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Integrating Nature in the City to Face Climate Change

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Climate adaptation and Water Sensitive Urban Design: the case study of a university campus in the city of L'Aquila

Adattamento climatico e Water Sensitive Urban Design: il caso studio di un polo universitario nella città di L'Aquila

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ABSTRACT AND KEYWORDS

Climate adaptation and Water Sensitive Urban Design
Climate change will drive global temperatures to unprecedented temperature peaks by 2050 and, at the same time, it will increase the frequency and intensity of extreme precipitation events worldwide, with estimated return times of as much as 100 or 200 years for recorded precipitation amounts. Urban and peri-urban areas are the most affected by the effects of climate change, due to their highly sealed surfaces that make it impossible for water to filter into the ground. The issue has been further worsened since land consumption has exceeded certain limits. Therefore, in order to achieve climate adaptation of urban and peri-urban areas, resilient and adaptive retrofit interventions will have to made, placed within the broader framework of Water Sensitive Urban Design (WSUD) and Nature Based Solutions. The study area for the urban regeneration project is located in Italy, in the immediate western suburbs of the city of L'Aquila, the capital of Abruzzo.

Keywords: climate adaptation, urban regeneration, urban planning, sustainability, design

Adattamento climatico e Water Sensitive Urban Design
I cambiamenti climatici porteranno la temperatura globale a picchi temperatura mai visti entro il 2050 e, al contempo, aumenteranno la frequenza e l'intensità di eventi estremi di precipitazione in tutto il mondo, con tempi di ritorno stimati di addirittura 100 o 200 anni per i quantitativi di pioggia registrati. Le aree urbane e periurbane sono le più colpite dagli effetti dei cambiamenti climatici, a causa delle superfici altamente impermeabilizzate che le caratterizzano e che rendono impossibile la filtrazione dell'acqua nel terreno. La questione si è ulteriormente aggravata da quando il consumo di suolo ha superato certi limiti. Per conseguire l'adattamento climatico delle aree urbane e periurbane, andranno quindi effettuati degli interventi di retrofit resilienti e adattivi, inseriti all'interno del più ampio quadro del Water Sensitive Urban Design (WSUD) e delle Nature Based Solutions. L'area oggetto di studio per il progetto di rigenerazione urbana si trova in Italia, nell'immediata periferia ovest della città di L'Aquila, capoluogo d'Abruzzo.

Parole chiave: adattamento climatico, rigenerazione urbana, pianificazione urbana, sostenibilità, progetto

1. Introduction

By 2050, global warming will lead to unprecedented temperature spikes: according to the predicted scenario of the International Panel on Climate Change (IPCC) the temperature will increase at least by 1.5 °C (IPCC, 2023), and at the same time the frequency and intensity of extreme precipitation events (Fowler & Hennessy, 1995; IPCC, 2012; Skougaard Kaspersen et al., 2017) and floods (Zhu et al., 2007; Arnbjerg-Nielsen, 2012; WMO, 2019) around the world will also increase. Although the situation is alarming in all places, urban and peri-urban areas are the most affected by the effects of climate change (Semadeni-Davies et al., 2008; Arnell, 2022). The unstable conditions of such areas, due to uncontrolled urbanization, inadequate urban planning, and pervasive soil sealing, combine with the increasing number of extreme weather events of precipitation and high temperatures (Güneralp et al., 2015; Leopold L B, 1968; Zhou et al., 2012).

In an effort to curb this dramatic situation, the United Nations Framework Convention on Climate Change already mandated the 198 signatory parties to pursue adaptation to climate change and mitigation of its causes in 1992 (UNFCC, 1992) . Climate change that is defined in 2007 by IPCC as a change in climate "attributable directly or indirectly to human activities, such that it alters the composition of the planetary atmosphere and adds to the natural climate variability observed over similar time intervals" (IPCC, 2007) . The same year that the EU Floods Directive (Directive 2007/60/EC, 2007) was ratified in Europe after a series of catastrophic floods. However, this directive deals only with fluvial floods, whereas for urban areas, pluvial floods, i.e., those generated by overloading the urban sewer system following extreme rainfall, are also very dangerous.

In fact, it is now known that highly impervious surfaces, typical of urban and peri-urban areas, make it impossible for water to be filtered into the ground, causing surface run-off to exceed the amount that can be drained by the water supply, resulting in flooding and decreased groundwater recharge (Abdellatif et al., 2014). As run-off increases, the amount of water that evaporates from the land itself decreases, resulting in a decrease in light and frequent rainfall and an increase in intense and less frequent rainfall, loaded instead with water from the seas (Kravčík et al., 2007). As a result of sealing, vegetation covers and green areas are decreasing dramatically (Goonetilleke et al., 2005). In this way it decreases the infiltration, which is a fundamental part of the hydrological cycle: numerous studies have shown that runoff for surfaces with green cover is generally between 0 and 20 % of the volume of water in the rainfall (the remaining percentage is partly absorbed by the soil and partly returns to the atmosphere by evapotranspiration), while for sealed surfaces runoff is more than 90 % (Armson et al., 2013; Leopold L B, 1968; McNaughton & Jarvis, 1983; Whitford et al., 2001). This means that by increasing surface runoff, the amount of water affected by infiltration and evapotranspiration processes decreases, and consequently there is a reduction in groundwater recharge (Mussinelli et al., 2021).

The issue has further worsened since land consumption has exceeded certain limits (Barrington-Leigh & Millard-Ball, 2015; EEA, 2019; Foley et al., 2005; ISPRA, 2022; Romano et al., 2020; Romano et al., 2017; Romano et al., 2017). Land consumption is an aggravating element of the phenomenon, as it multiplies the effects of the extreme rainfall event (Prokop et al., 2011). Land use changes, such as soil sealing and removal of vegetation, pose a danger to the balance of the water system (Goonetilleke et al., 2005). In addition, land use is a major cause of the loss of biodiversity and natural and agricultural lands (Falcucci et al., 2007; Fiorini et al., 2019; Martellozzo et al., 2018), while contributing to further increases in surface runoff.

To deal now specifically with the Italian territory, according to the International Disaster Database Italy is the European country affected by the largest number of disaster events in the 20th century. Extreme precipitation in recent decades has increased throughout the peninsula, both in number and in intensity, with estimated return times of as much as 100 or 200 years for the amounts of precipitation recorded (Fioravanti et al., 2021). As an example taken from a very long list of Italian cities affected in recent years by major floods (followed by landslides and flooding), Genoa, like the rest of the Ligurian territory, has undergone in recent decades a decisive artificialization and waterproofing of valley bottom and coastal soils, particularly near the mouths of streams, at the expense of territories located in higher elevation positions, which have been totally abandoned (Lombardini & Giusso, 2013). Such an arrangement means that floods are joined by mechanical phenomena, such as landslides, which bring with them enormous amounts of sediment and debris, as well as often a large number of victims (IRPI-CNR data show that from 1835 to the present, the city has been affected by 84 events between landslides and floods, with 86 victims and missing persons). This makes us understand how poorly governed and poorly controlled land transformation interventions cause extreme rainfall to result in catastrophic consequences. It is pertinent in this regard to recall what happened last year: on September 15, 2022, in the province of Ancona and in Cantiano in the Marche region, 400 millimetres of rain fell within a few hours, an amount that is usually recorded in 3 months. According to the Italian Society of Environmental Geology, such an extreme event had not occurred for at least 70 years.

On November 26, 2022, in Casamicciola, an Ischian municipality, rainfall during the extreme event far exceeded the maximum values of the previous 15 years: 126 mm of rain fell in six hours, resulting in 80000 tons of mud and debris that came down Mount Epomeo, sweeping away everything along the way.

In order to achieve climate adaptation of urban and peri-urban areas, resilient and adaptive retrofit interventions must be made that can bring effective climate improvements and that can be easily managed and/or modified as situations arise (Musinelli, 2018; United States Environmental Protection Agency, 2017).

In Italy we are still lagging behind a full maturation of planning and design capacity, despite the vulnerability and fragility of the territory. The first steps were taken in 2015, when the National Strategy for Adaptation to Climate Change (SNAC) was adopted, and only in February 2023 was the National Climate Change Adaptation Plan (PNACC) published, which was supposed to be subsequent to the SNAC, for the public consultation phase[1].

In 2014 ISPRA carried out a survey (Giordano et al., 2014) on the status of climate adaptation initiatives in Italian cities. Only 18% had not undertaken any initiative; but to date no Italian city has implemented concrete planning with evident results on the ground, except for the city of Bologna, which can boast the adoption of an Adaptation Plan carried out between 2012 and 2015 within a LIFE+ project "BLUE AP" (Bologna Local Urban Environment Adaptation Plan), or in other timid local-scale interventions.

In contrast, in Europe and around the world, the issue of climate change has already been introduced into urban policies long ago, and urban redevelopment projects, aimed at mitigating the effects of climate change, have already been implemented. New York, Chicago, Stuttgart, London, Copenhagen, Rotterdam... The last two mentioned are certainly those, among the European cities, that present the most innovative and interesting projects, in which interventions at the territorial and urban

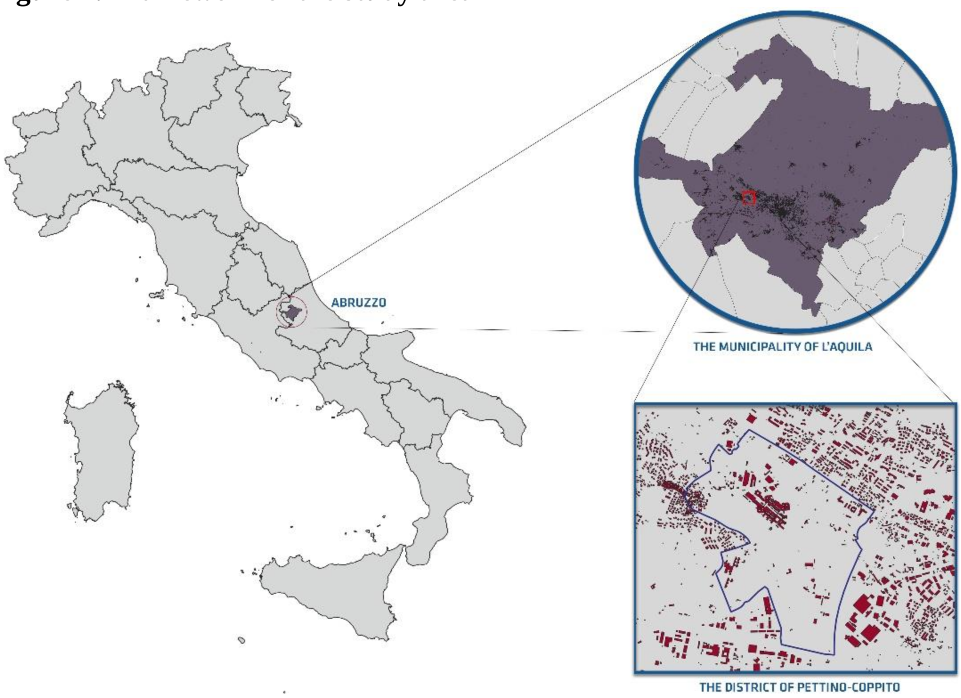
scales have been skillfully combined by implementing resilient and adaptive strategies, respectful of the context and attentive to the risks it presents.
Copenhagen, after a violent flooding of the city on July 2, 2011, in which 150mm of rain fell in three hours, adopted a Climate Adaptation Plan (Copenhagen Climate Adaptation Plan) back in 2012. This plan calls for the enhancement of green and blue infrastructure, through the creation of green roofs and tree-filled green areas, and the construction of water storage tanks in the event of heavy rainfall and de-paving solutions (Tersigni & Leone, 2019).
Literally founded on water, Rotterdam has always been subject to extreme precipitation events. That is why it was among the first cities to have a Climate Change Adaptation Plan. In addition, since 2008, reservoirs for water containment, both underground and surface, have begun to spring up in the city (Errigo, 2018; Tersigni & Leone, 2019).
These reservoirs take the form of water squares, which represent real best practices in Water Sensitive Urban Design (WSUD), which is defined as the interdisciplinary collaboration between water management, urban design and landscape planning aimed at combining the functionality of water management with urban design principles (Ashley et al., 2013; Hoyer et al., 2011; Wong, 2006).
Among the most famous water squares, we refer here to that of Benthemplein: these particular squares that are located below street level, in addition to their classic function as gathering and social spaces, perform the function of being flood basins into which rainwater can drain from surrounding impervious areas during an extreme rainfall event and be temporarily collected there. In densely built-up urban and peri-urban areas, it is difficult to find space for rainwater storage. Thus, by giving rainwater a visible place in public space, as in the case of a plaza, a perceptual-functional solution is created: the water plaza, in fact, combines, in a non-traumatic way, the storage of water following flooding with other important functions: in the plaza one can play games, one can play sports, one can converse among friends. This non-traumatic perception of risk means that people do not panic by having to cope with the event: the square changes state, but without negative consequences for the well-being of the population. The latter aspect is very important, so that numerous studies have been conducted on the implication of climate change on human quality of life and well-being (Ahern et al., 2005; Buizza et al., 2022; Giorgi, 2021; Orimoloye et al., 2019; Patz et al., 2005).
To achieve climate adaptation, it will then be appropriate to flank these types of solutions with Nature Based Solutions (NBSs), the two main definitions of which are given by the European Commission (EC, 2015) and the International Union for Conservation of Nature (IUCN, 2020), and fit into the broader strand of Water Sensitive Urban Design just mentioned. The use of these types of solutions for climate adaptation is increasingly encouraged (EEA, 2015; Eggermont et al., 2015), as there is now ample evidence of the validity of such interventions in reducing flood risk and decreasing surface runoff (Ferreira et al., 2020; IUCN International Union for Conservation of Nature, 2016; Ruangpan et al., 2020; Singh et al., 2020; Skrydstrup et al., 2022; UNEP, 2014; Wamsler et al., 2017).
Major NBS solutions certainly include green roofs, rain gardens (Liptan & Santen, 2017; Yuan et al., 2017), and permeable pavements; these both reduce and retard surface runoff and improve hydrological balance as they increase soil water infiltration and evapotranspiration (Gregoire & Clausen, 2011; Trinh & Chui, 2013). In addition, these types of solutions intervene on another important parameter, which is that of air temperature, because by lowering the velocity of surface runoff, the Urban Heat Island effect (UHI) is also reduced: this occurs when, as a result of

uncontrolled urbanization and land consumption, temperatures in urban and suburban areas are higher than those found in neighbouring rural areas (Fumiaki, 2011; Stewart & Oke, 2012; Tzavali et al., 2015; Zullo et al., 2019). Trees and greenery, on the contrary, by generating natural shading and releasing water into the air through the process of evapotranspiration, well succeed in lowering air temperature; in totally built-up areas evapotranspiration is minimal, and consequently the temperature is higher (Akbari et al., 2016).

2. Case study: The Coppito University Campus in L'Aquila

The present research identified the immediate western suburbs of the city of L'Aquila, capital of Abruzzo, in Italy, as the macro-area of study: the neighbourhoods of Pettino and Coppito (Figure 1). The choice of this territorial area was driven by its heterogeneous urban characterization (with rural and urban areas), as well as its vulnerability. Within this macro-area, the urban regeneration project will focus on a restricted area: the Coppito University Campus.

Figure 1. Framework of the study area



Source: Elaboration of the author.

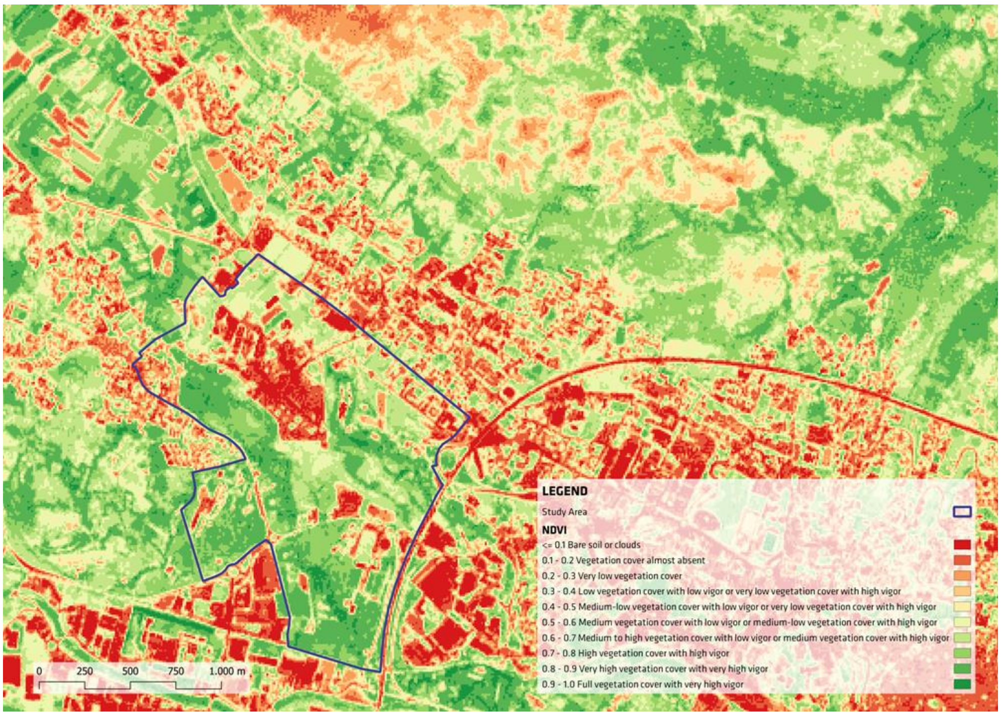
In the first instance, a diagnostic cognitive framework was developed that analyses the layout, dynamics and risks of the environmental and settlement system, as well as the urban and morphological characteristics of the area.

Starting from the analysis carried out on the Seismic Microzonation Map[2], it is shown that the terrain of this area is of calcareous type, and specifically the area is defined as "calcareous debris area of Mount Pettino" (Gruppo di lavoro MS-AQ, 2010). As is well known, this type of soil has difficulties in water runoff: in fact, water absorption occurs by micro-fractures in the soil; if we go to waterproof everything, we also delete this already not high absorption capacity.

The analysis from the Flood Defense Master Plan, shows in the southern part of the area a medium-high hydraulic hazard[3].

Problems related to hydraulic risk unfortunately affect not only fluvial and floodplain areas, but also consolidated city fabric and densely populated areas. The causes are to be found in the interface relationship between these areas and the mountainous morphology of the contiguous areas (Marucci, 2021). In fact, Croce Rossa, Torrione, San Sisto, Santa Barbara, Pettino and Cansatessa neighbourhoods, densely populated residential areas, have reported conspicuous damage and inconvenience in recent years, as a result of flash flooding attributable to increased surface water runoff and an inability of the water collection system to cope with the event. This is due to both climate change and the reforestation of abandoned agricultural fields and uplands, which have certainly increased tree cover, but have also increased the risk of fire (EEA, 2008). As can be seen from reading the NDVI[4] map (Figure 2), the multiple fires that have occurred over the past two decades have destroyed about 1200 hectares of tree area. The Madonna Fore (San Giuliano) fire in 2007 and the Arischia Monte Pettino fire in 2020, go to increase the vulnerability of the area, as it is from the San Giuliano ditch (Figure 3) that water, sediment and debris can (and already has) be channelled into the valley following heavy rains, causing disastrous effects. The potential extent of the flooding (which has already certainly happened as suggested by the calcareous debris composition of the soil) is shown in Figure 3.

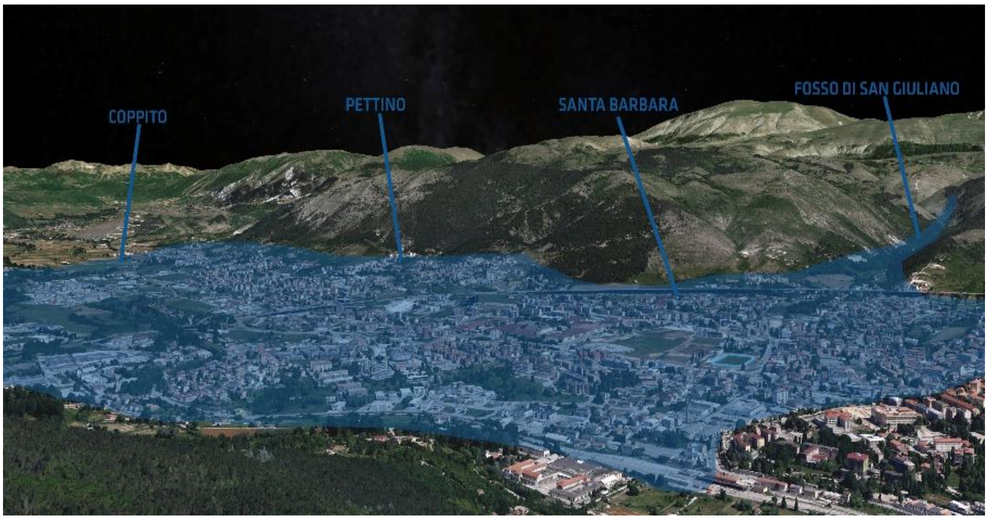
Figure 2. Normalized Difference Vegetation Index (NDVI) of the study area



Source: Elaboration of Federico Falasca.

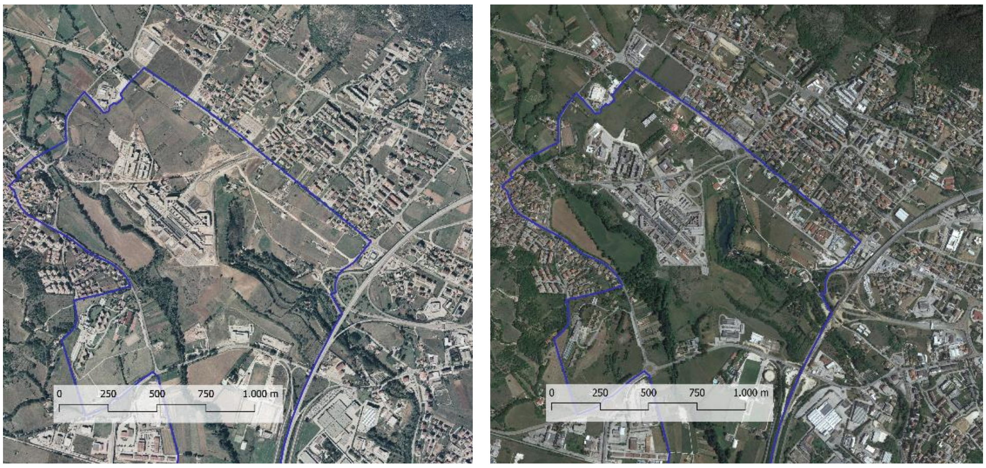
Now, to contextualize the evolutionary dynamics of urbanization, the agricultural area between the historic centres of Coppito and Pettino saw its first urban development in the late 1960s, when planning and construction work began on the S. Salvatore Regional Hospital, designed in 1967 by Eng. Marcello Vittorini. The construction of the buildings lasted 20 years, from 1972 to 1992. In the same 1990s, construction was completed on the University Campus buildings, that host as many as 4 of the 7 total departments of the University of L'Aquila.

Figure 3. The San Giuliano ditch and the potential extent of flooding



Source: Google Earth.

Figure 4. Evolution of the urban fabric



a) 2000 b) 2023
Source: Elaboration of the author.

The two orthophotos (Figure 4) show how, in the last 20 years, the settlement situation has been fairly stabilized, although, from the comparison, several micro-episodes of urbanization are still appreciable, probably due to the aftermath of the 2009 earthquake, and concerning in particular the bangs of the surrounding residential neighbourhoods, but also the pertinential context of the University buildings.
From the successive interventions over the past 60 years, a large green area, mainly privately owned, has been saved, for reasons partly environmental (Lake Vetoio) and partly of risk (Aterno River overflow area), which comes to be configured de facto, as physiognomy and location, as an "urban park," although not recognized and stated as such. It is an area that constitutes the natural connective of various functional spaces, with a high intensity of use, currently not frequented in the typical perspective of the urban park and therefore considered exclusively as the (conspicuous) residue of the intervening transformations. A residue today characterized by a visible conformation still rural and agricultural, whose signs

emerge in many places, and testify the condition of the area in the years after World War II. In essence, it is a coexistence of roles generated by the profound lack of territorial and urban design that marked the expansion of this compartment, which progressively became a functional polarity almost more important than the historic centre (even before the earthquake) and which today is undoubtedly the first-level urban polarizer of the entire city. The most organic urban designs are recognizable in the Hospital area and in the University area of first setting, but only at a large-scale observation. In local detail, the total lack of planning direction appears in all its evidence, which contradicts the central and strategic role that the area plays in the overall territorial framework. This is a very large area, more than 200 ha, that is similar to the entire historic centre (Figure 5) of which constitutes, as mentioned, the most relevant antipolarity of the entire settlement system of the L'Aquila basin.

Figure 5. The urban dipole configuration

Source: Elaboration of the author.

As Dilorenzo and Stefani wrote in 2015, "the institution dedicated to education and research is identified by the university, as the highest and noblest form: it is for this reason that the relationship between university and urban context turns out to be such an important issue in the management of city development policies in contemporary times" (Dilorenzo & Stefani, 2015). The study area can thus rightly be considered the second de facto "city centre" in a classic urban dipole configuration (Figure 5), well known as a standard model in urban planning of the polycentric city, and essentially already recognizable as such from a functional point of view, but much less from a perceptual and qualitative point of view, well before the 2009 earthquake event.

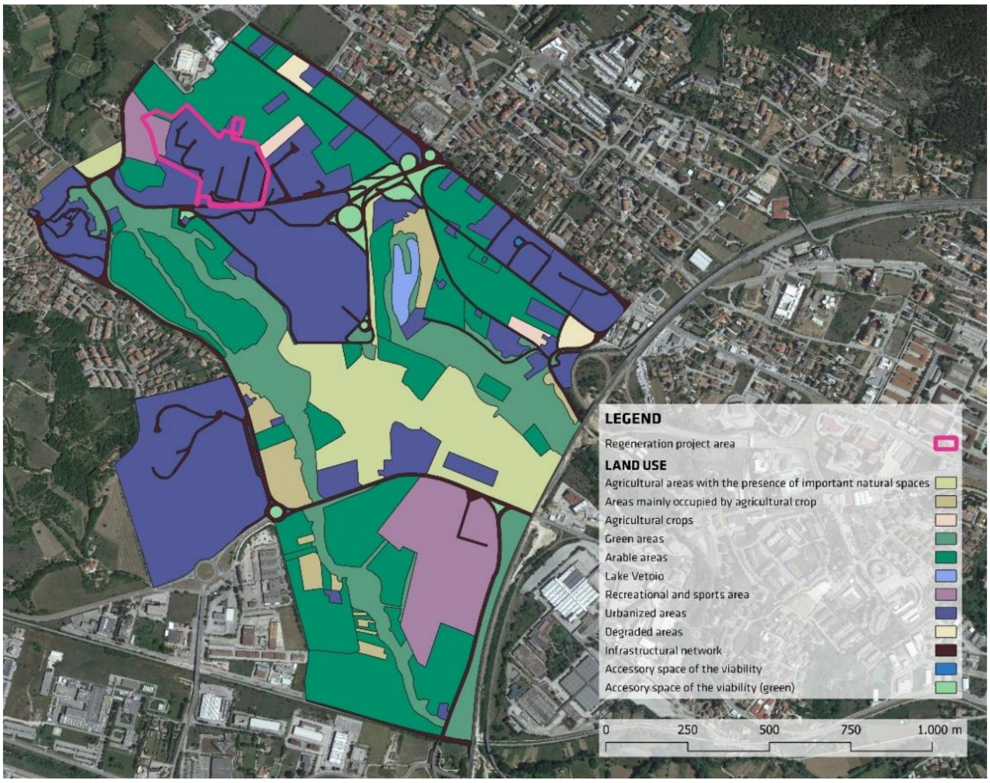
Comparing permeable areas with impermeable areas (Figure 6), moreover, it is evident that in the university campus area there is a significant imbalance in favour of the latter, at the expense of green/agricultural/seeded areas. This situation stems from the almost total use of open areas for vehicular usability, especially as parking areas: most of the parking lots are characterized by impermeable bottom and trees are absent except in a few portions, and in an unsystematic way.

Figure 6. Permeable and impermeable areas

Source: UniCo[6].

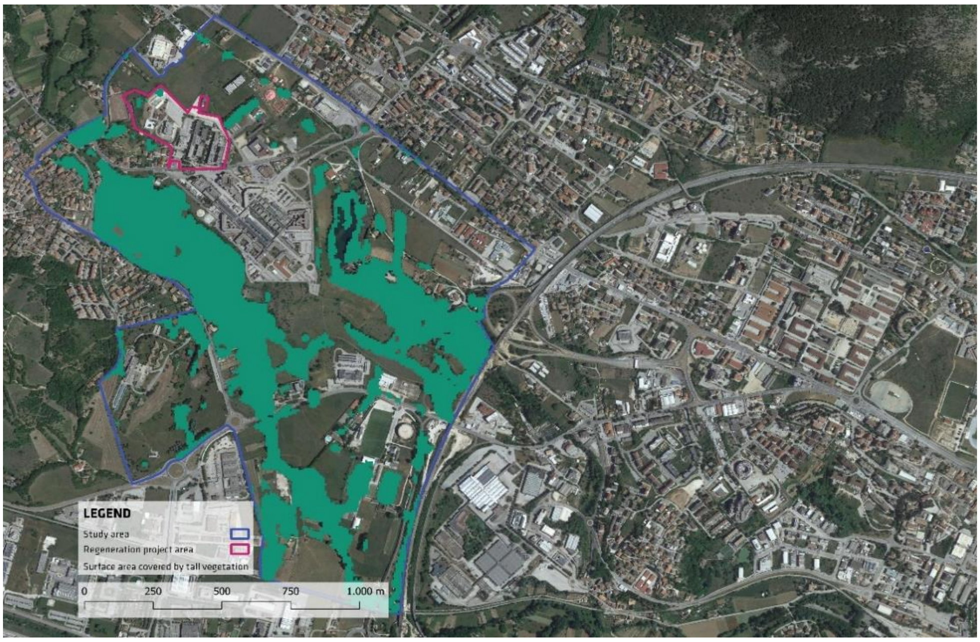
In this regard, the Land Use Map shows a general picture that very well configures the co-presence of heterogeneous uses of the area. In particular, the presence of large and compact urbanized areas, as opposed to distributed and disjointed agricultural areas, throughout the examined area is evident. The predominant land cover is urbanized land: the urbanization density is 37 % (excluding the infrastructure network), equivalent to 80 ha. The arable land category occupies 27 % of the area of interest: in fact, the territory surrounding the University Campus is occupied by different types of agricultural land. Surveyed green areas, those with tall vegetation, occupy 13 %, with a total area of 30 ha (Figure 7).
The NDMI[4] (Normalized Difference Moisture Index) was used to assess this tree cover. Within the area, there are approximately 117 ha of forest area, mostly in riparian environments of the Aterno River and Lake Vetoio. Specifically, the Coppito University Campus has a tree area value of 3600 m^2 (1,6 %), while the Hospital Campus has no detectable tree area through satellite systems (Figure 8).
The Coppito University Campus area is substantially devoid of liveable outdoor green areas for students, with very little tree planting and almost total soil artificialization, which has irreversibly affected the area’s natural surface runoff, as well as resulting in urban heat island effect (Figure 8).

Figure 7. Land Use



Source: UniCo[6].

Figure 8. Tree cover evaluation



Source: UniCo[6].

As a result of the analysis carried out, the critical points found can be summarized as follows:

- the prevailing land cover is that of urbanized land;
- the soil is limestone type with low water absorption capacity;

- the water collection system is inadequate for recorded flow rates;
- numerous fires in past years have increased the vulnerability of the area;
- there is a critical lack of urban planning and project in the area;
- the natural water flow is convicted by the presence of number of impermeable areas at the expense of permeable ones;
- there are several parking lots, all characterized by impermeable soil;
- the lack of green areas liveable by the population.

So, in attempt to solve these critical issues, we will apply some of the adaptive design solutions set out in the previous section in the Coppito University Campus area.

3. The computation of rainfall volumes for the project of water squares

The pivotal intervention of the project, will be to size and realize water squares based on expected rainfall volumes, taking as reference the best practices mentioned in the first paragraph.

To calculate rainfall volumes for sizing the squares, we will need rainfall heights. From the Hydrological Annals of the Abruzzo Region, we obtained a historical data set from the L'Aquila Pluviographic Station. These data inherent the maximum annual rainfall for the past sixty years, for 1, 3-, 6-, 12-, and 24-hour events.

We use Gumbel's statistical-probabilistic method, according to the statistical expression:

$$h(T_r) = \bar{h} + F \cdot \sigma(h) \qquad (1)$$

In which fixed a return time T_r in years, it will be calculated for all durations $h(Tr)$ with rainfall height equalled and not exceeded for an established return time T_r, defined as the average duration in years of the period in which the value of rainfall height h is exceeded only once.

Moving on to the data processing stage, we go on to calculate the mean value of rainfall heights over the n observed years ($\bar{h}$) and the standard deviation (or mean square deviation) $\sigma(h)$ for the various durations.

According to Gumbel's EV1 distribution function, adopting for the frequency factor F the expression: $F = \frac{Y(T_r) - \bar{Y}_N}{S_N}$, we have:

$$h(T_r) = \bar{h} + \frac{\sigma(h)}{S_N} Y(T_r) - \frac{\sigma(h)}{S_N} \bar{Y}_N \qquad (2)$$

With $Y(T_r)$ reduced Gumbel's variable:

$$Y(T_r) = -\ln\left[-\ln\frac{T_r - 1}{T_r}\right] = -\ln\left[-\ln\left(1 - \frac{1}{T_r}\right)\right]$$

$\bar{Y}_N$, estimation of the mean value of the reduced variable:

$$\bar{Y}_N = \frac{1}{N}\sum Y(T_i)$$

S_N, estimation of the mean square deviation of the reduced variable:

$$S_N = \left\{\frac{1}{N-1} \cdot \sum\left[Y(T_i) - \bar{Y}_N\right]^2\right\}^{0,5}$$

In which: N, sample size; i, rank of the sample ranked in descending order; T_i return time of the sample data ranked in descending order, determined, according to

Gringorten, as follows: $T_i = \frac{N + 0{,}12}{i - 0{,}44}$.

Having established a return time of 20 years (which is a value that can be perceived by the public and compared with planning choices), we obtain from tabulated values for a given value of *N* (number of years observed), that Gumbel's estimated value of the reduced variable $Y(T_r)$ is 2,9702, that the estimated value for $\overline{Y}_N$ is 0,5570 and the estimated value for S_N is 1,2201.

Given these data, we go on to solve expression (2), from which we obtain the values shown in the following table (Table 1).

Table 1. Rainfall heights h for T_r= 20 years

h_{mean}	σ(h)	S_N	Y_N	T_r	$\ln \frac{T_r - 1}{T_r}$	$Y(T_r)$	h
mm				years			mm
18,4	9,005	1,2526	0,5692	**20**	-0,051293	2,9702	**35,7**
24,3	9,004	1,2526	0,5692	**20**	-0,051293	2,9702	**41,6**
29,0	8,442	1,2526	0,5692	**20**	-0,051293	2,9702	**45,2**
36,6	9,357	1,2526	0,5692	**20**	-0,051293	2,9702	**54,5**
44,7	11,153	1,2526	0,5692	**20**	-0,051293	2,9702	**66,1**

Source: Elaboration of the author using the data provided by Prof Davide Pasquali.

Having established a return time T_r, it will be possible to obtain the values of precipitation heights h for each duration and define the design rainfall that recurs every T_r years, calculated by the equation

$$h = a \cdot t^n \qquad (3)$$

In which: *h(mm)* precipitation height; *t* its duration; *a* and *n* two parameters dependent on the rainfall characteristics of the area.

The values of *a* and *n* were estimated by linear regression on the logarithms of *h* and *t* using Excel spreadsheet. By operating in this way, we also obtain the value of R^2, a regression, which is an indicator of the condition of the data approach to the function, which is the better the more R^2 is equal to 1. We thus obtain for the design rainfall for T_r equal to 20 years, the monomial function $h = 34{,}23 \cdot t^{0{,}1913}$ (Figure 9).

However, it is now necessary to verify that the function is reliable through statistical tests of fit. The one chosen is the test of "fiduciary bands".

With the method of fiduciary bands, we estimate the dispersion around Gumbel's law, and we calculate $h(t) = x_0 + \frac{Y(T_G)}{a}$ and the 95% confidence interval, $h(t) - 1{,}96 \cdot \sigma^* \le h_F \le h(t) + 1{,}96 \cdot \sigma^*$ by applying the formula $\sigma^*_{h(t)} = \sqrt{\frac{P_{(h_t)} \cdot [1 - P_{(h_t)}]}{N \cdot [f_{(h_t)}]^2}}$ in which for the computation of $P_{(h_t)}$ and $f_{(h_t)}$ are used, respectively, the probability function of non-exceedance

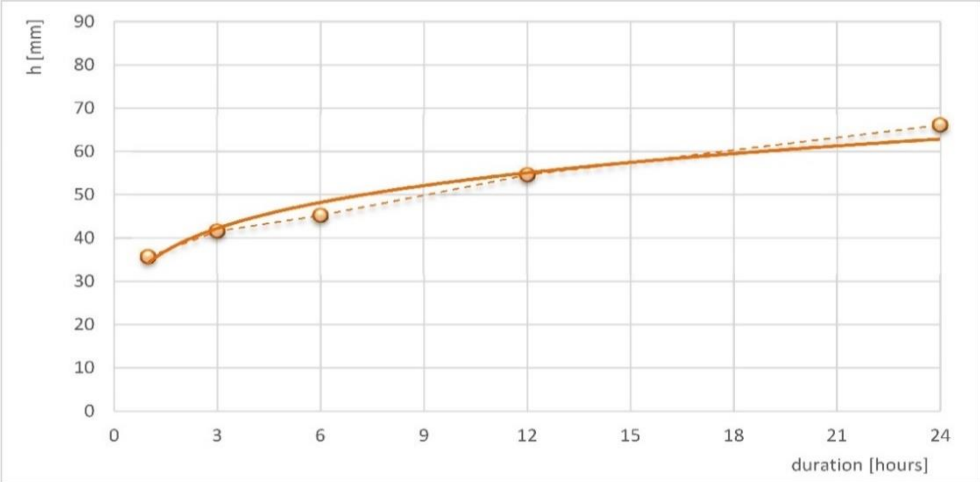
$$P_{(h_t)} = \exp\{-\exp[-a(h_t x_0)]\}$$

and the Gumbel probability density function calculated on the theoretical values

$$f_{(h_t)} = a \cdot \exp[-a(h_t - x_0)] \cdot \exp\{-\exp[-a(h_t x_0)]\}.$$

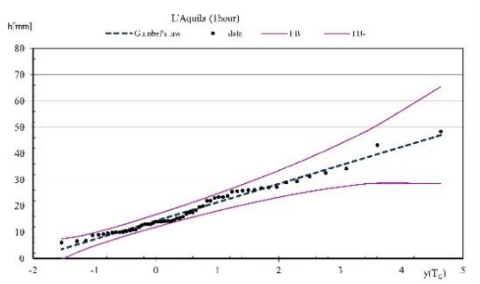
We thus obtain FB+ and FB-, which go to identify the fiduciary band, graphically represented in Figure 10 for each duration.

Figure 9. Pluviometric Possibility Curve (PPC) for T_r= 20 anni

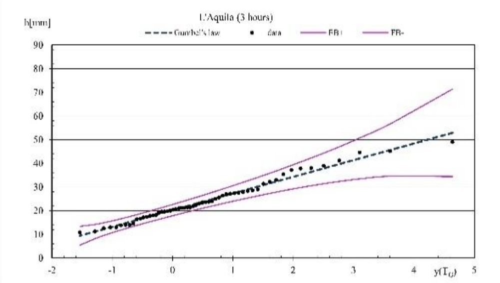


Source: Elaboration of the author using the data provided by Prof Davide Pasquali.

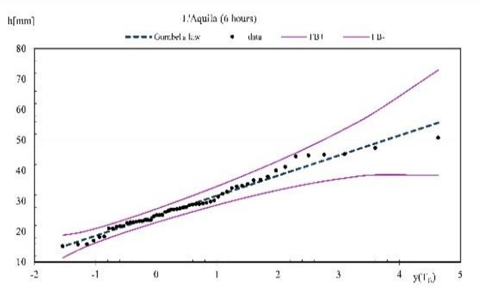
Figure 10. Fiduciary Bands



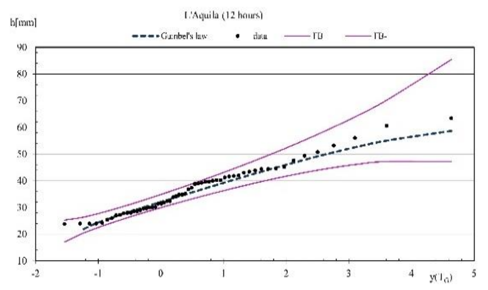
a) 1 hour



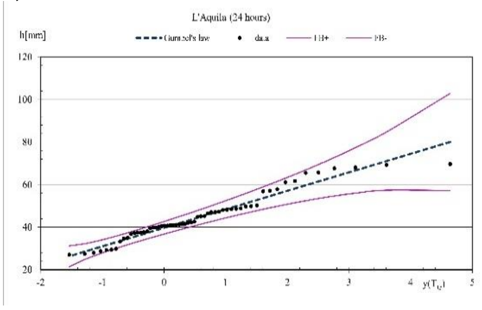
b) 2 hours



c) 6 hours



d) 12 hours

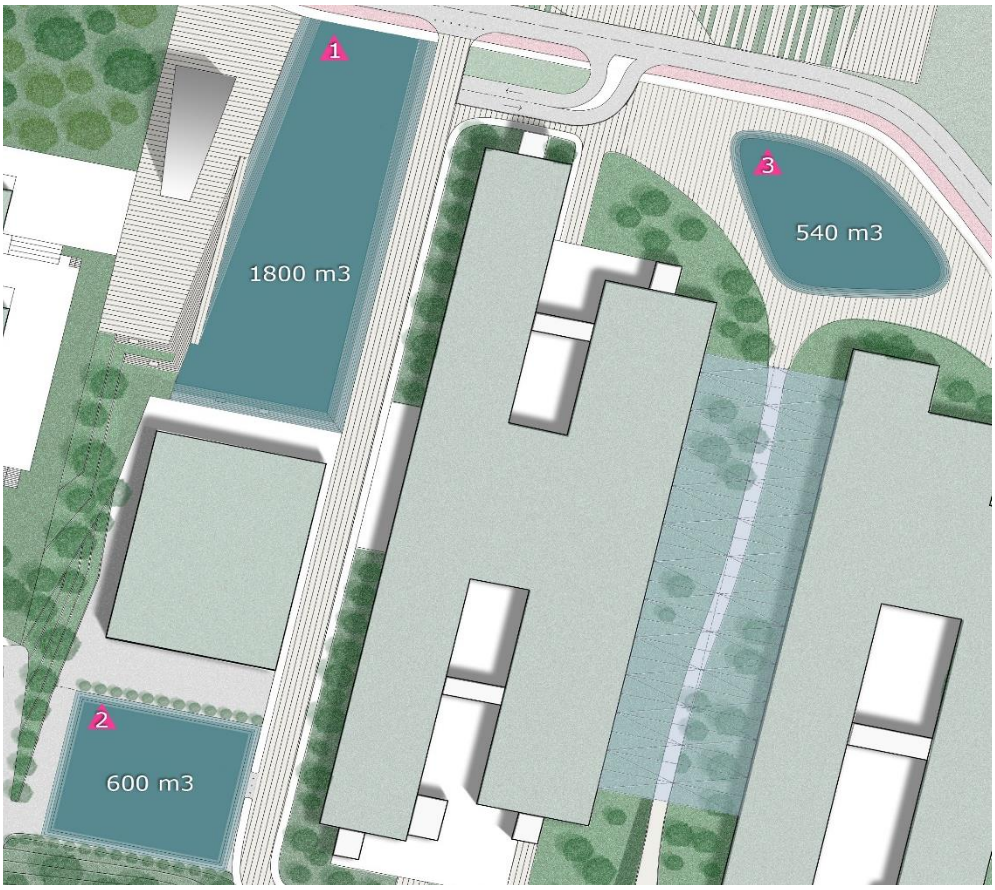


e) 24 hours

Source: Elaboration of the author using the data and sheet provided by Prof Davide Pasquali.

Having calculated the area of the covered and urbanized surfaces of the University Campus area, which is about 40,000 m^2, we have all the data to be able to calculate the water volumes and properly size the squares.

Figure 11. The water squares: location and size



Source: Elaboration of the author.

Figure 12. The water square

a) The empty water square b) The filled water square

Source: Elaboration of the author

The volumes (V) obtained for different rainfall durations are as follows, respectively:

– for t_p =1 hour, V= 1428 m^3;
– for t_p =3 hours, V= 1664 m^3;
– for t_p =6 hours, V= 1808 m^3;
– for t_p =12 hours, V= 2180 m^3;
– for t_p =24 hours, V= 2160 m^3.

We can reasonably state that, for a return time of 20 years, the squares should be able to contain the exceptional rainfall events for all durations taken into analysis up to 2160 m^3 volumes of water.

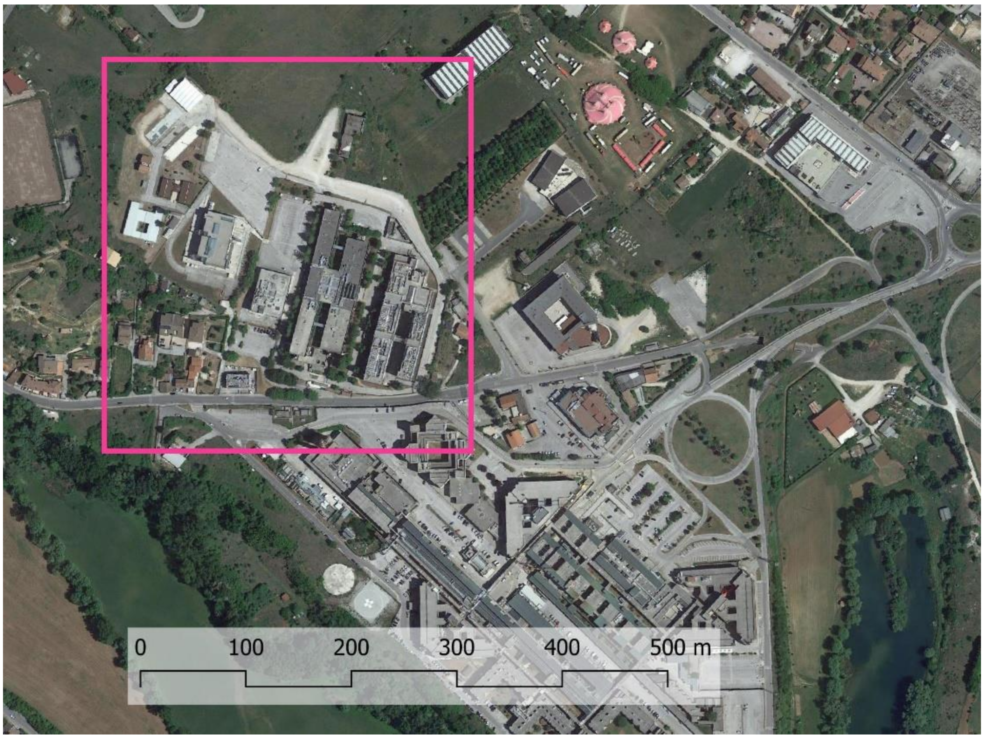
So, combining these data with the project design, the squares are sized as follows, arriving to contain up to 2940 m^3 of water, thus higher than the 2160 m^3 derived from hydraulic calculation (Figure 11):

– Square 1 will contain up to 1800 m^3 of water;
– Square 2 will contain up to 600 m^3 of water;
– Square 3 will contain up to 540 m^3 of water.

4. The urban regeneration project

The urban regeneration project (Figure 14) fits right in the strand of Water Sensitive Urban Design and in that of Nature-Based Solutions. It is proposed to be resilient and adaptive, solving the critical issues highlighted in the previous section. A reconfiguring project for the entire urban layout, it is proposed to transform the green matrix from a residual and marginal space to a functional connective of the urban hub, positively affecting environmental parameters (Figure 13).

Figure 13. Framing of the regeneration project area



The pink square indicates the regeneration project.

Source: Elaboration of the author.

There is a total of three water squares (Figure 12a-12b), designed with different sizes as mentioned above. These squares were also designed to allow them to be easily left in case of filling and have different levels according to the volume of water to be contained. The accompanying canal system will then allow the delayed outflow of water into the urban drains. As a retrofitting and regeneration operation of the existing urban heritage, once the possibility of implementation on structures was analysed, 15200 m^2 of green roofs were included in the project, the extensive application of which brings benefits both on lowering temperature and in reducing stormwater runoff (Figure 13). De-sealing and de-paving work then affected the area of the parking lots (Figure 15a-b-c-d), which were totally removed to be placed in

structure below the elevation of the main water square. The de-impermeabilized area thus becomes an urban park (Figure 16a), thanks to a green infrastructure enhancement and reforestation operation with native tree species, which will help to purify surface water, increase and conserve the biodiversity of the area, and significantly decrease the urban heat island effect. Within the urban park are planned seating and equipped areas that are available to both the users of the University and the population of the surrounding neighbourhoods. It should be added that the northern part of this urban park is designed to be a rain garden.
At the same time, high albedo permeable materials will be used in the parts that must remain paved due to functional necessity (represented with a striped pattern in Figure 14). Finally, a new vehicular and bicycle mobility has also been designed on transposing the indications of the PUMS (Urban Plan for Sustainable Mobility) and the Biciplan of the city of L'Aquila (Figure 16b).

Figure 14. The urban regeneration project of Coppito University Campus

Source: Elaboration of the author

5.Conclusions

It seems clear that in order to increase the resilience of urban areas (Heinzlef et al., 2022), a paradigm shift in the design of adaptive systems is therefore required: a holistic approach is needed, characterized by interventions that are no longer monofunctional, but rather multifunctional and equipped with the capacity to respond to multiple threats (Balletto et al., 2022; Derkzen et al., 2017). The winning approach to the problem is to work by implementing best practices of sustainable and resilient regeneration of urban contexts, while also going to deeply reconfigure the settlement system.

Figure 15. Areas subject to regenerative design interventions


a)


c)


b)


d)

Source: Photos of the author.

Figure 16. The urban park


a) The urban park


b) The sustainable mobility around the park

Source: Elaboration of the author

It must be understood that the city and we must be able to adapt to such sudden and violent events, because their extraordinariness will become, if it is not already becoming so now, increasingly ordinariness: awareness and sensitivity to climate change have increased, but actions for adaptation and mitigation remain insufficient to date. It is evident, unfortunately, that cities today still have serious difficulties in adapting to climate change and do not yet understand how they can base successful urban regeneration strategies for the coming years on this adaptation (EEA, 2012).
The University Campus taken as a case study, is a research space, and a public one at that, so it naturally emerges as the most appropriate space in which to apply experiments of this kind. It is an area in which research is done, and therefore a venue in which to deal with innovative issues (which, for obvious reasons, cannot happen in the private sphere). Last but not least, the University of L'Aquila is part of the RUS (Sustainable Universities Network), which promotes the 17 SDGS of the ONU

Agenda 2030, and this experimental urban project is fully in line with these goals. Urban planning and design have a duty to assist and guide toward a valuable outcome that will influence the entire image of the city. Indeed, once indicators are established to quantify the benefits that will come from such solutions, the experimentation will be transferable to the entire urban area.

Notes

1. The proposed Plan, Environmental Report, and Non-Technical Summary of the Environmental Report are available at the link: https://va.mite.gov.it/it-IT/Oggetti/Documentazione/7726/11206 of MASE the Environmental Assessments portal VAS-VIA-AIA.
2. The Seismic Microzonation map is available for reference at: https://www.comune.laquila.it/pagina1755_microzonazione-sismica.html, in the section L'Aquila Ovest (Cansatessa, Coppito, Pettino).
3. The Flood Defense Master Plan map is available at: http://geoportale.regione.abruzzo.it/Cartanet/viewer
4. The NDVI (Normalized Difference Vegetation Index): describes the vigor level of the crop and is calculated as the ratio of the difference to the sum of reflected near-infrared and red radiation, i.e., as (NIR-RED)/(NIR+RED).
5. The NDMI (Normalized Difference Moisture Index) describes the level of crop water stress and is calculated as the ratio of the difference to the sum of reflected radiation in the near-infrared and SWIR, i.e., as (NIR-SWIR)/(NIR+SWIR). The optimal threshold of NDMI for the detection of tree structure is 0.31, a value through which the area covered by tall vegetation could be determined.
6. For the data of the case study analyses, reference is made to what is elaborated in "UniCo - Preliminary feasibility studies for the redevelopment of the Coppito University campus." Scientific responsible: prof. Bernardino Romano. Research group: prof. Pierluigi de Berardinis, prof. Federico De Matteis, PhD Eng. Lorena Fiorini, PhD Eng. Eleonora Laurini, prof. Francesco Zullo, prof. Alessandro Marucci, PhD stud. Chiara Di Dato, PhD stud. Eng. Federico Cavalieri, PhD stud. Eng. Camilla Sette.

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Conflicts of Interest

The author declares no conflict of interest.

Originality

The author declares that this manuscript re-elaborates and supplements the contents of the following paper: Sette C. (2022), "Adattamento ai cambiamenti climatici nelle aree urbane e periurbane: soluzioni progettuali resilienti e adattive", in Moccia F.D., Sepe M. (a cura di), XIII Giornata Internazionale di Studi INU - 13°Inu International Study Day "Oltre il futuro: emergenze, rischi, sfide, transizioni, opportunità - Beyond the future: emergencies, risks, challenges, transitions, and opportunities" (Napoli, 16 December 2022), *Urbanistica Informazioni*, n. 306s.i., INU Edizioni, Roma, pages 468-470.

The author also declares that the manuscript is not currently being considered for publication elsewhere, in the present of any other language. The manuscript has been read and approved by all named authors and there are no other persons who satisfied the criteria for authorship but are not listed. The authors also declare to have obtained the permission to reproduce in this manuscript any text, illustrations, charts, tables, photographs, or other material from previously published sources (journals, books, websites, etc).

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