THE ROLE OF VERTICAL FARMING IN RE-THINKING AND RE-DESIGNING CITIES WITHIN A CIRCULAR PERSPECTIVE

TEMA
Technologies Engineering Materials Architecture
e-ISSN 2421-4574
Vol. 6, No. 1 - (2020)

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DOI: 10.30682/tema0601i

Highlights

Vertical farming as a new paradigm to connect urban and rural settings.
Urban agriculture sets a new layout for contemporary cities, giving new purpose to urban voids through innovative solutions.
Trento AgroFarm is based on vertical farming as a flywheel to recover an abandoned area of the city in a circular perspective.
Circuits – concerning production, water, energy, social engagement, and the circular economy – are proposed as a means of intervention.
The local community is actively involved in the sustainable food cycle production where architectural fields support this process.

Abstract

One of the key issues of the contemporary city is "urban voids", characterized by disused buildings. Such spaces can be the starting point for a new urban setting, where the city reconnects to the rural environment. Vertical farming can be a new paradigm connecting these often-opposed concepts, bringing several advantages. This paper presents an experimental case study about a typical situation in a peripheral context of the city of Trento. An industrial building under decommissioning is restored as a vertical farm through a circular economy perspective, combining natural resources with ICT, consumption, and reuse processes.

Keywords

Food Innovation, Urban agriculture, Vertical farming, Urban regeneration, Circular economy.

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1. FOREWORD

For centuries, rural and urban settings have been two opposing realities, although strictly interrelated. Today, however, the nature of this relationship is fading. Echoing the words of Andrea Branzi (as paraphrased by Buonanno, 2014, p. 12 [1]), city and countryside are now "sclerotic" concepts: the world is no longer divided in two since the city itself represents a seamless system. Thus, the contemporary city [2] can be read as a unique and inseparable system of constructions and nature, and as such, it needs to be investigated and designed. In fact, urban dynamics are increasingly linked to environmental and ecological issues [3]. The consequences of human activities are not fully understood yet, in particular regarding the effects of settlements and infrastructures on nature, as well as the excessive and uncontrolled abuse of natural resources. 1.7 planet Earths [4-5] would be needed to meet humankind's current needs and absorb its waste. The main crucial factors are above all the urban sprawl high use of land, the agriculture depletion of soil, the pollutant emissions released into the air, soil and water, the waste, and consumption of millions of water liters.

In addition to environmental and ecological problems, the contemporary city has to deal with numerous abandoned and unused buildings and factories: numerous warehouses are underutilized despite being infrastructured. In Italy alone, more than 700 km^2 of factories and 2100 km^2 of surrounding areas are purposeless [6]. This is the result of the profound economic crisis that has affected the country since the late 2000s, but the trend of abandoning large industrial areas is also part of a larger process: as a result of the 19th-century city, human activities are now going to retract.

The research project presented in this paper defines a methodological framework useful to provide solutions to these issues and is applied to an existing warehouse in the city of Trento. The transformations proposed are centered on a system of circuits based on circular economy principles. Urban agriculture, especially in the form of vertical farming, is the key driver of other environmental and social dynamics. Thus, the regeneration phenomenon is accompanied by a development of the area also in terms of energy, water, economic and social sustainability.

2. STATE OF THE ART: BACK TO AGRICULTURE

Within this complex framework, the concept of urban resilience [7] can be applied to the agricultural field, in order to define a strategy able to answer specific questions posed by the contemporary city. The challenge is, therefore, to change direction to a more sustainable and adaptable urban planning towards greener cities. Currently, the experiences of urban and peri-urban horticulture are going in this direction (Food and Agriculture Organization of the United Nations (FAO)) [8]. Food production goes beyond the rural limit, towards something that is increasingly occurring within the city limits or in its immediate suburbs. Today agriculture can play an important role in giving new purpose to urban voids through innovative solutions, thus being an inner component of the contemporary city.

The framework proposed so far is not only a green infrastructure or ecological corridor but also a reality that begins to stand beside the city, supporting and feeding it. To reduce social and environmental costs of industrial agriculture, permanent cultivation initiatives, also called permaculture, are increasingly widespread. The first principle of permaculture is that food has to be produced close to consumers: urban agriculture goes into this direction. Urban farms are becoming more prominent and tend to shorten the distance between the place of production and consumption. Pioneers in this field are the cities of New York and Detroit. In the case of the latter, the city, in crisis for years due to deindustrialization, has managed to reinvent itself through urban agriculture. Similarly, in Italy, the significant increase in the number of municipal gardens stands out among the different types of urban green; in three years, from 2011 to 2014, there was an increase of 30% in the uncultivated public areas assigned on loan for agricultural use to citizens [9]. In Trento, for example, a real *Bank of the Earth* [10] has been set up: it is a collection of uncultivated public and private lands, which owners can temporarily lease to new farmers.

The fusion between urban and rural has so far been hindered by the rigid regulatory constraints imposed by urban zoning, according to which each function is located in a specific area of the territory. The overcoming of this planning model is prevented by an uncertain cultural and social condition, by the industrial crisis, and by the need to transform the consolidated urban territory. Today, urban agriculture provides cities with unique opportunities: it refers not only to the social gardens' trend but also to the multiple possibilities for urban renovation by promoting:

- urban redevelopment, utilizing new production technologies, spatial devices, and design skills that integrate vegetable production at the different scales of the city;
- urban renewal and social inclusion in terms of re-functionalization of space through the creation of social gatherings and new environmental solutions to face climate change;
- educational activities and sustainable processes of the food supply chain through the physical, symbolic, and cognitive approach between producer and consumer.

Among the different forms of urban agriculture, vertical farming [11-15] is becoming a widespread cultivation technique. As a particularly articulated form of cultivation without soil, vertical farming brings agriculture itself to its extremes: it emerged with the development of cultivation techniques becoming the synthesis of the urban and the rural worlds. Vertical farms are food self-production centers: climatic conditions suitable for the production of different types of plants are recreated inside the buildings so that vegetables can grow out of the soil through nutritious watery solutions and with the light transmitted through a LED lighting system.

While many revolutions have changed human lifestyles over the last century, agriculture has remained behind as compared to other sectors. Technological and industrial improvements took over, however, we can only speak of horizontal development, as Peter Thiel defines it in his book *Zero to One* [16]. The indoor vertical cultivation technique aims instead to develop the first process innovation in agriculture, a "vertical development". Some advocates of vertical farming define this technique as the third green revolution, comparing it to the upheaval launched by Apple and Tesla in their respective sectors. "Food is one of the final frontiers that technology has not tackled yet. If we do it well, it will mean good food for all": this is what Elon Musk's brother says (as quoted by Severson, 2017 [17]). In fact, this type of agriculture is a strategy to recover unused buildings, allowing the cultivation on different overlapping vertical levels and guaranteeing the progress of a sustainable approach: food safety, reduction of human activities' impact, containment of land use and emissions of harmful substances into air and groundwater.

The interest shown in this research field by different professional profiles is growing. Some "vertical greenhouses" have already been built in Japan, South Korea, Singapore, the Netherlands, the United States, while others are under construction, for example, in Sweden, Canada, Saudi Arabia, and Italy. In 2012, the first vertical farm in the world was built in Singapore: *Sky Green Farms*. Starting from the very high number of inhabitants and from the hectic lifestyle that has little to do with the rhythms of the natural environments, the construction of a vertical farm in this context aims at making some areas of the metropolis food self-sufficient. One of the peculiarities of this system is the rotation of the greenhouse at the speed of one millimeter per second to allow solar lighting to all plants.

Urban farming [18], and in particular the indoor technique, does not solve the production issue related to the primary sector alone, but it offers unforeseen opportunities integrating food production and architectural renewal in a circular perspective. *Trento AgroFarm* is an experimental project that aims at highlighting how these innovative aspects can be integrated through vertical indoor farming (Fig. 1).

Indeed, agriculture can contribute to developing a circular urban management process, in which the continuous

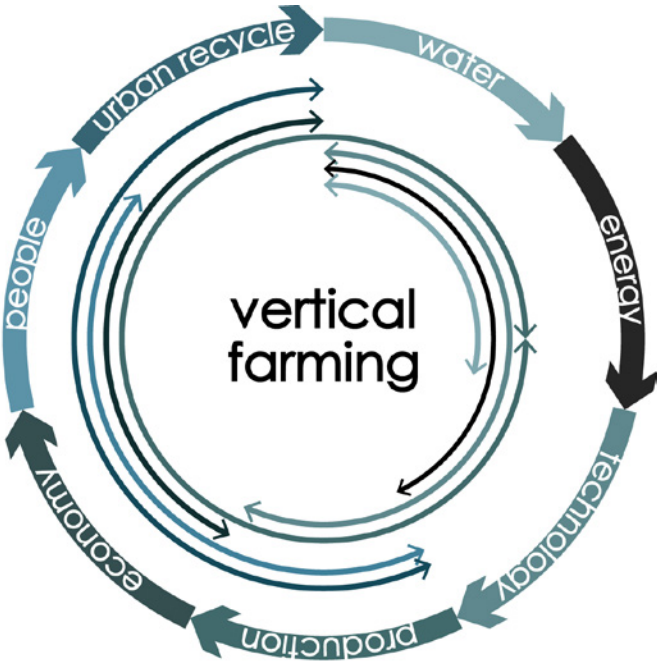

Fig. 1. *Vertical farming. A circular process.*

expansion of cities is curbed by exploiting and redeveloping the existing building heritage. Moreover, it can play a crucial role in coordinating water and waste flows. By also focusing on cultural and social aspects, vertical farming becomes more than just one technological innovation. *Trento AgroFarm* uses vertical farming as a flywheel for the recovery of an abandoned area of the city of Trento. Therefore, it represents an excellent example of the circular economy, able to funnel natural resources, technological inputs, consumption, and reuse (Fig. 2).

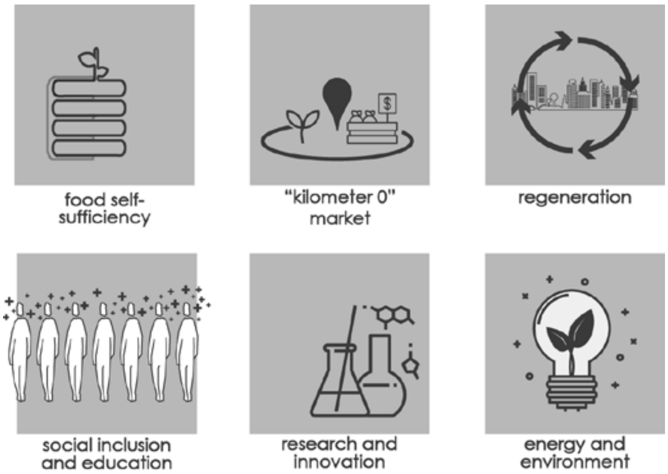

Fig. 2. *Trento AgroFarm goals.*

3. TRENTO AGROFARM: TOWARDS A NEW SCENARIO OF URBAN AGRICULTURE

Trento AgroFarm is an experimental design project that envisions and tests how an industrial urban void can offer an opportunity for urban regeneration and circular economy. This is done by addressing the challenges of water and energy resource efficiency, reduction of the ecological footprint, and empowerment of social dynamics. First, the knowledge framework was settled on a regional and urban scale, in order to describe the environmental, productive, social, and cultural context in which the city of Trento is set. Afterward, the suitable area to this type of intervention has been defined: it has to be an area already characterized by a construction and developed substrate, ready to be converted into a new productive and cultural landscape. A multi-criteria analysis has been drawn, focusing on a series of parameters central to the activity [19], such as the population density, the presence of commercial activities and the real estate value [20], and it was finally decided to intervene on Casa Girelli: the headquarter of a historic Italian wine company, founded in 1959 in Trento (Fig. 3). Casa Girelli, which extends for about 18150 m^2, is located in the Clarina district, a residential neighborhood in the southern area of the city. It is able to offer a large user base for future planned activities, as well as being close to the city center. The place can also weave a network with the other food poles in southern Trento and connects with the vast surrounding green areas and open spaces.

Fig. 3. *Casa Girelli.*

In 2014, the sale of the site and the reclassification of a larger area became a matter of discussion. Despite the solicitation of the property itself, the timeline for this substantial change is still not known and will probably take a long time. Considering the many abandoned areas that receive only *ex-post* buffer solutions, the desire to prevent this abandonment process drove to the choice of this area as the design idea, planning a new life cycle before the site is actually decommissioned. The main goal of the project is to reconcile multiple functions, which support and complete the merely productive aspect, thus designing a pole that catalyzes the interests of a wide part of the population. In addition, agricultural production is drawn back into the urban circuit, making the city more self-sufficient from a food production point of view: a *zero-km* consumption possibility is offered, and educational and research programs lead to forms of inclusion and awareness. The project starts a redevelopment process, from the architectural to the urban scale, which aims to achieve a high level of energy and environmental sustainability. For these reasons, a layout of multiple sustainable cycles has been developed. The different natural and social resources involved work together, following the circular economy philosophy. All the aspects are then summed up into the architectural new design of the site: *Trento AgroFarm* (Fig. 4).

4. AREAS OF INTERVENTION: THE CIRCUITS

A series of circuits (Fig. 5), regulating the development of a vertical farm based on production, water, energy, social, and economic sustainability, have been identified. These aspects have been put into context with the architectur-

Fig. 4. *Trento AgroFarm site plan.*

al qualification of the spaces. Through the intersection of these circuits, it is possible to create a dynamic and resilient structure, fitting within the urban system, feeding it, and at the same time, drawing strength from it.

As for the recovery design of the existing structure, a series of small interventions have been defined to preserve the original feeling of the area, adapting it to the new features and enhancing its characteristic elements (Fig. 6). In particular, the natural elements of water and sunlight provide the project with energy and are transformed into real architectural components. For this reason, among the various aspects analyzed, the focus has been placed on the water and energy circuits, as highlighted below.

4.1. THE WATER CIRCUIT

One of the basic components needed for vertical hydroponic cultivation is water. This technique grows plants with a 95% water saving compared to traditional cultivation, an important aspect considering that the food sector plays a crucial role in assessing the water footprint. The project aims to make the production cycle autonomous from the point of view of water supply. For this reason, *Trento AgroFarm* is equipped with a system for the recovery and collection of rainwater: after having been processed, it is destined to the fertigation system, to undrinkable internal uses, and for the air treatment unit (Fig. 7).

A forecast model of the city's rainfall was created. The statistical-probabilistic study of the data [21] provided the maximum rainfall height values h for a predetermined return time T (20 years) and an annual, daily, and hourly duration. Thus, the SCS (Soil Conservation Service) method was applied to calculate the volumes of water falling on the waterproof surfaces, such as roofs and paved areas. These volumes are then conveyed through a channeling system, which marks the external flooring, into an underground collection infrastructure, made of "first flush tanks". These ensure a first purification step of water from polluting agents. The tanks were sized according to the crops' water needs and to collect the water volumes in case of extreme weather events.

Part of the overall water volume, calculated in approximately 14500 m^3 per year, is stored inside some already existing tanks. Once intended to house the wine, they are thus preserved and re-valued. A percentage of the collected water is destined for hydroponic cultivation. The total stored volume is compared with the water needs of the crops to verify the possibility of water self-sufficiency. In order to have the first indication, all the calculations were referred to a cultivated type-species, lettuce: it has been selected because it is an intermediate-range species and for data availability. The consumption of water is not only related to the intrinsic needs of the plant, but also

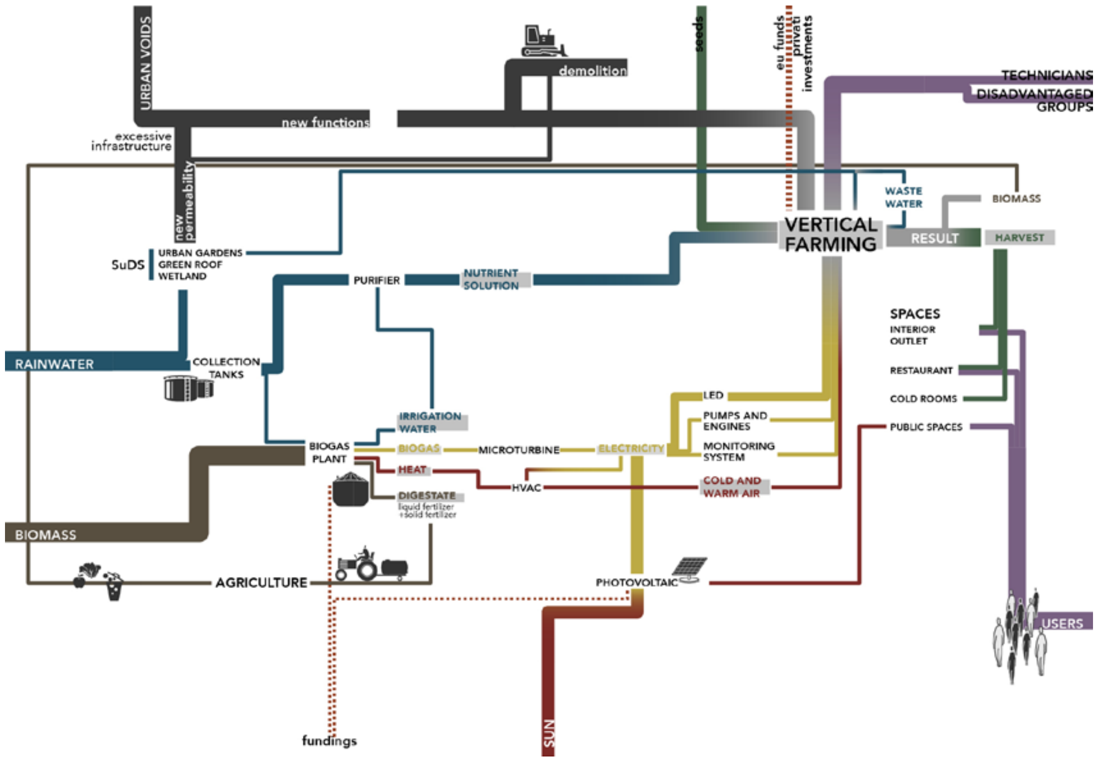

Fig. 5. *Trento AgroFarm sustainable circuits.*

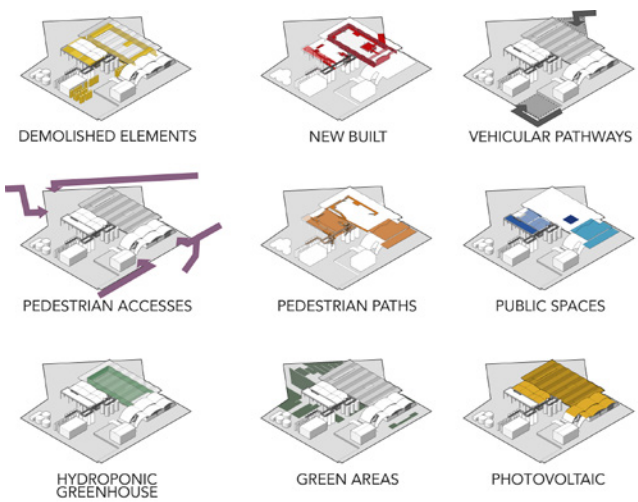

Fig. 6. *Trento AgroFarm architectural strategies and devices*

climatic parameters. Thanks to the control of the internal conditions, it is possible to have a precise estimate of the quantity of water necessary for the growth of the plants.

The water destined to cultivation, about 1100 liters per day for a total cultivated area of 4600 m^2 (surface used on the ground equal to 385 m^2), is managed by the fertigation unit. It is then further treated, distilled, and enriched with nutrients to generate the stock solution. The irrigation system is a closed cycle: in this way, the water that is not absorbed by the roots and does not evaporate is not dispersed but returns to the circulation. The system gets completely emptied only after a certain number of cycles, and the watery solution can be used to irrigate the external green areas and urban gardens within site.

In order to wrap up, the sustainability of the designed water cycle is demonstrated by comparing water needs with rainwater volumes collected. The water that is not necessary for internal uses is released into the municipal white-water network. In this way, the annual water load weighing on the network is about 75% reduced thanks to internal uses and the absorbed water by the permeable soil. The project site, now completely impermeable, is ecologically reconnected with the external spaces, thus increasing the permeability of the surfaces. In particular, in addition to public green spaces, the lot opens up toward the west, granting direct access to a new system of urban gardens. On the other hand, the surfaces still waterproof are used to collect rainwater, as previously described.

4.2. THE ENERGY CIRCUIT

One of the most critical aspects connected to a vertical farm is electricity consumption. In fact, one of the main variables related to the growth of plants is light. The natural source of the sun is replaced and integrated with artificial light. With this in mind, the choice of using a LED system is drawn by several advantages. First of all, the LED allows selecting and transmit to the plants only the wavelengths they actually need, in particular the blue and red spectrum, which are around 400 and 700 nm in the visible range. Moreover, compared to traditional lighting techniques, the use of LEDs leads to high energy saving (up to 70%), as the light is consumed almost completely by the plants themselves. In addition, the light emitted by the diodes produces way less heat than traditional systems, avoiding overheating and the risk of burning the plants. Finally, LEDs are very durable, thus allowing a profitable long-term investment: they have a product life cycle of 7-8 years. On the basis of the plant species' needs, the type of LED system was identified, and therefore the energy consumption related to its use was calculated, with reference to a daily duration of 18 hours.

The second aspect that weighs on the energy bill of the vertical farm is the internal air conditioning system, necessary to maintain a constant and controlled temperature of the cultivated environment. As a point of reference, a 20°C average temperature and 50% relative humidity were con-

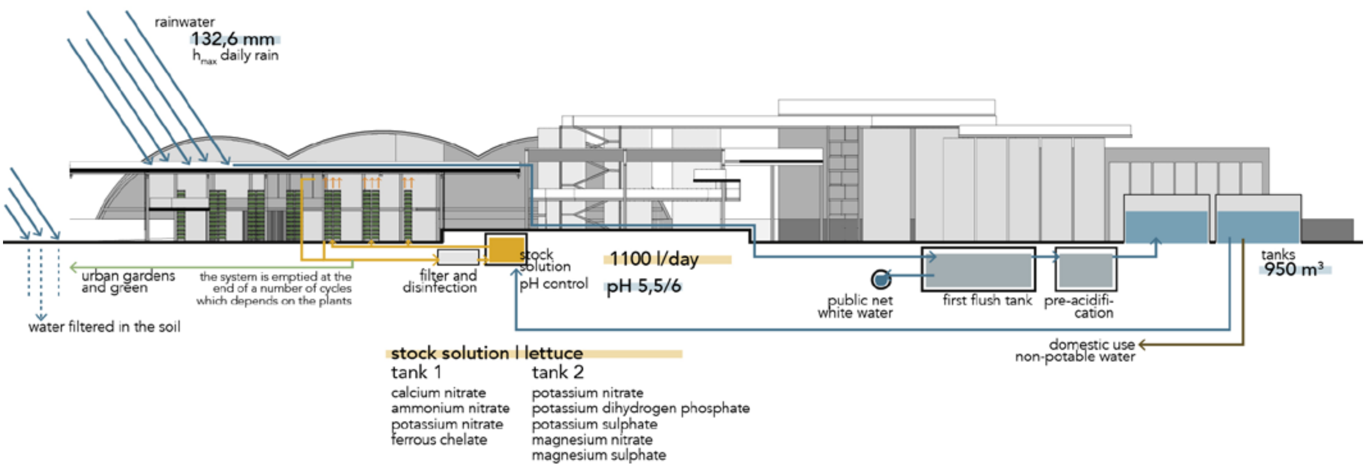

Fig. 7. *Trento AgroFarm water circuit.*

sidered. The hydroponic greenhouse energy requirement has been calculated in the different months of the year for heating and cooling according to current regulations [22-25] so that the power necessary for the operation of the air treatment unit (AHU) was identified. In order to increase the project's energy sustainability, the goal has been to cover the high estimated consumption through renewable energy sources, and in particular, a photovoltaic system integrated with a biomass plant. Photovoltaic has undergone considerable development in recent years, producing an important share of electricity from renewable sources in European countries [26]. On the one hand, the project envisages the installation of a traditional photovoltaic system, which produces the most significant share of energy deriving from solar. This is joined by an integrated photovoltaic system: Building Integrated Photovoltaic (BIPV) is the set of technologies designed to be applied to buildings as an integral part of their envelope. The BIPV also assumes a role in the architectural language. As part of the project, the distance between the photovoltaic cells allows sunlight to filter through into the rooms below with games of light and only a limited reduction in energy efficiency. For this reason, the BIPV was chosen to replace the roof in correspondence with the internal inhabited spaces and the covered external square. The design of the plant has therefore evolved hand in hand with the architectural project.

The photovoltaic system was designed to optimize the energy produced throughout the day, positioning the panels on the surfaces that determine a meaningful yield thanks to their exposure [27]. The approach followed is the one reported in the paper "Effect of module orientation and batteries on the performance of building integrated photovoltaic systems" (Lovati et al. 2017) [28]. Once the different design parameters required were supplied to the free software "POW" (Photovoltaic Optimization Ware), the simulation was started. The result of the process indicated that it was not economically efficient to cover with photovoltaic part of the north-facing roof, because it would have resulted in a minimum contribution in terms of electricity production (Fig. 8).

In general, the results provided have been limited by the area: a sufficient photovoltaic surface has not been provided to the program to cover the high electrical consumption. In particular, the sum of the traditional and integrated plant covers 23% of the vertical farm's energy consumption, with an average installed power of 888.1 kWp. Through the hourly, day-by-day monthly calculation, it was possible to optimize the production in

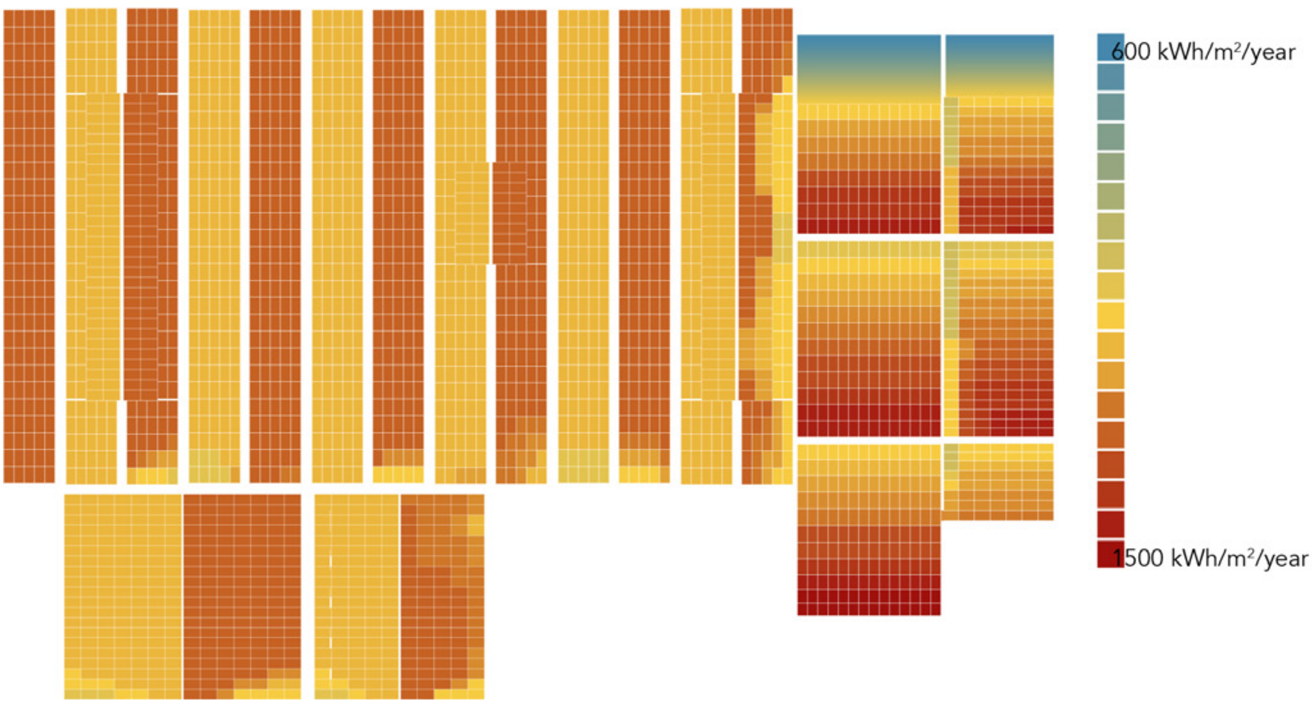

Fig. 8. *Cumulative annual radiation produced by Trento AgroFarm photovoltaic system – rooftop view.*

such a way that almost all the energy supplied was also self-consumed by the building. This result is clear from reading Figure 9.

The energy demand not covered by photovoltaics could be virtually met with biomass: the advantages linked to this choice are manifold. In fact, through the biomass plant, the waste deriving from hydroponic crops would be recovered and integrated with the organic waste produced by the city of Trento. In this way, the discarded waste becomes a starting point for a new production cycle able to generate the energy necessary to make the food circuit work. In addition to the production of electricity, the system also generates heat, generally unused, which also warms up the internal cultivated environment, thus reducing consumption related to the mechanical ventilation system.

4.3. THE SOCIAL CIRCUIT

In addition to the more strictly engineering aspects, *Trento AgroFarm* engages a series of important effects in the urban area, involving the community within the food chain and not only at the end of the cycle, at the time of consumption. Even to a lesser extent, a phenomenon of decentralization of the agricultural function with respect to urban spaces happened in Trento. *Trento AgroFarm* is an opportunity to restore centrality to production, weaving a direct link between the population of the neighborhood and the entire city. In fact, the architectural design aims at creating a strong relationship between cultivated spaces and public paths (Fig. 10). In addition, *Trento AgroFarm* develops programs about consumer orientation and nutrition education. Last but not least, it offers job opportunities for the local population. Taking up the model proposed by *Vertical Harvest*, *Trento AgroFarm* provides innovation not only in agriculture but in the social field, playing a key role in answering the demand for employment by disadvantaged social groups.

5. CONCLUSIONS

This contribution aims at proposing a complex and integrated design path, within which a new possibility of urban regeneration was developed through a renewed link with the rural environment. *Trento AgroFarm* represents a circular system, in which each resource is the starting point or integration of another cycle, affecting different aspects that concern the life of the city and its future. It prefigures the possibility of a new urban productive landscape capable of recovering and generating resources. Blue and green infrastructures for the collection and purification of water and the permeability of the soil [29] are combined

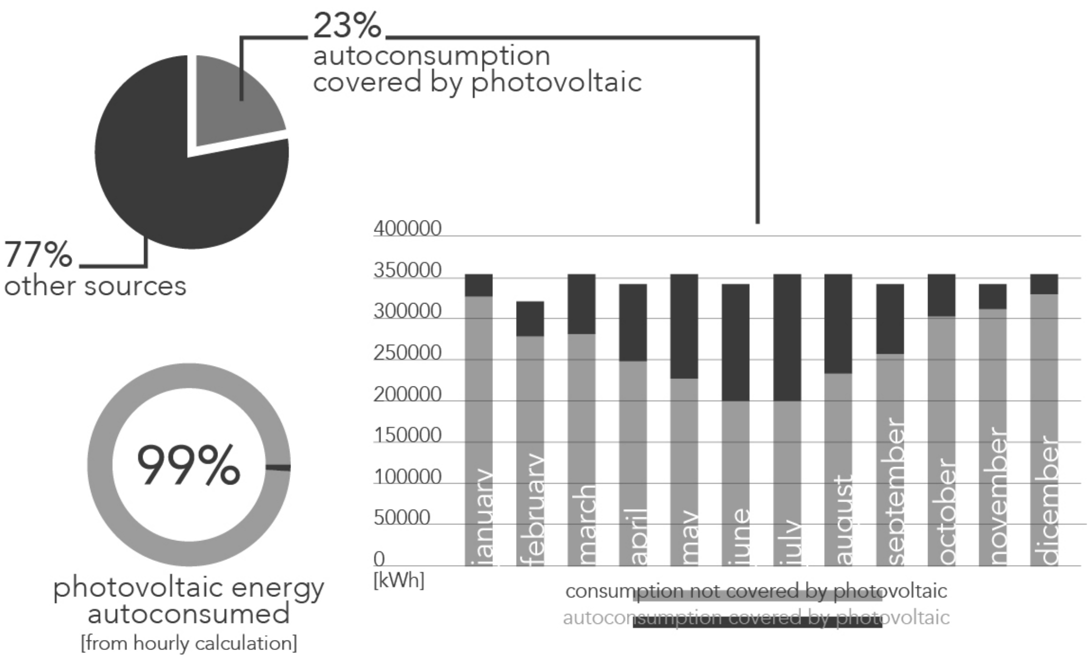

Fig. 9. *Trento AgroFarm. Daily production-consumption of photovoltaic energy.*

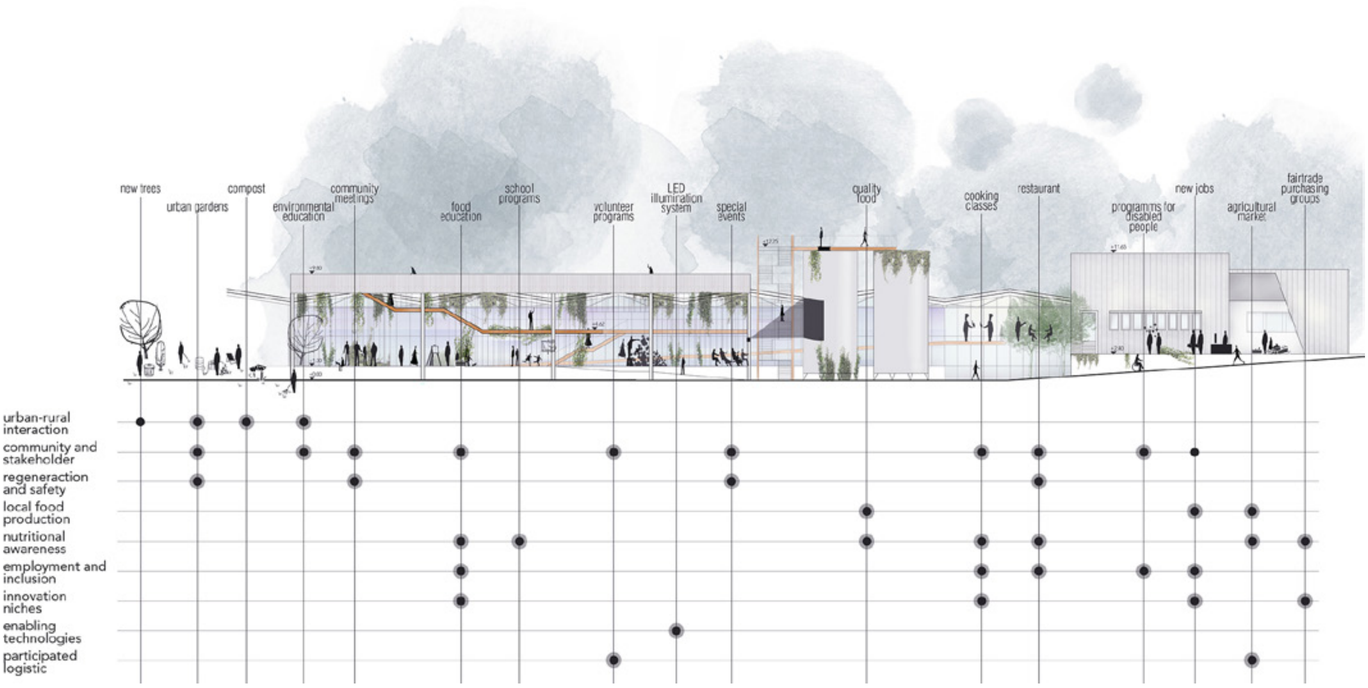

Fig. 10. *Trento AgroFarm. Social development.*

with productive aspects related to food and energy, engaging community, research, and urban renewal. In order to preserve the quality of the urban texture anticipating the abandonment of the buildings, the regeneration process is addressed through different time phases, developing from the beginning basic and pop-up actions able to enliven the site and make the population feel part of the transformation process. In this way, the project offers an innovative system to create conviviality by introducing vertical farming as processes of recovery and transformation of the urban fabric as well as an opportunity to achieve a higher quality of life for sustainable urban development.

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