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The Environmental Dimension of Urban Design: A Point of View

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Abstract

International research on sustainable architecture ascertained the responsibilities of urban forms for buildings' energy-environmental performances, highlighting the necessity to broaden the field of intervention in urban design. Furthermore, goals concerning the sustainable city increased design complexity, due to the involvement of different interrelated disciplines, which modified design processes by incorporating external contributions. In particular, environmental analyses are growing in importance and need to be reintegrated into the urban project at the conceptual stage. This 'environmental awareness' accompanies the history of the city, and numerous pieces of evidence clearly show the mutual and in-depth relationship between urban form and local microclimates. Lessons from the ancients constituted the fundamentals in urban design until the Modern Movement, during which knowledge of the past also influenced the work of G. Vinaccia, an Italian pioneer in microclimatic urban design. After the World War II, most of the lessons had been forgotten in favour of technology systems that have since revealed their failures. The current design condition requires a discovery of past abilities, coupling them with contemporary scientific advances. This work introduces a methodology through which to integrate current urban design processes with environmental data and analyses. It is illustrated through a case study and is supported by software.

Keywords: urban design, environmental design, sustainability, sustainable architecture, Gaetano Vinaccia

1. Introduction

During the last few years, actions directed towards the sustainability of architecture mainly involved buildings. Nevertheless, several international research groups have ascertained the

influence of the urban form on local microclimate.¹ In fact, the way in which buildings are arranged on a site heavily affects their owners' energy performances and environmental behaviours. The growing awareness of these issues is gradually attracting the attention of both international organizations and international researchers towards the urban dimension (urban block or district), thus broadening the field of architectural interventions. In this light, urban design, which lies in-between urban planning and architectural design, has become the appropriate tool through which to operate in achieving sustainability's goals. This recommendation, however, is not novel. In 1976, the European Commission suggested it during the first United Nations Conference on Human Settlements, 'Habitat' (Vancouver), in which the 'design of human settlement' was recognized as a strategic matter in contrasting the «social, economical, ecological and environmental deterioration» of urban areas [1]. Nevertheless, the latest 'sustainable urban design' seems to increase its own complexity due to the involvement of different interrelated disciplines, such as fluid dynamics, climatology, technical physics and computer engineering. This interdisciplinary perspective demands updates to the design process in order to incorporate external contributions while maintaining architecture at the heart of the process. In particular, both environmental data and analyses need to be reintegrated into the urban project from the design's initial phases. In fact, this has been an ordinary consideration in the history of architecture, in which several pieces of historical evidence prove in a clear way the in-depth relationship between urban form and local climatic conditions. Examples occur throughout history, starting from vernacular settlements until the Modern Movement's masters, and most of the 'environmental' knowledge of past designers is also stated in important recommendations contained in ancient manuscripts (Vitruvius, Aristotle, Varrone, Columella, Palladio, etc.). Nevertheless, most of the established abilities have been forgotten in favour of building technology systems, with an illusory belief in their supremacy. The energy and environmental crises of the 1970s clearly displayed their failure, encouraging designers to rediscover projects' environmental components as a function of a sustainable future. In this light, the past's lessons on 'sustainable practices' have grown in importance, especially when coupled with scientific and informatic progress. Computer advances, in fact, make it possible to study increasingly broad areas (CitySim, ENVI-met, Virtual Environment) and contribute to supporting urban design's processes with environmental analysis software. The latter acts as useful 'feedback' tools, able to verify (qualitatively) the environmental behaviour of the project's concept by taking into account different climatic data (air temperature, relative humidity, wind velocity and main directions, etc.) and form parameters (sky view factor, aspect ratio). In this way, designers experiment with a new methodology in the project's development, one that allows them to evaluate the initial urban proposal and, gradually, to modify it in relation to the main criticalities that emerged from previous environmental analyses' results. Nevertheless, modifications must respect a project's fundamentals and collaborate in the improvement of its overall performance.

¹ Examples are the Martin Centre for Architectural and Urban Studies of Cambridge; the 'Urban Physics' research group (ETH, TU Delft and Cypro University); the Centre for Advance Urbanism and the SENSEable Lab of MIT; the Harvard Centre for Green Buildings and Cities and the City Form Lab; the EPA's EPFL Solar Energy and Building Physics Laboratory (Luisanne); the Environment People and Design (ePad) Research Group in Nottingham (UK); the Berkeley's Center for Environmental Design Research (U.S.A.) and the UCL-Institute for Environmental Design and Engineering in London (UK).

In this light, this work aims at introducing a methodology that is able to integrate current urban design processes with environmental data and analyses. The method is illustrated through an urban-design case study in Sardinia (Italy). It concerns the urban expansion of Monserrato in developing a new university district of 1.4 km.² All the design phases were supported by Heliodon and ENVI-met software. The work was preceded by a study on the main directions of current 'sustainable design', highlighting both the necessity (and the advantages) of broadening the field of intervention to include the urban dimension (urban blocks or districts), and its current interdisciplinary character. Previous goals are also supported by several examples in the history of architecture, which show the ancient roots of this environmental approach.

2. Sustainable design: from buildings to the city

As stated above, the relationship between a building and its context has a heavy influence on both local microclimatic conditions and a building's energy-environmental impact, shifting designers' and planners' attention from buildings to the block dimension. The urban structure substantially affects a building's access to sunlight and ventilation, defining its capability to exploit passively the heat produced by solar radiation on vertical surfaces, the natural daylight and ventilation of inner spaces, as well as the reduction in environmental and noise pollution. The necessity of this 'change of scale' has been affirmed, in the last few years, in several national and international scientific works, in which authors highlighted the achievable benefits both in relation to climate change goals and energy issues. Among the most significant attestations, the U.S. Green Buildings Council stated that the neighbourhood level was «the primary scale at which building professionals can begin to address impacts of climate change». In fact, «the design and pattern of neighbourhoods [...] play an important role in amplifying or dampening climate effects» [2]. Evidence of this is the Urban Heat Island phenomenon (UHI), fostered by cities' higher densities and the *albedo* properties of common urban materials, and the more frequent extreme weather events, such as flooding, strengthened by urban pavements' waterproofing and inadequate storm-water runoff.

Furthermore, in relation to the energy issues, several pieces of national and international research supported the block dimension as the only possible way to decrease buildings' consumption and, therefore, to improve their environmental impacts. A recent study by Hachem, Athienitis and Fazio [3] showed how different layouts of the same building typology (terraced houses) modify their energy consumption, increasing their values between +6 to 8 and +25%. Orientation and buildings' arrangements are considered central in the project's process by its authors, conferring on the initial phase of the design huge energy responsibilities, which were estimated as being between 65 and 85% of successive building energy demands.

² The International Congress of Modern Architecture focused on the work of Hannes Meyer, Mart Stam, Walter Gropius, Erns May, and Alexander Klein on *Existenzminimum* ("minimum dwelling"), aimed at reducing building costs (including the cost of land consumption) by a reduction of the worthless surfaces of houses. Research on typology reached some standard formulations of the new working-class building environment, in which the amounts of daylight, fresh air, heat, and silence were radically maximized.

The results of this study are comprehensible in relation to the microclimatic consequences of different buildings' arrangements. The influence of the modification of urban geometry on the urban microclimate was well known until the 1970s, in the main works of the climatologists T.R. Oke [4] and H. Langsberg [5], which became the theoretical basis of reference for most of the successive work on environmental design. As stated by Givoni in 1989 [6], and reported later in Steemers' and Ratti's work [7], the influence of climatic change on outdoor temperature, solar radiation and wind speed, caused «by 'the structure' of the city [...] result in modified energy consumption». An urban grid's orientation, density and a building's typology heavily influence the wind pattern and the solar access in urban areas, while also defining the microclimatic conditions of outdoor and inner spaces. Further significant studies on the energy and environmental 'costs' of urban form have been developed during the last few years by several scholars (K. Steemers [7–10]; V. Gupta [11, 12], R. Compagnon [13], R. Knowles [14], E. Ng [15, 16], F. Allard [17, 18] and B. Blocken's research group [19, 20], including J. Carmeliet and M.K.A. Neophytou [21]).

Interest in this 'change of scale' in sustainable design is slowly extending from scientific research into concrete actions. In 2010, the European Commission introduced the *Advisory Group ICT Infrastructure for Energy-Efficient Buildings and Neighbourhoods for Carbon-Neutral Cities* [22] and, in June 2014, the European Urban Knowledge Network (EUKN), together with the Cellule Nationale d'Information pour la Politique Urbaine (CIPU), presented the *Certification Systems for Sustainable Urban Neighbourhoods* «as tools to evaluate and maintain high quality standards in urban development» [23]. Although practical initiatives are still few in number, they clearly envisage architects and planners' future goals.

3. Environmental lessons from history

Even though the application of sustainable environmental theories and practical solutions in the urban dimension appears to be novel today, it was actually a common praxis in the past. It concerned both vernacular settlements and the foundation of ancient cities, such as Greek and Roman examples. Furthermore, the ability of past designers to plan in accordance with local weather and environmental features guided their constructive practices for the following centuries. Palladio's works included important environmental devices, although these were mainly applied to individual villas, whereas the Hygiene Movement and the successive Modern Movement (XIX-XX centuries) extended them to the urban dimension.

3.1. Vernacular settlements

According to G.D. Carlos et.al. [24], the morphological consolidation of vernacular settlements is constrained by three main concerns, among which are local microclimatic conditions. A building's aggregation system is «the primary instrument to attenuate the relation between the inhabitants and the natural elements», controlling a building's exposure, both to the sun and the wind. Climatic challenges, together with available construction technologies and relief constraints, usually originated «a *diffuse* or *compact* spatial organization, and a *scattered* or *dense*

building aggregations». Furthermore, the energy supply, based mainly on wood and animals' muscle strength, contributed in developing a 'discrete' urban model, limited in its growth by the presence of natural resources in the surrounding area [25]. Examples exist in every continent, and each morphological configuration responds through its own buildings' spatial organization to the local conditions. A significant example of hot-dry climate architecture is the medieval citadel of Shali in the Oasis of Siwa (Egypt), as described by A. Picone [26]. Here, housing aggregation creates an absolutely compact nucleus that seems from the outside to be «one single large building» [27] (**Figure 1**). This compactness allows the reduction of surfaces facing solar radiation, thus increasing buildings' mutual shadows. Since the traditional Arabian courtyard is missing in Siwa's houses, it is the streets (very small with curved geometries) that perform as temperature regulators.



Figure 1. The Oasis of Siwa (Egypt), «one single large building».

A second example of a vernacular climate-sensitive architecture is the 'solar communities' of Pueblo Indian tribes of south-west America, built during the eleventh and twelfth centuries A.D. The most well-known ruins of the Long House at Mesa Verde, Pueblo Bonito and Acoma Pueblo (or 'sky city') in New Mexico prove that their sophisticated design skills were able to provide year-round comfort for people dwelling within these structures. A study by R. Knowles [28], conducted during the 1980s, deepened knowledge of the settlements' environmental behaviour, focusing on their correlation with solar dynamics. Concerning the Long House case study, both the location and the siting of structures within the cave collaborate to «mitigate extreme environmental temperature variations by responding to the differential impact of the sun during summer and winter, night and day» [28]. Both the southern orientation and the conformation of the cave allowed the Ancestral Puebloans to exploit passively the low winter sunrays to heat houses and, at the same time, to shade them from the high summer

sun. Building's adaptation to solar dynamics also characterized Pueblo Bonito. Furthermore, in this case, the dwelling «relied primarily on its form to respond to solar access». Its semicircular form, coupled with the buildings' disposition to take the form of terraces descending towards the city centre, helps to mitigate the extreme seasonal climatic effects. The use of terraces is also common in Acoma Pueblo buildings [29]. Here, the urban structure is organized in three main rows oriented east–west and each row is distanced from the others in order to ensure the exposure of the entire facade to winter rays. Openings' orientations and dimensions, the different employment of natural materials and the buildings' shapes contribute effectively to their overall performance. In particular, «even more surprisingly is the orderly town plan that guarantees all residents full, equal access to the sun's heat» [30].

A final example is the vernacular underground settlements and their bioclimatic advantages. An interesting research project conducted by Vegas, Mileto, Cristini, and Checa in 2014 [31] collected several examples of cave dwellings, highlighting their environmental weaknesses (land consumption, lack of ventilation and the risk of dampness) and potentials (great insulation potential, great heat retainer and very low energy costs). Among the outstanding cases, the Berber dwelling of Matmata in Tunisia [32] responds to the extreme conditions structuring its hypogean houses around a circular courtyard, located at approximately 11 m below ground level. This has a 5–12 m diameter, and it is provided with a tank for the collection of rainwater. The circular form allows part of the courtyard to always be shaded, whereas the underground condition protects it from hot sandy winds.

3.2. The 'oriented' urban grid: the new city

According to Secchi, «the grid is the ordering element, par excellence» [33]. Its application dates back centuries and «certainly, it is not a founding shape of the Occident culture». Important examples exist worldwide and all of them share similar organizing principles: an urban grid, oriented along the cardinal points that define the dimension and orientation of blocks, and a building typology, which was mostly southern oriented and provided by transition components, which mitigated the outer climatic conditions. Repetition of such communal features is probably due to similar environmental conditions, since, according to Los's research [34], the first ancient 'solar cities' originated between the 30th and 40th parallels; thus, they were characterized by hot and temperate climates. Among the oldest examples El Lahun working-class neighbourhood (Egypt, 1800 B.C.), Babylon (Mesopotamia, 2300 BC) and the Pakistani settlement of Mohenjo Daro (Indus civilization, 2750 BC) where «street grid [was] oriented according to prevailing winds» [35].

The grid plan shows so basic a principle that it is not necessarily linked to influencing or dependent relationships among populations. Furthermore, several scholars often find in its recurrence the evidence of cultural exchanges among Western and Eastern communities. As stated by Castagnoli [36], the use of an urban grid defines, upstream, the existence of the authorities' planning intentions; and for this reason, it is a common feature of foundation cities (as colonies, military camps and reconstructions). Although the application of a grid structure can be ascribed to different purposes (political, religious, military, etc.), most scholars agree

on both the importance of its orientation and how the orientation is strongly related to astronomical issues: in particular, to the sun's path and the winds' main directions.

Although the grid's origin is not precisely known, nor is the mutual 'contamination' of different cultures, the first use of a north–south-oriented urban grid is usually attributed to Hippodamus of Miletus. Furthermore, it is important to point out that «it can be proposed that the name of Hippodamus goes not connected with the far ancient orthogonal system, but with that developed plan for a regular reticulated city, which can be identified during the fifth century [...] therefore [Hippodamus was] not an icon, nor a simple theoretician, but an urban planner, who played an important role in the urbanism of the fifth century». This kind of planning, which could not be documented before these data, is characterized by two main features: the presence of a complete urban plan and an in-depth study of residential blocks. Von Gerkan insists on the topographical and sanitary meaning of Greeks cities' orientations, whose purposes were more suitable wind exposure and access to the sun's rays [37]. Both Hippodamus's works and the later essay by Hippocrates, *On Airs, Waters and Places*, attempted to reconcile urban studies with environmental theories, paying attention to the city's healthiness. In reference to this, it is interesting to underline that Hippodamus was also called a 'meteorologist' (meterewlogoc) by Hesychius and Photios.

Ruins of the Greeks' 'solar cities' show as urban grids, and blocks were designed to take into account the different seasonal heights of the sun in order to guarantee the correct solar access in buildings over the whole year. Priene and Olynthus's plan testified to these 'solar principles': in particular, Olynthus's block-long row of houses distinguished the northern façade (thicker walls without openings) from the southern one, which was open to the sun. In addition, both the houses' and the rows' distance from one another contributed to the 'solar' strategy, avoiding the buildings' mutual shadows in wintertime. The case of Delus, moreover, confirms the importance of the southern orientation, which was declined to single houses where topographic conditions impeded the application of the wider urban grid. The real functioning of the ancient Greeks' environmental urban design was finally proved by Tatcher's studies on rooms' solar-heating capabilities, whose results demonstrated comfortable performances «on 67% of the days during the colder months» [38].

Even if most Roman cities were based on the same reticular structure, their models appeared to be less strict, showing several rule variations. Furthermore, the grid's orientation to the functions of the sun and the winds still remains a feature that it has in common with the Greek model.

According to Vinaccia's statements [39] (Italian architect, a pioneer in microclimatic design issues during the 1930s–1940s), the city's inclination with regard to the north depended mainly on both the main winds' directions and sun exposure.

His studies on Roman *castra* (Roman military camps) advanced interesting and important theories on Ancient knowledge regarding a city's healthiness. In particular, Vinaccia's research highlighted that the north–south-oriented plan was extremely rare, «perhaps due more to fortuity than to sacred precepts' observance». Conversely, a plan's disposition on territory depended mainly on the local necessity to avoid 'annoying' and insalubrious winds inside the

urban areas. The author's theories found their foundation in ancient manuscripts, particularly in Vitruvius, who stated that: «[cities] will be well built if winds are wisely kept out from squares and streets; [winds] which offended if cold, vitiate if hot, harm if wet» [40]. The Ancients knowledge of winds was proved by the construction of a bronze wind rose, representing a triton, on which were depicted the 12 main winds. The station was probably built by Flavius Eutropius, during Valentinian II's empire. According to the winds' mythological representation, the 'annoying' winds came from north/north-westerly directions (cold winds), whereas the 'unhealthy' ones arrived from the south-south-east (usually, hot wet winds) (Figure 2).

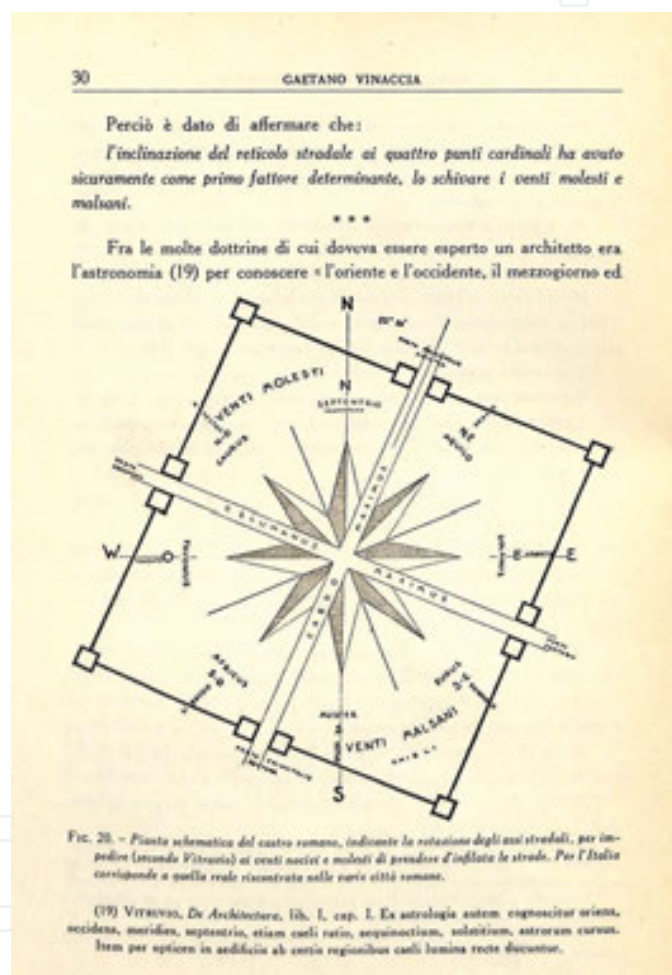


Figure 2. Roman castrum orientation plan in function of winds directions. The plan is extracted from Vinaccia's *Orientation issue in Ancient Roman Planning* (1939).

Plans' focus on wind conditions needed to be coupled with local solar dynamics. In regard to Roman castra located in Italy, Vinaccia affirmed that their orientation, useful to prevent the built-up area from injurious winds, also aimed at assuring the best exposure to the sun during the entire year. The rotation of almost 22°N, which, according to Vinaccia, corresponds with the average orientation measured for Italian cases in the study, allowed sunrays to reach all

the buildings' facades, including the northern ones. This 'equisolare' orientation, which will be better investigated in the author's successive works, permitted designers to rationalize solar radiation prorating it in function of seasonal needs. This theory finds its roots in ancient essays, in which Latin authors (Varrone, Columella, Cato and Vitruvius) related the buildings' dispositions with local «orienting urban points», which corresponded to the horizon's sunrise and sunset points in solstices and equinoxes. The depth of past studies shows the Ancients' advanced knowledge on both the sun's path (during seasons and at different latitudes) and solar radiation intensity, as a function of solar height and the hours of the day.

Currently, the Department of Architecture at the University of Cagliari (Prof. G. M. Chiri) is studying the effectiveness of Vinaccia's theories on Roman castra's orientation. At the moment, the research has examined the fluid-dynamic behaviour of several Italian case studies, analysing the relationship between urban forms and local wind conditions. Analyses have taken into account the urban grids' orientations and the main wind directions during the winter and summer seasons. CFD calculations have been developed in collaboration with the CONSELF Company (<https://consself.com/>). A short example, representative of the work, is summarized in **Box n.1**.

Box n.1

Luca - Roman Castrum

(authors: G.M. Chiri, I. Giovagnorio, and D. Usai)

According to Livy, the Roman castrum of *Luca* (Lucca, Italy) was founded in 180 B.C. The name root, 'luk' ('marshy place'), which reveals its Celtic-Ligur origin, originated from the environmental context in which it arose (1). Urban form and location were influenced by the Serchio River, which still flows today to the northern part of the modern city. Thanks to its position, *Luca* was a relevant road hub until the Middle Ages. The Roman city was quadrilateral – it shows just a little irregularity on the northern side – and its east–west fronts measured around 500 m, whereas the north–south ones were around 650 m. The urban grid, constituted by secondary orthogonal streets, defined rectangular blocks (*insulae*) of 105 × 120 m.

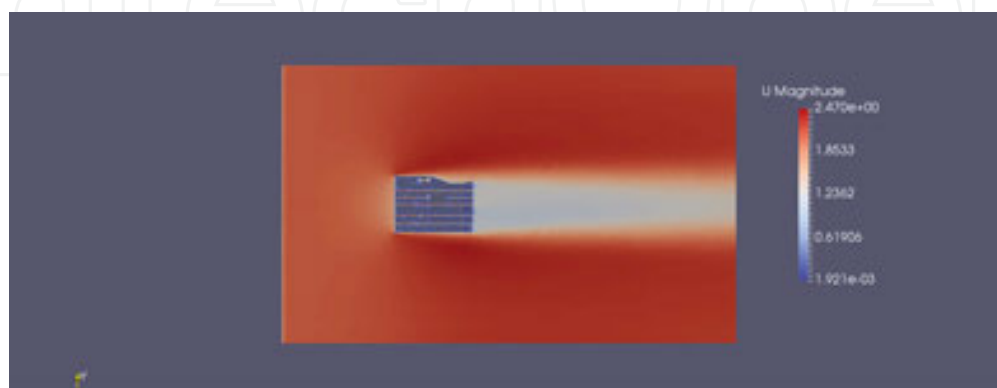


Figure 3. *Luca*'s wind flows in summertime.

According to results gathered in 2005 by Frisia et al. (2) on paleoclimatology, and quoted by Chen et al. (3) in 2011, «the “Roman Classical Period” temperatures were similar or slightly higher than those of today with the highest temperatures reached between around 400 BC and 0 AD». This correspondence supposes similar data to those of contemporary conditions. In this light, the validation of Vinaccia's statements has been done, taking into consideration Lucca's current weather data (Meteonorm database source)—in particular, the winds' main directions and monthly values in the wintertime ($\approx 90^\circ$ N and ≈ 3 m/s) and the summertime ($\approx 270^\circ$ N and ≈ 2.5 m/s).

Analyses on wind flows have been developed with the support of the CONSELF company (CFD software); the results confirm Vinaccia's theory. In fact, Lucca's environmental condition as a 'marshy place' led the Romans to orient the urban grid in the direction of the main winds, in order to remove insalubrious humidity throughout the year (**Figure 3**). Contrary to common belief, Lucca's north–south orientation is not due to religious or astronomical precepts but to practical, healthy needs.

3.3. The Renaissance treatises

Knowledge of Latin was rediscovered during the Renaissance, following the humanistic culture's diffusion. Architecture acquired an intellectual rigour typical of the liberal arts, such as literature and science. Its progress, coupled with advancements in drawing techniques, contributed to transforming design practices in a scientific, exact procedure [41]. The birth of perspective allowed designers to describe objects' proportional features directly (their shapes and mutual positions) and, indirectly, their dimensions and physical characteristics. Relationships among urban and architectural elements took inspiration mainly from Roman models; nevertheless, according to Benevolo, «thus, Renaissance architecture achieves its model of proportionality and regularity in single buildings, whereas it is not able to establish, or change, a whole city». However, L.B. Alberti's urban theories, contained in *De Re Aedificatoria*, pose the basis for the planning experiences of the fifteenth century. Since at its origins were Latin's principles, in particular those of Vitruvius, also the Renaissance theories on design practices pointed attention to local microclimatic characteristics [42]. According to Benevolo [41], European colonies in American territories are the most significant urban planning examples of the sixteenth century. New cities employed the urban grid, usually defined by square blocks. This model was codified by Philip II into the first town-planning act of the modern era, in 1573. The law included recommendations to protect the public square from the main winds. Microclimatic advantages of the old grids, compared to the successive Jeffersonian one, have been studied by R. Knowles [28] for the city of Los Angeles. The author highlighted the relationship between Spanish grids' orientation (nearly 45°) and sea breezes, and the grid best performances in relation to the sun's access throughout the year.

In Renaissance examples, bioclimatic buildings were more common. They exploited passive cooling and heating systems, using natural ventilation and solar radiation. Sirocco rooms in Sicily [43, 44], Raffaello's Villa Madama (1517) and Vatican Loggias [45], in Rome, and the Costozza's Villas (Vicenza) [46], appear to be particularly significant examples. The latter was quoted by Palladio in his essay *I quattro libri dell'architettura* (*The Four Books on Architecture*),

one of the most important Renaissance treatises, which was published in 1570 [47]. The ancient relationship between architecture and local environmental conditions also permeates Palladio's work. Several important references are reported in the treatise concerning both the building and the urban issues. Particularly interesting are Palladio's considerations on the villas' sites (Chapter XI, Book II) and on urban streets (Chapter II, Book III), where reflections extend from buildings to the surrounding areas. Concerning the latter, the author suggests orienting and dimensioning them as functions of the sun's access and local wind conditions, in strict coherence with Vitruvius's recommendations.

3.4. Bioclimatism in the European Modern Movement

In the early nineteenth century, cities' awful conditions after the Industrial Revolution led to the Hygienism movement. Hygienists condemned the squalid, crowded working-class slums, considering the absence of fresh air and sunlight the main reason for lethal diseases' development [48–50]. This belief mobilized several studies, besides concerning disciplines correlated to the architectural issues (such as medicine, physics, sociology), which proved the absolute efficacy of sunlight and solar radiation on living spaces' healthiness. Starting from the end of

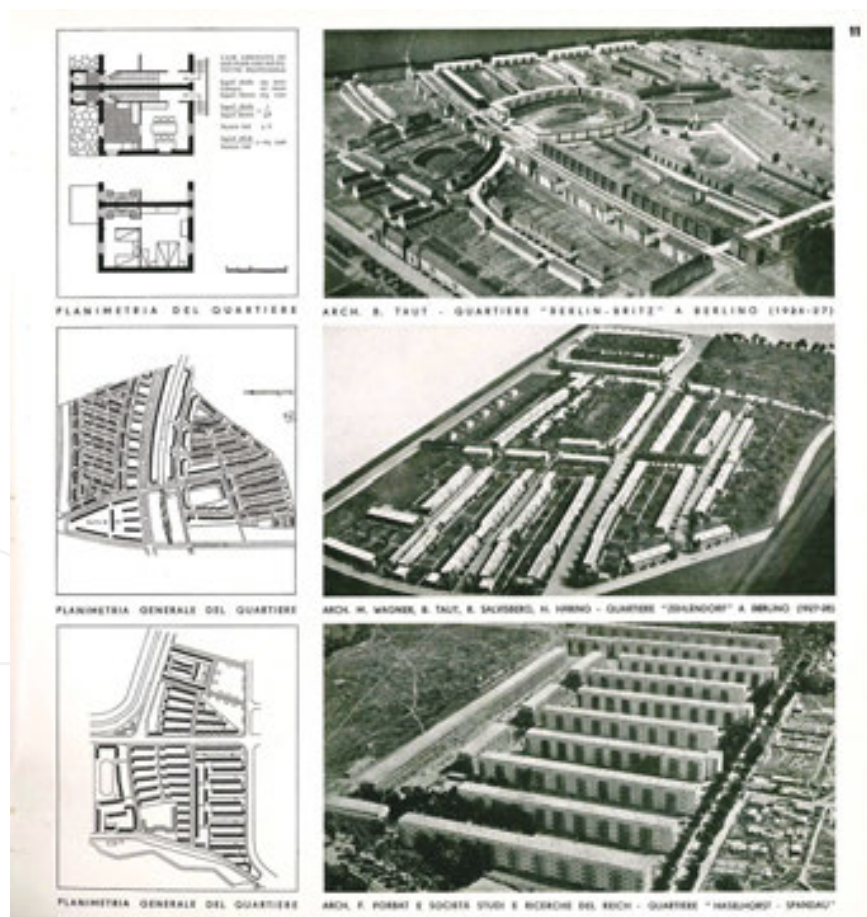


Figure 4. Examples of German modern 'row-houses'. Extraxt from Diotallevi, Marescotti, *Aspetti e Problemi della Casa Popolare*. Casabella n.164 (1941), p. 11.

the nineteenth century «architects and planners began to study the question of solar orientation more scientifically» [51], with the exception of a few rare previous examples, such as Port Sunlight in England, built in 1860 [51, 52]. A broad classification of European solar studies on buildings and the grid street orientation had been developed in Harzallah [50] and Montavon's [49] doctoral theses. The growing interest in buildings' salubrity fed the international architectural debate, focusing initially on building typological research (CIAM II, Frankfurt am Main, 1929) [53, 52, 56, 58] and, later, widening the scope to the city (CIAM III, Bruxelles, 1930) [54]. During the third CIAM congress, Siegfried Gideon [55] defined the goal of the so-called Modern Movement as that of reaching the most efficient formulation for a typological scheme for building on a different scale. The proposal for new neighbourhoods based on the *Zeilenbau Plan*—linear high-rise blocks— which was developed in the early 1920s in Germany, became the standard (**Figure 4**).

The influence of the German avant-garde on urban solar studies is demonstrated by its early research and urban experiences. In 1824, Faust expounded in his *Sonnenbaulehre* (building orientation theory) [56] the plan for a solar city. According to Plessner [57]), Vitruvius largely inspired Faust. His Sonnenbau system aimed at providing as much sun as possible to houses by planning settlements on a north–south-oriented grid and by ensuring the correct distance between the blocks. The Sonnenbau theory was supported by the Bayern architect, Gustav Vorherr (1778–1847), who designed in 1818–1821 the so-called “Sun Road” [58]. The road, placed on the border between the ancient city centres of Munich and Ludwig, is strictly south oriented. Interesting theories on buildings' solar orientation were also published in 1879 by Franz Knauff [59] and Alfred Vogt [60]. In 1919, Theodor Fisher (1862–1938) realized the Alte Heide plan, in which each block is at a distance from other ones by twice its height, in order to prevent façade shading. Five years later, Otto Heasler (1880–1962) developed the principle in the Georgsgarten Siedlung. This rule, later called the Heiligenthal rule after R.F. Heiligenthal's studies [61] on German city planning, became the *Neue Sachlichkeit's* standard approach for housing-climate control between 1925 and 1933, after attracting the enthusiasm of the international architectural community. The linear high-rise blocks were south–north oriented in order to ensure maximum and equal insulation for the apartments. Gropius's diagrams aimed to define a new universal typology for new settlements and were applied in «numerous long, narrow apartment buildings that soon dotted the German landscape» [51]. The history of architecture reported several examples: W. Gropius's Daamerstock Siedlung (1929), the Siedlungen of E. May in Frankfurt (1925–1930) and the Siemensstadt Colony of H. Scharoun in Berlin (1929–1931). In 1927, Ludwig Hilberseimer published his *Großstadtarchitektur* [52], starting from a criticism of the Siedlung model. In his plan for a ‘vertical city’, the urban grid is oriented as a function of sun exposure and the dimensions of both streets and blocks adhered to ventilation and sunlight requirements in order to ensure the provision of space, air and sun to each house. In his studies, Hilberseimer conferred great importance to the block's arrangement, defining both different typologies in terms of orientation [34], building density and shape in relation to the sun's access at different latitudes [49].

France also developed pioneering studies strictly connected to solar urban design. According to Butti and Perlin, «The possibility of extending the same benefits [spacious, sunlit working-

class communities] to urban residents inspired Augustin Rey, a French housing official, to investigate the feasibility of comprehensive urban solar planning» [51]. In 1912, his studies focused on the minimum blocks' distance in order to avoid winter shadows among buildings. Rey analysed the winter sun's path for several cities and correlated the different land areas' consumptions in relation to north–south and east–west blocks' orientations. His knowledge of the daily difference in the time it took to reach the maximum solar radiation and the maximum air temperature—*la vague thermique*— led Rey together with Barde and Pidoux, to develop the heliothermic theory [62], «*qui prétend rendre compte de «l'échauffement» des bâtiments en tenant compte à la fois de leur exposition au soleil et de la température de l'air*» [63]. The wide dissemination of the heliothermic axis influenced the work of several important designers, such as Le Corbusier, who presented at the third CIAM in Brussels his plan for the Ville Radieuse, which was oriented by 19 northeast degrees [64]. The axis's effectiveness was disputed during the 1940s; it opposed the “hygienists”, the partisans of east–west exposure, to the “climatologists”, who were advocates of southern exposure, among whom was Vinaccia (1943), who counterposed his *equisolare* orientation theory [65]. Even though Vinaccia did not have available contemporary tools to demonstrate the correctness of his opinion, it is interesting to highlight (as recent research has confirmed) the inefficacy of Rey's theory [63, 66].

The *Cité Industrielle* (1917) of Tony Garnier [67] was also designed by the author as a function of healthy principles. According to Butti [51], he was «heavily influenced by studies of ancient Greek city planning, the young designer [...] bore a close resemblance to Olynthus and Priene». Long rectangular east–west oriented blocks recall the ancient Greek organization, as well as buildings' arrangement, whose form «was to achieve good ventilation and high levels of sunlight into all homes».

Although Italy shows representative examples, such as Vinaccia's works, the international debate on urban healthiness arrived several years after the previous experiences. Ireneo Diotallevi and Franco Marescotti are still often considered the Italian forerunners for the topic of building-related illnesses. In *Costruzioni-Casabella*, they published some evidence for the relation between wellness and housing. These articles, which were grouped together in *Ordine e destino della casa popolare* (1941) [68], aim to directly link illness and the shape of buildings, focusing on the lack of insulation and ventilation as the main factors for the onset of disease in the working class.

Within the national architectural debate, the Roman architect Gaetano Vinaccia attempted to use several publications to discuss the relationship between urban form and local microclimates. Because of his status as a minor architect, his biography has not been studied in depth and only modest information is available [69]. In examining his productions, we can recognize four different phases [70]. In the first period, from 1919 until 1926–1927, he applies his knowledge to the field of architecture, achieving only mediocre success. The second, from 1926 to 1930, which corresponds to his studies in Freiburg where he graduated in civil engineering, can be considered as the more fruitful experience of his life, due to the opportunity to be in contact with the most advanced research in architecture, meteorology and civil engineering. The third occurs during his stay in Rome, when, as a board member of the architectural magazine *Casa d'Oggi*, he tried to influence the debate on typology, which was led by rationalist

architects worldwide. The last phase was during his attempt to lead the field towards an Italian approach to urban microclimate design and closed with the publication of his most frequently cited work, *La Città di Domani, Come il clima plasma la forma urbana e l'architettura: la sanità e l'igiene cittadina, Vol. 1* (1943) [65]. This work, which is the first complete treatise on the matter, marks him out as an absolute pioneer, even if his influence on architecture and urbanism has not been considerable, due to the unfavourable context in which his studies evolved.

Although most of Vinaccia's theories were already known in distinct international scientific sectors (climatology, physics, astronomy, etc.) he was perhaps the first to organize these into a systematic approach, also thanks to his education as an architect, which contributed to a more humanistic idea of architecture and planning. In this light, it is important to highlight the author's attempt to found a new scientific discipline, called *Polisclimatology*, in-between planning and microclimatology. His nature as a 'polyhedral' architect, able to manage design's various aspects that were related to distinct disciplines, made him an absolute innovator and his ideas extremely contemporary in our own time.

4. Contemporary experimentations

After World War II, the illusory belief in the technological system's supremacy led architects to forget their past environmental tradition. This trend continued until the 1970s–1980s, when the international oil crisis and environmental disasters (global warming, 1986; the hole in the ozone layer, 1985; the Chernobyl disaster, 1986; etc.) showed clearly the environment's weaknesses. This induced technicians to rethink the global development model in favour of a more sustainable one. Bioclimatism in architectural and urban design practices, which had in Rudofsky's vernacular research (1964) [71] and Olgay's architectural regionalism (1963) [72] two anticipatory events, caught on again. Scientific and technological progress that had occurred during the last few decades, allowed integration of the design process with important external 'environmental' contributions of interrelated disciplines (technical physics, fluid dynamics, microclimatology, computer engineering, etc.). According to the Bjarke Ingels Group (BIG), «[computer information models] allow us to shift the ultimate performance of a building away from the mechanical room and back into the permanent attributes of the design» [73]. Complexities resulting from this interdisciplinary perspective call for an update to the current process without being overcome by them.

On this topic, Monserrato's master plan tests a methodology (**Figure 5**) through which to integrate both environmental data and analyses, starting from the design's initial phases. It has been supported by Heliodon and ENVI-met software that act as useful 'feedback' tools able to verify qualitatively the environmental behaviour of the project's concept. In particular, the environmental analyses focused on the microclimatic consequences of urban form, taking into consideration different climatic data (air temperature, relative humidity, wind directions and velocities, hours of sunlight and direct solar radiation) and form parameters (aspect ratio and the sky view factor). Analyses were conducted in relation to winter and summer solstices, characterized by the most extreme environmental conditions during the year. The initial urban

proposal has been gradually modified and re-evaluated several times in relation to the main criticalities that have emerged from analyses' results and bio-climatic diagrams' information (Olgay). Nevertheless, modifications respect the master plan fundamentals and collaborate in the improvement of its overall performance.

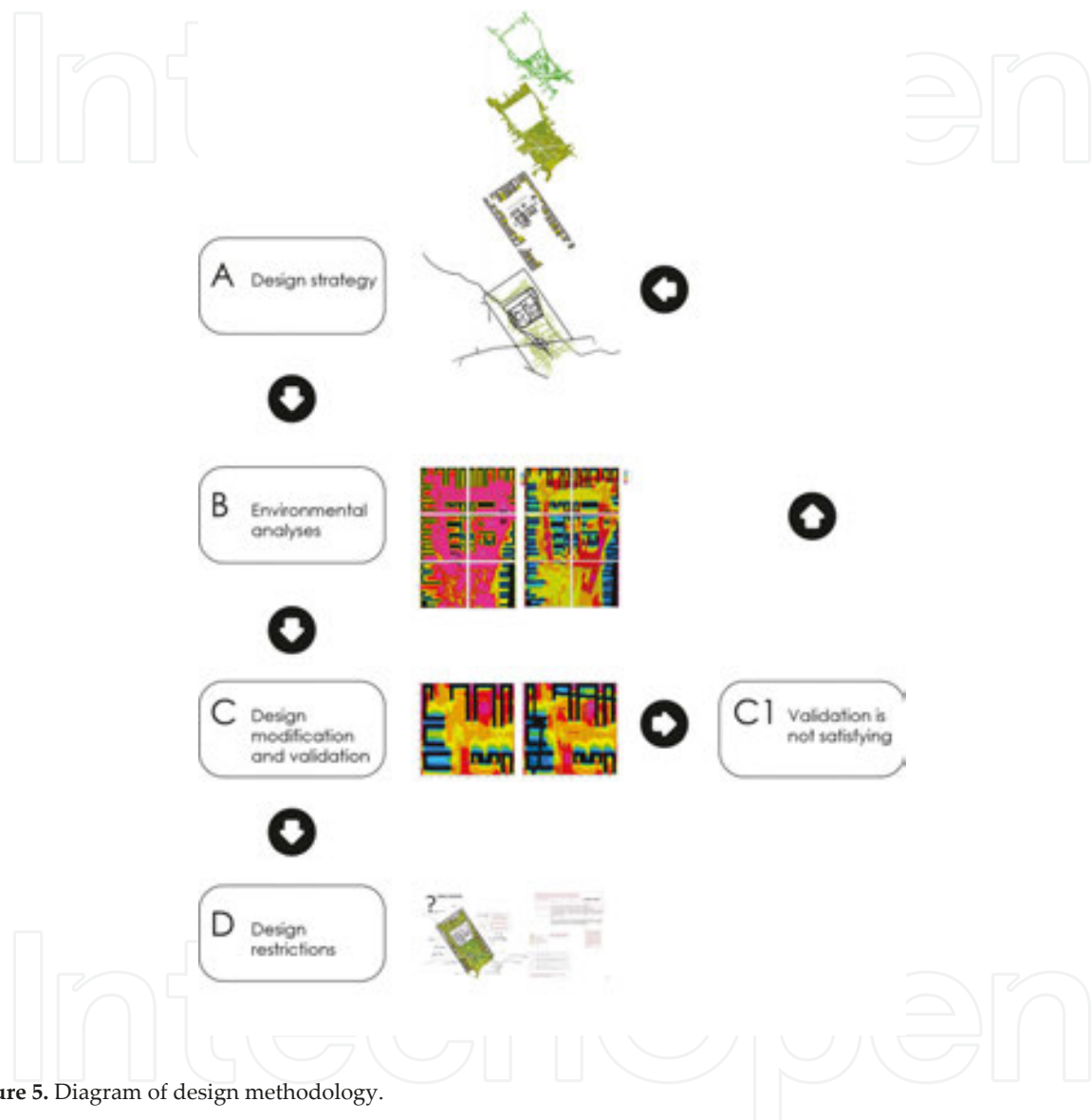


Figure 5. Diagram of design methodology.

The case study concerns a new urban expansion around the Academic Citadel area, in Monserrato (Sardinia, Italy). The main goals of the master plan were the reconnection of the University with the city centre, starkly separated by Highway 554; the urban sprawl's containment and, finally, the respect of local agricultural tradition. With these aims, the project designed an anti-sprawl territorial system, which encircles the existing Citadel with a new urban district (1.4 km²) linking it to the north-west city's edge (Figure 6). The blocks are arranged on the perimeter of the area along the existing position that is already in common with the historical city centre, the Citadel and the waterways system. The Citadel and the new

expansion are interconnected by a wide central park, towards which the 'c-shaped' blocks open their inner courts. Their connection is achieved through a podium, which bends back on itself, defining two different public spaces. The park's layout makes a direct reference to the previous rural pattern, with past tracks of land's plots, which host pedestrian and cycle paths bordering different green areas (lawns, gardens, etc.) (Figure 7). The blocks' dimensions are contained between 50 and 200 m, and the maximum height remains constant, opposing the increasing altitude of the terrain. Functions and the infrastructure network are designed in order to assure mixed use within the 400 m.



Figure 6. View of the master plan.

Environmental analyses evaluated environmental criticalities, taking into account man's thermal comfort in open spaces. Results recognized that the worst performances occurred during the summer season, when north-west blocks reached high wind velocities and high solar radiation values in courtyards, which were exposed to direct sunrays for most of the day. Uncomfortable conditions were also confirmed by Olgyay's diagrams, in which this cluster of blocks moves away from average seasonal values.

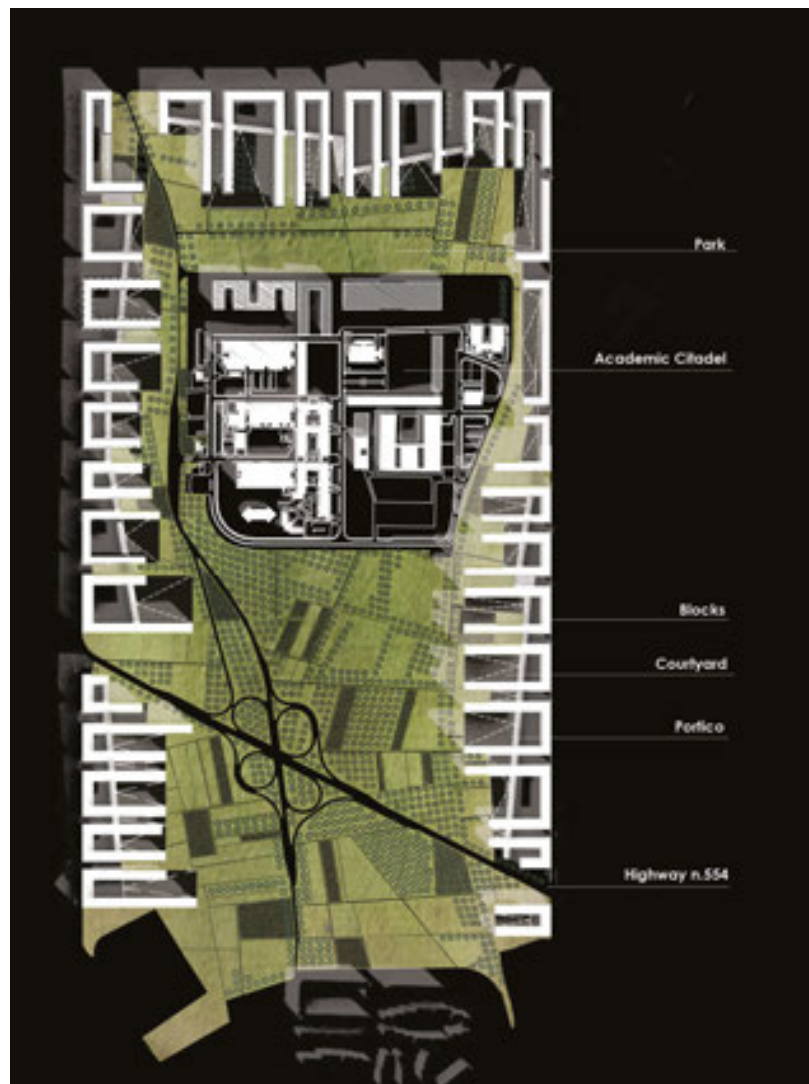


Figure 7. Monserrato plan.

In order to mitigate environmental weaknesses, the initial design has been modified, focusing on the northern part. Specifically, modifications concerned the blocks' height, which was raised in order to protect courtyards from the cold mistral, the introduction of a portico in each courtyard aimed at increasing shadows, and, finally, greenery's variation and implementation. The 'updated' master plan has been tested again in order to verify the variations' efficacies, confirming the performances' improvement. The additional vegetation, together with the portico, collaborate in reducing wind velocities without obstructing airflows. At the same time, the insertion of the latter increased shadows on courtyards' surfaces, reducing direct radiation by 20% and sun hours by 25–30% (**Figure 8**—above).

Referring to the transformation process adopted in several contemporary urban designs, such as the ZAC Bercy (Paris) by the architect J.P. Buffi [74], the work defined a set of restrictions in order to preserve the master plan's overall strategies and shape. Typological and morphological rules did not represent such blocks' final configurations, but they did have the task of

explaining clearly to designers the spatial relationships among parts, guiding their successive work on single blocks (Figure 8—below). The restrictions list of Monserrato metadesign coupled general rules with technical datasheets that referred to specific blocks. The former are structured in six main sections (1. edges; 2. blocks; 3. special blocks; 4. pedestrian routes and courtyards; 5. park and gardens; 6. roads), whereas the latter include special, additional rules combined with explanatory drawings.



Figure 8. Design's comparison of sun hours analysis (above) and examples of design general rules (left) and datasheet (right) (below).

5. Conclusion

According to most current scholars, goals in sustainable architecture need to be approached via the urban dimension. The necessity of this 'change of scale' has been proved, in the last few years, in several national and international scientific works, in which authors highlighted the benefits that are achievable—in relation to both climate change goals and energy issues.

In order to overcome sustainable challenges, urban design, which falls in between city planning and architectural design, becomes the appropriate tool through which operate, thanks to its ability to solve 'upstream' the buildings' environmental and energy deficiencies. The strategy was common in ancient times, when bioclimatic urban solutions were applied, both to mitigate extreme environmental conditions and to exploit passively the sun's heat in wintertime. Examples of 'solar cities' across the history of architecture until World War II, after which technology-system diffusion and the functions' specializations, were deemed less interesting in environmental practices. Despite the fact that bioclimatism partially caught on during the energy and environmental crises of the 1970s and 1980s, it was mainly applied to single buildings, neglecting urban theories. Today, when important research has shown the limits of strategies related to energy consumption reduction in single buildings and favours broader policies, ancient lessons have acquired relevance. In particular, the 'polyhedral' figures of past architects have gained in prominence, as they have provided us with extensive interdisciplinary knowledge. A significant example is the figure of Gaetano Vinaccia, an Italian architect and pioneer in urban microclimate design. Although he is classified as a minor architect and only a little information is available regarding his biography, his most cited work, *La Città di Domani, Come il clima plasma la forma urbana e l'architettura: la sanità e l'igiene cittadina, Vol. 1* (1943), can be considered the first complete treatise on urban environmental design and marks him out as an absolute innovator. These urban environmental principles, which allowed past technicians to manage urban shapes and functions without renouncing quality of space, have to be recovered by contemporary architects. Scientific progress over the last few decades allows architects and planners to reintegrate the project process with the important contributions of external disciplines. Complexities resulting from this multidisciplinary perspective call for an update to the current process, without it being overcome by those complexities. In this light, the methodology tested through the Monserrato case study offers a point of view on current design practices.

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