Chapter 70
Adaptive "Velari"

Alberto Raimondi and Laura Rosini

Abstract As it is known, the global phenomenon of rising temperatures causes uncomfortable and often harmful conditions for human beings living in moderate-climate zones, such as the Mediterranean area, especially in the hottest periods. Examinations of metropolitan cities can witness that high temperatures generate Urban Heat Island (UHI), due to population, buildings, vehicles and human activities in general. With the increase of rising temperatures in the latest decades, people living in big cities have gotten used to tackling heat discomfort with electricity charged cooling systems. As a result, the energy consumption for air-conditioning causes UHIs' effects to further grow. It is scientifically confirmed that the behavioral habit of relying on artificially generated cold whenever temperatures rise will eventually make the climate crisis more problematic in the near future. Energy communities are used to producing, storing and consuming energy on site; therefore, power sources must be in close proximity to users. Albeit neglected in the Modern Era, the most proximate and sustainable energy supply is directly available to us: sunlight. The origin of hot temperatures, discomfort and energy waste is, indeed, the most exploitable power generator men can access to. In Southern Europe or Middle East cities, the use of veils as urban-scale shading devices is part of the consolidated tradition; a well-known example can be found in the Spanish city of Sevilla, where textile curtains named "Sevillans" are stretched between buildings. At the present time, we're witnessing that the climate mitigation action of shading systems can be pursued in combination with energy production, with the development of membrane integrated flexible photovoltaic cells (PV). Masdar City in the United Arab Emirates, designed by the Foster Studio, or the Solar trees of the German pavilion at EXPO 2015 in Milan and the Promenade of the EXPO 2021 in Dubai are some innovative yet relevant cases. The use of PV cells for sun-shielding purposes is optimal to respond to a double-sided problem with a single object. Manufacturing an *adaptive velario* using composite fibers (i-Mesh), could both allow us to design the shape and modulate the density of integrated PV cells as needed. **Method**: To identify the best position for the adaptive tensile canopies, it is necessary to superimpose different site-specific data: temperatures in the urban area, in particular close to buildings; surfaces

A. Raimondi (✉) · L. Rosini
University of Roma Tre, Rome, Italy
e-mail: alberto.raimondi@uniroma3.it

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that receive most of the daytime radiation; sunlight and ventilation. To develop the most suitable solutions to many environmental scenarios, three-dimensional simulations performed with virtual models must be used both at urban (Envimet) and at building scale (in-Sight). **Expected results**: An algorithm capable of determining the "Velari" best position and the proper shading/density factor. A model, applied to a case study in Rome, to serve an evaluation of the benefits of this technology in terms of decreasing surface temperatures of external horizontal and vertical surfaces of buildings and streets.

Keywords Urban shading · Parametric textile · Heat islands effect · BIM model

70.1 Introduction

The average planet temperature is rising, and cities' are following at a doubled rate due to the phenomenon of urban heat island (UHI). At the latest United Nations Conference (COP 26) for climate change, that took place in Glasgow, the United Nations Environment Programme (UNEP[1]) has presented a manual designed to guide governments in the prevention and mitigation of the negative effects of UHIs. Among all the strategies displayed throughout the handbook, the ones providing "public shading structures" are considered the easiest and most effective ones to be implemented and therefore achieve the highest benefits.[2]

The research is part of the largest ongoing research on the city's potential transformation, carried out by the UR of Roma Tre University in Rome. In particular, the study observes the proximity of buildings in order to identify the actions that ideally take action on climate change effects in urban areas. Roma Tre's research group is operating in the context of a bigger project, conducted by six universities and research centers: *PRIN 2017—TECH-START—key enabling TECHnologies and Smart environmenT in the Age of gReen economy. convergent innovations in the open space/building system for climaTe mitigation.*

70.2 State of the Art

Protection from solar radiation is a widely developed topic in scientific literature, both regarding buildings and external spaces. From traditional applications, as the case of Sevillian tents spreading between buildings of the historic city center, along with contemporary projects, such as the city of Masdar City in the Arab Emirates designed by the studio Foster + Partners, or more experimental structures, as the

[1] United Nations Environment Programme (UNEP) has been the global authority that sets the environmental agenda.

[2] Beating the Heat: A Sustainable Cooling Handbook for Cities, p 56.

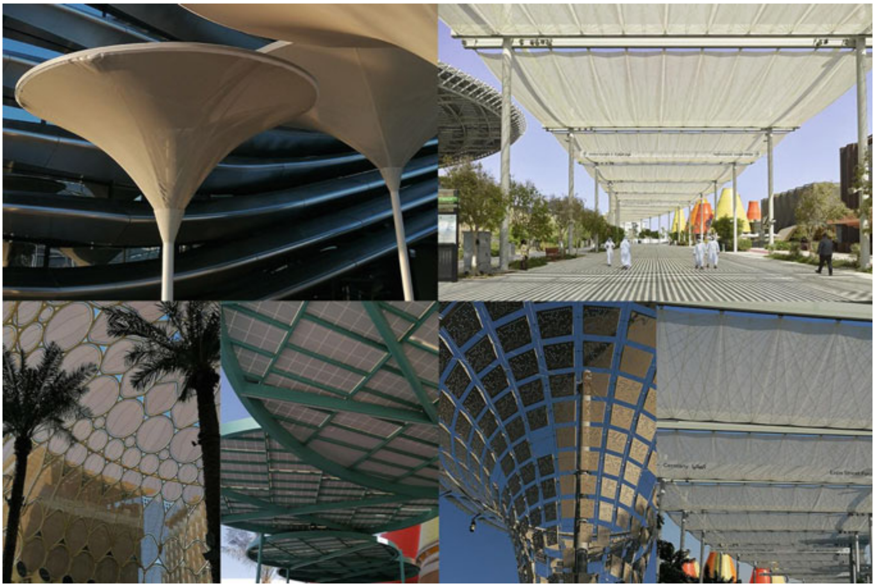

Fig. 70.1 Shading systems, Dubai Expo 2020 Promenade—January 2022 (*Source* author's photos)

Solar tree of the German pavilion at EXPO 2015 in Milan or the Promenade of EXPO 2020 in Dubai, the most intuitive ways for human-beings to tolerate heat have always involved shading (Fig. 70.1).

Along with different material canopies, planting in urban environments has been yet another solution of sure validity to screen street surfaces and building stories; however, implanting tall trees remains impossible in many built areas, causing exposure to heavy radiation loads for every irradiated element; this is why, especially in warmer countries during summertime, a large amount of heat gets accumulated inside and outside buildings, leading to air-conditioning exploitation. Studies on the efficacy of urban veils (Garcia-Nevado et al. 2020) state that up to 6 °C of temperature reduction can be obtained with shading systems. The degree reduction span is mainly dependent on which orientation does the investigated road spread over; along with this, differences in results are due to the percentage of perforation of the fabric (Solar Absorbance) and the reflectance power of the material (Solar Reflectance). Integration of thin-film photovoltaic technology in membranes, albeit being an ongoing scientific and industrial development, is the key concept for the proposed study: a drapery with embedded solar cells can perform the double function of shading and producing energy (Xiang et al. 2021).

Therefore, we've set up a case study that pivots around photovoltaic textiles that are composed of natural and polymeric fibers I-Mesh (Cesario 2017). We've worked on a Building Information Modeling (BIM) based mock-up. This model allowed us to observe how the imagined solar veils impacted on the urban context of Testaccio district in Rome, and consequently estimate how to tailor their characteristics to different needs.

The adaptive velarios were, indeed, conceived as adjustable elements whose texture can be adjusted to a range of spot-specific demands, insisting on both SA and SR factors.

70.2.1 Targets

- Verify the effectiveness of the shading solution on city-streets tracks
- Evaluate the best shape and position of the textile canopy in order to lower surface temperature of buildings
- Identify the most suitable solar-cells-weaving for the veils surface (that directly affects the Solar Absorbance Factor) as a function of the radiation intensity.

70.2.2 Case Study

The Testaccio district, in Rome, is the urban context for this study, and it is characterized by a homogeneous configuration of regular routes and squared block buildings. It has been affected by numerous redevelopment projects in recent years, and this, for us, makes it a setting of favor for innovative environmental technologies research.

The application of an urban-scale active shading system, has been set on a selected quadrant, that's bounded by Via Luigi Vanvitelli to the north, Via Nicola Zabaglia to the west, Via Galvani to the south and Via Marmorata to the west. Within this portion of the city, two roads have been chosen on the basis of their features; in fact, the aim was to examine how the shading solution responded to different conditions and, thereby, how to modify targeted parameters in order to enhance its performance. As a starting point, we set three default solar curtains of different geometries and imposed three incremental values for percentage of absorption of the solar flow of the fabric, so that the shielding could be boosted if required.

70.3 Methodology

70.3.1 Equipment

The study was carried out simulating the radiation conditions of the site surfaces with a three-dimensional model of the selected urban area, in such a way as to quantify the accumulation of thermal energy in the outer walls of buildings. The support used is Autodesk Revit 2022 software, which is based on BIM. This program offers the possibility to perform solar radiation analysis thanks to a plug-in: Autodesk Insight. In order to run the process, the first data to be provided are type of analysis, period of the year and time interval of observation. Furthermore, geolocation settings allow to simulate a realistic scenario.

70.3.2 Site

The two roads selected for the analysis of solar radiation have opposite orientations; they meet at right angles and the roads' transversal span and extension are similar; these latter features have less impact on the results, enabling a deeper focus on the characteristics of the surrounding (i.e. proximity to urban voids or buildings, presence planting and green areas or dense built-up area…). As follows, we collected the foregoing information about Aldo Manuzio and via Mastro Giorgio (Table 70.1).

For each route, the study was set up choosing three road sections, corresponding to three building plots with different boundary conditions; from these different points of observation, it was possible to identify two categories of varying properties:

- Architectural characteristics
- Environmental conditions.

As for the architectural factors, the following variations could be pointed out:

- Height of buildings
- Morphology of facades
- Position and amount of openings
- State of preservation of masonry.

The environmental factors are.

- Orientation of irradiated ground areas and external surfaces of the structures
- Path and height of the sun.

Since we can't operate on the environmental traits, it became necessary to lay out a modulation of the solar blinds instead. Choosing three fixed standard shapes and three progressive shading factors, we configured types as the baseline of our

Table 70.1 Analyzed streets characteristics

	Orientation	Section (m)	Spread length (m)
Via Aldo Manuzio	SW–NE	13.5	260
Via Mastro Giorgio	SE–NW	12.5	275

Table 70.2 Geometry of solar veils and solar absorption factor of their fabric

Geometry	Quadrangular	Trapezoid	Triangular
Typology	1	2	3
Average area (sqm)	160	120	100
SA factor (%)	30	30	30
Additional SA factor (%)	60; 90	60; 90	60; 90

study. To respond to the architectural and environmental factors previously listed, the default geometries are: quadrangular, trapezoidal, triangular (Table 70.2).

The ability of the fabrics to filter the incident solar flow (Absorbance Factor) has been set at an initial minimum value of 30%. The adequacy of this basic value has first been verified as the initial step of the analysis and design process.

If the results are not satisfactory in the starting examination, this may lead to an increase in the Absorbance Factor (AF). The other percentages of radiation absorption were set at 60 and 90%, so as to estimate a noticeable increase in shading performances by doubling and thirding the original SA factor of the fabric.

An additional variation of the standard solutions could be set on the reciprocal position of the hanging supports of the sheeting; based on the aesthetics and configuration of facing buildings, one portion of the same road can be suitable for top level anchorages, either aligned or unaligned, or for a height-varying hanging deployment between its two sides.

The following unfolded workflow is based on a cumulative radiation analysis, which indicates the total energy load insisting on an area in a set period of the year, and it's expressed in kWh/m^2. In this case, the results show a single day cumulative analysis.

The date refers to the first day of June (1 June), which has been chosen as the starting point for investigating the whole summer temporal span in a later development of our research.

70.3.3 Analytical model in Autodesk Revit.

Navigating Revit's modeling interface, an Analyze section can be found between the other BIM disciplines. The installation of Insight plug-in provides Solar Analysis and Light Analysis tools (Fig. 70.2). This paper deploys the workflow for the solar analysis, as the main focus of the investigation is to quantify the solar energy radiation on buildings and street pavements. The available solar analysis types are Cumulative Insolation, Peak Insolation and Average Insolation, and they determine the energy loads stored inside the elements of the model. This can be built simply using default Autodesk Revit families for walls and roofs. In fact, there is no need to customize the elements with physical information as the solar radiation analysis does not take into account material features.

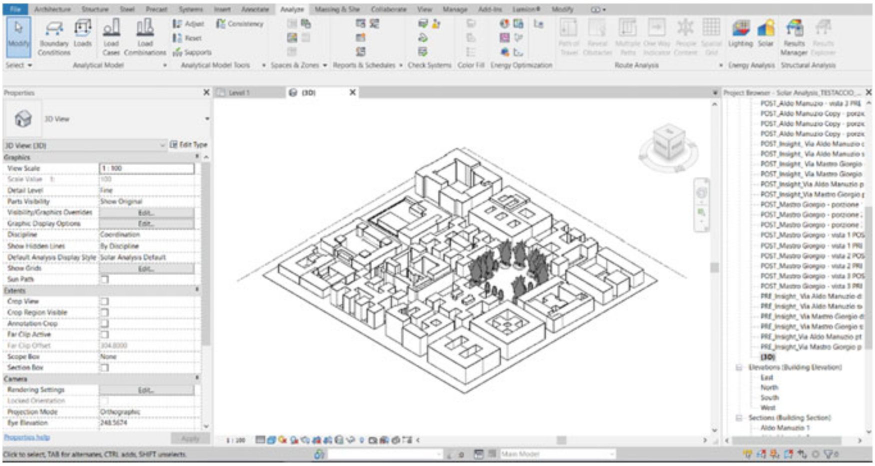

Fig. 70.2 Interface and analysis tools (*Source* Autodesk Revit)

The following method is the one adopted to develop the Adaptive Velario research; thus, the steps are illustrated providing illustrative information relative to the context of this study.

The initial key data to be included in the model are.

- Geolocation of the site: Testaccio, Rome
- Type of study: one day solar study
- Date: 1 June (Fig. 70.3).

The next step is to generate a duplicate of the model (named energy model) from a three-dimensional view, as the Insight plug-in does not run in bi-dimensional views. Therefore, starting the analytical process requires to provide the software with a few further inputs:

- Study Type: custom
- Surfaces: user selection
- Type and units: cumulative insolation—kWh/m^2 (Fig. 70.4).

We can now proceed by selecting wall and roof surfaces in the model. The surfaces in question are.

- Ground surface of the road
- Vertical surfaces of facades that define the road (Fig. 70.5).

By updating the analysis window, the cumulative insolation loads are shown both in kW/h and kWh/mq units.

Aiming to compare a lifelike scenario and a virtual simulation of how the designed velarios would perform in reality, it is necessary to target the right options for shading system modeling. Solar curtain modeling requires several consecutive steps to create recognizable three-dimensional elements, which the software can run the simulation

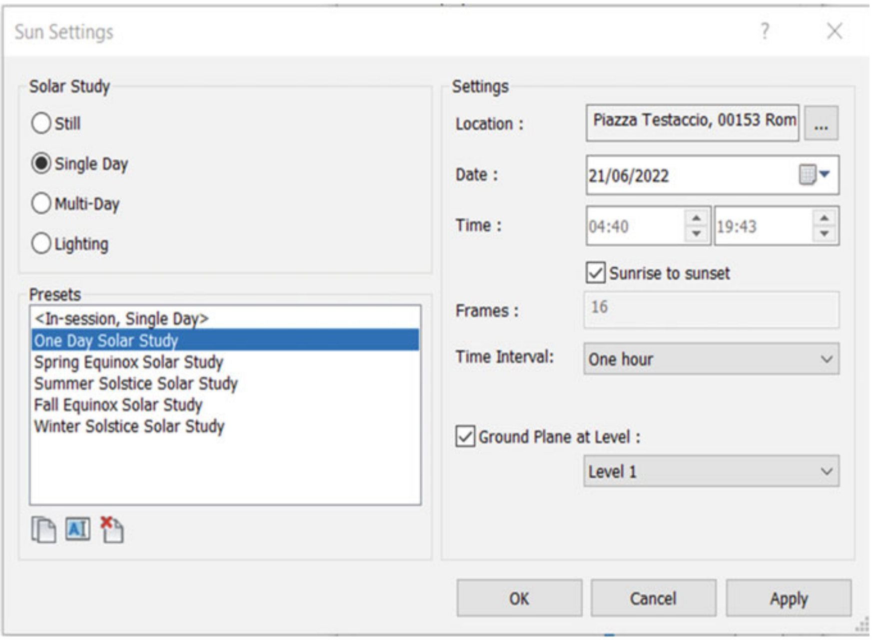

Fig. 70.3 Sun settings (*Source* Autodesk Revit)

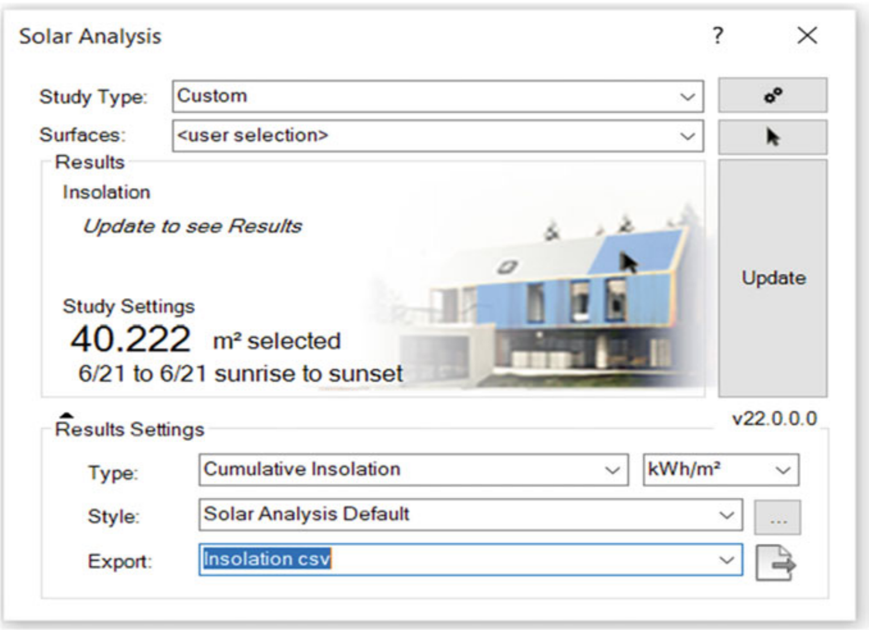

Fig. 70.4 Solar analysis settings (Source: Autodesk Revit)

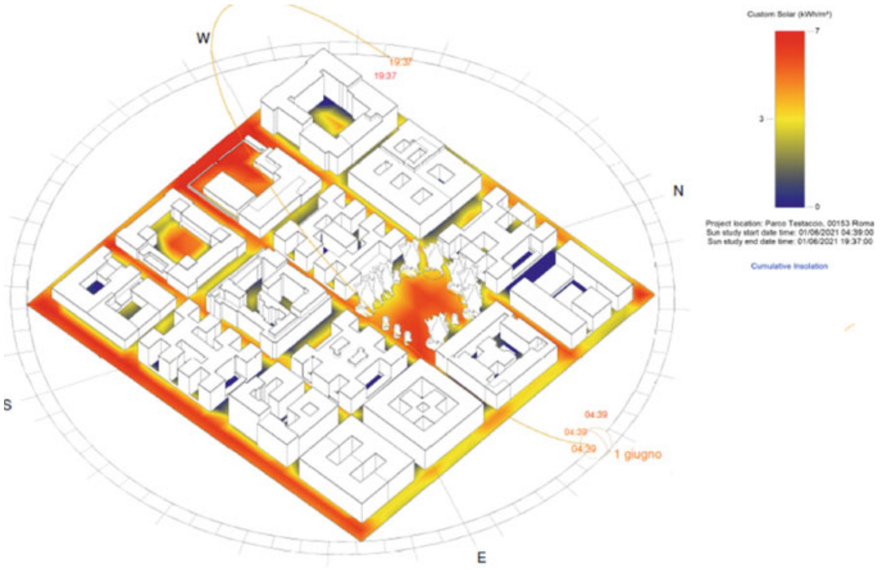

Fig. 70.5 Solar analysis output at ground level (*Source* Autodesk Revit)

with. The program does not provide a special category for shading systems. In contrast to what previously said about the irrelevance of assign material characteristics to wall and roof families, the only way to make the solar fabric interact with the analysis tool is editing the element's material parameters.

The surface type in question is provided in the basic Revit material library: Analytical Surfaces—Shades.

The following steps are.

- Roofing elements modeling using a basic *Roof* family (Fig. 70.6)
- Determination of geometry to be chosen between the three standard ones
- Editing type properties of the element: thickness and material
- Type duplication: three analytical roofing types must be created
- Setting the *Absorptance* parameter of the three types between 30, 60 and 90% (Fig. 70.7).

70.4 Solar Analysis Development

At first, the solar analysis has been performed on the model to produce results that simulate the starting condition of the examined roads (Fig. 70.8).

After the creation of solar veils with *Absorptance Factor* (AF) of 30% and the setup of different position hanging supports according to the morphology of the buildings, the analysis process has been repeated.

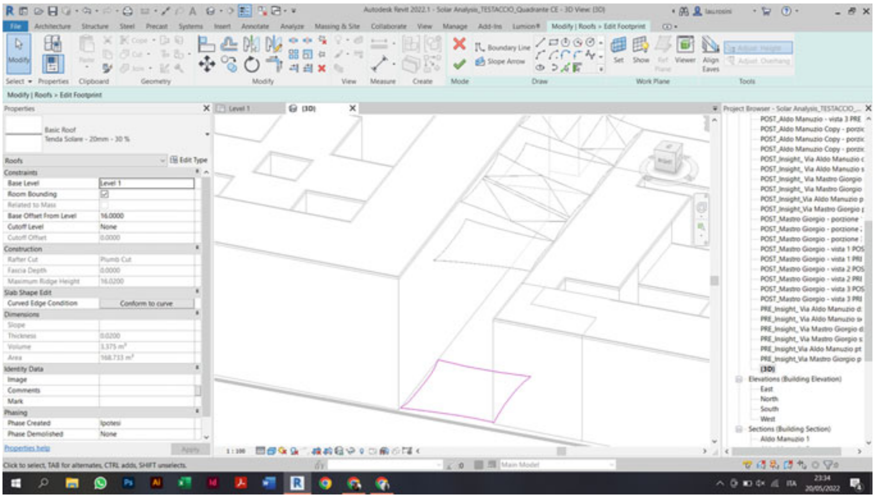

Fig. 70.6 Shading elements design: *Roof* tool (*Source* Autodesk Revit)

We have therefore evaluated the compliance of the basic solution of the fabric with a 30% AF factor to the shading needs of the different cases (Fig. 70.9). In the eventuality of unsatisfactory solutions, the AF factor of the veil could be gradually increased and the analysis of the sector run as many times as required (Table 70.3).

70.5 Solar Analysis Results

The comparison between the before and after scenarios is now summarized by observing results from quadrant 2B and 2E (Fig. 70.10). Via Aldo Manuzio spreads from West to East (to simplify), which means that the facades facing North are sun-lit during the first hours of the day, when temperatures are lower than the rest of the daytime. At the same time, facades facing South get insulated from midday, when they get affected the most by solar energy loads, to sunset; however, during the latter hours of the day, these facades are shaded by the facing buildings (Fig. 70.11).

The observation of this phenomenon brought us to the conclusion that a simple Absorption factor of 30% could be sufficient for this case. In terms of energy loads, the difference between the before and after results is mostly valuable for the ground surface. The road can be affected by a solar energy of 1 to 5 kWh/m^2. The simulation after installing the veil provided a reduction of up to 1 kWh/m^2 (Fig. 70.12) (Table 70.4).

Via Mastro Giorgio spreads from South to North which means that it gets irradiated during the middle part of the day, when sun height is at its highest and so do temperature (Fig. 70.13).

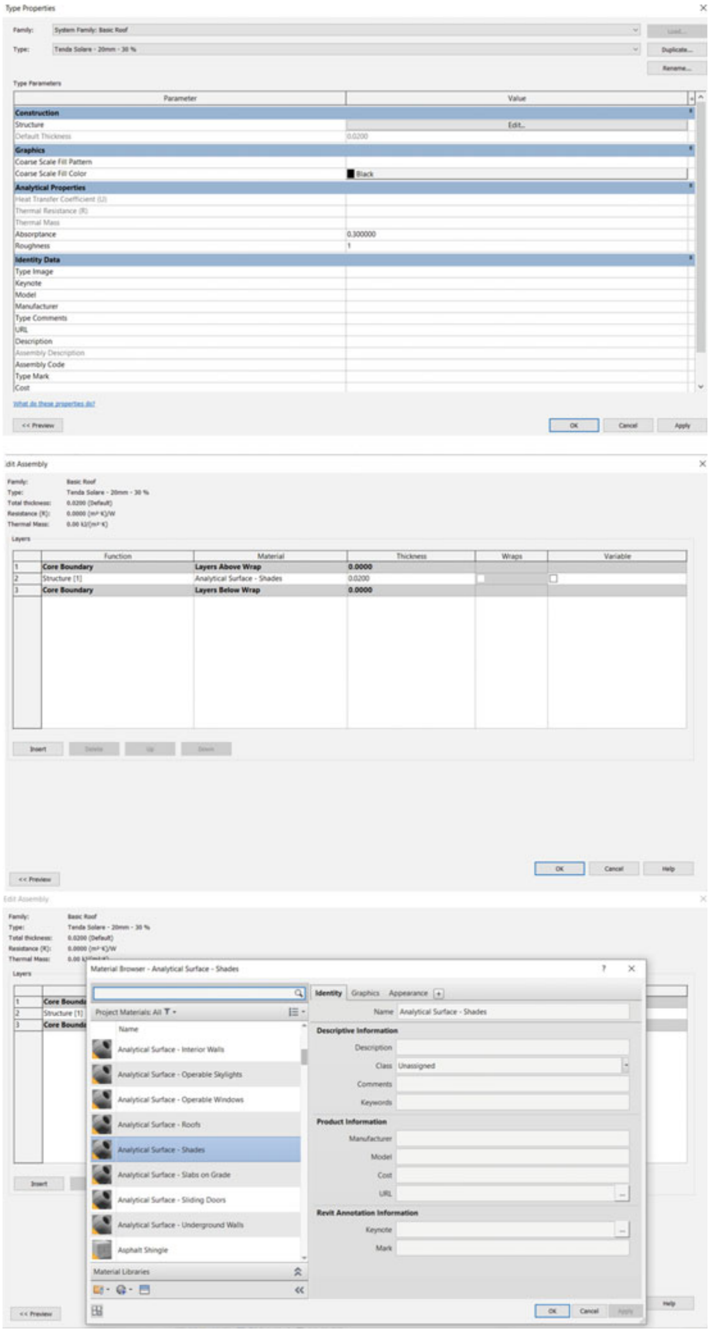

Fig. 70.7 Shading elements material parameters editing steps (*Source* Autodesk Revit)

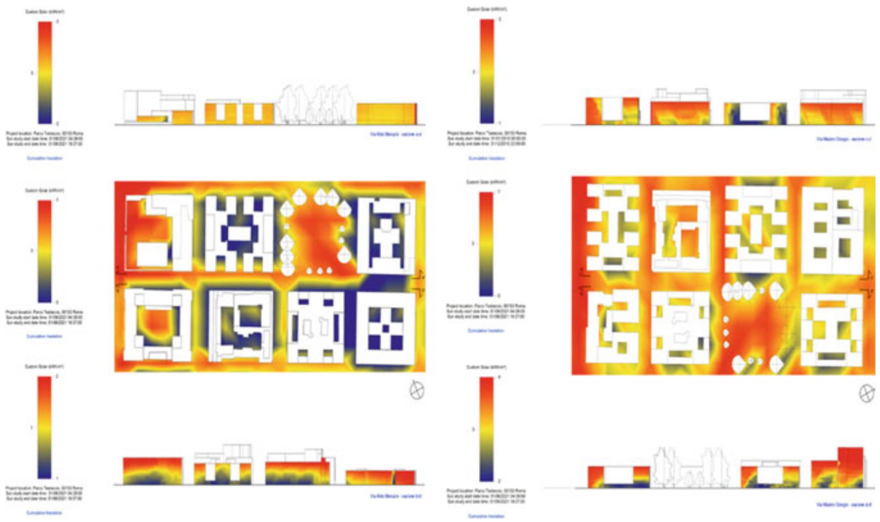

Fig. 70.8 Solar analysis output: via Aldo Manuzio; via Mastro Giorgio—Before—Autodesk Revit

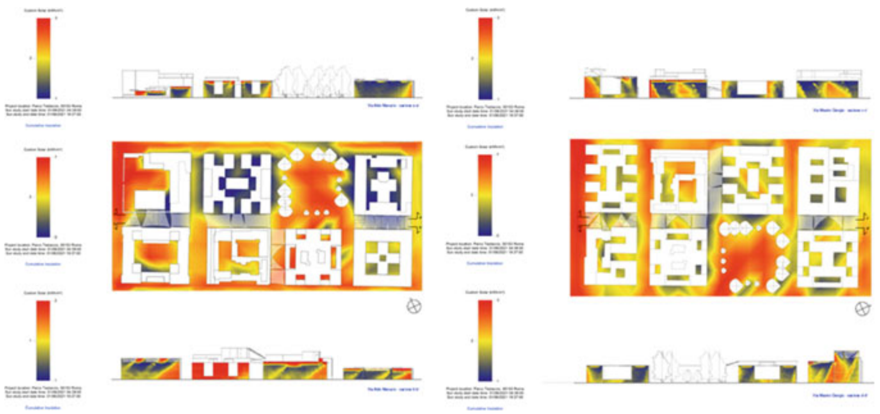

Fig. 70.9 Solar analysis output: via Aldo Manuzio; via Mastro Giorgio—After—Autodesk Revit

This portion of the site has been verified with successive steps. It required to be tested with all the three options of AF (30, 60 and 90%) and only the last one got a decent reduction of insulation and energy load. The surfaces showing a valuable difference with a 90% AF are the South-West facing facade and the ground surface, that could, respectively, accumulate an amount of solar energy equal to 4 and 5 kWh/m^2 (Fig. 70.14 and Table 70.4).

Table 70.3 Adaptive Velari parameters description

Via Aldo Manuzio (SW–NE)	Portion 1 section C	Portion 2 section B	Portion 3 section A
Facing buildings height	Different	Equal	Slightly different
Solar veils typologies	1 + 2 + 3	2 + 3	2 + 3
Anchoring position	uneven	even	uneven
AF (%)	30	30	30
Via Mastro Giorgio (SE–NW)	*Portion 1 section F*	*Portion 2 section E*	*Portion 3 section D*
Facing buildings height	Different	Equal	Equal
Solar veils typologies	1 + 3	1 + 3	1 + 3
Anchoring position	Uneven	Even	Even
AF (%)	90	90	90

Fig. 70.10 Analyzed sectors. The coding indicates portions and sections along the streets' extension—Autodesk Revit

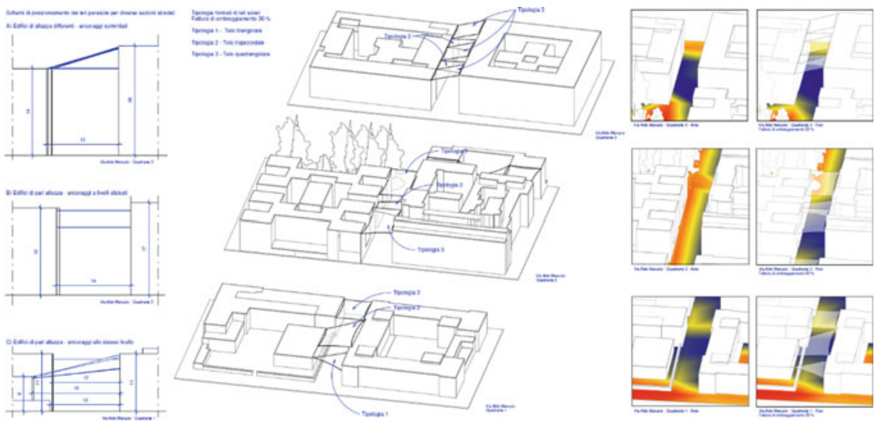

Fig. 70.11 Analysis output comparison: via Aldo Manuzio—Autodesk Revit

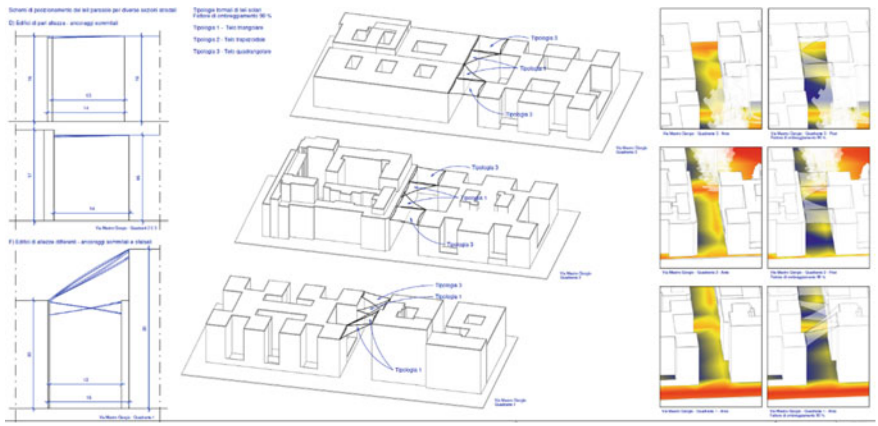

Fig. 70.12 Analysis output comparison: via Mastro Giorgio—Autodesk Revit

Table 70.4 Results details

Via Aldo Manuzio (SW–NE)—2B	Before: irradiation spread	Before: Energy load (kWh/m^2)	After: Energy load (kWh/m^2)
SE facing facade	Even	> 3	≤ 2
NW facing facade	Uneven	≤ 2	≤ 2
Ground surface	Uneven	≤ 5	~ 1
SE facing facade	Even	> 3	≤ 2
Via Mastro Giorgio (SE–NW)—2E	*Before: irradiation spread*	*Before: Energy load* kWh/m^2	*After: Energy load* (kWh/m^2)
NE facing facade	Slightly uneven	≤ 3	~ 1
SW facing facade	Uneven	≤ 4	~ 2.5
Ground surface	Even	> 5	~ 1

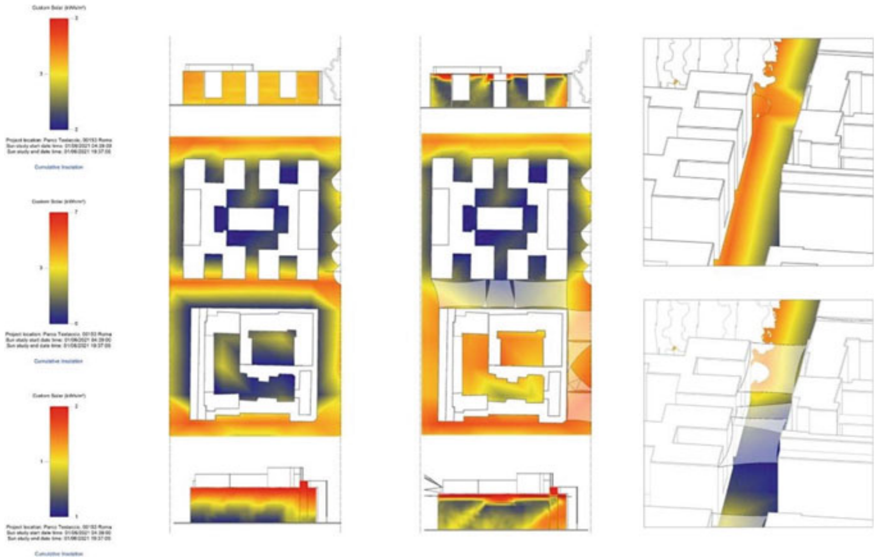

Fig. 70.13 2B quadrant—via Aldo Manuzio: results comparison—Autodesk Revit

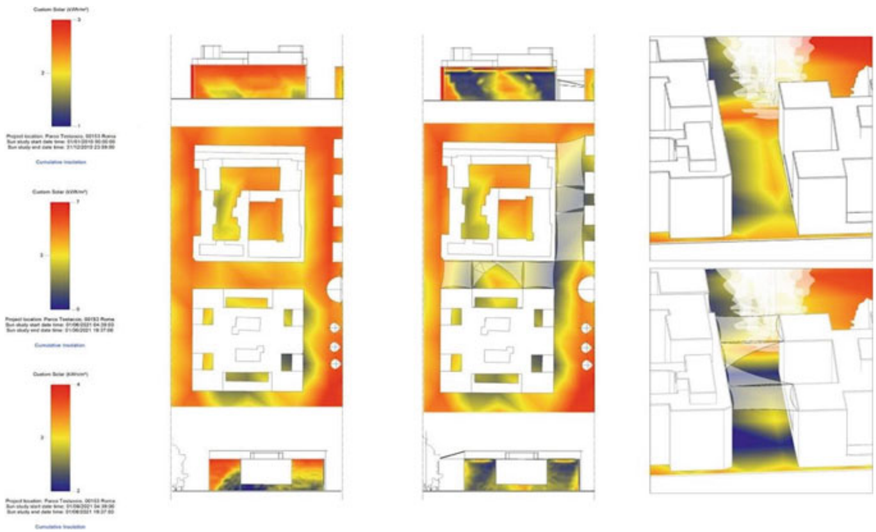

Fig. 70.14 2E quadrant—via Mastro Giorgio: results comparison—Autodesk Revit

70.6 Conclusion and Future Perspective

In this initial phase of the research, we had the validation that systems such as velars, mounted at the top of buildings are able to produce a significant reduction of temperatures on the surfaces of urban canyons. The reduction of the stored heat load varies depending on the orientation of the road and how the sun radiates on the outer walls of the buildings; as a consequence of environmental effects on street surface and on facades, the type of fabric can be chosen from three Solar Absorbance values: 30, 60 and 90%.

Future developments will consist in studying a further modulation of fabric texture, in order to obtain point-directed shading, insisting where it's strongly needed and a looser tissue density where it is not; this facilitates ventilation and light permeability, along with inhabitants' well-being. Moreover, the research aims to outline the embedding of thin film PV cells into the velarios for in-site electricity production.

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