Università degli studi di Milano-Bicocca

Data Science Lab for Smart Cities

Final Essay

Geospatial analysis of the city of Milan for Vertical farming hub suitability: a possible government action on rundown areas

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Abstract

As a result of the constant increase in population and scarcity of natural resources, technological evolution is pushing more than ever towards techniques aimed at reducing environmental impact while ensuring efficiency and productivity.
The following report reports on an important innovation in agriculture: Vertical Farms.
The benefits of this new technology are reported, focusing on the social and environmental impact that the construction of new hubs in different areas of the city of Milan would have. The final objective is to propose new policies to address the gap between vegetable consumption and production, favouring the wellbeing of citizens, reducing environmental impact, food waste and inequality.
A geospatial analysis is conducted on abandoned and/or disused areas that can be reached within 15 minutes on foot or by bicycle, to identify the best areas according to certain indicators. Analyses were conducted taking into account three different hub construction hypotheses. In addition, the effects of individual hubs and aggregate effects were evaluated.
Some identified areas are able to support the consumption of the neighbouring population.

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1 Introduction

Over the last decade, the topic of agriculture in large cities (UA) has been the focus of numerous multidisciplinary studies worldwide. This is because sustainable agriculture has multiple positive impacts such as resilience, self-reliance, and social, economic, and environmental sustainability.
Central for modern cities is the role of urban agriculture toward social-related aspects and pressing issues, such as food security, community capacity, and equitable food systems.
In addition, involvement in growing practices and food production, can contribute to community services and charity, education and social inclusion, as well as a tool for nonprofit organisations and food planners to achieve their missions with disadvantaged communities. Other issues towards UA concern climate regulation, greenhouse gas emissions, air quality, biodiversity, storm-water runoff, rainwater harvesting, cultural and sustainability, health issues, while controversies around water and energy management. Also an important issue revolves around the use of space in order to decrease building areas and favour the collection and distribution of food.
The main issues can therefore be summarised in the following points:

- Land use and inclusion in society
- Environmental impact
- Socio-economic-health impact

One solution to the problems of the UA is provided by Vertical Farms (VF). Recent studies have indeed demonstrated the positive impact of VFs in cities all over the world [BT17].
Vertical farming represents a revolutionary approach to agricultural practices, offering a sustainable and efficient solution to the challenges of traditional food production. With the global population steadily increasing and land availability becoming limited, vertical farming presents an innovative method of cultivating crops within vertically stacked layers.
By harnessing cutting-edge technologies and creating controlled environments, vertical farms maximise space utilisation, reduce reliance on conventional agricultural methods, and offer promising solutions for achieving food security and environmental sustainability.
The first forms of green buildings date back 2500 years, with hanging gardens in Babylon of King Nebuchadnezzar II. Since then, many other civilisations have introduced various forms of vertical greenery and plant growth. Spatially closest to the researchers of this paper, the Roman civilisation was the first to successfully introduce vine-supporting structures, allowing the verticalisation of the plant, reducing the stress on the stem, all with a smaller footprint.
The first modern Vertical Farming structure, however, dates back to 1992, when the Menara Mesiniaga was built in the densely populated capital of Malaysia. Over the course of the 20th century, the idea of VF has expanded by incorporating best practices and technologies in waste reduction, planned production, climate, ventilation, irrigation, nutrients and irradiation of plants from renewable sources with centralised management, constantly monitored and corrected.
Unlike traditional agricultural techniques, vertical farming can have both a direct and indirect influence on a number of aspects of the city: economic, environmental, adaptive, social, urban/landscape, recreational, research, tourism, educational, inclusion and sharing. These benefits strongly depend on many aspects, such as design, products grown, the size of the hub, infrastructure, local and climatological conditions.
In general, one can group the types of impact into three categories: economic, social and climate.
The impact on these three aspects depends mainly on the application dimension. According to the literature [ZKK21] there can be three dimensions:

- Macro Scales
- Medium Scale
- Micro Scale

In this paper we will analyse the micro-scale impact of vertical farming in the city context of Milan. This choice is due to the recent transformation of Milan into independent districts detached from the idea of a cohesive city. Examples of this are the districts of City Life district or Garbaldi district [Bon19].
At the economic level, the main impacts on the micro scale are the possibility of developing new alternative districts that favour inclusiveness and accessibility, the possibility of combating food waste and building an economy of sharing based on mutual exchange between residents and with local activities such as restaurants.
From a social point of view, vertical farms help to increase participation and at the same time combat social exclusion by creating a new standard of shared space. These new areas also make it possible to increase tourism and build new recreational spaces.
Finally, from a climate point of view, vertical farms adapt to climate change by decreasing consumption and waste and favouring the development of a circular economy.
These impacts are summarised in the following figure.

VF IMPACTS		
ECONOMIC	SOCIAL	CLIMATIC
Modular plant or vegetable cultivation is easy both to assemble and to dismantle, which results in its low cost, low investment risk possibility of alternative development in city centres, green facades and green roofs improve the energy properties of buildings, thus reducing heating and air conditioning costs.	Creating new, intimate neighbourhood spaces supporting small social groups and creating small gardens for the elderly and the disabled in the immediate vicinity of their residence.	The possibility of of creating new aquatic-plant-animal mid.o habitats sustainable (e.b food aquaponic production crops), and achieving the 3Rs (reduce, TeLse, and recycle) on a micro scale. On a local scale it's much more possible to create a self- sufficient zero energy and zero waste system, the possibility of testing new green technologies supporting vertical agriculture before introducing them to cities on a larger scale, the possibility of using organic waste for the purposes of vertical agriculture, improving the energy efficiency of buildings - reducing heat loss and air conditioning costs by introducing vegetation on the facade, protection of the building structure - protection against UV of radiation, temperature fluctuations.
COUNTERACTING FOOD LOSS The possibility of creating local vertical farms based on existing buildings (green walls, green roofs, green architecture), the possibility of using almost any space of the building for the cultivation of plants - vegetables, fruit, herbs (e.g. terraces, roofs,balconies, corridors in buildings).	PARTICIPATION The possibility of f creating places for social participation supporting e.g. the harvesting of local crops, the posibility of organising workshops based on multifunctional city farms, trainings courses involving the local community.	ADAPTATION TO CLIMATE CHANGE Adaptation to to climate change with the help of of properly designed "green'" architecture, and lower energy consumption by increasing the thermal insulation properties of buildings.
THE ECONOMY OF SHARING On the basis of new neighbourly spaces, the creation at places of exchange of goods by residents.	COUNTERACTING SOCIAL EXCLUSION Counteracting social exclusion by creating a new quality of neighbourhood space.	LANDSCAPE Making downtown buildings more attractive in the form of green roofs and green facades, and the possibility of creating new canons of aesthetics in the form of green architecture of multi-functional buildings (office buildings, vertical ecofarms, catering services).
	TOURISM AND RECREATION Creating new, resident-friendly, intimate neighbourhood spaces and increasing the attractiveness of the area due to the aesthebtes of new green architecture.	SUPPORTING ECOLOGICAL CORRIDORS Vertical greenery on a local scale is part of ecological micro- corridors and biologically active surfaces (hedges, squares, lawns, rain gardens).

2 Research objective and indicators

The aim of the following report is to provide an initial feasibility analysis of the realisation of Vertical Farming Hubs (HVF) in the areas owned by the city of Milan that are listed as forsaken as well as in a state of degradation.
Starting from the fruit and vegetable production gap of the current Urban Agriculture (UA) of the territory of the city of Milan [PL19] we have provided a possible estimate of the response to the demand for the product, by means of the production located within the city territory. We have also estimated the average production with different VF production techniques, the number of residents that each Hub is able to support within a 15 minute walking or cycling radius, the number of restaurants within the same radius to estimate the reuse of waste for composting and finally an estimation of the number of jobs that each Hub would require.
The results of the research and various geospatial analysis techniques on abandoned and neighbouring areas led us

to consider 10 hubs in total.
Ideally priority could be given to households under a certain ISEE threshold that adopt virtuous and sustainable behaviour.

3 Problems

3.1 Identification

Our research will focus on analysing the problem of the availability of 0 km products, or in any case products produced in neighbouring areas, from which the city of Milan suffers as a high-density and concrete city. The issue of non-sustainability is increasingly felt, and this also includes the sustainability of the entire agrifood chain; from seed to table.
By virtue of what the city signed in the 2015 Milan Urban Food Policy Pact (MUFPP) during the Expo, the city has an obligation to commit to guarantee healthy and accessible food for all, preserve biodiversity, and develop and promote efficiency and active research [FAO].
The pact was signed by 260 cities around the world for a common vision towards sustainable food policies, while providing a real framework for monitoring achievements [Mild]. On the basis of some of the points indicated within the aforementioned framework, we have developed this research, with the aim of providing possible answers, albeit insufficient to resolve them completely, to problems such as: curbing and managing food waste in the catering sector (also Action No. 26 and 36 of the MUFPP); encouraging a redevelopment of degraded areas, paying attention to land use and identification to potential production areas (also Action No. 22 of the MUFPP); make available a production and distribution of products with a very low environmental impact (also Action n° 25 and 27 of the MUFPP); ensure access of low-income residents and vulnerable groups to food assistance programmes (also Action n° 14 of the MUFPP); do not limit VF research to private sectors (also Action n° 19 of the MUFPP).

3.2 Importance and city impact

The city of Milan is currently unable to achieve food self-sufficiency and the Lombard capital population growth [Rev], will further aggravate this finding.
Intrinsically, the AU alone cannot meet the demand of an ever-growing, particularly dense and steadily decreasing area of agricultural land. This direction envisages a steady increase in external dependence for supply, resulting in increasing distances, gentrification, land use and further unbalancing of employment in the various productive sectors[PL19], according to the study conducted by CREA, Research Centre for Agricultural Policies and Bioeconomy. The same study focused on the production capacity of the UA of Milan (which includes private residential gardens, public gardens, agricultural fields, up to unauthorised vegetable gardens, according to the photo interpretation carried out by the same researchers [PL16]) showing not only that the harvest produced is not sufficient to meet the needs of its inhabitants, but also an obvious need to import the significant production gap (not always coming from neighbouring regional areas or from Italy itself), resulting in increased pollution for road transport, spoilage of part of the harvest, use of pesticides and other pollutants in their production on the ground.
The current area devoted to fruit and vegetable production is estimated to be 1 km^2 that can satisfy in the best production scenario about 63700 people.
Given the intrinsic nature of cereal and wheat production, as well as the extent of this production in the Italian landscape, our research was limited to the gap analysis of fruit and vegetable products.
The importance of conscious management of public land and investment in research is becoming increasingly clear, in order to comply with the 'Milan Urban Policy Pact' signed during Expo 2015 between 180 countries, of which Milan has become a participant and promoter, to achieve a sustainable food production system that is as efficient as possible [FAO].
The development of the Hubs with the active or total participation of the Municipality of Milan would in fact guarantee research activities aimed at efficiency and increased production, but also dissemination of know-how, in favour of an increasingly topical issue such as the accessibility of sustainable and healthy food, in view of an ever-increasing growth in the population of cities and an increasingly unpredictable climate that threatens crops. (A few points that we can address or try to counter with our research and our VF Hubs)
The construction of Hubs of this type has an additional objective: to restore dignity to degraded areas, for an improvement in urban decorum and the safety of those areas. In fact, it is estimated that there are approximately 178 unused and degraded areas on the territory of the city of Milan, with a total area of approximately 0.63 km^2 (0.34% of the entire surface area of Milan). These areas may be a potential threat to the security of the citizenry as, if poorly supervised, they are easy access for criminal activities or a refuge for homeless people in poor sanitary conditions.
The facilities will also provide a zero-kilometre production of vegetables, reducing the carbon footprint of production and subsequent distribution by road expected from traditional fruit and vegetable production in the area. The use of advanced techniques such as hydroponics and aquaculture would also result in 90% less water consumption than traditional field-based agriculture [Al-18],relying in fact on water recirculation with constant addition of nutrients and fertilisers, as well as potential collection in cisterns, specifically located on the sides of the buildings, to

collect white water from the eaves over the entire surface of the Hub's roof.
Traditional agriculture is in fact known for its poor efficiency in terms of water use. Most of the water is actually wasted and absorbed by the fallow land; with the prospect of increasingly scorching summers, increasingly scarce rainfall and the risk of natural disasters of varying magnitude and severity.

3.3 Indicators

Gap in feeding Population %

The existing gap between vegetable production in the Milan area and the estimated needs of its population (analysis conducted by CREA) is assessed: this value will be used as a benchmarking to assess the production potential of the VF Hubs as a whole and the ability to reduce the gap. With reference to the photo-interpretation analysis of the research conducted by CREA, the agricultural areas of UA in Milan, destined for horticulture, are 98 hectares (about 1 km^2), i.e. 4% of the total area of agricultural land, contributing, in the best open field horticulture production conditions, 15.7 square metres per person per year.

Amount of abandoned areas on Milan's land (also indicator no. 27 and 29 of the MUFPP)
This index indicates the absolute and relative value of degraded areas on Milan's land surface. Analysing the PGT 2019 dataset, 178 abandoned areas were found and a total of 0.63 km^2 (0.34% of the entire surface area of Milan) was calculated from the surface area of each abandoned area.

Access to km0 Horticultural production (also indicator no. 19 of the MUFPP) The indicator shows the number of people who are covered by a 15 minute walk or 15 min Home Delivery by Cargo Bike, considering the buildings around the various VF Hubs. It is calculated as the number of buildings for average residents per building (28 = ISTAT data) covered by 15 walk or 15 min Home Delivery by cargo Bike.
The number of residents depends on the location of the hubs.

Average amount of food waste produced by the restaurant industry(also indicator no. 33 of the MUFPP)
The index considered here was calculated as the average value of waste produced by restaurants around each VF hub, which can potentially be used by them as a new resource and fertiliser in fruit and vegetable production. An average value of 50 kg of food waste produced in the restaurant industry in Milan per day is estimated, including preparation waste and uneaten dishes. Considering the number of restaurants in Milan, the amount of waste is estimated at 2049.6 tonnes per week. [Milb] [Mill].
The total number of restaurant was calculated within the area of 15 min Walking distance, in order to minimize the transportation emissions.

Employment increase (also indicator no. 21 of the MUFPP)
Each VF Hub, depending on the cultivation methods used and the distribution services it adopts, requires a variable number of employees and specialised figures. An average value of workers needed of per 100 square metres for each Hub has been estimated, taking as a basis for calculation the number of employees of the PlanetFarm company [Far] [Rep] retrieved from the balance sheet published in the companies register and the areal extension of the building in Cavenago Cambiago (MB) (8000m^2) calculated with the Google Earth tool for the plotted areas.

4 Data analysis

4.1 Data and preprocessing

The main data sources for this study were obtained through the geoportal of the Municipality of Milan [Milh], the geoportal of the Lombardy region [Mili]. The analysis was limited to the area of the city of Milan, with a view to broadening and deepening the issue of non-sustainable production advanced in the article by Giuseppe Pulighe and Flavio Lupia: Multi Temporal Geospatial Evaluation of UrbanAgriculture and (Non)-Sustainable FoodSelf-Provisioning in Milan, Italy. The city, at the time of our analysis, has a surface area of 181.7 km^2 [Ist15] and a resident population of approximately 1'406'242 (2019) [Ist19].

Topographical DataBase of Milan (DBT) [Mila]
DBT dataset, presents all topographical elements useful for urban planning in 2020, with a total of 470'200 records, classified according to class, stratum and theme of the urban element [Loma].
For our analysis, we particularly considered all buildings in the neighbourhood of the distance abandonment areas, which had class code "EDIFC" (020102 Building) and later those in the calculated area of Walkability/Cargo Bike for residential use only.

ImmDegrado Area[Milg]
Abandoned areas in the PGT 2019 of the Municipality of Milan and their geometry. These are privately owned abandoned buildings that could be purchased by the Municipality of Milan, at a subsidised price, given their reduction in buildability to a maximum of 0.35 sq.m/sq.m and the loss of volumetric rights if they are not redeveloped within a maximum period of time [Mile].
The dataset presents useful information for our analysis regarding the address of the abandoned area, the category of use and the geometry of the area (both polygons and multipolygons present).

ImmDegraded Points
Indicator points of abandoned areas, as above, in Point type. [Milg]

The above datasets were downloaded as *.zip* folders and checked for completeness. In particular, for the datasets relating to the degraded areas, the presence of the relative 4 formats necessary and/or useful for geospatial analysis (*.dbf*, *.prj*, *.shp*, *.shx*) was ascertained for each file contained in the folder.
The DBT dataset was contained in a single file in *.gpkg* format, easily readable by major libraries such as Geopandas.
Given the volume of observations contained in the DBT dataset and the slowness in writing and reading it, it was decided to transform all the files used into Geofeather files, with a considerable increase in speed in reading (x2) and writing (x5) (documentation benchmark) [PyP].
After each file import, before being analysed by the various functions we produced, the files were transformed to standardise the projection used by the various technical offices of the Lombardy Region and that used by Folium with the OpenStreetMap map base (*EPSG:4326*).

4.2 Forsaken buildings

Three different approaches were used for the analysis of abandoned areas: renovation and redevelopment of the existing building stock; construction of new hubs in the abandoned areas; merging of adjacent abandoned areas and subsequent construction of new hubs.
The analysis of the existing heritage is the approach that has required the least attention to the areas, as the regulations allow for the possibility of reconstructing a building, even one that has been heavily dismantled of its structure, on the original perimeter, without taking distances into account, maintaining the same volumetric footprint; in fact, making the intervention fall under the category of building renovation [Lav].
In this regulatory perspective, we have considered the building stock lying on brownfield sites with at least 65% of the building envelope to be owned. In the case of multiple buildings, 2 buildings were considered for renovation purposes if the areal area of the smaller building exceeds 50% of the larger building, otherwise only the building with the larger areal area.
In **Figure 1** we can see an example of the found buildings in 6 different areas.

The second hypothesis for the reconstruction of new buildings took into consideration the present regional and municipal regulations on land use. In particular, we ascertained in advance that the urban regeneration of abandoned and degraded areas was not bound by stringent regulations on change of use for Vertical Farming hubs, also considering the nature of public interest to which it would refer according to Articles 40 and 40 bis of the REGIONAL LAW of 11 March 2005. [Nor] [Lomb] [Lomc]
The distances to be maintained in the case of new construction as referred to in the PGT. Implementation Rules and Text RE 24-02-2016 were assessed as follows [Milj] [Milk] [Milf]
In particular, Art. 85 and 86 of the RE Text 24-02-2016, distances to neighbouring buildings of at least 10 metres, distances to the perimeter of other properties of at least 5 metres (without cadastral areas, 5 metres on each side were used, with negative buffer) and distances calculated from other buildings with window frontages as sin(30°) x Hub height and thus at least 5 metres.
Neighbouring buildings were identified by considering the neighbourhood of the buffered areas, always relating the relative distances from metres to decimal degrees. [Milf] [Milc]
In **Figure 2** we can see the previous 6 areas reduced by the distance limits.

The third hypothesis examined evaluates the possible presence of adjacent brownfield areas, which are then unified and considered in their entirety. For research and adjacent areas, the intersections of the buffered areas of each deprived area were assessed.
In **Figure 3** an example.

Of the areas defined according to the distance constraints, the potential locations of the VF hubs were calculated. We considered it ideal, for the purposes of the analyses and resource production/consumption estimates, to construct the growing chambers with a rectangular plan, calculating the maximum rectangle inscribed in the Polygon created after applying the distance constraints. The polygons analysed presented almost all irregular shapes and in particular non-convex. According to the mathematical literature, solving the problem of the inscribed polygon of this entity is not easy and is affected by the size of the concave area to be considered, resulting in quadratic computational problems or higher if direct approaches are used [Kna+12].

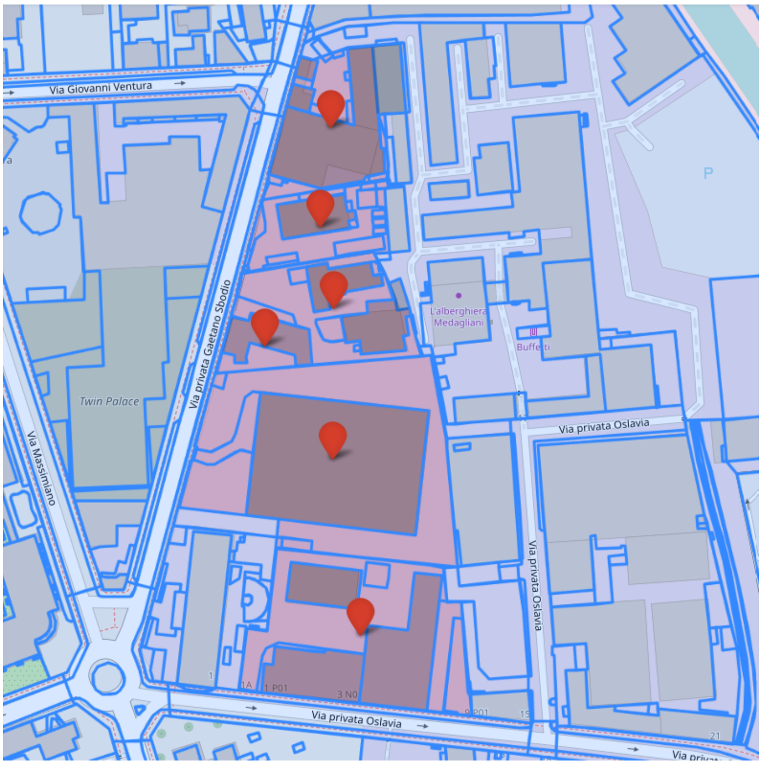

Figure 1: Lambrate distric of Milan and buildings renovation

Figure 2: Lambrate distric of Milan with 6 potential areas and inscribed rectangular Hubs of VF

Many scientific articles have found solutions to reduce non-quadratic computational times, but without providing the relevant documentation for their algorithmic construction in common programming languages [Cab+16].
For this reason, we decided to create and implement from the ground a simple and functional algorithm based on metaheuristics [SG13].
As a first step, masks composed of hexagons with a side of 3 metres were applied to the individual concave areas and only the hexagons within the polygons were considered. Subsequently, hexagons and the iterated expansion of its neighbours were randomly evaluated, constructing a rectangle from the figure composed of the union of the hexagons, circumscribing its perimeter, and evaluating in each case whether this rectangle lay within the polygonal area being evaluated. In the **Figure 4** an example.

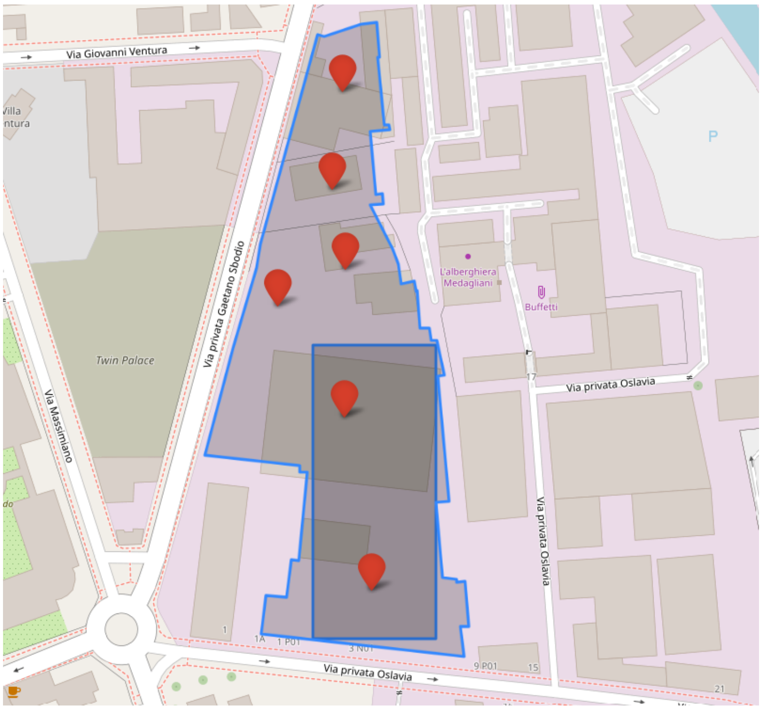

Figure 3: Lambrate distric of Milan with a bigger area and an inscribed rectangular Hub of VF

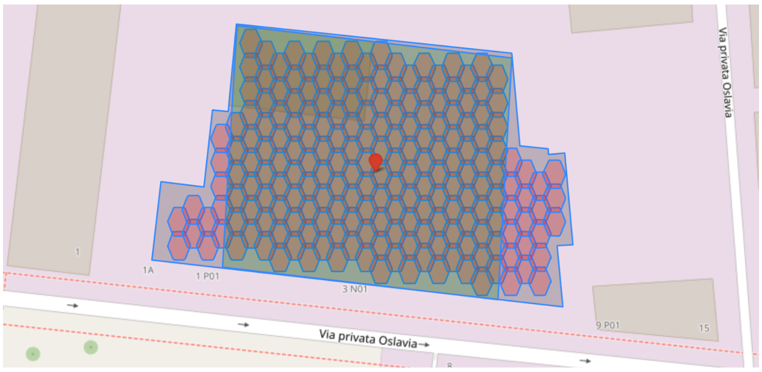

Figure 4: An example of area, the grid mask of hexagons and the finale largest rectangular found

With this construction, we were able to evaluate local maxima and decide to stop the search once several stop criteria had been reached, depending on the size of the neighbourhood, the maximum area found and/or the initial number of the grid of hexagons, in fact obtaining satisfactory and interesting results on convergence. Of course, limits were set by the quadratic nature of the problem, which was further affected by the number of hexagons in the mask (which in turn were a direct consequence of the side size chosen).
In the **Figure 5** the stop criteria code.

```
#STOP CRITERIA:
if (count_maximal_reached >= 10 ) and ((final_area_convex >= 0.80 * r.geometry_newArea.area) or
                                      ((final_area_convex >= 0.70 * r.geometry_newArea.area) and (len(df) > 300)) or ((countDF/len(df) >= 0.50) and (len(df) > 300)) or
                                      ((final_area_convex >= 0.60 * r.geometry_newArea.area) and (len(df) > 400)) or ((countDF/len(df) >= 0.35) and (len(df) > 400)) or
                                      ((final_area_convex >= 0.50 * r.geometry_newArea.area) and (len(df) > 500)) or ((countDF/len(df) >= 0.15) and (len(df) > 500)) or
                                                                                                                   ((countDF/len(df) >= 0.10) and (len(df) > 700))):
  break
```

Figure 5: Stop Criteria

4.3 Accessibility analysis

The accessibility analysis was made by considering the number of buildings that can be reached in a $3.24km^2$ area on foot (according to the area of a square $= side * side = (speed * (1000/60) * 15 * 2)^2$), estimating an average speed of 6 km/h.
The actual accessibility to residential buildings is calculated by considering the connecting roads in each area.
The analysis uses graph theory to find the routes that can be travelled in the set time, at the set speed.
All It is divided into the following steps:

- Graph construction of practicable roads in the given area, using the potential hub coordinates as center of the square.
- Identification of residential buildings within the graph
- Construction of a sub-graph including only residential buildings and connecting roads
- Identification of the potential hub node in the sub-graph
- Calculation of buildings reachable in 15 minutes

The first step then is to derive the graph of the roads that can be travelled in the indicated including all buildings available.
The nodes represent buildings and edges represent the connecting roads. Each node is also characterised by geographical coordinates.
Next, the coordinates of the residential buildings in the same area are found and to simplify the computational operations, each building is associated with the nearest node using a KDTree algorithm [Sci]. A subgraph is then derived where the nodes represent the residential buildings and the arcs represent the connecting roads.
Having constructed the graph of Milan of interest we go on to calculate the number of buildings actually reachable in 15 minutes from the potential Hub.
Using a KDTree algorithm [Sci], the potential hubs are identified.
Taking into account the travel speed and thus the maximum distance that can be travelled, all nodes that can be reached in 15 minutes are calculated using an iterative BFS algorithm [Gee]. The BFS algorithm is a graph traversal algorithm that explores vertices in the order of their distance from the origin vertex, where distance is the minimum length of a path from origin vertex to node.
Finally, the graph is transformed into a GeoData frame [Geo] in which the coordinates of the buildings and the distance to the Hub are saved.
In the same way, neighbouring residential buildings, which can be reached by bicycle, are calculated by setting a travel speed of 20 km/h.
Neighbouring restaurants are instead calculated in the area of the polygon that includes all residential buildings. All graph operations have been executed thanks to the Openstreetmap python library [Ope].
In **Figure 6** a graph example .

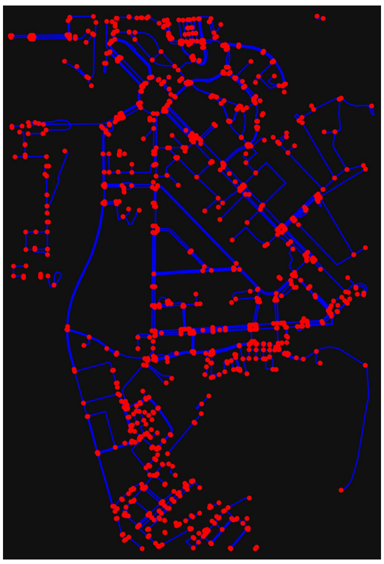

Figure 6: Graph of streets and buildings in Vigentino district

5 Visualization

The following representations were made using the Folium library [Fol], which allows for a dynamic visualisation. The rectangles show the position and size of potential new hubs. Within each rectangle, the net area for cultivation can be seen.
The hubs are marked with markers that show information on the indicators under consideration.
The areas in brown represent areas that can be reached within 15 minutes on foot (inner polygon) and by bicycle (outer polygon), respectively. The intersecting areas have been merged into a single polygon. For each hub there are all indicators in a popup panel divided by walk and cargo-bike accessibility.
Colours have been chosen to help colourblind people.
In **Figure 7** a static example of interactive map.

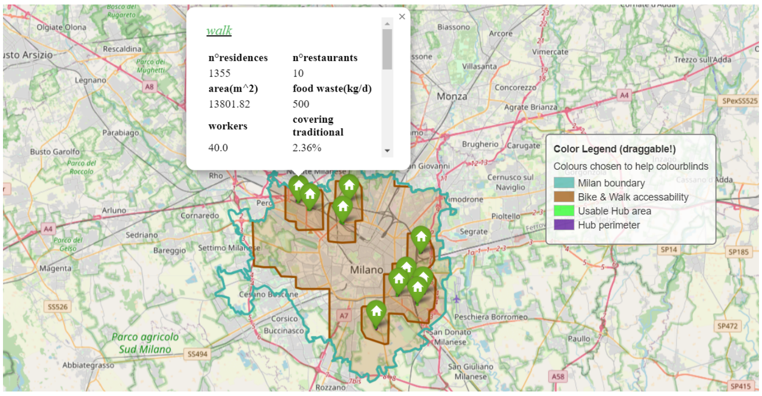

Figure 7: Static example of the interactive map.

If you want play with the interactive map click here

6 Results and Indicators

Premise The results obtained are for single-storey buildings. In many realities, these hubs are spread over several floors, as in the case of Signapore's Sky Greens.

Reduction in Gap in Feeding Population %
Given the average annual production of vertical farms and considering the average per capita consumption of vegetables in Italy, the percentage of people who can be fed was calculated.
According to the available data, traditional agriculture satisfies roughly between 2.35% and 4.7% of the population of Milan. By our estimates, however, Vertical Farms would satisfy between 13.84% and 16.92% (in the case of new building). While the same indicator ranges between 7.64% and 9.34% (in the case of renovation of existing buildings).
In detail the **Figure 8** shows traditional farming results.

	Area (km2)	Productivity	Feeding Population	Feeding Population (% on total 2023)
Vegetable Gardens (existing on land)	0.98 km2	2.5 kg/m2/year	31 869	2.35%
	0.98 km2	5 kg/m2/year	63 738	4.70%

Figure 8: Traditional feeding Gap

The following the **Figure 9** shows the results achieved.

A coverage index was also calculated for each hub. This takes into account the different levels of accessibility. A further distinction was made between traditional agriculture and low-intensive and high-intensive vertical farms.
As the figure below shows, considering the area within walking distance, we obtain an average coverage between 75% and 81%(in the low-intensive case) and between 91% and 99%(in the high-intensive case).
Extending the area that can be covered by cargo-bike, the values vary between 21% and 23% (low-intensive case) and 26% and 28%(high-intensive case).
In the **Figure 10** below there is the covered index in walk accessibility condition.

	Area requalified (km2)	Productivity	Feeding Population	Feeding Population (% on total 2023)
+ 10 VFH	0.20 km2 (only +20.04% UA in Renovation)	90 kg/m2/year	103.646 (Renovation) 187.753 (Area & Build)	7.64% (+ 163%) (Renovation) 13.84% (+ 294%) (Area & Build)
	0.25 km2 (only +25.51% UA in Area & Build)	110 kg/m2/year	126.680 (Renovation) 229.483(Area & Build)	9.34% (+ 198%) (Renovation) 16.92% (+ 360%) (Area & Build)

Figure 9: VF feeding Gap

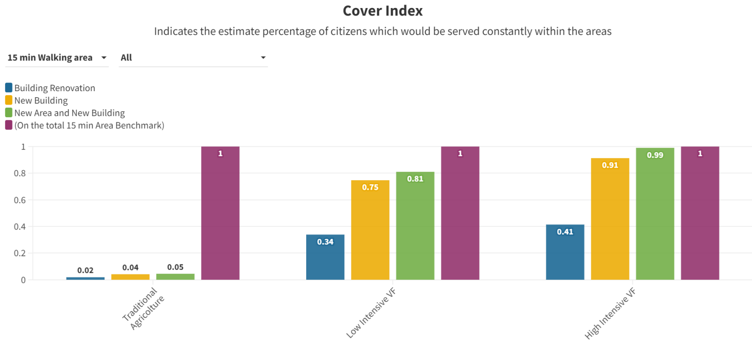

Figure 10: Cover index Walk

In this **Figure 11** the same index in cargo-bike accessibility condition.

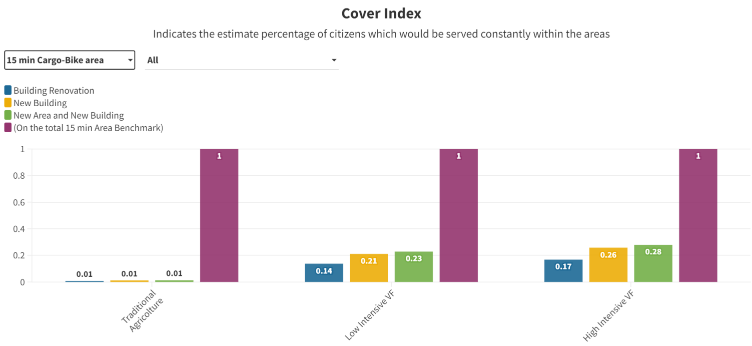

Figure 11: Cover index CargoBike

Amount of abandoned areas that have been redeveloped (also indicator no. 27 and 29 of the MUFPP)
For the purposes of our analysis, depending on the 3 different redevelopment scenarios assumed above, either 10 areas out of 0.24 km^2 (considering the scenario of construction of a new building), 0.25 km^2 (considering the scenario of construction of a new building and new area) or areas out of 0.20 km^2 (considering the scenario of renovation of the original building).
The results are shown in the following **Figure 12**

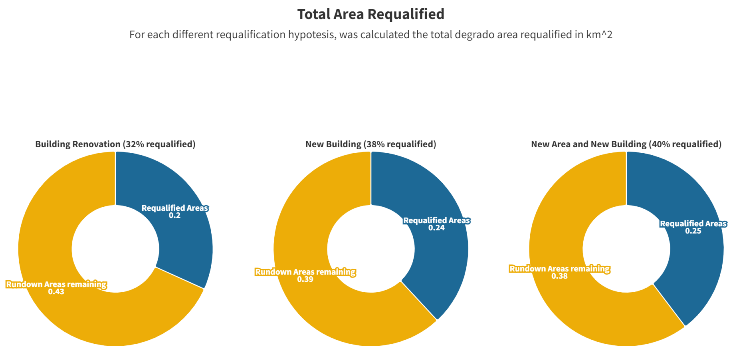

Figure 12: Total area requalified

Access to km0 Horticultural production (also indicator no. 19 of the MUFPP)
In the first two construction scenarios, access is guaranteed to 232288 persons in the first case and 231756 in the second (walk case), the numbers are 822248 and 821856 (bike case). This slight deviation depends on the fact that by hypothesis the polygon on which the centroid was calculated, later used to construct the graph, is different.
In the renovation hypothesis, on the other hand, the number of residents is 264012 (walk case) and 754292 (bike case).
Given the smaller size of the areas covered in terms of accessibility (see **Figure 10**), we assume that the hubs in the third hypothesis are located in more densely populated areas. This assumption is confirmed by calculating the population density per square kilometre.
As the graph below shows (**Figure 13**, some hubs under 'renovation' assumptions are located in areas with higher density.

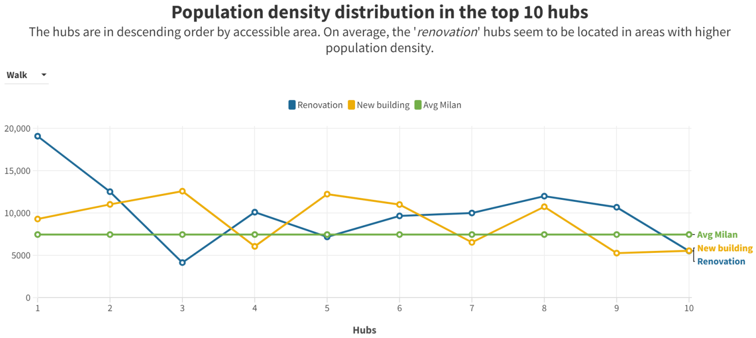

Figure 13: Population density distribution

Average quantity of food waste recoverable for composting (also indicator no. 33 of the MUFPP)
From the locations of the different hubs, between 6.73% and 9.68% of reusable waste has been estimated. Of course, depending on the processing capacities of the composting stations, the amount of food actually collected and/or used may be less, also by mutual agreement between the individual hubs and the participating restaurants, which may in turn provide an initial filtering of the waste delivered.
The following the **Figure 14** shows the results achieved.

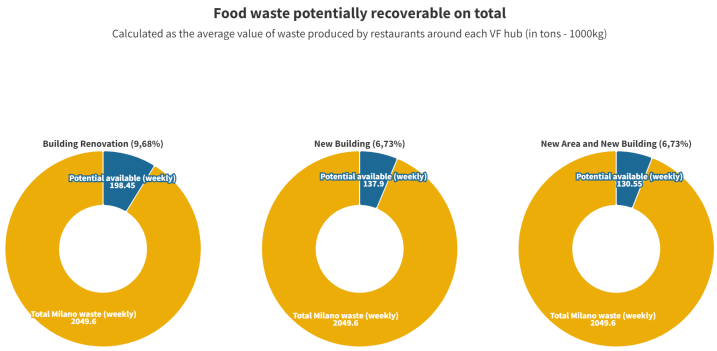

Figure 14: Food recoverable

Employment increase (also indicator no. 21 of the MUFPP)
On the basis of the available data, the following three hypotheses were estimated on average, respectively 42(new building), 46(new area new building) and 20 employees (renovation).

7 Conclusion

Encourage 0-km fruit and vegetables even in metropolitan cities by facilitating access to quality produce for the less affluent segments of the population. Given the resilience that highly controlled production can provide to a natural process of plant growth, VF hubs would provide a constant food source for an estimated portion of the population, especially encouraging the social side of inclusion, access to quality and reduced inequalities among the population, for those who cannot afford access to fresh produce and do not have the capacity or availability of a cultivable urban area [Mee17]. Encouraging multi-purpose use of different spaces, both public and private, such as courtyards, balconies and gardens, for productive, self-production and mutual exchange scenarios of horticultural products, also providing benefits in terms of pollution reduction, efficiency, distance reduction, production sharing, temperature regulation, CO2 emission reduction, water wastage reduction, biodiversity and bee pollination.
A further element that the policy actor should consider is the delivery of products by cargo bikes in the Hub's coverage area, both in terms of travel distances and the quantitative availability of production.

Ethical and social implications
The gap between production and needs still remains wide. For this reason, it is desirable that the service and the harvest in general be made available at subsidised prices to the lower income brackets of the population and to those who are below the poverty line, with active participation (or total control) of the Milan municipality itself in achieving the common goal of social and economic justice as envisaged in the 1st of the 5 priority sheets of the Milan Urban Food Policy Pact

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