Climate-resilient urban transformation pathways as a multi-disciplinary challenge: the case of Naples

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Abstract. The effects of climate change in cities are already visible with extreme events globally increasing in both frequency and intensity. It is essential to consider the impact of urban regeneration strategies on local microclimatic conditions in order to guide urban planning and design in a resilient key. The complex management of information required to define adequate intervention strategies at a local level is a growing challenge for public administrations. The paper presents the first results of the ongoing H2020 project CLARITY (2017-2020) aimed at developing climate services for the integration of adaptation measures in urban redevelopment actions focused on activities performed in partnership by the UNINA team and the City of Naples, one of the project's case studies.

Keywords: Urban microclimate; Multi-scale design; Multi-level governance; Urban adaptation co-benefits; Naples case study

Introduction

The climate-resilient transformation of cities is a multidisciplinary challenge and a unique opportunity to bridge the "forecasting" approach typical of climate science and risk studies with the holistic "back-casting" perspective of urban, environmental and technological design. In this context, the project is the materialisation of a future urban vision, where mid- to long-term mitigation/adaptation strategies need to be synergised with short-term social, economic and environmental co-benefits aimed at tackling specific urban regeneration needs by assessing and prioritising the design alternatives, thus shaping and phasing the preferable and feasible scenarios.

The methodology adopted by CLARITY aims at identifying climate change scenarios at city level that take into account the variability of urban microclimate and the contribution of districts' morphology, building and construction typologies, surface materials and characteristics of open spaces in either amplifying or reducing the impact of extreme heat and flood events in order to identify and prioritise suitable adaptation measures.

To this end, dedicated GIS-based and parametric design tools have been developed to refine the information derived from climate models, with a typical resolution of 10 km and a detail of up to 250 m (city plan) and 5 m (district development)[1]. Satellite data at pan-European (Copernicus) and local (national to regional database) levels have been processed to extract detailed information on key parameters to model the response of urban environment to climate stresses (albedo, emissivity and run-off, buildings and green fraction features, etc.).

The City of Naples is currently integrating such information in a multi-scale planning perspective, from strategic vision to district level design by updating the local Sustainable Energy and Climate Action Plan (SECAP), the new City Plan (PUC), and the Urban Regeneration Project in the eastern suburbs (PRU Ponticelli). The scope is to drive the urban policy towards climate-resilient transformation pathways. In particular, simulations and reports produced within project CLARITY have been publicly discussed by the Municipality of Naples and integrated into the Preliminary City Plan and Environmental Report[2].

Climate change scenarios for the city of Naples

Naples, like many cities in the Mediterranean area, is already facing a significant climatic variation, compared to the 1971-2001 "historical" reference period. The last few years have shown a constant increase in minimum and maximum temperatures (to which more frequent episodes of heat waves are associated), while seasonal precipitation patterns present an increasingly evident alternation between periods of drought and extreme events characterised by high rainfall concentrated in a few hours (often resulting in surface flooding episodes).

Climate projections confirm these trends, with uncertainties related to the entity of the expected variation, depending on the different GHG emission scenarios (RCPs). Recent studies (WHO-UNFCCC, 2018; Ministero della Salute, 2019) estimate an increase in the number of heat waves and extreme precipitation, and in the duration of drought periods in Italy.

However, annual average values processed with statistical methods from observations on single weather stations (Fig. 1, top) do not allow to represent the critical issues that cities face in relation to climate change. More precise information about the frequency of extreme temperature and precipitation events (often concentrated in limited periods of the year and, therefore, not "caught" by annual average values) is required, taking into account the effect of urban environment features, such as urban heat island and surface run-off, in aggravating the expected impact.

CLARITY project has, therefore, focused on defining these aspects, identifying in detail the increase in frequency of heat waves and heavy rainfall until 2100, and processing accurate modelling of urban morphology and land use to capture the effect of built environment features on the urban microclimate.

Detailed analysis of extreme events related to climate change

Heat waves

Heat waves occur when high temperatures are recorded for several consecutive days, often associated with high levels of humidity, strong solar radiation and absence of ventilation (Pyrgou et al., 2017). These weather-climate conditions can represent a health risk for urban communities (Italian Ministry of Health, 2019; Ng and Ren, 2015).

EURO-CORDEX data processing allowed to estimate the number of events expected in the period 2020-2100, starting from the 1971-2011 historical series. The projections refer to the IPCC emission scenarios RCP8.5 and RCP4.5. Figure 1 shows the summary of some significant extreme events for the Naples area. The data analysis shows that events similar to those recorded in recent years (36°C for periods even longer than 6 consecutive days) will increase significantly in terms of frequency and intensity in the next thirty years, reaching intensity levels never recorded before (over 9 consecutive days with temperatures above 38 °C).

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Surface flooding

Surface flooding events usually occur when high amounts of rain are concentrated in a limited period of time. The scientific complexity linked to the projection of precipitation scenarios with sub-daily detail led to the decision to observe daily trends and assimilate them to concentrations of less than 6 hours, which is a recurring characteristic in the case of Naples. Figure 1 shows the number of expected events in which the amount of rain exceeds the minimum threshold observed in recent storms in Naples. The data analysis shows that events similar to those recorded in recent years will increase significantly in terms of frequency and intensity over the next thirty years, reaching levels never recorded before (100 mm/day) in the second half of the century.the second half of the century.

Analysis of the "local effect" and supporting data for urban planning

As mentioned, the sole analysis of data derived from the observation of past events recorded by local weather stations and projected in the future through statistical "downscaling" of Regional Climate Models (RCM) cannot capture the microclimatic variability linked to the settlement characteristics of the urban environment. The urban morphology and the land cover greatly influence the thermal stress conditions and the ability to absorb rainwater, resulting in significant diversification of the main hazard parameters.

In order to support urban planning, CLARITY has developed specific simulation models running in a GIS environment and able to capture the urban "local effect" of heat waves and floods, thus providing more precise information on the climate adaptation strategies to be implemented in different parts of the city. The first essential element of information is the creation of a GIS database of land use that contains all the parameters necessary for "local effect" simulations. The datasets shared by the City of Naples (currently used for planning purposes at various levels) have been verified and corrected (in terms of geometries and intended uses) through comparisons with recent high resolution satellite images (Pleiades 2018 data), and integrated with the input parameters required by the models.

The resulting land use map is extremely detailed, and includes essential elements not present in ordinary cartographies, such as the presence of trees and the characteristics of albedo, emissivity and run-off of the different urban surfaces.

The processing of the different datasets through the simulation models developed by PLINIVS-LUPT Study Centre for CLARITY has allowed to identify the expected levels of hazard related to heat waves and surface flooding phenomena. This information is the hazard component at the basis of the corresponding impact models, currently being calibrated, which will allow to identify the effects of heat waves on the population (in terms of impact on human health, including the increase in mortality), and the effects of flooding on buildings (in terms of interruption of road networks and economic damage to property or production activities).

Heat waves - local effect

The thermal stress variation in the different city areas is simulated through the Mean Radiant Temperature (Tmrt) indicator, which is widely validated in the literature as representative of perceived outdoor comfort (Chen et al., 2016). This is essentially derived from air temperature, surface temperature, urban morphology and surface characteristics of buildings and open spaces[3].

It is noteworthy that, although Tmrt does not consider wind as a parameter, extremely low wind speeds are recorded during heat waves and, therefore, the simplification adopted, which has been widely recognised in the scientific literature (e.g., Gulyás et al., 2006; Oke et al., 2017), is suitable in relation to the objectives of the simulation.

Heat wave simulations can be carried out according to different temperature thresholds. The simulation shown in figure 2, as an example, has been included by the Municipality of Naples in the PUC as a useful element to support urban planning, since it allows to highlight areas characterised by critical conditions depending on land use and urban morphology (like medium-low density areas with prevalence of dark horizontal waterproof surfaces, lack of green areas and trees).

Each cell of the grid can be analysed more in detail to determine to what extent the specific land use and building-open space configurations influence Tmrt values and, therefore, the heat outdoor discomfort and associated health risks (Fig. 3). Such detailed analyses allow to appreciate some aspects that link urban morphology and land use to microclimatic conditions.

In the ancient centre area, building density determines shading conditions that reduce thermal stress. Differences between cooler green areas and overheated asphalt roads can be noticed in bigger squares. In the courtyards of historic buildings, differences can be observed between the larger and smaller ones, where the latter are cooler due to greater shading. The presence of green areas and trees represents a thermal stress reduction factor in the larger courtyards. In Rione Traiano and Ponticelli areas, the greater distance between the buildings and the limited presence of trees cause considerable overheating, which is reduced, especially in the case of Ponticelli, by the large green areas present in some urban blocks.

The model also allowed to develop further simulations related to the perceived discomfort conditions detected by the UTCI indicator (Fig. 4). The damage classes are calibrated with reference to weak population groups (children under 15 and elders over 65) for the Naples climate zone (D'Ippoliti *et al.*, 2010).

Surface flooding - local effect

Flooding simulations are extremely complex due to the large number of parameters involved and the level of detail needed to repre-

01 | Top, annual rainfall and temperature averages in the period 1971-2100 for the city of Naples for concentration scenarios RCP4.5 (green) and RCP8.5 (red). Source: CMCC – Centro Euromediterraneo sui Cambiamenti Climatici (D'Ambrosio e Leone, 2018); middle, historical and projected heat waves in the period 1971-2100; bottom, historical and projected extreme precipitation events (Source: ZAMG / PLINIVS-LUPT, CLARITY project)

02 | Mean Radiant Temperature map in Naples for a typical day of heat wave with air temperature 36-37°C (250x250m grid) (Source: PLINIVS-LUPT, CLARITY project)

03 | Detailed analysis of the Mean Radiant Temperature in some areas of Naples, for a typical heat wave day with air temperature 36-37°C (Source: PLINIVS-LUPT, CLARITY project)

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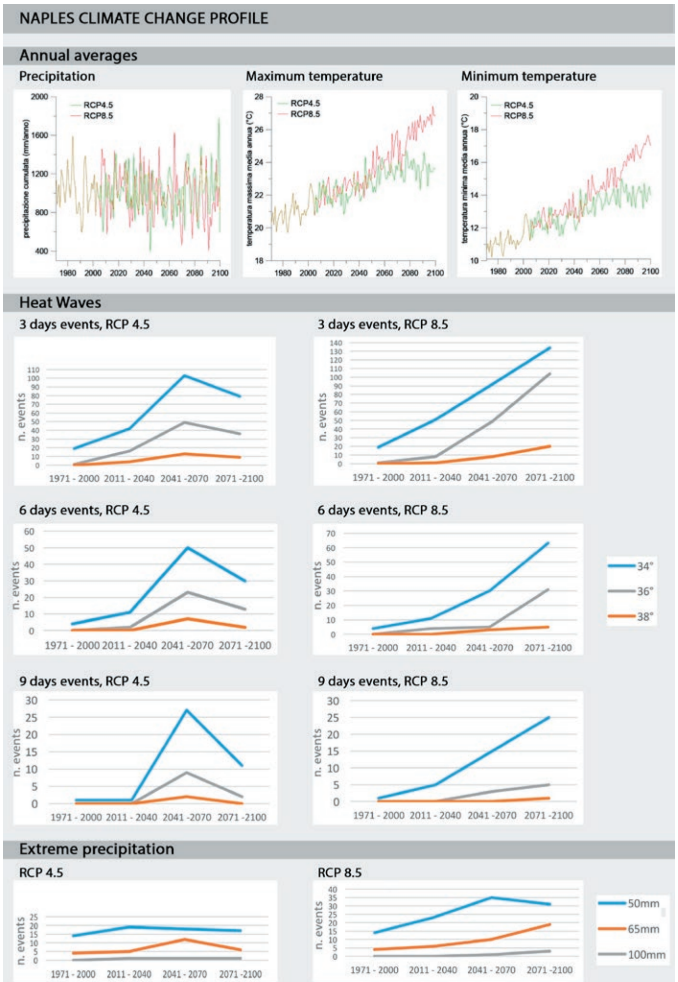

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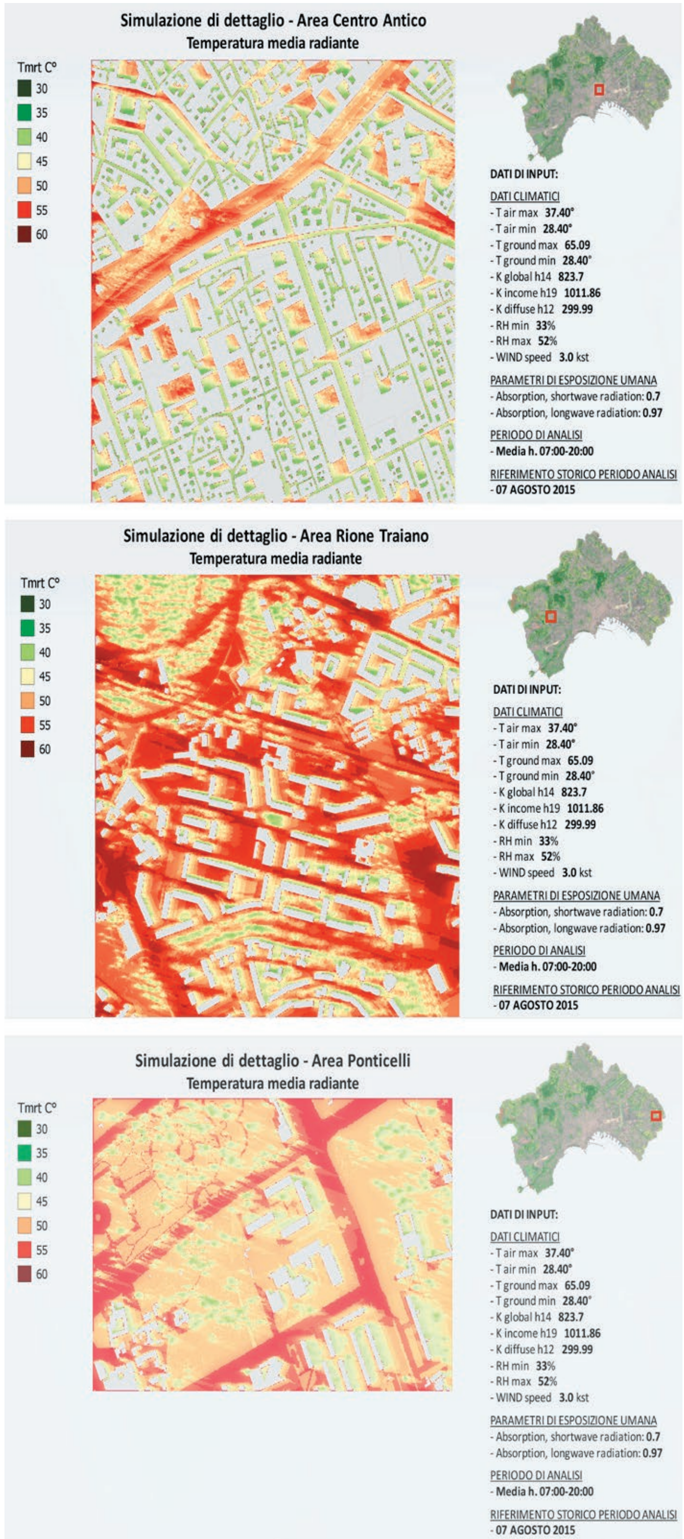

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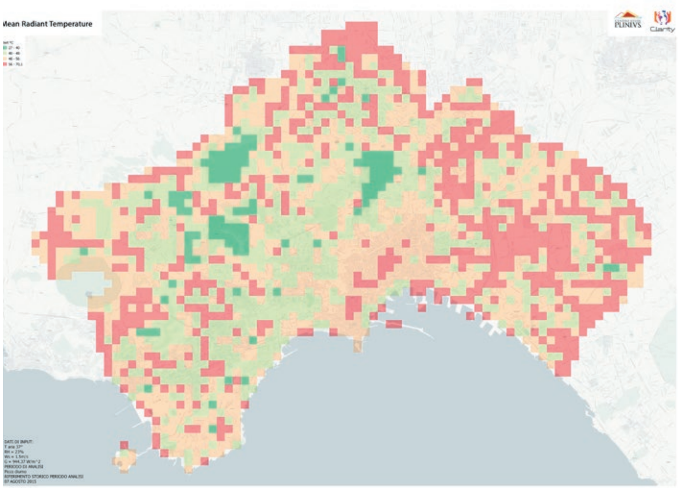

04 | Universal Thermal Climate Index (UTCI) map for a typical day of heat wave with air temperature 36-37°C (250x250 m grid) (Source: PLINIVS-LUPT, CLARITY project)

05 | Flood risk probability of urban areas in Naples (Source: PLINIVS-LUPT, CLARITY project)

Tab. 01 | Performance indicators to quantify climate benefits associated with the various adaptation measures (Source: PLINIVS-LUPT, CLARITY project)

sent the dynamics of the phenomenon, which depends on the duration and intensity of the event. The main variables are linked to the absorption capacity of urban surfaces, calculated on the basis of the run-off index, as well as the morphology of the water catchment areas in the city determined by natural orography, which include the run-off streams. In the Naples case, most of the city's sewer follows the natural orography, and almost all natural streams are today converted into roads in which most of the rainwater is channelled.

In relation to the urban planning objectives, the drainage capacity of urban surfaces is particularly important, along with the maintenance and adaptation of sewage systems. It must be balanced taking into account the specific features of each river basin and other hydraulic characteristics (including the height of aquifers, which are very near to the surface in some areas of the city).

A simplified approach[4] was adopted to determine the surface flooding probability of urban areas in case of extreme rain events by assigning a "risk coefficient" to each of the parameters (orography of drainage basins; concentration of run-off streams; run-off coefficient for each land use; emergency calls related to flooding events, intended as a proxy of sewage system capacity). The overall picture produced at city level (Fig. 5) highlights priority areas for deeper analyses to be conducted using continuous simulation modelling tools that usually require a very high computational capacity, if applied to large urban areas.

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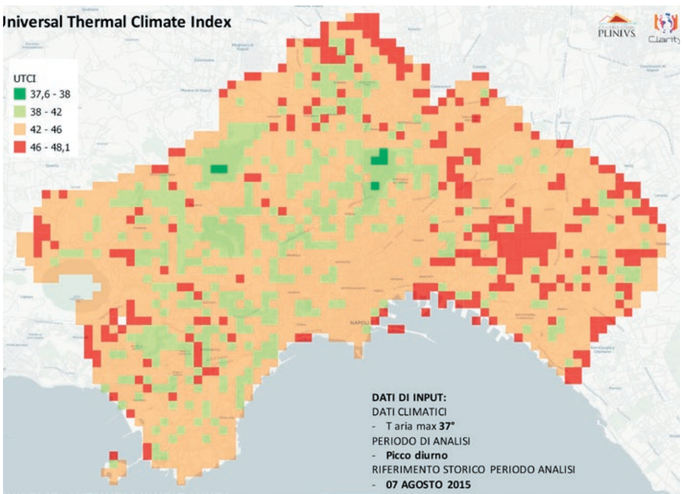

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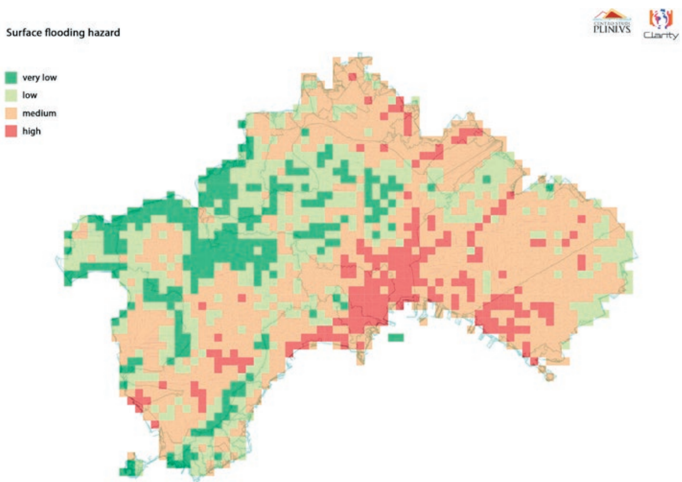


Climate adaptation strategies for the city of Naples

The goal of integrating climate adaptation measures into urban planning is a strategic priority at international level. The available literature allows to identify a series of adaptation measures in response to the impact of extreme temperature and precipitation events, whose effectiveness can be linked to a series of indicators defining each measure's contribution to controlling the urban microclimate.

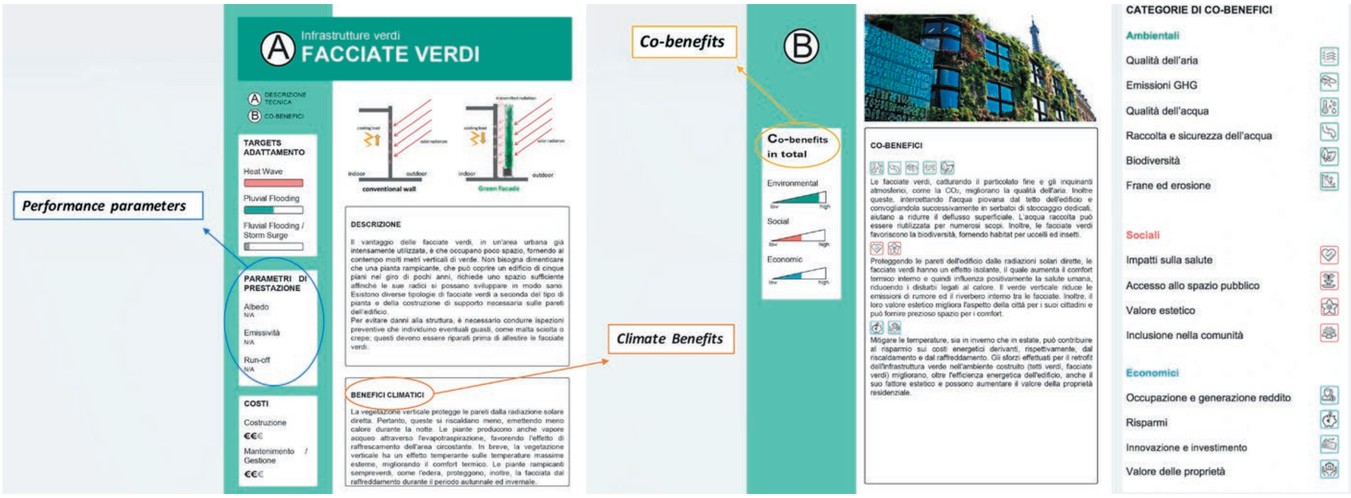
The systematisation process of relevant literature performed within CLARITY has allowed to identify a catalogue of the most recurring adaptation measures, classified according to their ability to provide climate benefits in terms of:

1. reduced impact from heat waves, acting on the surface temperatures of buildings and open spaces, improving the conditions of perceived thermal stress and reducing the Urban Heat Island (UHI);
2. reduced impact of flood events, acting on the capacity of urban surfaces to guarantee adequate rainwater drainage and storage.

To assess the climate benefits linked to each adaptation measure and, therefore, the positive effect on urban microclimate, performance indicators have been defined (Tab. 1), based on the parameters affecting the results of "local effect" simplified models. The way such parameters affect the urban microclimate is complex to

| Tab. 01

Performance parameter	Description	Range
Albedo	Fraction of incident solar radiation that is reflected. It therefore indicates the reflective power of a surface. Higher factor corresponds to higher reflectivity.	0-1
Emissivity	Effectiveness of a material in emitting thermal radiation. Surfaces with high emissivity factors remain cooler thanks to their rapid heat release capacity.	0,8-0,99
Run-off	Correlates the amount of rain with the amount of surface run-off. This value is higher for areas with low infiltration and lower for permeable and well-vegetated areas.	0-1
Transmissivity	Portion of transmitted solar radiation (measured e.g. under the canopy of trees) with respect to the actual values of the global radiation measured at the nearby open site. The value varies from 0 to 1, where the lower the value the higher the shading effect.	0-1
Sky View Factor	Represents the ratio at a point in space between the visible sky and a hemisphere centered over the analyzed location. The value varies from 0 to 1, where the lower value corresponds to higher density.	0-1



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06 | Example descriptive sheet from the catalogue of adaptation measures (Source: PLINIVS-LUPT, CLARITY project)

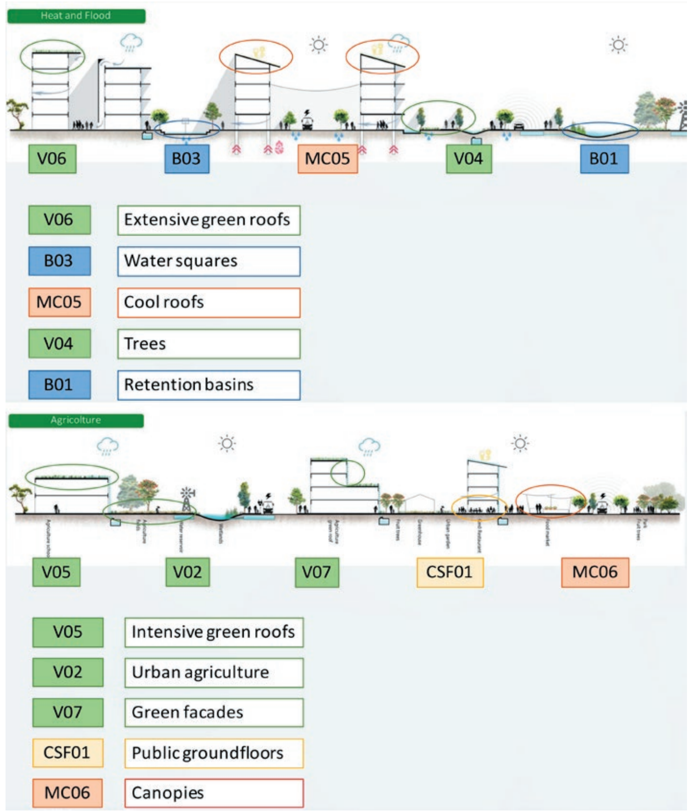
summarise, and effective design approaches should address the potential synergies among different adaptation measures, besides managing possible trade-offs induced by their application in urban environments. As an example, while reducing the absorption and consequent storage of heat on urban surfaces, high albedo pavements can cause thermal discomfort due to the reflection of solar radiation at human height. Their use should be considered mainly in dense building fabrics or coupled with the integration of appropriate shading elements. A low Sky View Factor results in increased net heat storage within buildings and in an increase in UHI, but it also characterises dense urban areas where relative shadow between buildings contributes to reducing direct solar radiation, thus limiting thermal stress.

The application of CLARITY models allows to take into account those variables simultaneously, supporting the identification of the most suitable adaptation measures, depending on the specific urban morphology and land use.

However, the choice of climate adaptation measures to be integrated into urban transformation actions is linked not only to the expected climate benefits, but also to the possibility of conveying a series of social, economic and environmental co-benefits. Identifying and communicating the co-benefits of climate adaptation is a priority for urban decision-makers. It allows to broaden the consensus regarding resilient urban transformation strategies by local communities (Leone and Raven, 2018; Floater et al., 2016), which are often bearers of urban redevelopment needs indirectly related to the improvement of microclimatic conditions (e.g., better housing quality, greater provision of equipped public spaces and green areas, better accessibility to transport systems, etc.), thus triggering a virtuous loop supporting public initiative in the implementation of interventions.

Independently from the assessment of the effect of adaptation measures through modelling and simulations, this information has been provided to the Municipality of Naples in a descriptive form (Fig. 6) and included in the Preliminary City Plan (PUC), reflecting the climate benefits and the co-benefits of 18 common adaptation measures.

In order to maximise the impact of adaptation measures in terms of climatic benefits and associated co-benefits, such measures should



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07 | Example of adaptation strategies in the Ponticelli area, aimed at maximising an integrated adaptation action to the risk of heat wave and flooding (top) and urban agricultural improvement (bottom) (Source: PLINIVS-LUPT, CLARITY project, processed by Leone and Tersigni, 2018)

be integrated into more complex "adaptation strategies" relative to the identified urban transformation/regeneration objectives (Fig. 7), considering how only widespread application of the measures in the urban area can guarantee the effectiveness of the adaptation action, and only their diversification according to other priorities for urban transformation can deliver the expected co-benefits.

Conclusions

The application of CLARITY tools by local authorities can support the development of coherent multiscale urban planning and design strategies. The different degree of detail achievable with the analysis output allows to use the tool from the strategic planning level up to urban district design, ensuring the consistency of the measures adopted by plans and projects across multiple scales and urban governance bodies.

The main feedback from the Naples case is that, despite the growing interest in climate change, other urban regeneration priorities (housing needs, public space quality, social cohesion, scarce budget for design and maintenance, etc.) are often overarching issues for public officials and communities. In addition to user-friendly analysis tools, such as the thematic maps provided by CLARITY project for the Naples City Plan, a cultural challenge that research in this domain has to tackle is how to effectively communicate the multiple societal co-benefits of climate-resilient pathways.

The objective of overcoming the globally observed "adaptation gap" (Neufeldt et al., 2018) can only be achieved through cooperation among multidisciplinary research teams. Local authorities can effectively support the translation of scientific advancements into actionable results for urban decision-makers, thus improving the quality of urban governance actions tackling the key priorities and innovative perspectives emerging as global societal challenges.

ACKNOWLEDGMENTS

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The outcomes of the Naples case presented herein were jointly developed by UNINA-PLINIVS, ZAMG and the City of Naples.

NOTES

[1] The paper presents the results of the "Expert Study" conducted as part of CLARITY Demonstration Case (DC1) in Naples. Reference to other case studies can be found in Havlik *et al.*, 2020, while the online "Screening services", on a 500x500 m grid, can be accessed at https://csis.myclimateservice.eu/ (accessed 7 May 2020).

[2] Available at: http://www.comune.napoli.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/37912 (accessed 7 May 2020).

[3] The "PLINIVS Simplified Heat Wave Model" is based on the transposition in a GIS environment of the SOLWEIG model, developed by Lindberg et al. (2011, 2016). Due to limitations in length and the journal's scope, the details of the model cannot be presented here, and can be found in the deliverable CLARITY project "D3.3. Science support report v2", available at http://www.clarity-h2020.eu/deliverables (accessed 7 May 2020).

[4] Due to the length limitations and scope of the journal, the details of The "PLINIVS Simplified Surface Flood Model" cannot be presented here, and can be found in the deliverable CLARITY project "D3.3. Science support report v2", available at http://www.clarity-h2020.eu/deliverables (accessed 7 May 2020).

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