarios, representing the

best combination of the design parameters.

Chapter 4 deals more specifically with the analysis and comparison of different densification strategies. If the case study of Yverdon focuses on design optimization, the two selected case studies in the Swiss canton of Geneva enlarge in fact the perspective to densification planning in existing urban areas. Since Geneva is currently facing a serious dwelling vacancy issue, many densification plans and policies have been provided for by political authorities. Besides traditional densification in urban development zones, soft densification of the existing urban fabric is also encouraged by the current legislation.

Roof raising has been systematically applied in Geneva city center since 2008, when a law introduced the possibility of adding up to two residential stories in selected buildings. A previous and more permissive law dating from 2006 was changed also because of the protests of tenants' representatives claiming a reduction of quality of life in the lower stories. The new law was finally approved by a public vote in 2009. Nonetheless, some of the criticisms may still be valid, in particular those concerning daylighting. In addition to roof raising in the city center, the 2030 Geneva cantonal master plan and a recent legislative act promoted soft densification of some residential suburbs as well. Although many of these suburban areas will be transformed into medium/high-density neighborhoods so as to mightily face the dwelling shortage, some of them were confirmed as low-density areas in order to preserve their urban character, allowing though a little increment in density. In this thesis, a possible implementation of housing infill is thus proposed for a residential area in Vernier, a suburban municipality of Geneva. However, as for roof raising in the city center, the new infill dwellings may affect the performance of existing buildings. Therefore, using the results of the Yverdon case study as a reference of a high-performing neighborhood, both soft densification strategies in Geneva are analyzed and compared in order to evaluate their consequences in terms of solar thermal potential, energy need for space heating and spatial daylight autonomy as well as to quantify the possible increment of built density (FAR).