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Article

A Green Roof Case Study in the Urban Context of Milan: Integrating the Residential and Cultivation Functions for Sustainable Development

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Abstract: Green roofs are increasing in popularity because of both their pleasant appearance and their positive effects for the urban ecosystems and the building indoor climatic conditions. Though this technology has already been applied all over the world, it is still commonly considered of difficult application and management. Easy and fast approaches for green roofs must therefore be examined and encouraged in order to increase their number to counterbalance urban overheating. This thesis case study aimed to represent a prototype of a green roof integrated with a residential function in order to achieve an easy management of the cultivation area. The project was designed in terms of sustainability and was analyzed for its social, environmental and economic impacts, pointing out the numerous benefits that can be derived by the combination and juxtaposition of humans and native plants. The proposed solution is favorable in terms of a sustainable development: it aspires to be reproduced and extensively applied to other facilities of a city as a solution for the overheating and overpopulation of contemporary cities.

Keywords: green; house; college; students; native plants; water; greenhouse; green roof; air quality; supra-elevation

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1. Introduction

It is well known that the presence of green technology in cities brings many benefits in terms of people wellness, climate change and air pollution. Despite this, green areas are not yet as widespread around cities as we hope. Most of the time, this derives from a lack of space that cities currently have due to the excessive number of inhabitants that need to find a place to live within urban areas.

Therefore, building roofs have been identified as representing wide surfaces with a high potential of transformation [1]; turning them into green roofs would indeed help to create an elevated green system that could work towards the mitigation both of air pollution and climate change.

Though green roofs have a great charm, their use has not yet widely occurred because the process implies significant costs and supplemental weights and maintenance that people only consider when they are conscious of the additional value that green roofs bring to a building. The integration of plants on top of an existing building brings along structural and management problems that must be faced in advance. First of all, the additional load derived from the presence of plants and their terrain that rest on existing structures must be considered; consequently, the species must be chosen according to the weather conditions to which they are resistant, and an appropriate irrigation method should be adopted to optimize the use of water.

Urban vegetation exhibits economic, social, aesthetic, and ecological values [2,3]: it contributes to the quality of life, influencing individuals' psychological and physiological well-being.

Despite the difficulties and restraints of designing a green roof, such as cost, weights, and maintenance [1], a green roof has many benefits [1,3–5] that make its application worth simultaneously considering the urban and building dimensions. The presence of vegetation on top of the buildings can mitigate the so-called urban heat island effect and reduce air pollution and greenhouse gas emissions while, at the building scale, acting as a thermal insulator and reducing the use of energy for both cooling and heating needs.

Compared to the European cities of Madrid, London, and Barcelona, the city of Milan has the smallest green coverage per km^2. In terms of air quality, the index value registered by the Italian city last year belonged to the "Moderate" AQI (air quality index) category, with an annual index value in 2020 of 73.1 Particulate Matter 2.5; in the same year, the city of Madrid had an index value of 55.9 PM2.5, still belonging to the "Moderate" AQI category; instead, the air quality index registered in the city of London belongs to the "Good" AQI Category, with a value of 47.8 PM2.5 (Figure 1).

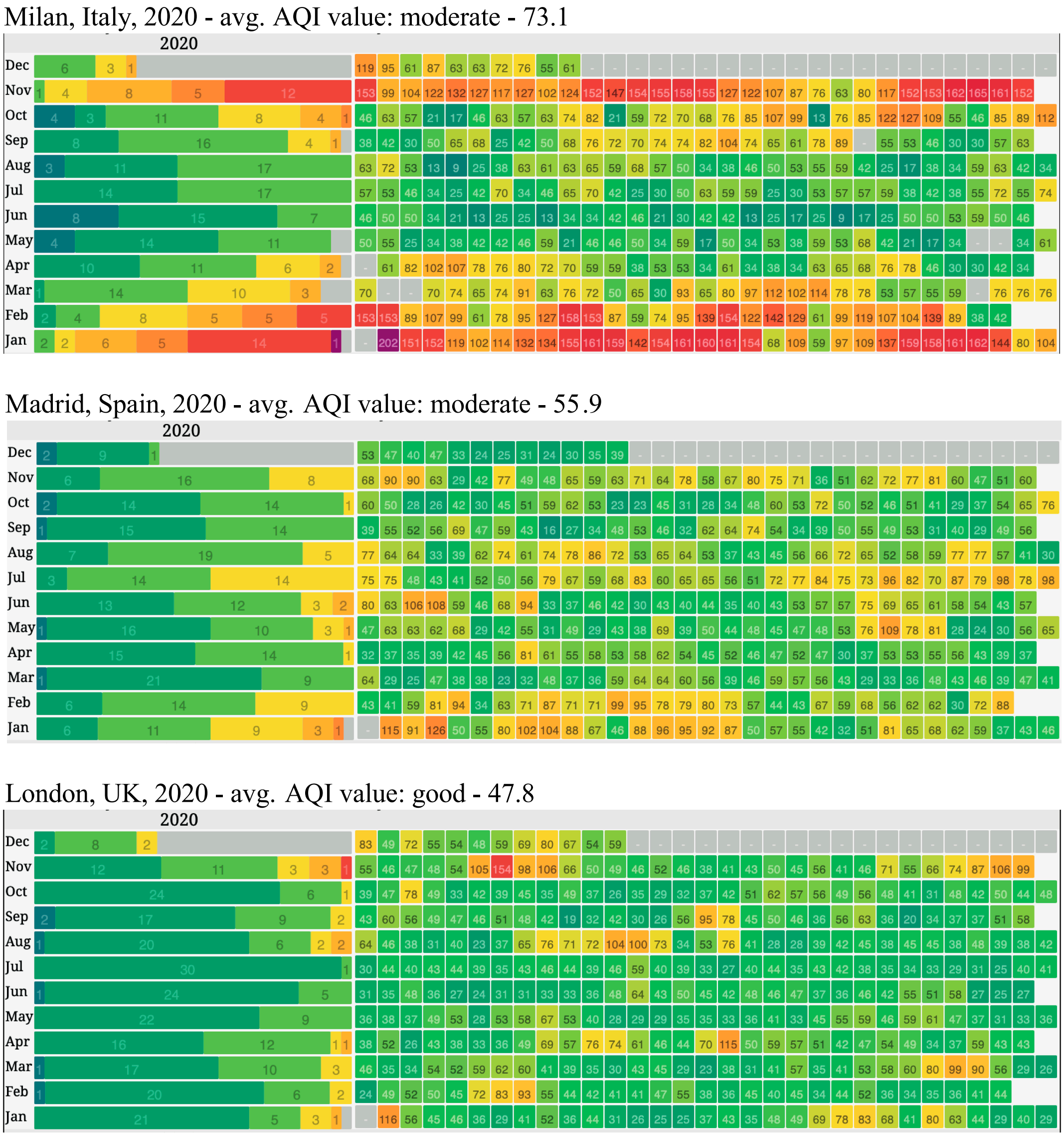

Figure 1. 2020 AQI (air quality index) comparison among the cities of Milan, Madrid, and London; www.waqi.info.

PM stands for Particulate Matter: "It is a complex mixture of solids and aerosols composed of small droplets of liquid, dry solid fragments, and solid cores with liquid coatings" [6] present in the atmosphere and categorized, according to the diameter of the particles, as Particulate Matter 10 and Particulate Matter 2.5. The ambient air quality standards define "the maximum amount of pollutant that can be present in outdoor air without harming human health" [6], which has been internationally identified to be an annual average of 12 $\mu g/m^3$ of PM2.5, to which an AQI index value of 0–50 PM2.5 corresponds.

As indicators of the air quality of a city, the PM value and other parameters (such as the amount and the location of green areas, green transport, and urban waste) contribute to defining a city as "green" and "ecological". Especially, the presence of widespread green areas in a city plays a fundamental role in the absorption of CO_2, the mitigation of the urban heat island effect, and the reduction of acoustic noise.

The European Union is moving in the direction of improving the ecological imprint of its cities while at the same time reducing their consumption. The presence of green areas in cities has been globally recognized as a crucial element that plays a key role in environmental, energetic, and social development. As it is possible to notice in Figure 2, the cities of Milan and Madrid are working in order to increase the percentage of green coverage per km^2 over the next 10 years. Compared to Barcelona and London (especially considering that this last has registered a better index value of PM2.5), Milan and Madrid will register the biggest increase, positively affecting their air quality. In order to expand green areas into a city that is already packed, the city of Milan decided to turn existing building roofs into green ones [7]. This transformation, encouraged by the city project "Milano Clever Cities", will contribute to a major program of achieving a rise of green coverage within the city of the 625% in the next 10 years.

Figure 2. Actual green coverage per km^2 in 2020 vs. future green coverage per km^2 in 2030.

Given all the benefits [1,3–5] that come from the transformation of existing buildings' roofs into green ones, this investigation concentrated on the analysis of a case study project that was applied in Milan: the analyzed master thesis proposal focused on the design of a compartmented supra-elevation that acted as a college for students and a green roof. The investigation considered all the steps that should be followed when designing a green roof and analyzed all the possible benefits and problems that can occur when adding an extra level to an existing building.

The aim of this research was therefore to analyze the application of a green roof while considering all the difficulties of the process in order to encourage the implementation of an easy concept through a specific method of operation that embraces both a design point of view and an agricultural one. The proposed solution responded to the environmental (the city), social (the residents), and economic (reduction of expenses) conditions and needs. The solution was analyzed at the architectural, agricultural, and management levels. The case study represents a theoretical solution that has positive effects on both the urban ecosystem and the building itself, aspiring to set an example that could encourage the easy reproduction of the method to other facilities of the city [8].

"Overall, vegetation is shown to be a significant, if not essential, component of the urban environment, [thanks to which] improvements in quality of life are also exhibited at the community level" [2] (p. 1): this study therefore aimed to prove the advantages that could come from the application of a green roof mixed with a students' college on top of an existing building, implying that these can be applied at both the individual and community levels, as well as at the building and urban scales.

2. Literature Review

Nowadays, sustainability does not only refer to the concept of the conservation of the environment. Sustainable development is a new concept of evolution that embraces the social, economic and environmental dimensions. At the intersection of these three extents, it is possible to identify sustainability itself, with the environmental dimension having a significant impact on both the social and the economic ones [2]. When developing sustainable cities, it is necessary to analyze them from these three points of view because sustainable constructions do indeed respond to the requirements of sustainable development when the three pillars (social, economic, and environmental) [2] are respected along all the phases of designing, building, and using buildings.

Green roofs actually represent a sustainable solution for the evolution of our cities: many researchers have highlighted the advantages of substituting existing roofs with green ones, advantages that contribute to their recognition as both elements of the building and as components of sustainable urban ecology and agriculture. Green roofs symbolize elements that connect people to nature, representing functional, ecological, economical, aesthetic, and visual benefits of buildings in an urban concrete environment [1].

The well-known environmental advantages of green roofs in cities, as clarified by Korol E. and Shushunova N. [9], include increases in the living quality of inhabitants and their social interactions. Therefore, they are one of the key elements in urban planning and architectural design, with the potential to create more desirable buildings and cities with high living standards; in addition to the environmental, mental, and physical benefits provided by the presence of green areas, their application could also decrease the feelings of overpopulation and high density in cities [1].

According to the research conducted by Joshi M.Y. et al. [4], around the 20% of the existing building roofs in Liege, Belgium, are capable of being turned into green roofs—the research considered the structural conditions, slopes, dimensions, and the necessity of green areas into specific compartments of the existing buildings of the city. From a more general view, it is possible to assume that the percentage of suitable roofs can be increased by diminishing the number of limits and considering major structural interventions to allow for the biggest number of roofs to this transformation. Building adaptations could be realized by adopting specific strategies that would obviously create an increase in costs at the time of interventions, but those costs would be later saved with a clear design approach that leads to decreases in energy and management obligations.

A new integrated approach is exactly that which the case study analyzed here aspired to explore by contrasting the downsides [1] and technical difficulties for the green roofs highlighted by Dauda I. et al. [5].

Starting from the existing literature, the research intended to represent an effective case study of the application of a green roof integrated with a residential area. It considered all the aspects that play a role during all the phases of the transformation and management of a green roof. The particularity lies in the fact that the three main elements (plants, humans, and buildings) are combined together into a system that allows for price-energy saving gained by the juxtaposition of the three (social, economic, and environmental) dimensions. The research highlighted all the possible benefits that can be achieved by the application of this or of a similar method: analyzing all the aspects that are possible to be faced along the transformation, the study proposed not an intensive, extensive, or a modular green roof, but rather a "compartmented" one that considered a wider sustainability perspective along its life cycle [10,11], aiding environmental protection, with positive social and economic impacts too.

3. Materials and Methods

The research analyzed a case study of a master thesis project located in the city of Milan and focused on the design of a compartmented supra-elevation that would act as a college for students with an integrated green roof, or, alternatively, a house for plants [12].

The project would be located on top of an existing building of the Politecnico di Milano, Leonardo Campus, under the assumption that the university itself has approved a program based on the concept of a "sustainable campus": the aim would be to transform the campus, improve its ecological footprint and social accessibility, and increase the percentage of green coverage. Based on a Renzo Piano's project idea, the transformation that is already occurring in the Architectural Faculty of the Leonardo Campus will see the plantation of 100 new trees, along with the construction of new sustainable buildings and the restitution to the students of a big but unused open area (transformed into a green but accessible space). The designed case study of a compartmented green roof would act in continuity with the wider sustainable program, thus proposing an innovative way to transform existing roofs into green ones, focusing on the necessity of increasing the green coverage within the city and the campus and providing a greater number of accommodations for students.

The research was analyzed from several points of view, including its architectural configuration, its bioclimatic effects, and its management. The case study consisted of the concept of addition of an entire floor to an existing building. The design took its first steps by structurally analyzing the existing building and valuing the interventions that would have to be undertaken in order to reinforce the building to resist to the additional loads; simultaneously, in order to not cause too many structural interventions, the additional floor was designed with lightweight construction elements minimized in their thickness in order to obtain a maximum reduction of additional structural weights. Later, the project was defined based on the principles of the sustainability: green courtyards were placed in order to obtain a bioclimatic effect that positively affect the interior temperature of the floor throughout the whole year, the plant configuration and the species of the green roof were studied to minimize the use of the water for irrigation reasons, a photovoltaic system on the roof was included to gain sustainable solar energy, and the management of the green roof was based on the concept of social wellness and was conceived to achieve the social inclusion.

The case study proposed in this research comprised four single units that would be used to cover the whole floor surface of the examined building. Additionally, the case study exhibited a configuration that could be easily adapted to different characteristics, replicated on top of multiple buildings, and transformed in order to fit different contexts.

3.1. The Structural and Architectural Configuration

An existing building located in the Politecnico di Milano, Leonardo Campus, was chosen for the design of a compartmented supra-elevation covering the whole area of the available roof with a total surface of 3260 m^2. The necessity of turning existing roofs into green ones for the above-mentioned reasons linked to a demand to increase the number of student accommodations within the city led to the provision of an additional level with both functions combined together: a student college and a house for plants.

Rather than a proper green roof, the level was designed to have an open central courtyard as the main core of the project, while the rooms all faced an openable and closable courtyard that would act as a greenhouse. Therefore, the courtyards and the species placed in them were studied according to their orientation and function. The general configuration of the project was studied by starting with a single unit of student rooms and openable–closable courtyards (Figure 3). This unit would be repeated 4 times and located on the corners of the floor areas, ultimately obtaining accommodations for a total of 48 students—6 in each unit, with each composed of 2 single rooms and 2 double rooms [13]. The common spaces (on the east and west sides) would be located in the middle between two single units in order to make them accessible from both; public areas were located in the middle of the north and south sides to make accessible for all students—their functions were chosen for comfort, with the gym and the kitchen placed in the north and the common room and the cafeteria placed in the south. Additionally, the fronts were designed according to their orientation, with the north front more opaque than the south one, which would also have integrated solar shading to prevent overheating. The east and west fronts were similarly conceived with the presence of punctual but movable solar shading systems that were designed by considering the orientation and inclination of the sun rays over the year.

Figure 3. Architectural drawings of the front and floor plan of a single unit of the building. In the plan, the relationship between the living boxes (students' rooms with bathrooms and common rooms; shown in gray) and the house for plants (openable–closable courtyards hosting the pallet containers for plants; shown in green) is shown in detail [12].

In addition to the architectural configuration (Figure 4), a structural analysis was necessary for the development of the project; additional structural elements were considered in order to strengthen the existing structure and make it resistant to supplemental loads. Specifically, since the existing building was more than 50 years old, it was built with concrete prefabricated elements that should have been reinforced or substituted soon anyway because of their ageing. Modifications would be made to adapt the building to the new Italian seismic regulations (introduced less than 50 years ago, so the building did not comply with them). An additional concrete pillar row was designed to reduce the existing span, while the prefabricated beams sustaining the existing roof were completely substituted with a reticular structure able to resist to the additional loads of the new floor that would replace the existing roof. Furthermore, in order to reduce the total weight of the additional floor, all the constructive elements were specifically selected to opt for lighter but still effective solutions such as Ethylene TetraFluoroEthylene (ETFE) cushions [14] instead of glass as roof elements. Thanks to a precise balance of all the elements, the reduction in terms of weight per m^2 could reach a diminishment of more than 150 kg, thus achieving an average final weight of 105 kg per m^2.

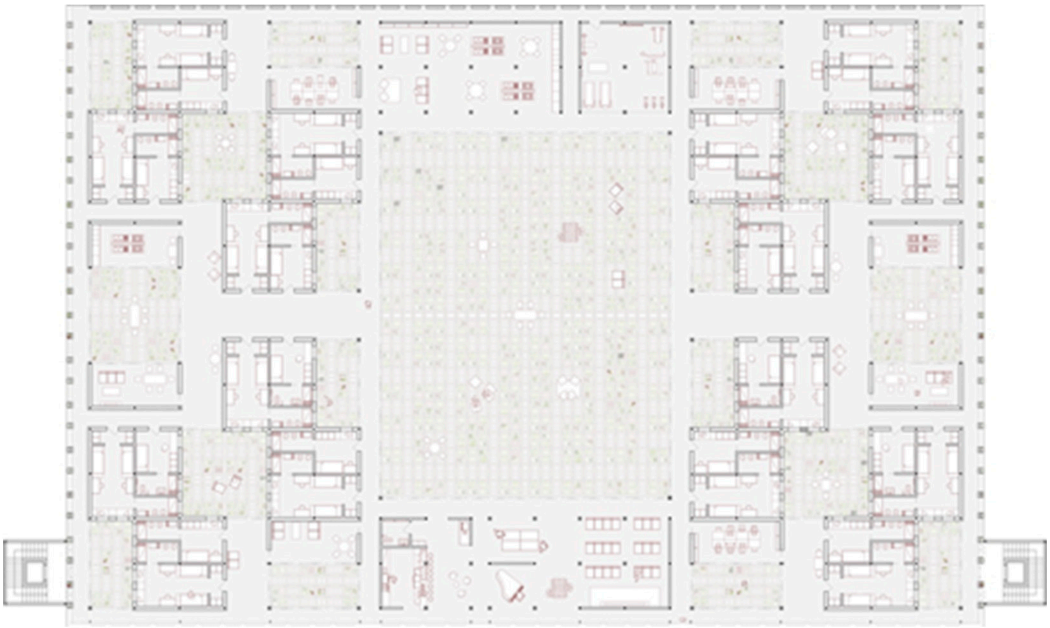

Figure 4. Plan of the whole building supra-elevated floor—architectural configuration. The opened central courtyard is located at the center of the whole floor [12].

Once the new compartmented supra-elevation was arranged in its architectural and structural configuration, the plant species were selected according to the length of their roots in order to minimize the amount of necessary terrain and to additionally reduce the new weight; plant management and natural weather resistance were also taken into consideration.

Lastly, an irrigation method (later more specified) was chosen to prevent excessive weights determined by the quantity of water seepage that came with it.

Urban farming—growing food in the city on rooftop gardens, close to the customers, with educational and social benefits—has become a big trend [15] and excited many people that see the perfect combination between urban and rural life in "hortitecture".

Plants can be accommodated within a building system—they can actually be more than a decorative addition to buildings. They can be an integral part of a building's ecological performance. Plants can produce food, absorb noise, absorb pollution, absorb carbon dioxide, and absorb particulate matter, and they can cool urban temperatures by transpiring water [15].

The analyzed case study combined living boxes, the effective rooms of the college, with courtyards, the so-called "houses for plants". The presence of the patios would provide many advantages, including ventilation, illumination, and the creation of multifunctional areas that could be set up for agricultural purposes and social interaction moments.

Urban and building ecosystems were therefore the two main concepts that, as faces of the same coin, this case study analyzed and aspired to combine in order to achieve mutual benefits.

3.2. *The Agriculture and Irrigation Aspects*

The design of a green roof implies a careful analysis of the background in which it is designed—background meaning the surrounding context, supporting building, and the weather conditions that the green roof will face. The objectives of the green roof had to be considered too.

In this specific case, the green roof would host a 1100 m^2 vegetable garden able to produce half of the students' monthly needed amount of vegetables.

The two different conditions of the courtyards entailed the presence of specific species able to resist both natural and specific weather conditions: the biggest courtyard would indeed be completely opened and cover an area of almost 600 m^2; the smallest ones would have a total area of almost 500 m^2 and work more as greenhouses, being openable and closable at the roof level realized with transparent sliding ETFE cushions.

The selected species that would live in the new project were differentiated between vegetables (Figure 5) and aromatic plants (Figure 6) [16], both chosen from the most common (native or not) plants cultivated in the Italian territory, especially in the Lombardy region that has a continental climate with very warm summers and cold winters. The subdivision of the species among those ones behaving better in warm climates and those one that prefer cold climates would allow for an organization based on a common triennial rotation. The difference between the species cultivated in the opened central courtyard and those present in the small compartmented patios would depend on the arbitrary choice of the people managing those spaces. Obviously, it is possible to assume that the location of the plants would be decided according to their illumination and shadows needs, as well as external weather conditions, because the greenhouses patios temperatures and illumination conditions could be managed according to the species' needs.

January:	February:	March:	April:	May:	June:	July:	August:	September:	October:	November:	December:	Latin name:
Chicory	**Chicory**	**Chicory**	**Chicory**	**Chicory**	**Chicory**	**Chicory**	**Chicory**	**Chicory**	**Chicory**	**Chicory**	Chicory	NS - Chicorium intybus
Lettuce	**Lettuce**	**Lettuce**	**Lettuce**	**Lettuce**	**Lettuce**	**Lettuce**	**Lettuce**	**Lettuce**	**Lettuce**	**Lettuce**	**Lettuce**	NS - Lactuca sativa
Fennel	Fennel	**Fennel**	**Fennel**	**Fennel**	**Fennel**	**Fennel**	Fennel	Fennel	Fennel	Fennel	Fennel	NS - Foeniculum vulgare
Artichokes	**Artichokes**	**Artichokes**	**Artichokes**	**Artichokes**	Artichokes	Artichokes	Artichokes	Artichokes	Artichokes	Artichokes	Artichokes	NS - Cynara cardunculus var. scolymus
Peas	**Peas**	**Peas**	Peas	Peas	Peas	Peas	Peas	Peas	**Peas**	**Peas**	Peas	NS - Pisum sativum
Zucchini	Zucchini	Zucchini	**Zucchini**	**Zucchini**	**Zucchini**	**Zucchini**	**Zucchini**	**Zucchini**	**Zucchini**	Zucchini	Zucchini	NS - Cucurbita pepo
Cauliflower	Cauliflower	Cauliflower	**Cauliflower**	**Cauliflower**	**Cauliflower**	**Cauliflower**	**Cauliflower**	**Cauliflower**	Cauliflower	Cauliflower	Cauliflower	NS - Brassica oleracea
Cabbage	**Cabbage**	**Cabbage**	**Cabbage**	Cabbage	Cabbage	Cabbage	Cabbage	Cabbage	Cabbage	Cabbage	Cabbage	NS - Brassica oleracea
Onion	**Onion**	**Onion**	**Onion**	Onion	Onion	Onion	Onion	Onion	Onion	**Onion**	Onion	UK - Allium cepa
Garlic	**Garlic**	Garlic	Garlic	Garlic	Garlic	Garlic	Garlic	Garlic	Garlic	**Garlic**	Garlic	UK - Allium sativum
Fave	**Fave**	**Fave**	Fave	Fave	Fave	Fave	Fave	Fave	**Fave**	**Fave**	**Fave**	UK - Vicia faba
Celery	**Celery**	**Celery**	Celery	Celery	Celery	Celery	Celery	Celery	Celery	Celery	Celery	UK - Apium graveolens
Potatoes	**Potatoes**	**Potatoes**	**Potatoes**	**Potatoes**	**Potatoes**	Potatoes	Potatoes	**Potatoes**	**Potatoes**	Potatoes	Potatoes	NN - Solanum tuberosum
Spinach	Spinach	**Spinach**	**Spinach**	Spinach	Spinach	Spinach	Spinach	**Spinach**	**Spinach**	Spinach	Spinach	NN - Spinacia oleracea
Carrot	Carrot	**Carrot**	**Carrot**	**Carrot**	**Carrot**	**Carrot**	**Carrot**	**Carrot**	**Carrot**	Carrot	Carrot	NN - Daucus carota subsp. sativus
Pumpkin	Pumpkin	Pumpkin	**Pumpkin**	**Pumpkin**	**Pumpkin**	**Pumpkin**	**Pumpkin**	**Pumpkin**	**Pumpkin**	**Pumpkin**	Pumpkin	NN - Cucurbita pepo
Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	Brussels sprouts	NN - Brassica oleracea gemmifera group
Green beans	Green beans	Green beans	Green beans	Green beans	Green beans	Green beans	Green beans	Green beans	Green beans	Green beans	Green beans	NN - Phaseolus vulgaris
Radishes	Radishes	Radishes	Radishes	Radishes	Radishes	Radishes	Radishes	Radishes	Radishes	Radishes	Radishes	NN - Raphanus raphanistrum subsp. sativus
Chard	Chard	Chard	Chard	Chard	Chard	Chard	Chard	Chard	Chard	Chard	Chard	NN - Beta vulgaris
Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	Savoy cabbage	NN - Brassica oleracea var. sabauda
Chili Peppers	Chili Peppers	Chili Peppers	**Chili Peppers**	**Chili Peppers**	**Chili Peppers**	**Chili Peppers**	**Chili Peppers**	**Chili Peppers**	**Chili Peppers**	Chili Peppers	Chili Peppers	NN - Capsicum annuum
Valerianella	**Valerianella**	**Valerianella**	**Valerianella**	**Valerianella**	**Valerianella**	**Valerianella**	**Valerianella**	**Valerianella**	**Valerianella**	**Valerianella**	Valerianella	NN - Valerianella locusta
Shallot	**Shallot**	**Shallot**	Shallot	Shallot	Shallot	Shallot	Shallot	Shallot	**Shallot**	**Shallot**	Shallot	NN - Allium cepa
Tomato	**Tomato**	**Tomato**	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	Tomato	NN - Solanum lycopersicum
Chickpea	**Chickpea**	**Chickpea**	Chickpea	Chickpea	Chickpea	Chickpea	Chickpea	Chickpea	Chickpea	Chickpea	Chickpea	NN - Cicer arietinum
Aubergine	Aubergine	**Aubergine**	Aubergine	Aubergine	Aubergine	Aubergine	Aubergine	Aubergine	Aubergine	Aubergine	Aubergine	NN - Solanum melongena
Maize	Maize	Maize	**Maize**	**Maize**	Maize	Maize	Maize	Maize	Maize	Maize	Maize	NN - Zea mays
Lentils	Lentils	Lentils	Lentils	Lentils	Lentils	Lentils	Lentils	Lentils	Lentils	Lentils	Lentils	NN - Lens culinaris
Beans	Beans	Beans	Beans	Beans	Beans	Beans	Beans	Beans	Beans	Beans	Beans	NN - Phaseolus vulgaris

Figure 5. Period of cultivation of vegetables. NS: native species; UK: unknown; NN: not native [12].

For an easier cultivation and rotation of species, rather than a common green roof, an innovative method was used to simplify the management of the vegetable garden. Inspired by the "Orto fra i cortili" project realized in Milan by PiuArch on top of their architectural firm, the green roof would comprise a surface made of pallets that, when rotated according to their function, could be used as walkable surfaces or containers for plants (Figure 7). The limited depth of the terrain, 12.5 cm, suits the system and lets the selected vegetables grow, in addition to having the advantage of only adding limited weight to the existing structure. Species could, in this way, rotate and be subjected to fast and easy changes in order to always be able to meet their requirements and facilitate their management.

The chosen irrigation method, micro-irrigation, was applied with the same logic of minimizing weights: frequent but small applications of water by dripping has the advantage of only wetting a portion of the soil surface, thus calibrating the amount of water necessary by each species.

January:	February:	March:	April:	May:	June:	July:	August:	September:	October:	November:	December:	Latin name:
Oregano	Oregano	Oregano	Oregano	Oregano	Oregano	Oregano	Oregano	Oregano	Oregano	Oregano	Oregano	NS - Origanum vulgare
Lavender	Lavender	Lavender	Lavender	Lavender	Lavender	Lavender	Lavender	Lavender	Lavender	Lavender	Lavender	NS - Lavandula spica
Rosemary	Rosemary	Rosemary	Rosemary	Rosemary	Rosemary	Rosemary	Rosemary	Rosemary	Rosemary	Rosemary	Rosemary	NS - Salvia rosmarinus
Sage	Sage	Sage	Sage	Sage	Sage	Sage	Sage	Sage	Sage	Sage	Sage	NS - Salvia officinalis
Thyme	Thyme	Thyme	Thyme	Thyme	Thyme	Thyme	Thyme	Thyme	Thyme	Thyme	Thyme	NS - Thymus vulgaris
Licorice	Licorice	Licorice	Licorice	Licorice	Licorice	Licorice	Licorice	Licorice	Licorice	Licorice	Licorice	NS - Glycyrrhiza glabra
Rocket salad	Rocket salad	Rocket salad	Rocket salad	Rocket salad	Rocket salad	Rocket salad	Rocket salad	Rocket salad	Rocket salad	Rocket salad	Rocket salad	NS - Eruca vesicaria
Chamomile	Chamomile	Chamomile	Chamomile	Chamomile	Chamomile	Chamomile	Chamomile	Chamomile	Chamomile	Chamomile	Chamomile	NS - Aster
Coriander	Coriander	Coriander	Coriander	Coriander	Coriander	Coriander	Coriander	Coriander	Coriander	Coriander	Coriander	NS - Coriandrum sativum
Parsley	Parsley	Parsley	Parsley	Parsley	Parsley	Parsley	Parsley	Parsley	Parsley	Parsley	Parsley	NS - Petroselinum crispum
Laurel	Laurel	Laurel	Laurel	Laurel	Laurel	Laurel	Laurel	Laurel	Laurel	Laurel	Laurel	NS - Laurus nobilis
Saffron	Saffron	Saffron	Saffron	Saffron	Saffron	Saffron	Saffron	Saffron	Saffron	Saffron	Saffron	Naturalized - Crocus sativus
Wild fennel	Wild fennel	Wild fennel	Wild fennel	Wild fennel	Wild fennel	Wild fennel	Wild fennel	Wild fennel	Wild fennel	Wild fennel	Wild fennel	Naturalized - Foeniculum vulgare
Celery	Celery	Celery	Celery	Celery	Celery	Celery	Celery	Celery	Celery	Celery	Celery	UK - Apium graveolens
Ginger	Ginger	Ginger	Ginger	Ginger	Ginger	Ginger	Ginger	Ginger	Ginger	Ginger	Ginger	UK - Zingiber officinale
Anice	Anice	Anice	Anice	Anice	Anice	Anice	Anice	Anice	Anice	Anice	Anice	NN - Illicium verum
Mustard	Mustar	Mustard	Mustard	Mustard	Mustard	Mustard	Mustard	Mustard	Mustard	Mustard	Mustard	NN - Brassica
Turmeric	Turmeric	Turmeric	Turmeric	Turmeric	Turmeric	Turmeric	Turmeric	Turmeric	Turmeric	Turmeric	Turmeric	NN - Curcuma longa
Mint	Mint	Mint	Mint	Mint	Mint	Mint	Mint	Mint	Mint	Mint	Mint	NN - Salvia dorrii
Basil	Basil	Basil	Basil	Basil	Basil	Basil	Basil	Basil	Basil	Basil	Basil	NN - Ocimum basilicum
Dill	Dill	Dill	Dill	Dill	Dill	Dill	Dill	Dill	Dill	Dill	Dill	NN - Anethum graveolens

Figure 6. Period of cultivation of aromatic plants. NS: native species; UK: unknown; NN: not native [12].

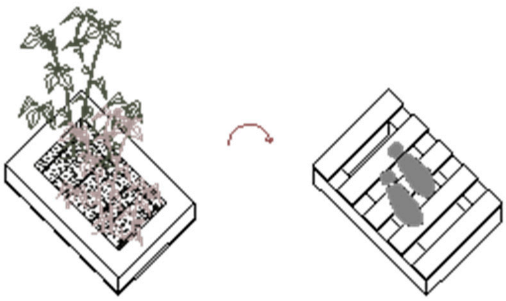

Figure 7. The double use of the pallets [12].

Furthermore, considering sustainability, the water used for irrigating the plants would come from a rainwater collection system, with the rainwater tank located on the ground of a free area at the side of the building. The system would work through the systematic presence of eaves and drainpipes located along the courtyards. Each ETFE cushion covering the courtyards would be equipped with lateral eaves and an opaque roof. All these elements would then be slightly inclined towards a main eave that would be able to carry the water to the closest drainpipe (Figure 8). The water collected by the drainpipes would be progressively delivered into the existing drainpipes that would then drain the water into the designated rainwater tank at the ground level.

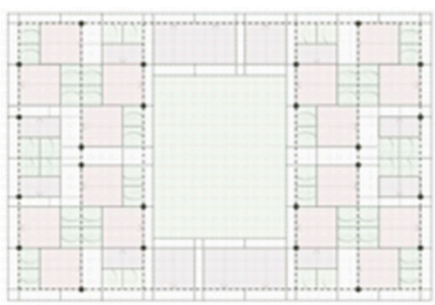

Figure 8. Dashed line: main eaves; dots: drainpipes [12].

The entire rainwater collection system and the possibility to close the courtyards in case of rain would allow for the accurate management of the quantity of water wetting the plants' terrain, along with the structural and environmental advantages of limiting the weight loading onto the structure and reducing the waste of water.

3.3. The Bioclimatic Effect

The compartmented green roof, studied for combining a vegetable garden with residential boxes, would have a huge advantage in terms of indoor bioclimatic conditions.

Related to the double notions of green courtyards and greenhouses, the concept of green roof was used in the case study with this double connotation to allow for a passive mitigation of indoor temperatures.

It is necessary for the building sector to increase the presence of passive systems that mitigate internal conditions by primarily taking advantage of the sun and its heat. In the case of a passive house, its design and construction are fundamental to maintain interior climatic conditions at a comfortable level without activating heating or cooling systems.

From this point of view, the alternation between the cultivating courtyards and the residential boxes set up a bioclimatic layout in which closed and not-heated zones of climatic mediation, located between areas of controlled temperatures and the outside, would work as filters to reduce the energy exchange between the inside and the outside and to create areas of differentiated temperatures.

Additionally, the courtyards scattered throughout the project layout would create interior microclimates that would allow for temperature mitigation and exchange between the residential boxes and the courtyards, with the latter acting differently according to the season and temperature variations.

This approach contrasts with one typical of the artificial climatization that forecasts an inside area with controlled and strict conditions and an outside with uncontrolled seasonal rigid temperatures [17]. Considering that the courtyards would mainly be closed in winter and opened in summer, it would be possible to examine the thermal exchange of the system throughout the whole year:

The transparent boxes, acting as closed greenhouses in winter, would collect heat during the day via the sun radiation passing through the transparent ETFE cushions used for the roof, heating up the space inside the courtyard and warming the wall mass that would slowly transfer heat to the residential opaque boxes during entire day and night (Figure 9a).

(**a1**) Winter day: walls collecting heat through the sun radiation.

(**a2**) Winter night: walls releasing heat towards the residential boxes.

(**b1**) Summer day: the heat collected by the walls during the day is mitigated by the cross ventilation.

(**b2**) Summer night: the perceived temperatures are cooled down again by the cross ventilation.

Figure 9. (**a**) Winter behavior of the level; (**b**) Summer behavior of the level; [12].

In summer, instead, the ETFE cushions would slide over the opaque roofs, leaving the courtyards completely opened during the whole day and night. This system would allow for cross ventilation among all the spaces, thus mitigating indoor temperatures (Figure 9b).

During the middle seasons of autumn and spring, the roof of the courtyards, not having a fixed configuration, could be arranged according to necessity and external temperatures while still generating spaces of comfortable conditions that would be suitable for different necessary functions.

Architecture with plant material tries to balance the human condition with the built and natural environments, thus increasing their mutual benefits. In order to do so, it is necessary to design spaces that both humans and plants could take advantage of—a building is one of these places because it is a habitat for humans that allows for the co-habitation of plants and animals.

Regarding the plants' weather conditions, the opened green courtyard would be exposed to natural conditions throughout the whole year and would act as a general green roof where it would be necessary to calibrate the presence of species able to survive to the specific seasonal weather; the small courtyards would work more like greenhouses, responding to different microclimates. The resulting advantage would be the possibility to manage the courtyards' indoor conditions and to create different habitats for different plants, thus allowing for the discretionary presence and cultivation of specific species through the simplification of their arrangement and maintenance by organizing them in accordance with the needed microclimate.

The selected species would be able to survive at the specific temperatures they require, with the only precaution being the need to place species that can live together and that need similar weather conditions next to each other in order to allow for equal nurture. A second measure that could be taken is the distribution of species in the layout according to their required direct solar radiation: an analysis of the shadows showed that the correct location of each species would be easy (e.g., with cauliflower located in more shadowed areas instead of tomatoes that need a significant sun radiation and warmer temperatures).

Cohabitation, or to live or exist together or in company, was the focus of the case study. The coexistence of humans and plants is necessary for our and our cities' futures. It is therefore fundamental to establish spaces in which both living creatures can gain mutual benefits. In the project, this aspect was investigated through the presence of openable and closable courtyards: the system, working through sliding ETFE transparent cushions used for the roof, would allow for the climate control of these filter spaces that are fundamental for creating inhabitable spaces.

3.4. The Sustainability of the Project

Environmental sustainability foreruns but brings along social and economic sustainability [17]: the concept of sustainability integrates these three notions by linking them to each other. Nowadays, it is impossible to conceive something sustainable from just one point of view because of the current complex system in which our communities are continuously in contact.

Relating these three images to each other, the case study proposed a model in which environmental sustainability would be achieved through a passive building that took advantage of a green roof for energetic and economic reasons; social sustainability would be accomplished by raising the wellbeing of students in the college.

Economically, the project aspired to be completely independent via the vegetable garden (producing half of the students' daily needed vegetables) and the integration of photovoltaic panels and a rainwater collecting system.

A total amount of 110% of the energy required by the supra-elevated floor would be collected by photovoltaic (PV) cells. Fixed transparent ETFE cushions would cover the public corridors, and these would be equipped with small but long stripes of PV modules [18–20] that would be fixed in a removable way onto the middle layer of the three-layer cushions. Being enclosed by transparent ETFE-films, the PV modules would be kept safe from external exposure, although the whole system would be affected by a 10% reduction of solar radiation gain. However, the system would still be able to collect the 110% of the energy required by the students for the use of the floor, and the small extra amount of energy gained could be saved and/or used for irrigation purposes.

The irrigation would take advantage of the rainwater collection system already explained above. Considering the recyclability and reuse of natural resources, all these arrangements were conceived with the aim of minimizing waste but maximizing outcomes in the pursuance of sustainability.

From a wider social perspective, considering that the students living in the college would not have enough time or enough diligence to take care of the green courtyards, the management of the vegetable garden would totally rely on existing communities of elderly people in accordance with the municipality: a similar structure of elderly communities taking care of the vegetable garden has already been positively experimented in another green roof built into the city of Milan, hence suggesting a positive outcome for the whole organization.

4. Results and Discussion

Humans and plants are the two main elements that the case study aspired to combine while foreseeing a new scenario based on their integration.

How are plants integrated within a building system, and what kinds of benefits can a new kind of nature–artifact combination offer? [15]. This research aspired to answer these questions with the noticeable result that, although the realization of a roof like this would require several specific precautions (which is why some are still reluctant to attempt this type of transformation) [1], the whole intervention would be justified by the undeniable advantages that would be provided by the juxtaposition of these two elements—humans and plants —and their integration into a building system.

The research evaluated various solutions and identified one that could be easily replicated to transform a consistent number of existing roofs into green ones.

Having defined several advantages (considerable in terms of urban benefits, energy savings, and bioclimatic behavior) that could be achieved through the transformation of existing roofs into green ones, the case study aspired to be an example of how to tackle this process in order to obtain as many benefits as possible. It suggests a method for dealing with this type of transformation by analyzing all the steps that must be considered along the process and lastly suggesting a model that could be easily replicated and applied to the majority of the existing buildings in the Mediterranean context. The case study does not represent an unmodifiable prototype; on the contrary, it appears to be a starting model on which basis the necessary adjustments (at least in terms of structure and species choice) must be specifically applied.

The case study aspired to add to the research on green roofs by defining an easy prototype and a replicable method in order to accelerate the process of transformation of existing roofs into green ones. It focused on the benefits that could derived from a widespread application and aspired to make them known in order to overcome those restraints that usually stop people from undertaking this transformation.

A green roof inhabited by humans and plants implies mutual benefits and displays easy management, reasons for which the outcomes of this research can be positively considered and analyzed while grouping them in three classes of interest:

The first is environmental sustainability: the building was designed by considering all the environmental aspects that it would face during the whole process from its transformation until its dismantling, as well as those that it will influence. Therefore, the structure was minimized in order to reduce its loads on the existing building, as well as to diminish the weight of constructive materials involved in the transformation. The construction process would also allow for an easy dry assemblage and successively disassemblage of components. The juxtaposition of “living boxes” and “houses for plants” would generate a bioclimatic effect at the floor level: this behavior would achieve comfortable conditions for the whole year, greatly minimizing the use of cooling or heating systems, as the transparent courtyards would register a temperature range between 15 and 25 °C throughout the year, with temperatures being mitigated in winter via exposure to the solar radiation and by cross ventilation in summer. These spaces would act as intermediate spaces that would mitigate the temperatures of the rooms next to them during the whole year.

The presence of the courtyards, acting as a green roof, would positively influence the floor level below by improving its thermal conditions and insulations.

Lastly, this compartmented green roof, replicated at a bigger scale in the city, would impact the urban heat island effect and give a major contribution to the absorption of CO_2 while simultaneously increasing the number of the students' accommodations within the city.

The second class of interest is economic sustainability: though this kind of transformation usually entails a conspicuous amount of money, it is possible to assume that this would be successively rewarded by the presence and payment of students living in the college.

Another primary advantage of this comes in the integration of the self-production of vegetables (with a reduction of the students' expenses) and the presence of PV cells that are able to collect more solar energy than what is strictly needed.

The third class of interest is social sustainability: the presence of green areas has well-known positive effects on humans' mental, physical, and social health [15,21], in addition to the advantages derived at the urban scale. These are all reasons for which the promotion of green roofs must be encouraged and boosted.

A compartmented system, like the one of the case study, is based on the presence of a green area that complements each room by providing them with external spaces for physical and mental relaxation, as well as social interaction, all of which are nowadays more than fundamental.

In terms of management, the whole green roof would be entrusted to a municipal community of elderly people. Green courtyards have been studied in order to maximize their flexibility and use, as well as to favor an easy handling of the roof garden: (i) the use of pallets, used as a terrain container, limits the overloading of construction elements, with advantages for the existing structure and its adaptation; (ii) following the triennial rotation method, the use of pallets also allows for an easier relocation of plants as needed based on their radiation and temperature needs, as well as the easier watering of the plants; and (iii) the juxtaposition of specific species that provide mutual benefits helps for non-using plant protection agents, thus limiting the counter-effects that come with their use.

Urban and building ecosystems are therefore the key concepts of this case study that aimed to represent a three-dimensional (environmental, economic, and social) prototype that would rely on the cohabitation of humans and plants. Green roofs are elements that have been identified as fundamental in the cities of tomorrow. Sustainable development is what the case study aspired to achieve through an in-depth analysis of this process of transformation while considering all the aspects involved in order to respond to queries about combinations of nature and artifacts.

5. Conclusions

The city of Milan aspires to become much greener in the near future. There will be a sharp increase in the addition of green areas to the city in the next 10 years (Figure 10).

The municipality is actually encouraging the transformation and realization of green roofs, together with green façades and free ground levels, in order to increase the amount of green areas into the city and, therefore, to enhance air quality. As testified by research [22], covering all the roofs, façades, and free ground spaces of the city with plants would allow for absorption of 614,732,749 kg/year of CO_2 and the production of 905,904,169 kWh of energy with savings of 2,093,324,364 kWh/year for cooling and 206,603,911 kWh/year for heating. The advantages of increasing green areas in our cities are undeniable. What is still under experimentation and what this research wanted to highlight is what kind of technique could be applied to reach this objective; this is worth investigating more in order to promote and encourage this transformation.

Figure 10. The green areas in Milan in 2020 (**left** image) vs. 2030 (**right** image) [12].

This research and its highlighted results suggest the importance of investigating the topic. The buildings of the city of Milan that could be subjected to this kind of transformation should be further explored; following the research conducted by Joshi et al. [4], future investigations could focus on the structural limitations applied to existing buildings while acknowledging that, as shown by this case study, all building roofs could be turned into green ones if subjected to the necessary structural adjustments. Consequently, the exact amount of CO_2 emissions that a green roof, like the case study one, would be able to absorb should further be investigated. All of this should be done in order to prove that the case study represents an efficient prototype that, if repeated on a larger scale at the urban level, could provide the nature and accommodations that cities are currently lacking.

As suggested by Rogora A. [17], the second fundamental role of institutions should be the experimentation and promotion of "pilot" experiences that could work as catalysts and activators of virtuous processes regarding sustainable themes that could be assumed and later repeated by other public institutions, private investors, companies, and individual citizens. This was the main aspiration of the case study—to find an innovative way to apply green architecture in a way that could be easily repeated in a Mediterranean context, with the final goals of mitigating the heat island effect and bringing benefits to a city and each of its buildings [8].

The research, together with the analyzed case study, aimed to understand and activate the potential of plant material to provide ecosystem services and improve the microclimatic conditions for healthy and livable cities [23].

The need for accommodation can no longer be interpreted as a quantitative problem, i.e., the necessity for shelter; it must also be considered a qualitative problem, i.e., to have a comfortable ambient environment in which to live and socialize. In order to increase the number of accommodations and services in our cities, it is necessary to increase the amount of green areas, which are fundamental for humanity's well-being. It is therefore necessary to develop new ways to combine these two aspects in order to create a system of green infrastructure that is able to enhance our quality of life.

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