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Sustainable Urban Agriculture as Functional Hybrid Unit—Issues of Urban Resilience

Magdalena Grochulska-Salak [1,*], Aleksandra Nowysz [2] and Anna Tofiluk [1]

[1] Faculty of Architecture, Warsaw University of Technology, 00-661 Warsaw, Poland; anna.tofiluk@pw.edu.pl
[2] Department of Revitalization and Architecture, Institute of Civil Engineering, Warsaw University of Life Sciences—SGGW, 02-787 Warsaw, Poland; aleksandra_nowysz@sggw.edu.pl
* Correspondence: magdalena.salak@pw.edu.pl

Abstract: The aim of the research is to present a review of urban agriculture as synergic green and blue infrastructure solutions and to evaluate modern hybrid units with biomass and food production, and water retention in urbanized areas. The synergy between technologies of biomass production and water reuse provides the basis for the idea of self-sufficient urban units and sustainable agriculture. The research work defines the criteria and typology for urban resilience solutions. The analyses concern the correlation between production, management, retention, and reuse of water as a part of solutions for the model of a sustainable urban agriculture system in a compact city. The obtained results describe typology for cultivation and production in the modern city. Creating a resilient city connected with requirements posed by civilization concern changes in functional and spatial structure of the compact city. The discussion is supplemented with conclusions to the issue of synergy in urban planning, architecture, and engineering solutions. The article describes implementation technologies for city resilience in the context of agricultural production, energy and water management for the local community, and the ecosystem services in the city.

Keywords: urban agriculture; urban resilience; compact city; water retention; hybrid unit

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1. Introduction

Re-urbanization is characterized by increasing the importance of the central city areas (after a period of intensive suburbanization and de-urbanization) [1–6]. This occurs due to the creation of comfortable conditions for the re-development of the residential function, as a result of which the population of downtowns increases. Thus, the compact city emerges [7,8].

The development of the compact city model is related to the introduction of a functional mix that offers a chance to satisfy various needs and expectations of users in a relatively compact and densely built-up urban tissue [9,10]. Numerous conditions that result from the multifunctionality of a city should be met. These include emphasis on the health, comfort, and well-being of city users and the relative self-sufficiency of settlement units. The analysis of the functional and technological connections provides the basis for the formation of synergistic spatial and functional systems that ensure the multifunctional character of the built environment.

This following paper focuses on the solutions rooted in the sustainable development concept and related to increasing the demand for agrarian areas which can supply cities with food [11,12]. Another point of focus refers to water management, including the issue of water re-use in the context of circular economy [13–17]. Both issues are closely related to residents' needs in re-urbanized areas of a compact city, namely, to ensuring security, understood also as access to food, the formation of shared green spaces, and social life development.

The partial transfer of agrarian function to cities corresponds with these needs. A properly designed sustainable urban agriculture system contributes to the reduction in food miles, ecological intensification, and food security in the region where it is implemented [18,19]. At the same time, it enables the ecosystem regeneration and restoration. [18]. The current interest in urban agriculture is related to the growing social awareness in developed countries, which is manifested in the desire to produce and consume local and good quality food, as well as to live in vicinity of greenery [16]. Research on sustainable urban agriculture is connected with the issue of water use for cultivation. The reuse of polluted water and rainwater subjected to treatment processes can be combined in order to supply urban farms with water [14]. Based on this assumption, research has been conducted on the possibilities of linking the issue of urban agriculture and water reuse in multifunctional units that constitute the compact city sustainable development [6,11,12].

The issue of sustainable development should comprise an optimal and efficient set of actions applied to improve the urban environment in connection with the development of social and economic structures. This should proceed with the use of civilization achievements. In this context, the integration of green and blue infrastructure is justified by the actions aimed at transforming the city structure through the implementation of sustainable urban agriculture.

In order to recognizing the problematics of urban resilience in terms of determining urban planning guidelines, it is necessary to link public spaces and development with green, blue, and social infrastructure in the functional-spatial structure of the city. Developing connections and dependencies between these issues can provide the basis for shaping a resilient hybrid urban unit. A building development complex in which the community and the ecosystem can coexist in a sustainable manner should offer a chance to regenerate and adapt to changes without losing functions and form necessary for its proper functioning. Due to climate change, stress factors are observed. These concerns should be addressed by modern urban design. In order to shape urban resilience, it is required to introduce hybrid urban units, considering their adaptation to climate change. Synergistic solutions provide the basis for regenerative design and resistance to stress factors for the ecosystem. Ecosystem resilience is based on the correct implementation of ecosystem services with synergy of blue-green infrastructure and biodiversity, as well as with an element of adaptation to climate change.

As a result of the research work and the development of the synergistic solution evaluation model, the dependencies, and the role of green and blue infrastructure in response to adaptation to climate change have been indicated.

Typology of climate change effects (stress factors) on the development of urban resilience issues:

- Accumulation of thermal energy heating and overheating—the heat island effect;
- Accumulation of precipitation water by localized heavy rainfall and snowmelt;
- Drought and periodically limited access to water in the ground and lack of rainfall;
- Accumulation of violent and intensive winds and changes in the atmospheric pressure system;
- Accumulation of air, water, and ground pollution;
- Accumulation of pathogens, organic pollutants, and bacteria;
- Accumulation of stress factors that influence changes to the urban ecosystem resistance;
- Decreased plant production from non-urban agricultural facilities exposed to the effects of climate change.

2. Materials and Methods

This research work was based on the search for source materials and the analysis thereof, authors' own research, and functional-spatial analysis followed by the evaluation of technological solutions and source literature presented in the reference section. The main aim of the research is to provide a case study review to create a catalogue of solutions that can be implemented in order to integrate green and blue infrastructure with the view to implementing sustainable urban agriculture system in the process of re-urbanization.

Furthermore, the study was based on the authors' own research and functional-spatial analysis, as well as on the evaluation of technological solutions. As a result, systematics and typology of urban farms, water retention, and water reuse solutions were developed. From the conjunction of both typologies, a typology of exemplary solutions and integrated actions was derived. These solutions can be implemented in the compact city resilience development model.

The working method is shown in the diagram (Figure 1).

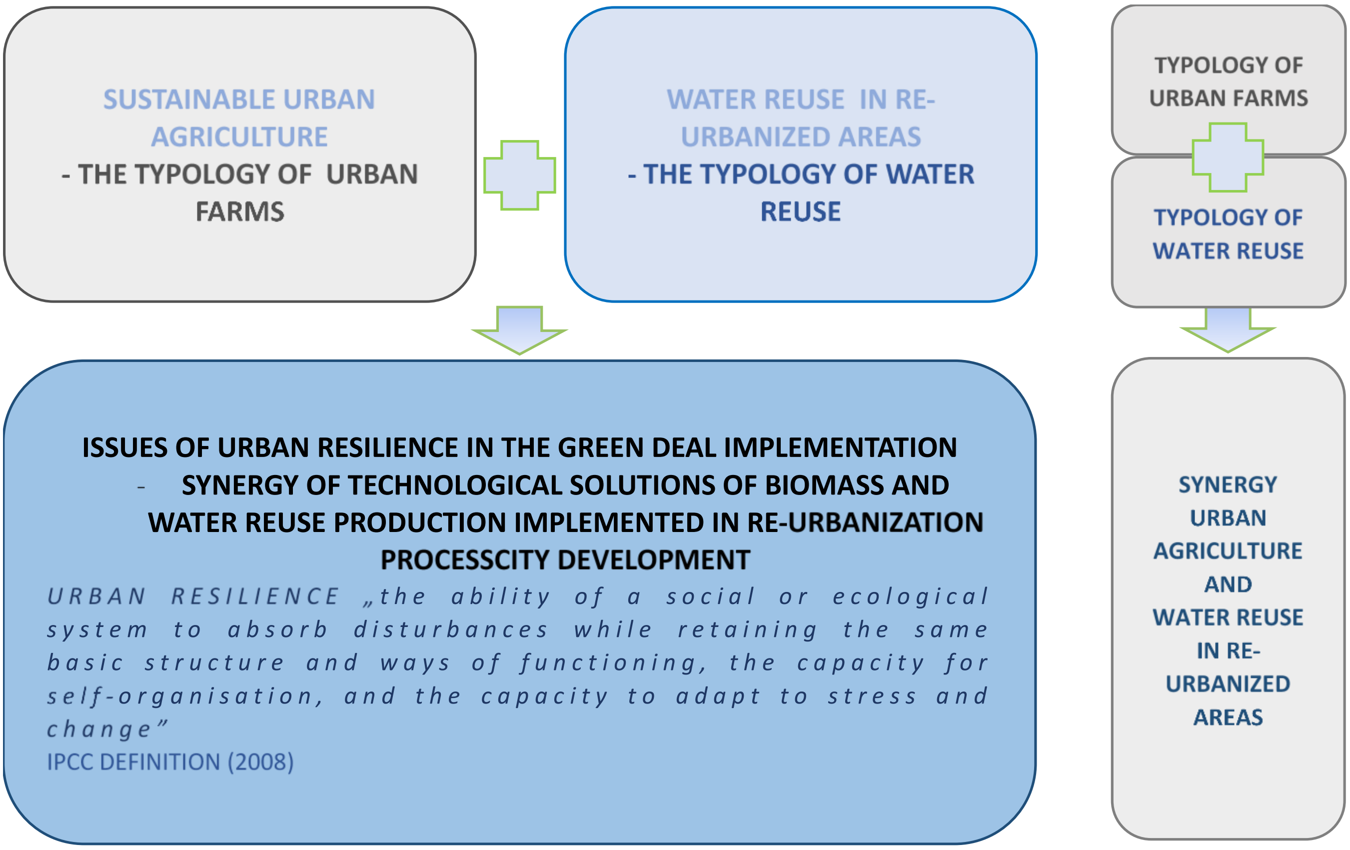

Figure 1. Research summary—typology of urban farms and water management.

In this paper, the results of the research work, together with the examples selected from the catalogue of solutions evaluated for describing synergistic solutions are presented as an element of urban resilience.

In the conclusion section, the analytical and modeling processes are summarized.

Specific issues:

1. Analysis of resilience and self-sufficiency elements of compact city landscape.
2. Sustainable urban agriculture urban farms in the city structure.
3. Shaping sustainable urban agriculture systems as "hybrid units" in compact city model.

Research aims:

The main research objective was to arrive at a typology for planning integrated activities to achieve synergies between green and blue infrastructure as urban agriculture. Another goal was to provide a case study based on the elaborated typology.

The scope of research and analysis:

- analysis of the changes in functional and spatial structure of a compact city in the context of self-sufficiency;
- model of a sustainable urban agriculture system;
- resilient hybrid urban unit within the city landscape;

- models of urban agriculture: intensive and extensive production;
- vegetation integrated with buildings;
- green and blue infrastructure in the context of urban agriculture system;
- examples of urban farming architecture linked with blue infrastructure as synergic solutions.

The research work concerns the development of methods and solutions that can be recommended and applied globally, with account to the specifics and conditions of a given location. Therefore, international publications and examples were analyzed in order to create a database, that is a catalogue of solutions. The analyzed examples were evaluated and a catalogue of solutions with which to integrate green and blue infrastructure with plant production in the context of hybrid units and urban resilience was selected.

The aim was to create a catalogue of solutions to be implemented in order to integrate green and blue infrastructure in the creation of a sustainable urban agriculture system.

The research work was divided into several stages. The presented issues are part of a general research on the resilience of the city in the process of re-urbanization and response to the determinants of the climatic, ecological and economic crisis. The research is based on the following issues: shaping of urban structure and space, availability of technologies and solutions that enable development of green and blue infrastructure, shaping of public spaces to improve comfort and quality of life in the city. One of the issues developed by the research team of the authors of this publication is urban agriculture and the introduction of a sustainable model of agriculture or production, taking into account environmental efficiency. Analyses are conducted on the topic Blue-Green Infrastructure (BGI) as a site for urban food production, especially under conditions of ecological crisis. As a result of the analysis and interdisciplinary work, it is justified to introduce hybrid solutions in the city, applying the principle of synergy to increase efficiency for the development of a compact-integrated city.

The main goal of the present article is to present general research characteristics, as well as to demonstrate results in order to summarize the typologies and provide recommendations for the application of synergistic solutions in urban policy. Furthermore, the article aims at recommending examples from database to prove that synergistic implementations should be developed. The systematization of solutions, the method evaluation, and the typology were supported by analyses of implemented examples. All the above offers the basis for theoretical guidelines with which to justify the necessity to implement synergistic solutions of green and blue infrastructure and urban agriculture in hybrid urban units in a compact city.

Urban agriculture serves as facilities for the production of plants in order to satisfy the needs of the local community. It houses food production and biomass productions (to be processed). Sustainable urban agriculture should comprise an optimal and efficient set of actions applied to improve the urban environment in connection with social and economic structure development. Such agriculture introduces greenery and biomass as a functional element into the city tissue. Furthermore, it increases the share of ecosystem services with a beneficial effect on the environmental parameters and microclimate.

The implementation of sustainable green infrastructure into the city leads to the growth in the production of tangible goods and intangible assets with which to fulfil the needs of the local community and the related urban centers.

Sustainable goals resultant from the implementation of urban farms as green infrastructure and production in the city are as follows:

- economic ones—optimization of production, transport, infrastructure, energy gains, development of new production sectors for self-sufficiency,
- social ones—services for the local community as a place for social integration, recreation and education, food production, new employment opportunities,
- environmental ones—improvement in the urban environment parameters, air purification, absorption of heat and water, obtaining fuels and energy from renewable

sources using biomass, supplementation of the city natural system, and improvement to ecosystem services.

Spatial and functional solutions for urban farms offer a variety of possibilities, which have been analyzed and described by various researchers. It is possible to examine spatial and social conditions, as well as parameters and technologies to create general typologies of urban agriculture forms [20–24].

Urban farms may be implemented as

- green and social open areas,
- gardens and biological areas on the building elements (roof, walls), or
- underground structures and urban infrastructure.

For the purpose of this research work, the following criteria were adopted for the classification of urban agricultural forms: location, space morphology, functions performed, the purpose of production, technology, the production scale, and characteristics of users and recipients.

Considering the criteria of production technology and location, urban agriculture can be divided into soil and soilless crops and into those occurring outdoors and indoors [21,22]. This division is crucial for discussing urban agriculture in the context of water retention and water reuse. Using soil-based cultivation, retention solutions and activities can be implemented to support infiltration along with sub-treatment with appropriate plant species. On the other hand, soilless cultivation with hydroponic technologies is essential due to the closed water cycle design.

Based on these variables, a typology of urban farms for urban biomass production was developed:

- the cultivation of plants planted in the open space or on the building roofs and walls;
- the semi-automated production of indoor plants; vegetation in pots in the ground or properly selected substrate (it is necessary to apply technical solutions with which to control and implement adequate hydration, lighting, and environment);
- the industrialized plant production in city buildings—fully automatic, highly specialized cultivation, in which the vegetation itself and its growth parameters are controlled.

Within the ground-based plant cultivation in open space and, native soil, gardens (community or allotment), and farms (horizontal and vertical) can be distinguished. Gardens differ from farms in their simultaneous implementation of agrarian and recreational functions. Farms, on the other hand, feature a more productive character.

Nevertheless, these outdoor spaces may be seen as reservoirs of urban biodiversity, as they lead to water retention in the soil. Thus, allotment gardens are of fundamental ecological importance, in addition to their social role [25].

As a result of the source literature analysis and the research conducted by the authors, a basic division was made into implementation processes:

- revitalization—plant cultivation in existing post-industrial buildings for environmental and social benefits with phytoremediation;
- eco-production—erecting new buildings for the needs of industrial production with increased crop efficiency;
- the biomass production for special needs, energy purposes, and food production,
- multifunctional building equipment and infrastructure solutions for urban resilience;
- the algae farm—to produce biomass and fulfil two main objectives: for bioethanol and methane; algae are used as fuel for heat production—biofuel, biogas, hydrogen fuel (hydrogen combustion does not cause dust or carbon dioxide emissions, whereas water is the by-product of this reaction).

The presented issues concern the shaping of urban farms to preserve environmental balance in urban spaces and to preserve connections concerning the coexistence of architecture. The subsequent step in the research was to identify typologies for water retention and water reuse options in order to identify solutions that integrate the green and blue infrastructure components.

Green infrastructure may be identified as a system of areas, cubature, and biologically active surfaces with biomass, vegetation, and organisms that live in the city, together with accompanying technical infrastructure for the implementation of ecosystem goals and social tasks [26,27]. Green infrastructure has been implemented to improve the quality of life and the urban environment parameters [28,29]. Vegetation in the form of biomass integrated with buildings may be introduced as roof gardens, vertical gardens, and road system elements [30].

The implementation of urban agriculture in the city structure needs to be recognized in the context of development strategies for green and blue infrastructure synergy [31–33]. Such implementations need to face future challenges posed by the expected sustainable development solutions in the field of water and risk management, ecosystem services, and the functional and spatial city structure.

Blue infrastructure consists of sites, areas, buildings, and technical infrastructure implemented on behalf of water resources management, storage, purification, transmission, and distribution of water from rivers and watercourses, natural and artificial water reservoirs, retention water reservoirs, and retention systems, as well as transmission networks [34,35].

Developing research on retention and water use, action categories, typologies, and examples were identified and entered into a database of recommended solutions.

Based on the analyses, the following typology in terms of water retention methods was determined:

- open-air retention tanks,
- underground retention tanks,
- solutions for reuse rainwater,
- solutions for wastewater treatment.

By developing the analytical model and integrating the described typologies of urban farms, water retention, and water reuse, guidelines and typologies for priority solutions to be implemented in the compact city were developed. A schematic research process is presented in Figure 2.

In conjunction with climate change stress factors described in the introduction, the analytical work identified criteria for integrated green and blue infrastructure solutions as elements of an urban farming system. Based on the regulation functions served by both ecosystem services and social services, areas were urban farms could be implemented were identified. The role of integration between urban green and blue infrastructure and resilience in a view of climatic changes may be defined as follows:

- Greenery as shading, cooling by transpiration and evaporation from open retention basins, water gardens;
- Delay water runoff or increased water infiltration with vegetation and systems for water retention and treatment in rain gardens and retention basins;
- Slowing water runoff and shading by drought resilient plants;
- Regulating environmental parameters with diversified vegetation;
- Regulating the parameters of wind flow through the selection of vegetation and its fragmentation;
- Greenery for oxygen production, pollutant absorption, carbon storage, and sequestration;
- Essential oils as antiseptics, regulation of biodiversity, and ecosystem resistance;
- Qualitative and quantitative regulation of species and ecosystem services;
- Increasing the efficiency of plant production under controlled conditions and with the use of water in a closed circuit.

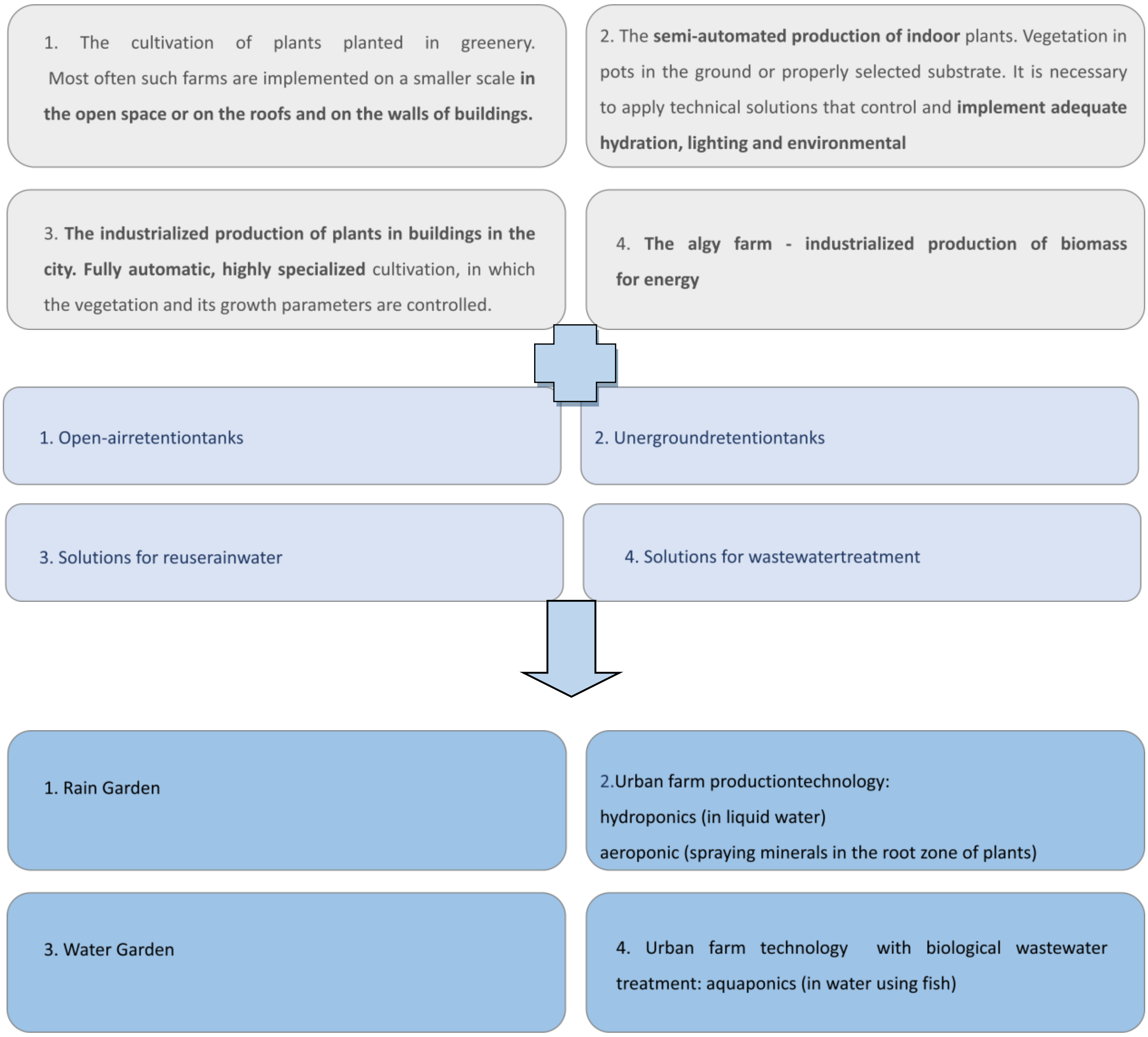

Figure 2. A schematic research process—integrating the described typologies of urban farms, water retention, and water reuse.

As a result of analyzes and evaluations according to the described criteria, the recommended solutions were selected for city resilience and for sustainable urban agriculture systems. These include Rain Garden, Water Garden, hydroponic and aeroponic urban farms, biological wastewater treatment.

3. Case Study Analyses Results—Selected Examples of Synergy Solutions from the Research Database

The research work concerns the development of methods and solutions to be recommended and applied globally, with account to specific conditions in a given location. Therefore, international publications and examples were analyzed in order to create a database that is a catalogue of solutions. The analyzed examples were evaluated, and a catalogue of solutions emerged in which the following issues were integrated: green and blue infrastructure, plant production in the context of hybrid units and urban resilience. Proposed solutions were selected.

Analysis results offer solutions selected as examples of green and blue infrastructure implementations with a plant production function. These include recommended examples from the catalogue created during research work on sustainable urban agriculture and blue-green architecture synergistic solutions in city resilience. Different categories of the adopted systematics according to the described typology are illustrated.

Recommended examples of synergistic solutions for a sustainable urban agriculture model include:

- **Community Gardens as "Pocket" Retention Areas—**examples: The Passage 56 community garden in Paris, The Salatpiraten community garden in Vienna;
- **Indoor Farms with Closed-Cycle Water Reuse Solution—**example: The Pasona Urban Farm in Tokyo;
- **Rain Garden—Urban Farm and Water Retention—**example: The Houtan Park in Shanghai;
- **Water Garden—Floating Fields as Urban Agriculture and Water Management—**example: The Floating Fields in Shenzhen.

3.1. Community Gardens as "Pocket" Retention Areas

This collection includes community gardens with an area of 200–300 m^2 implemented in urban space with in-ground cultivation and solutions for water infiltration and natural water retention. It is recommended to implement such solutions in intensive buildings as examples of land revitalization, as well as for of the sake of neighborhood integration functions. The selected crops are dedicated for local community, which leads to the creation of a habitat. These types of solutions support biodiversity, as the plants often include fruit-bearing plants. In community solutions, amateur rainwater harvesting methods are often introduced. This water is then used for crops cultivation, which leads the users to identify with the place they create. In most cases, such spaces are also equipped with ornamental plants, flowering plants and small elements of architecture in order to create spaces for integration and relaxation. Two examples of solutions from this catalogue group are described and illustrated below.

Passage 56 community garden, created in 2006 on an unused plot of land in Paris (Figure 3), resulted from a collaboration between the AAA architecture studio and local residents. The project began with a public consultation of several months. The garden developed gradually. The works began in 2006, and two years later the site was handed over to a group of 40 people for use [36–38]. Passage 56 occupies a plot of land which measures 5 × 40 m. It is a space between two residential buildings (Figure 4). On the street side, a two-story wooden structure built of recycled materials was placed. This block flanks the passage, filling the gap in the frontage, whereas the ground floor provides the entrance gate to the garden. On the first floor of this small building, an office for the members of the garden is located, while on the roof, the photovoltaic panels were installed to provide electricity. Inside the plot, a social and recreational space and a zone with crops were implemented. Finally, the garden is enclosed by a small structure which houses a storage room, a composter, and a rainwater tank.

Another example of this type of community garden is the Salatpiraten established in 2013 in Vienna. It is located in the central part of the city, in the seventh district, on a small Kirchengasse street, parallel to the greenery ring. It is in a densely built-up area short of large, open green spaces. According to the plan, it has a trapezoidal shape with one of its longer sides along the Kirchengasse street (Figure 5). The entrance to the garden is located towards the north of one of the shorter sides and faces the pedestrian walkway perpendicular to Kirchgasse. A toilet and a trash can were placed at the entrance. There are also old trees and seating places in the northern part of the plot. The garden covers a total area of 285 m^2.

The garden surface is unpaved and consists of wooden chips, which makes it possible to absorb rainwater. Rainwater is also used for plant watering. Crops (herbs, vegetables, and flowers) are grown in containers made of reused materials and elements (e.g., old drink crates). It seems that the garden was arranged spontaneously, with no plan in mind. The only noticeable rule is to leave a space in the central part of the site as a meeting and activity place for the locals. The garden is run by an association that aims to promote urban agriculture while integrating the local community (Figure 6).

Figure 3. Location of the Passage 56 community garden in Paris, France—an elongated parcel of land in a residential quarter, [compiled by A. Nowysz, based on site visit (26.07.2016) and source: www.google.pl/maps, (accessed on 27 June 2017)].

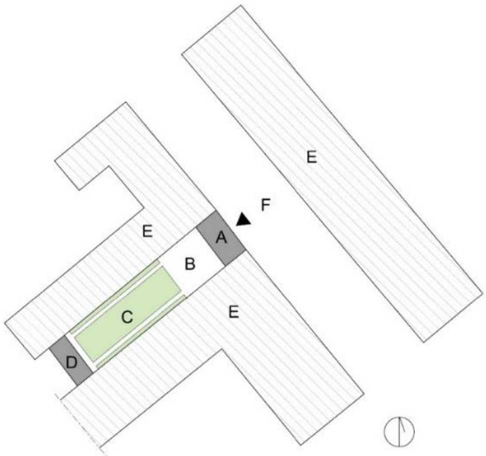

Figure 4. The diagram of the plan of the Passage 56 community garden in Paris, France. Legend: (**A**) pavilion with entrance gate, (**B**) recreational zone, (**C**) agrarian zone, (**D**) utility room and composter, (**E**) residential buildings, and (**F**) pedestrian and bicycle boulevard, [compiled by A. Nowysz, based on site visit (26.07.2016) and online source: www.google.pl/maps (accessed on 27 June 2017)].

Community urban farms developed in urban areas and cities with extensive building development, such as in Detroit, USA, provide an extension of community gardens with a larger area for greater crop yield. Cultivation is also implemented in the ground with irrigation and watering systems, as the main objective is to grow food in the city in order to supplement the social needs for vegetables and fruits. Areas of several thousand square meters make up urban revitalization areas in post-industrial crisis. However, it is necessary to verify the quality of food products and the environment. In this type of solutions, resting areas are not always arranged, whereas the amount of ornamental plants and small elements of architecture is reduced. Irrigation systems are introduced as part of urban agriculture. By growing crops on the ground, these areas exert a significant impact on the city structure, allowing natural infiltration and water retention.

Figure 5. Location of the Salatpiraten community garden in Vienna, Austria—a trapezoid parcel of land along Kirchengasse, [compiled by A. Tofiluk, based on site visit (09.2018) and online source: www.google.pl/maps (accessed on 24 May 2021)].

Figure 6. Salatpiraten community garden in Vienna, [photos by. A. Tofiluk—site visit (09.2018)].

Urban farms are arranged to ensure regional food security. They are established by the state (e.g., Cuban organopónico [39]), non-state organisations (e.g., NGOs), and by informal (e.g., cooperatives) bodies. Farms, established by means of bottom-up initiatives can also become part of local food systems, as exemplified by the city of Detroit, where community gardens and farms, established after the 2007 financial crisis, currently provide a source of food for many residents. The MUFI farm (Figure 7) may serve as an example of collective agriculture in the Detroit suburbs. It has been referred to as an urban agrihood [40]—an English neologism interchangeably used with the term of agritopia (Gr. agrós—field, topos—place). These two terms describe suburban areas where urban development is intertwined with small agricultural areas used for individual or collective food production.

The MUFI farm was established by the Michigan Urban Farming Initiative (MUFI) Foundation and was given to residents who grow it for self-supply. In turn, surplus production is transferred to food banks. The farm occupies vacant plots of land between single-family homes. Its total surface area amounts to about 5000 m^2 and consists of two rectangular plots, located opposite each other on both sides of the street. The first plot of 3000 m^2 was divided into equal cultivated beds and paths between them. The plot is enclosed by a low wall, which only marks the border, but creates no physical or visual barrier. On the second plot, a vacant building is placed. Te Michigan Urban Farming Initiative, which manages the farm, plans to renovate and use as it as their headquarters [41,42]. The renovation project also includes the addition of a greenhouse. As with the Havana organopónico, the main this site is mainly devoted to food production, and cultural and recreational functions have not been planned here.

Figure 7. MUFI (Detroit): (**a**) Location of the MUFI farm in Detroit [original study, based on: www.google.pl/maps, (accessed on 16 August 2018)], (**b**) Scheme of the MUFI farm. Explanation: A—crop beds, B—MUFI lot, C—MUFI headquarters (a vacant property), D—crops in a foil tunnel, E—road, F—housing lots, G—path, H—crops in a foil tunnel.

In 2018, a cisterna tank for rainwater used for watering crops was placed on the adjacent plot. The tank was built into the foundation of a demolished building. The pond supplies water to an urban farm via a drip-line irrigation system.

3.2. Indoor Farm with Closed-Loop Water Reuse Solution

The development of urban agriculture in conjunction with the development of urban cultivation technologies is represented by the implementation of in-building cultivation, which integrates greenery and irrigation and water retention systems. Hybrid building solutions that use vertical farms, water, and substrate cultivation, and the introduction of biologically active surfaces on walls and roofs are eligible for this category.

These urban farms embody the principles of biophilic design to the outside and inside of a building. Custom-made technological solutions are applied for lighting, cultivation, and irrigation, with the use of a closed cycle system. Solutions for sustainable energy and water management are introduced. Water retained on green roofs is slowed down, evaporated, and returned to the ground. Sometimes it is used for the field infiltration systems.

The industrialized biomass production process in the city is crucial to increase the productivity and self-sufficiency of hybrid urban units and to complement the community food supply system. It is therefore an element of social sustainability. However, the choice of building-integrated solutions to be implemented for the development of ecosystem resilience is of crucial importance. Worldwide, buildings with vertical crops are implemented in industrial buildings. In this case, no link to the urban green system is provided. Such implementations do not complement ecosystem services, because the land use fails to take biologically active areas into account. Thus, the present paper presents buildings that may serve as examples of multifaceted activities and hybrid solutions both inside and outside, in an intensive urban building development. The presented solutions affect the parameters and quality of the environment.

Another example of a recommended vertical farm in the city is a building located in Tokyo, partly adapted to the Pasona Urban Farm. The building combines office and agrarian functions. In their promotional materials Pasona management, states the following goals: creating a "healthy working environment" [43], drawing attention to contemporary food issues and the scarcity of biologically active land in Tokyo [44]. Pasona Urban Farm is housed in a building of early 1960s, renovated and transformed into office and farm space in 2010. It was designed by Yoshimi Kono, a Japanese architect. The original building is a modernist, 9-storey structure with a floor area of about 20,000 m^2, about 5000 m^2 of which is dedicated to crops. The flat roof and the double façade have been developed for food production: pots of orange trees have been placed in the loggias of the building, and an openwork layer of external panels has been used as a frame for climbing plants and vines. In the summer, the greenery shields the interior from the sun, while in the winter the plants shed their leaves and let the daylight in. About two-hundred species of plants are grown at Pasona Urban Farm, including grains, herbs, vegetables, fruits. A hydroponic and partly soil-based potting system is applied. The building is connected to an intelligent system that controls the parameters of the environment, monitors temperature, humidity, and air flow. The lighting system of the farm is also used to illuminate the office rooms. Part of the office space is merged with the agrarian space: in the entrance foyer, a pool of almost 100 sq. m was implemented for hydroponic rice cultivation. The rooms, which are entirely dedicated to plant cultivation, are open to the public, additionally serving as a recreation and leisure zone. Green walls act as dividers between the workstations. In the conference rooms, under the ceiling, a metal grid has been suspended, on which such plants such as tomatoes, pumpkins, and cucumbers are grown. Additionally, the interior furnishings were designed to serve both functions, e.g., the space under the benches is filled with drawers for seeds [45].

3.3. Rain Garden—Urban Farm and Water Retention

Rain gardens are yet another type of synergistic solutions with which to introduce urban agriculture, water retention and water use into urban areas. Water retention is the main role of rain gardens, nut they also serve the purpose of gradual infiltration of water into the ground. Oftentimes, infiltration systems are applied to support the infiltration of water into the ground. Moreover, additional systems of retention basins associated with hydrophilic greenery are implemented. Rain gardens are marked with their own specificity related to their location and the amount of rainfall, as well as to the function they serve. Not all rain gardens are devoted to the crop production function. However, energy crops, i.e., plants grown as biomass for energy purposes, can also be grown as crops in rain gardens. In some locations, it is also possible to grow fruiting plants adapted to periodic flooding. Properly selected and implemented rain gardens may provide an important element of the rainwater retention system in dense urban development. In public space design, as well as to shape the city resilience in the process of adaptation to climate change, these solutions are increasingly applied. A public park with an agrarian function in Shanghai is an example of a farm designed as rain garden. The riverside boulevard was built in 2010 for the 2010 Shanghai World Expo. The area along the Huangpu River, which had previously belonged to a steel factory and served as a shipyard, was permanently transformed into Houtan Park (Figure 8). Its area totals about fourteen hectares, while the Park was developed, according to a concept by Turenscape studio.

The project aimed to reclaim the degraded industrial site, namely, to restore the ecosystem, create a public space, and give it a productive character. This Park, in the form of a riverside boulevard, now offers a recreational space. It is equipped with a wetland area which serves as a flood zone. Once the project was implemented, the area was also bestowed with the river water filtering function. This wetland area is intersected by piers, which serve as footpaths connecting extended platforms. These platforms, in turn, were located deep within the vegetated and river landscape. The platforms and piers are equipped with elements of small architecture, such as red benches, at the same time providing the area with a distinctive visual accent. Recycled metal obtained from the previously existing industrial infrastructure was used for the construction of these elements. Moreover, a few post-industrial objects, such as openwork structures, were partially retained and now have a decorative function, namely they are sculptural elements of the park. The Park greenery consists of trees, tall grasses, and edible plants such as sunflowers, rice, and herbs. The growing areas take the form of agricultural areas, each dedicated to one species of plant, with piers and pedestrian platforms in between. The design was inspired by the agrarian landscape of the Shanghai farmlands from the first half of the 20th century, i.e., from before the industrialization of the region. Plants were selected considering their seasonality: sunflowers have yellow flowers in spring and edible seeds in summer, while rice grows in autumn, and green clover in winter [46–48].

Figure 8. Location of Houtan Park in Shanghai, China, [compiled by A. Nowysz, based on: www.google.pl/maps, (accessed on 16 August 2018)].

The wetland area in the park totals ~1.7 km in length, whereas its width varies between 5 and 30 m. The natural purification system of the river consists of terraces- planted at different heights and trimmed with stone dams that filter the water, U-shaped water corridors intended for stopping debris and allowing the water to flow, special plants that absorb heavy metals from the water, cascading terraces, and a gravel-covered area that filters the water. Approximately 2400 m^2 of river water flows through this treatment system daily, and its pollution level drops from 5 (the highest level in the classification) to 3 or 2 (classification developed by Shanghai Houtan Park—Shanghai, China, Methodology for Landscape Performance Benefits [49]).

3.4. Water Garden—Floating Fields as Urban Agriculture and Water Management

The Floating Fields project created at the 2016 Shenzhen Hong Kong Bi-city Biennale of Urbanism provides an example of combining water retention issues with urban agriculture. Thomas Chung, an architect, designed infrastructure for food cultivation, which includes artificial water reservoirs with crops, i.e., the so-called floating fields. The installation was located on a post-industrial site, next to the buildings of the former Dacheng Mill. The architect was inspired by the traditional Chinese method of farming on water, which consists in placing plants on small, wooden rafts through which the roots draw water. Such a model was also found in other traditional cultures, such as the chinampa in Mexico. The Chinese project aimed to create a prototype of the so-called polyculture, i.e., an environment in which both diverse types of crops and aquaculture occur and in extensive water gardens. These areas combine cultivation and water storage and are being implemented in urbanized areas with extensive development. Examples of such open retention reservoirs with vegetation are described below. However, it should be noted that rain gardens can and should be used also in densely developed urban areas. In such building developments, the cultivation of useful plants can be realized given proper selection of plants with filtering and purifying functions. Phytoremediation in combination with water retention may prove crucial for environmental parameters and quality. Water retention in open watersheds is important for adaptation, regulation of ecosystem services, biodiversity and reduction of heat island effect. However, the choice of parameters and solutions depends on local conditions. It is necessary to balance stored water, rainfall velocity, and evaporation water losses. Hybrid overflow systems connected to rain gardens are suggested in this case.

An existing ecosystem in the Pearl River Delta, called Mulberry-Dyke-Fish-Pond, in which maximum use of natural resources is accompanied by continuous restoration, was assumed as a model. The current landscape of this estuary result from agrarian practices used since the 19th century. Local farmers gradually adapted the floodplains in the area by creating ponds separated by earthen dams. These actions gave rise toa so-called "closed-cycle polyculture". Fish are bred in the ponds, while mulberry bushes are grown on land; their leaves, in turn, provide a source of food for silkworms, whose excrement is fed to the fish. Silt and river sediment fertilize the land, which promotes the growth of mulberry bushes. The system is based on the interdependence of its elements. In addition, as it located in a floodplain, farmers use water from the river to irrigate crops [50].

Taking the Mulberry-Dyke-Fish-Pond ecosystem as a model, in the Floating Fields project the land was shaped into rectangular interlocking basins, some of which were backfilled with farmland and planted with crops, while others were filled with fish water and bamboo rafts with seedlings, i.e., floating fields (Figure 9). Another element of this premise lies in the adaptation of a post-industrial pavilion. In its interior and on the roof mulberry bushes were planted and a silkworm farm was established. Plots were created in the pavilion and covered with crops, ponds and mulberry trees. Subsequently, they were connected by an irrigation system [51,52].

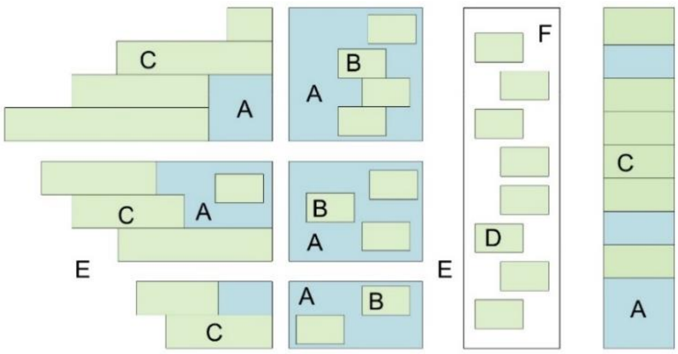

Figure 9. A schematic model of the Floating Fields in Shenzhen, China, growing edible plants on water rafts. Legend: A—pond with water (aquaculture), B—rafts with edible plant seedlings, C—soil cultivation area, D—soil cultivation area on the roof, E—public space, F—pavilion, in the interior and roof on which mulberry bushes are grown and silkworms are bred.

In addition, the area around Floating Fields constitutes a public space with recreational and cultural functions. The plots and rectangular ponds are separated by low walls formed by benches and piers. During the Biennale Festival and afterwards, the site hosted gardening festivals, food fairs, as well as the international forum: Envisioning Urban Agriculture and Ecology for Bio-Social Living.

As a result of research and literature review analysis, as well as case studies, a database was created in the form of a structured classification system. According to the authors of the research paper, the formation of sustainable, biologically active systems with urban crops should account for the implementation of all four types of urban greenery systems, public spaces and urban water retention system.

The biomass and food crops production are important as a complementary function to the functional and spatial structure of the hybrid urban unit.

4. Discussion

In the context of the forecast development directions for contemporary pro-environmental solutions [2], re-urbanization leads to formulating an innovative approach in shaping urbanized areas, namely, to regenerative design [53–58]. The issues related to blue and green infrastructure, presented in the above studies, form part of regenerative design and sustainable urban agriculture concepts. The pro-environmental architecture connected with technologies to enable the production of plants in building and between buildings allows for urban space integration, thereby complementing the functional and spatial structure of the compact and regenerative city. The presented typology and examples should be seen as a stand in the scientific discussion on the formation of modern compact city model. In such a city model, multifunctional urban units are formed with the implementation of hybrid solutions and integrated measures to improve functional, social and environmental efficiency. The present paper points to the complexity of problems and connections between certain issues in the formation of a functional and spatial city structure that is environmentally and socially effective in terms of urban farm implementation.

Systematization and classification of solutions may provide a discussion topic with regards to the formation of a crops system associated with urban infrastructure (public spaces, green, blue, and social infrastructure). The abovementioned recommended examples of synergistic solutions are dedicated to a sustainable urban agriculture model.

In intensive urban areas, a system of rain gardens and community pocket gardens, i.e., social integration spaces with a complementary urban farm function should be created. Community Gardens with "Pocket" Retention Areas—described above (The Passage 56 community garden, Salatpiraten in Vienna community garden) provide examples of how biologically and socially active areas can be introduced and natural water infiltration and retention processes can be supported. Such facilities in which cultivation and recreation areas are combined should form the social service center system of the modern city. Rain gardens (described on the example of Houtan Park) can prove vital in developing resilience concerning extreme weather phenomena and heavy rainfall. These gardens should be linked to a system of canal retention basins and water gardens (describe on the example of Floating Fields) and should further be supplemented with cultivated vegetation, including energy crops.

These solutions tied into hybrid unit systems are imperative for improving environmental performance and the quality of life. Their functioning is related to environmental parameters, adaptation to climate change, accessibility and effectiveness of green areas, urban greenery system and water resources management, also in the case of systems for biodiversity and water retention purposes [9,10,59]. All these aspects constitute an ecosystem, or a biologically active infrastructure which may be seen as the implementation of city sustainable development concept related to lifestyle changes and the way of thinking of contemporary and future generations [55].

Ecological, economic, spatial, and political incentives should define the city development treated as a complex organism, equipped with information systems and management methods. The optimization concept and analysis of impact effects determine the implementation of new solutions consistent with the needs of the local community. Due to increasing food and energy shortages, it is necessary to equip the city with industrialized intensive crop facilities. For this reason, Indoor Vertical Farm with Closed-Loop Water Reuse Solution (described example: Pasona Urban Farm) have been included among the database categories and recommended examples.

Analysis of the existing condition, forecasting, and optimization, as well as implementation of solutions constitute the multicriteria model for urban space and urban environment design, with the use of new information techniques and methods for shaping the urban ecosystem [55,60,61].

According to the publication authors, the research results indicate that vertical urban farms in buildings can constitute a nodal point in the system of social services. Such buildings should combine production, catering, storage, educational, and social functions. It is necessary to use solutions that counteract the isolation of production inside the building and biologically active areas outside. Depending on the adopted spatial solutions, production technology, and management model, urban agriculture can be applied for ecological, social, and economic purposes [12,18,19,62]. Urban agriculture is important in the ecological aspect, as it promoted biodiversity in the urban environment, water retention, and possible control of water consumption (use of gray water and rainwater), as well as it provides a method for organic waste composting. Urban agriculture can significantly reduce the demand for industrial food, the production of which is burdensome on the environment due to such factors as the high demand on energy consumed in the production and global distribution (food miles), generation of large amounts of waste, monocultures, large-scale greenhouses, and carbon dioxide emissions [62,63].

Farms should also be located in the city to foster food sovereignty [19,64–67]. Farms can be commercial, i.e., food is produced for sale, or social, i.e., food is produced for self-supply or donated to food banks. Therefore, urban agriculture is part of a broader movement towards the socialization of the city space and the self-organization of inhabitant groups of. On the other hand, however, urban farming constitutes a new area to be developed by the market. In both cases, urban agriculture provides important support to the local food system, thus influencing regional food security.

Vertical farms are more technologically demanding. However, due to efficiency and circular economy issues, vertical farming is increasingly common and has great implementation potential also in urban environments [68,69]. Indoor farming allows more control over the growing environment than the traditional outdoor cultivation. In indoor farming, the temperature and humidity of the air and the microflora can be controlled. Thus, problems resultant from flooding, drought, plant diseases, and pest presence are eliminated [69]. Therefore, the potential advantages offered by a closed urban vertical farm which operates with hydroponic technology will lead to the minimized impact of weather conditions on crop efficiency and year-round food production, reduced water consumption (due to closed circulation in hydroponic and aeroponic methods), greater control over food quality, lack of pesticides, herbicides and soil conditioners, as well as the absence of agricultural runoff, i.e., the runoff of contaminated water from cultivated areas during precipitation.

The prevalence of urban cultivation in the form of vertical farms stems from the increase in the agricultural area through the vertical multiplication of a single parcel of land. No simultaneous annexing of further natural spaces is required. Another beneficial effect of applying vertical farming on an industrial scale lies in the release of land currently occupied by large-scale greenhouses and monocultures. In this way, these areas can regenerate to their original ecosystem [69–71]. Thus, the ecological rationale behind vertical agriculture is provided by the possibility to abandon extensive agriculture and to start the process of degraded area reclamation.

However, the concept of closed urban vertical farms with controlled microclimate raises other doubts, such as economic viability (expensive technology, high rent of plots in the city, lack of detailed studies on energy consumption costs), or the phenomenon of light pollution associated with greenhouse facilities [72,73]. The plants grown in an urban environment are at a risk of being contaminated, with heavy metals found (such as arsenic, chromium, zinc, cadmium, copper, nickel, lead, mercury) [74]. The degree of food contamination depends primarily on the location of the crop and the degree of site contamination. In a publication entitled *Urban Agriculture Food, Jobs and Sustainable Cities*, the results of studies conducted on urban agriculture food security up to 2001 are combined. The case studies show that heavy metal contamination of crops grown in the city varies depending on their location. Due to vehicular traffic, most heavy metals accumulate in the soil along streets, near sewage outflows into rivers, in industrial and post-industrial zones, and areas below polluted areas and near landfills [75].

Due to urban pollution and local conditions, urban farm type, species, and technology should be selected based on spatial and environmental, and social analyses. Studies show that it is possible to create a city structure integrated with the urban greenery system which includes elements of green and blue infrastructure. This way, the assumptions of space, green and water management synergy are implemented [35].

Biomass production in the city is possible as synergy between technologies of biomass production and water reuse. Sustainable Urban agriculture provides the basis for self-sufficient urban units [24]. The analyses prove correlation between urban farms and water management with technologies for the implementation of reuse strategy. These solutions, in turn, foster city resilience in the context of agricultural production, energy and water management for local community and the ecosystem services in the city [18,19,24]. The presented results are part of a research on resilience and a model for self-sufficient urban units created in the re-urbanization process. The abovementioned models and typologies for coexisting and interdependent agricultural production, renewable energy solutions and water reuse systems integrate green and blue infrastructure with water reuse technologies in circular economy processes. Sustainable Urban Agriculture with Water Reuse strategy should provide an important part of the urban resilience in the process of re-urbanization in order to arrive at a compact city.

5. Conclusions

Pro-environmental architecture may be connected with technologies that enable the production of plants in buildings. This approach makes integration of urban space possible, thereby complementing the functional and spatial structure of the city. New technologies may be applied for plant production in buildings. Urban agriculture implemented in the city structure needs to be recognized in the context of future challenges posed by spatial economy. These challenges refer to the projected sustainable development in relation to ecosystem services, as well as functional and spatial city structure. Re-urbanization is important in the context of forecast development directions for contemporary trends towards pro-environmental solutions in shaping of the city. These concepts are referred to as eco city, smart city, and compact city model. Forecast directions for further development of the indicated ideological assumptions lead to formulating a new approach to urbanized areas design This approach is known as regenerative design.

The regenerative design model characteristics lead to the definition of urban design guidelines for the needs of new standards for functional and spatial structure associated with the city's natural system.

The typology of urbanized area transformations, with reference to defining the connection between buildings and biologically active areas and infrastructure in the city is indicated. Complementary functions combined with an urban farm should involve sports and recreation, and multi-family buildings. Such facilities enable integration of residents and realization of social events.

The research result concerning the development of urban guidelines and new standards for functional-spatial shaping forms a typology of solutions, also those related to blue infrastructure and water management. These include the following:

- rain garden
- water garden and aquaponic urban farm production,
- urban farm production technology: hydroponics (in liquid water), aeroponic (spraying minerals onto the plant root zone),
- urban farm technology with biological wastewater treatment: aquaponics (water with fish).

The use of greenery and water influences the shape of favorable microclimate. A graduation tower could offer an appropriate complementary function. The supplementary function should be served by housing, hotel and conference facilities, depending on the size and purpose of the urban farm unit in the production system in the city structure. Urban production and cultivation can be combined with office and public buildings for exhibitions, conferences and social integration purposes.

Functions in the "hybrid model" include:

- shaping the parameters of the urban environment
- regulation of the microclimate parameters and water cycle in the urban environment
- ensuring biodiversity in the ecosystem, habitat for small animals and insects
- improved insulation parameters of buildings
- preventing the "heat island" phenomena [76–78]

- social: forming place identity, integration of local community
- utilitarian: recreation areas, windbreaks, aeration corridors, cultivation gardens, urban farms
- production: biomass, energy, food

A hybrid unit integrated into the city structure determines the functional program of the land and building development. In the urban space, it is recommended to use biologically active surfaces integrated with the building. These should constitute equipment and furnishings of buildings, "green roofs and walls" connected with the system of urban greenery and the system of spaces directed to circulate air in the city and water management [76,79–83].

It is recommended to implement productive development in the city structure to grow plants for food needs. The benefits from functional hybrid model with urban farm include:

- reducing food transportation to cities
- provision of fresh fruit and vegetables
- control of water consumption, use of rainwater and grey water,
- year-round production (vegetation control)
- elimination of the impact of natural disasters on agriculture
- production of healthy food without toxins
- use of biogas for energy production
- recycling of waste as a natural fertilizer,
- social advantages:, such as jobs, green and recreational areas,
- Autarky—multifunctional unit in the city structure connected with the greenery system
- counteracting the urban heat island phenomenon
- regulation of environmental and microclimate parameters
- ensuring exchange of air in the city
- ecological and climate-forming
- social advantages related to improving the quality of life in the city

Modern urban planning and architectural solutions should be focused on the integration of several functions in a hybrid urban development unit. Firstly, the production function should be fulfilled, including cultivation of plants with the use of modern technologies integrated with water reuse solutions. Thanks to that approach, the planned new urban and architectural units may become self-sufficient to a considerable extent. Designing such sustainable urban units to constitute a multi-element interacting systems with optimized parameters is in line with the resilient and sustainable compact city concept. Hybrid urban unit emerges as a combination of public utility and production functions within individual multi-functional buildings and biologically active surfaces for ecosystem needs, regulation of urban environment and urban resilience. A system made up of greenery areas and green-blue infrastructure should be formed as a hybrid system of synergic solutions, with integrated plant production, water retention, water reuse, and ecosystem services. Nowadays, shaping modern city with hybrid urban unit resilience is based on the proper implementation of ecosystem services with synergy between blue-green infrastructure and biodiversity, as well as an element of adaptation to climate change. The recommended examples of synergistic solutions for sustainable urban agriculture model have been described above. According to the authors of this paper, the research results indicate that particular components from all four abovementioned categories of urban agriculture system elements should be implemented in the city structure (Community Gardens as "Pocket" Retention Areas, Indoor Farm with Closed-Loop Water Re-use Solution, Rain Garden—Urban Farm and Water Retention—described, Water Garden). Applying these components in hybrid solutions provides a basis for building a production-, social-, and ecosystem-efficient urban agriculture system.

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writing—original draft preparation, M.G.-S., A.N. and A.T.; writing—review and editing, M.G.-S., A.N. and A.T.; visualization, M.G.-S., A.N. and A.T.; supervision, M.G.-S., A.N. and A.T.; project administration, M.G.-S. funding acquisition, M.G.-S., A.N. All authors have read and agreed to the published version of the manuscript.

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